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Centre of Excellence for Biosecurity Risk Analysis

Ministry for Primary Industries
Manatū Ahu Matua

<table>
<tr><th colspan="5">CEBRA Report Cover Page</th></tr>
<tr><td>Title, ID, & Output #</td><td colspan="4">Year 1 Report: Valuing Australia’s Biosecurity System, Project 1607A – Milestone 6</td></tr>
<tr><td>Project Type</td><td>Standard</td><td colspan="2">CEBRA Project Leader</td><td>Tom Kompas</td></tr>
<tr><td>Sponsoring Org.</td><td>Australian Government Department of Agriculture and Water Resources (DAWR)</td><td colspan="2">Project Sponsor</td><td>Matthew Koval</td></tr>
<tr><td>Project Leader/s</td><td>Paul Pheloung</td><td colspan="2">Collaborator/s</td><td>Ahmed Hafi</td></tr>
<tr><td>Project Objectives</td><td colspan="4">The current and proposed work is the primary contribution to a multi-year departmental project plan for determining the value of Australia’s biosecurity system.
The overall objectives of the multi-year project are to: (1) set out and design the methods that are needed to measure the value of the biosecurity system as a whole, and its various components (Year 1); (2) to further develop and adapt the preferred approach for valuation and the aggregation of values specific to the Australian context (Year 2); and (3) work towards providing component measures and an aggregate value measure of the biosecurity system across different biosecurity measures and threats, taking into account the different desired outcomes (Year 3).
Put simply, the department seeks reliable, robust and repeatable methods to value components of the biosecurity system, in terms of benefits to Australia, and to use these methods to provide estimates of that value.</td></tr>
<tr><td>Outputs</td><td colspan="4">Year one of CEBRA Project 1607A - Value of Australia’s biosecurity system has delivered:
- a comprehensive review of the biosecurity economics literature;
- a detailed description of Australia’s biosecurity system;
- four small case studies highlighting critical issues identified by the project team; and
- a framework for accurately estimating the value of Australia’s biosecurity system (this report).
In short, 1607A has developed a scope for a multi-year project to estimate value at the system level.</td></tr>
<tr><td rowspan="2">CEBRA Workplan Budget</td><td>Year 2016-17</td><td></td><td></td><td></td></tr>
<tr><td>$270,000</td><td></td><td></td><td></td></tr>
<tr><td>Project Changes</td><td colspan="4">Nil</td></tr>
<tr><td>Research Outcomes</td><td colspan="4">N/A</td></tr>
<tr><td>Recommendations</td><td colspan="4">N/A</td></tr>
<tr><td>Related Documents</td><td colspan="4">Project Business Case</td></tr>
<tr><td>Report Complete</td><td colspan="4">Yes</td></tr>
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Year 1 Report: Valuing Australia's Biosecurity System

CEBRA Project 1607A – Milestone 6

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28 November 2017

Acknowledgements

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Executive Summary

Australia operates one of the most comprehensive biosecurity systems in the world. However, due to the system's size and complexity, it is unclear exactly how much monetary *'value'* it generates and where that value is generated within the system. Without a clear understanding of the net benefits obtained from the existing investment in biosecurity activities it is difficult to determine the extent to which the system is achieving its desired objectives (its *'health'*) and also whether there is scope to increase either the value or health of the system by altering the allocation of resources.

Past attempts to value the biosecurity system have been based on ad-hoc and/or qualitative statements of overall benefits or limited to specific major pests or diseases, such as an estimate of the consequences of an incursion of foot and mouth disease in Australia. Consequently, where estimates of value do exist, they have typically been calculated using different measures of value; inconsistent or incomplete monetisation of impacts; incompatible assumptions or counterfactuals; and/or over different temporal or spatial scales. To the best of our knowledge, no equivalent economic evaluation of an entire biosecurity system, or at least a major part of the system, has ever been successfully completed.

Given the scale of the task of estimating value at the system level, a staged approach is required. The first phase of CEBRA project 1607A delivered a comprehensive review of the biosecurity economics literature, and identified suitable methods, measures and indicators of the types of value generated by biosecurity interventions. The purpose of this report is to develop that review into a framework for estimating the value of Australia's biosecurity system through a multi-year project.

We begin by explicitly defining the set of participants, their activities and outputs that collectively comprise Australia's biosecurity system. Then, following the generic framework of Boardman *et al.* (2011), we propose a specific combination of approaches for estimating the value of that system based on its unique characteristics (rather than some theoretical ideal). Throughout the report we draw on a number of case studies to highlight several important issues, or their solutions, that have been identified by the project team over the first twelve months.

In total, we provide seventeen recommendations (see over) that collectively outline a measured and pragmatic approach for estimating the value of Australia's biosecurity system. Wherever possible, we recommend leveraging the existing tools employed by the Department of Agriculture and Water Resources (DAWR) and the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), augmenting these methods only where necessary to improve accuracy or defensibility (such as accounting for changes in consumer surplus). Importantly, we also propose limiting the scope in several respects (such as the breadth of impacts considered), to help keep the valuation tractable in its first iteration.

Finally, although the recommendations that comprise our framework are not novel or controversial from an economic evaluation standpoint, we are not aware of any existing analysis of an Australian biosecurity program that has fully implemented this approach. Consequently, we also recommend that this approach be used as a standardised template for conducting any future evaluations of Australian biosecurity interventions, including those outside the scope of our project, so that their results can be more readily incorporated into any future estimates of the system's value.

Preliminary Recommendations

Section 3.1

- That the current biosecurity system be defined as per its description in section two.
- That the scope of the valuation be limited to activities that directly address a market failure.
- That the counterfactual be defined as the complete absence of all activities considered 'in scope'.

Section 3.2

- That standing be inclusive of Australian 'society as a whole'.

Section 3.3

- That impacts be limited to direct, first-round, impacts.

Section 3.4

- That the Risk Return Resource Allocation (RRRA) model be used to estimate pest arrival rates.
- That integrated bio-economic [partial equilibrium] models be used to estimate impacts.
- That ABARES RRRA consequence method be extended to consider post-border interventions.
- That ABARES RRRA consequence method be extended to include modelling of non-market impacts.

Section 3.5

- That impacts are monetised using economic surplus measures (producer and consumer surplus).
- That ABARES revised consequence method be used exclusively to monetise impacts.

Section 3.6

- That the discount rate be set at 7 percent, with sensitivity analyses at 3 and 11 percent.
- That benefits be calculated over a sufficiently long and variable horizon, such that their discounted value at a point in the future is zero.

Section 3.7

- That expected [risk-adjusted] net present value (eNPV) be the nominated indicator of value.

Section 3.8

- That a sensitivity analysis be considered to be 'in scope'.
- That value of information principles be used to guide any additional data collection/analysis.

Section 3.9

- That the limitations of the final value estimates be considered prior to their use in other contexts.

1 Introduction

1.1 Biosecurity in Australia

Australia has a comparative advantage relative to many developed countries due to its vast and diverse geography, extensive natural resources and the absence of most of the world's major pests and diseases. This allows producers to achieve higher yields with lower production costs, and receive higher prices for goods in premium international markets. Australia also has a mega-diverse natural environment that provides significant *'ecosystem services'* including clean air and water, pollination and social amenity (Daily, 1997; Millennium Ecosystem Assessment, 2005; Pejchar & Mooney, 2009). In turn, this biophysical environment helps to facilitate Australia's strong economy and high standard of living.

Whilst Australia's island geography has long acted as a natural barrier to the movement of pests and diseases (Kloot, 1984; McLoughlin, 2001), globalisation is increasing the rates of movement of both people and goods into Australia from areas where these pests and diseases are more widespread (Ricciardi, 2007; Hulme, 2009). As a consequence, the frequency of pest and disease incursions into Australia continues to increase for most taxonomic groups (Dodd *et al.*, 2015; Seebens *et al.*, 2017). The goal of Australia's biosecurity system is to reduce the likelihood and adverse consequences of these pest and disease incursions on human, animal and plant health, the environment and the economy (Nairn *et al.*, 1996; Beale *et al.*, 2008; COAG, 2012).

Understanding how much value is generated by the biosecurity system and where within the system it is created is critical for ensuring that the system remains both efficient and effective as risk profiles change due to increasing global connectivity (Beale *et al.*, 2008; Heikkilä, 2011; Dana *et al.*, 2014). However, due to the system's size and complexity (not to mention, uncertainty about future threats and our changing capacity to mitigate them), the precise magnitude of its benefits is challenging to estimate (Hulme *et al.*, 2013; Lodge *et al.*, 2016). Challenges also exist in estimating the costs of operating the system without a clear understanding of the activities undertaken by the full suite of participants. Nevertheless, our challenge is to estimate the system's value as accurately as possible.

1.2 Estimating the value of biosecurity systems

A wide range of methods have been used in the scientific literature to infer the economic benefits arising from biosecurity activities. Based on the >300 economic analyses identified in our literature review, several general observations can be made. Typically, these analyses fall into three broad categories: consequence analysis, cost-benefit analysis and optimisation. However, only the latter two, cost-benefit analysis and optimisation, provide measures of 'value', and the overwhelming majority of these studies focus on either a single species or a single intervention. None of the reviewed studies fully considered multiple species <u>and</u> multiple interventions simultaneously (although see Hafi *et al.*, 2015) as is the case in an operational biosecurity system.

Unfortunately, estimating the value of a system is more complicated than just adding together the values of its parts. To illustrate why this is the case, we will work through a selection of issues arising from a simple example based on a well understood threat – foot and mouth disease (FMD). In 2013, ABARES estimated that the economic impact [consequence] of a large FMD outbreak in Australia would be $52bn (Buetre *et al.*, 2013). However, this doesn't imply that the value of preventing an FMD outbreak is $52bn, only what the consequences would be should an outbreak occur.

Instead, the value of the system is determined by the reduction in both the likelihood of an FMD outbreak occurring and the consequences of an outbreak when one does occur (the change in 'expected value'), minus the costs of implementing the system. This is illustrated in Table 1.

Table 1: A stylised approach for estimating the expected net present value of a system aimed at preventing, detecting and eradicating foot and mouth disease.

No Biosecurity System (the 'counterfactual')		
	Annual likelihood:	0.05 (1:20 years)*
	Consequence:	-$100bn *
Expected Value (loss):		-$5bn
Biosecurity System (the 'status quo')		
	Annual likelihood:	0.01 (1:100 years)*
	Consequence:	-$52bn (or -$6bn?)
Expected Value (loss):		-$520M
System Cost:		$100M *
Expected Net Present Value:		**~$4.4bn**

* Indicates hypothetical estimates included for the purposes of illustration.

What becomes clear, when presenting the information in this way, is the importance of correctly describing what would happen in the absence of the biosecurity system as the reference point (the 'counterfactual') from which we estimate the system's net present value. Since the counterfactual cannot be observed, it must be estimated, and no such analysis has been undertaken for Australia. We also don't know the relative likelihoods of the two outbreak scenarios (small and large) modelled by Buetre *et al.* (2013). Calculating an expected value requires an understanding of the distribution of possible outcomes and their relative likelihoods in order to identify the most likely scenario, however, what Buetre *et al.* (2013) report are essentially realistic best and worst-case scenarios.

Each of these estimates are also based on an assumption of *ceteris paribus;* all things remaining as they are. That is, when the consequences of an FMD outbreak are estimated, it is assumed that no other pest or disease outbreaks will occur. Whilst this may be a reasonable assumption in the status quo scenario, in the absence of a biosecurity system (the counterfactual) it is likely that outbreaks of several pests or diseases will co-occur. As such, the interaction between the outbreaks must be considered in order to prevent the double counting of damages. In this scenario we are therefore interested in the additional, rather than absolute, consequence of each additional pest or disease.

Once we start to aggregate together the consequences of multiple outbreaks it also becomes critical that the consequences are estimated using consistent measures and assumptions so that we don't end up comparing apples with oranges. For example, the consequences estimated by Buetre et al. (2013) are measured in terms of impacts on producers (ignoring consumers) whereas the consequences of many pests and diseases, particularly those affecting the environment, are often measured in terms of impacts on consumers (ignoring producers) (e.g. Beville *et al.*, 2012; Akter *et*

al., 2015). If the aim is to aggregate the consequences of these two outbreaks into a single estimate of monetary 'value' then impacts on both producers and consumers (e.g. surplus measures) must be estimated for each pest or disease (Sinden & Griffith, 2007; Soliman *et al.*, 2010; Heikkilä, 2011; Epanchin-Niell, 2017).

It is important to emphasise at this point that this example is not intended to suggest that the analysis of Buetre et al. (2013) is not informative. Rather, it seeks to highlight the significantly higher information requirements needed for moving from consequence analysis to cost-benefit analysis (valuation) and the substantial complexity that arises when trying to aggregate the costs and benefits of multiple species and interventions (see also Liu et al., 2014; Hafi et al., 2015). If we are to make a defensible estimate of the value of Australia's biosecurity system, we will first need to develop novel ways to cut through this complexity without divorcing ourselves from reality.

1.3 Aims and organisation of this report

This report summarises progress made to date on the Centre of Excellence for Biosecurity Risk Analysis (CEBRA) project 1607A – Value of Australia's biosecurity system. The primary focus of this report is on synthesising the findings of our systematic review of the biosecurity economics literature (our previous report) into a framework suitable for estimating the value of Australia's biosecurity system. Importantly, this framework has been designed to make maximum use of pre-existing approaches, such as DAWRs Risk Return Resource Allocation (RRRA) model, and, wherever possible, leverages the approaches and findings of current and previous ABARES and CEBRA projects.

Our report begins with a detailed description of Australia's biosecurity system, developed jointly by the CEBRA 'value' and 'health' project teams, as a consistent basis upon which any estimates of value (or health) will be made. Then, we use the following generic nine step framework developed by Boardman *et al.* (2011) to propose a specific combination of approaches for estimating the value of that system based on its unique characteristics:

1. Specify the set of alternative projects (including the counterfactual).
2. Decide whose benefits and costs count (standing).
3. Identify the impact categories, catalogue them, and select measurement indicators.
4. Predict the impacts quantitatively over the life of the project
5. Monetize (attach dollar values to) all impacts.
6. Discount benefits and costs to obtain present values.
7. Compute the net present value of each alternative.
8. Perform sensitivity analysis.
9. Make a recommendation.

Within each step we provide some context to the issues requiring consideration, recommend a particular method or approach and then discuss any issues or actions that may arise from our recommendations. Throughout the report we also use case studies and examples to illustrate some of the more complex issues, or their solutions, where they have already been identified. Finally, the report concludes with a concise summary of the key recommendations, issues requiring further consideration and brief outline of the next steps for the project.

2 Defining the biosecurity system

The Australian biosecurity system is complex, comprising multiple actions undertaken by a range of participants at different points along the biosecurity continuum – off-shore or pre-border, at the border, and on-shore or post-border. The broad goal of the system is articulated in the Intergovernmental Agreement on Biosecurity (IGAB), an agreement between the Commonwealth, state and territory governments, with the exception of Tasmania. The goal is defined as being '*to minimise the impacts of pests and diseases on Australia's economy, environment and the community, with resources targeted at managing risk effectively across the continuum, while facilitating trade and the movement of animals, plants, people, goods, vectors and vessels to, from and within Australia'* (COAG, 2012).

Beneath this overarching goal the objectives of the national biosecurity system are identified in the IGAB as being to provide arrangements, structures and frameworks that:

- reduce the likelihood of exotic pests and diseases, which have the potential to cause significant harm to the economy, the environment and the community, from entering, establishing or spreading in Australia;
- prepare and allow for effective responses to, and management of, exotic and emerging pests and diseases that enter, establish or spread in Australia; and
- ensure that, where appropriate, significant pests and diseases already in Australia are contained, suppressed or otherwise managed (COAG, 2012).

Through meeting these objectives, the biosecurity system helps to deliver some important outcomes for Australia's economy, environment and people. By reducing the impacts of pests and diseases, an effective biosecurity system supports the sustainability, profitability and competitiveness of Australia's agriculture, fisheries and forestry industries, which, in turn, helps drive a stronger Australian economy. The reduction in pest and disease impacts also contributes to the health of the environment through better functioning ecosystems. It supports a healthier population by reducing the incidence of mortality and morbidity arising from pests and diseases, and underpins resilient communities through its protection of social assets in natural and built environments and the amenity value they create.

2.1 The external context

The Australian biosecurity system does not operate in isolation – global and domestic factors define the context within which biosecurity activities take place. Changes in these factors change the biosecurity risks facing Australia. For example, over time, the scale of biosecurity risks will increase with growing volumes of trade and passenger movements. Containerised imports to Australia are forecast to grow by 50 per cent between 2013 and 2025 and non-containerised imports by 27 per cent (DIRD, 2014). Passenger arrivals by air are expected to increase by more than 90 per cent by 2030, and there is a significant increase forecast in the movement of passengers by sea, including on cruise vessels to remote locations (DIRD, 2014).

Pressures on the biosecurity system will also change as the origin and destination of trade and passenger movements shift, leading to increasingly diverse and potentially higher risk import pathways (Hulme, 2009; Dodd *et al*., 2015). Similarly, international supply chains are expected to become more complex over time with final goods made up of components from multiple origins that may involve different risk profiles, while the growing use of online shopping requires new

approaches to risk management. Other global trends with implications for biosecurity risk are the intensification of agricultural industries, the expansion of monocultures that can concentrate the impacts of pests and diseases, and urbanisation that brings biosecurity risks closer to agriculturally sensitive areas (Craik *et al.*, 2017). The global distribution of pests and diseases is also likely to change in response to factors such as climate. At the same time, technological advances are bringing new opportunities to manage biosecurity risk in innovative and cost-effective ways.

In the domestic context, there is much to protect. Australia's agriculture, fisheries and forestry industries generate significant value and have a reputation for quality and safety that supports their access to international markets. Australia also has a mega-diverse natural environment with many unique native animals and plants (Mittermeier *et al.*, 1997; Mittermeier *et al.*, 2011). Together these characteristics contribute to a strong economy and high standard of living, including access to a rich natural environment. While the immediate impact of biosecurity management is to regulate imports to protect Australian primary industries from unwanted pests and diseases, it also directly underpins export market access and the quality of the environment.

Consistent with its international obligations under the World Trade Organization, Australia has defined its tolerance to biosecurity risk, or its appropriate level of protection (ALOP), as being very low but not zero. This definition is included in the Biosecurity Act 2015 and has been reached with the agreement of all states and territories. It recognises that a zero-risk stance is impractical because it would mean that Australia would have no tourists, no international travel and no imports. It also ignores the potential for pests and diseases to be introduced through natural processes such as wind. Australia's biosecurity risk management measures established in import risk analyses are designed to achieve the broad objective of ALOP.

2.2 Principles of the national biosecurity system

There are a number of principles that underpin the operation of the national biosecurity system that are outlined in the IGAB. These are that:

- biosecurity is a shared responsibility between all participants in the system, including governments; industry; natural resource managers, custodians or users; and the community;
- the attainment of zero biosecurity risk is impossible in practical terms;
- the biosecurity continuum is managed to minimise the likelihood of biosecurity incidents and to minimise their impacts;
- the biosecurity continuum is managed through a nationally integrated system that recognises and defines the roles and responsibilities of all sectors and sets out cooperative activities;
- activity in the system is undertaken and investment is allocated on a cost-effective, science based and risk management approach that prioritises the allocation of resources to the areas of greatest return;
- relevant parties contribute to the cost of biosecurity activities, with governments contributing in proportion to the public good accruing from those activities;
- governments, industry and other relevant parties are involved in decision-making according to their roles, responsibilities and contributions; and
- Australia's national biosecurity arrangements comply with its international rights and obligations.

These principles provide a guiding framework for the operation of the biosecurity system and strengthen the collaborative approach between the Australian, state and territory governments and other participants.

2.3 Participants in the biosecurity system

Given the broad ranging objectives of the national biosecurity system, encompassing economic, environmental and social dimensions, there are many participants. These are, principally, the Australian government, state, territory and local governments, industry representative groups, land holders and producers, research providers, relevant non-government organisations (NGOs) and the general community. Each of these has different roles and, in some cases, formal responsibilities.

Governments, as regulators, have prime responsibility for the development, implementation, monitoring and enforcement of the system (Beale *et al.*, 2008). The Australian government is responsible largely for the pre-border and border elements of the biosecurity system. It also conducts some specific post-border activities such as the Northern Australia Quarantine Strategy (NAQS) and shares funding with the states and industry for other pest and disease control and surveillance programs, including those conducted through Animal Health Australia and Plant Health Australia.

State and territory governments are responsible for animal and plant health within their jurisdictions, and participate with the Australian government and industry to coordinate national programs. They share enforcement activities with the Commonwealth. There are formal institutional arrangements under the National Biosecurity Committee (NBC) that provide a forum for Commonwealth and state and territory collaboration and decision making on priority biosecurity issues (see Box 1).

Box 1: National Biosecurity Committee

The National Biosecurity Committee (NBC) provides advice to the Agriculture Senior Officials' Committee and the Agriculture Ministers' Forum on national biosecurity and on progress on implementing the Intergovernmental Agreement on Biosecurity. The NBC is also responsible for managing a national, strategic approach to biosecurity threats relating to animal and plant diseases and pests, marine pests and aquatics, and the impacts of these on agricultural production, the environment, community well-being and social amenity. A core objective of the committee is to promote cooperation, coordination, consistency and synergies across and between Australian governments. The NBC is supported by four sectoral committees (Animal Health Committee, Plant Health Committee, Marine Pest Sectoral Committee and the Invasive Plants and Animals Committee) that provide policy, technical and scientific advice on matters affecting their sector. The NBC also forms expert groups and short-term task specific groups from time to time to provide advice and deliver key initiatives.

Local governments provide biosecurity-relevant services, including controls on domestic and feral animals, weeds and wildlife, and are essential participants in emergency responses to pest and disease incursions(Beale *et al.*, 2008). In some jurisdictions, local governments may have a regulatory role to direct landholders to control noxious weeds.

Farmers and industry groups manage biosecurity within their areas of operation, including developing biosecurity plans and adopting measures that reduce biosecurity risk. Animal Health Australia and Plant Health Australia are important partnerships between industry and governments that work to achieve biosecurity outcomes through a range of projects and programs (see Box 2).

Box 2: Animal Health Australia and Plant Health Australia

Animal Health Australia and Plant Health Australia are not-for-profit companies that facilitate partnerships between the Commonwealth and state and territory governments and industry. Animal Health Australia facilitates improvements in Australia's animal health policy and practice in partnership with the livestock industries, governments and other stakeholders; builds capacity to enhance emergency animal disease preparedness; ensures that Australia's livestock health systems support productivity, competitive advantages and preferred market access; and contributes to the protection of human health, the environment and recreational activities (AHA, 2017). The purpose of Plant Health Australia is for government and industry to have a strong biosecurity partnership that minimises pest impacts on Australia, enhances market access and contributes to industry and community sustainability (PHA, 2017b).

Other businesses and individuals participate in the biosecurity system. These include those directly engaged in biosecurity activities, such as those involved in importing goods to Australia, including importers, customs brokers, freight forwarders, managers of facilities under approved arrangements, retailers and others along the supply chain, as well as those in ancillary activities such as travel and shipping (Beale *et al.*, 2008). Other community members and groups, including NGOs, contribute to the biosecurity effort in diverse ways, including through coordinated or individual passive surveillance activities, and general awareness raising efforts.

The research community is another essential element of the biosecurity system and supports Australia's science based approach to biosecurity risk management. Biosecurity relevant research is delivered through a range of funding mechanisms and by multiple providers, including the CSIRO, universities, the Rural Research and Development Corporations (RDCs), Cooperative Research Centres (CRCs) and government agencies. Many organisations that are involved in biosecurity risk management, including AHA, PHA, the Invasive Plants and Animals Committee and Rural RDCs have developed research and development strategies. The National Biosecurity Committee has endorsed overarching national biosecurity Research, Development and Extension priorities that are intended to provide a strategic and unified guide to investment in high priority research activities (DAWR, 2016c; Craik *et al.*, 2017).

The concept of 'shared responsibility' across the many participants in the national biosecurity system has underpinned the system for some time and is a core principle of the IGAB. However, as the recent review of the IGAB identifies, the roles and responsibilities of participants in the national biosecurity system are not well articulated and have not been agreed formally. This limits the broad understanding and effectiveness of the 'shared responsibility' concept (Craik *et al.*, 2017).

2.4 Resourcing the national biosecurity system

A diverse range of inputs is required to ensure the effective and efficient operation of the national biosecurity system. In financial terms, the system represents a significant investment by participants with expenditure totalling nearly $1 billion in 2015-16. The Australian government currently spends approximately $624 million a year on its biosecurity responsibilities. States and territories collectively spend in the order of $375 million each year. Industry participants contribute to the system directly through levies on production and fee for service payments (approx. $575 million), and together with landholders and community groups make substantial in-kind contributions.

The most important element of resourcing in the biosecurity system is the human resource, encompassing both the number, or capacity, of people who work within the system and their capability. A diverse range of skills is required to ensure the effective operation of the system. These include veterinary and plant sciences, taxonomy, diagnostics, epidemiology, and entomology. Advanced skills in statistics, data analytics and risk analysis are becoming increasingly important inputs to effective biosecurity risk management. The human resources in the biosecurity system also include government officers who perform policy, management and operational functions, in offices and in the field. Also critical are the skills of those participants in the system that provide in-kind support such as producers who manage on-farm biosecurity and community groups that undertake and report on passive surveillance activities. Skills shortages in some key science-based areas are an emerging concern in the biosecurity system.

There are also extensive physical resources that support the biosecurity system. These include inspection facilities at major points of entry to Australia – airports, sea ports and international mail centres; diagnostic facilities, including laboratories, equipment and taxonomic collections that support activities at the border and post border; post-entry quarantine facilities to screen high risk materials before they are cleared for entry to Australia; and information technology (IT) systems that facilitate the collection, management and analysis of the significant amounts of data generated by the biosecurity system. While many of these resources are managed and operated by the Australian and state and territory governments, industry also contributes physical resources, including approved premises for quarantine purposes and facilities and IT infrastructure operated by customs brokers and freight forwarders.

2.5 Biosecurity is a complex system

A characteristic of the biosecurity system is the complex interactions that occur between different participants at different stages of biosecurity risk management. The many components of the system are interconnected and interdependent and can interact with each other in unpredictable ways such that outcomes of the system cannot necessarily be forecast on the basis of known components. Some interactions are non-linear in nature so that small changes in inputs, for example surveillance effort, can have large impacts on outcomes, such as detection of invasive species, and vice versa. There are also multiple feedback loops in the system that may not be readily apparent (see Box 3). Consequently, the outcomes of risk management interventions may be highly dependent on the context in which they are implemented – the same action may lead to different outcomes in different sets of circumstances.

Box 3: Feedback loops in the biosecurity system

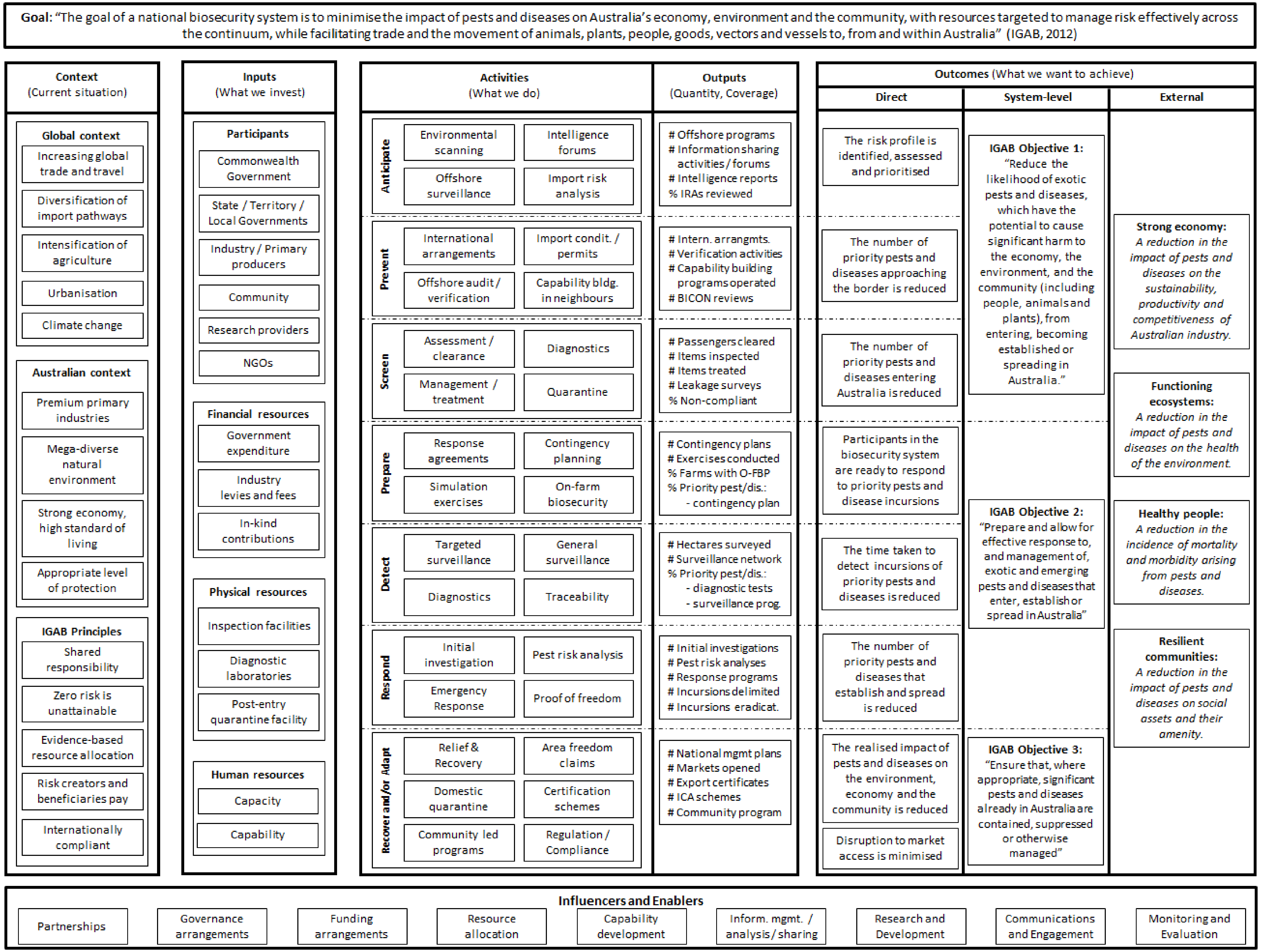
In 2015-16 the Australian government Department of Agriculture and Water Resources reviewed the global risk profile of a range of pests, including the bacterial pathogen *Xylella fastidiosa*. Xylella is an invasive bacterial plant pathogen that causes significant environmental and economic impacts. Xylella is spreading around the world and, although not present in Australia, is of major concern to Australia's plant industries. Following this review, the department implemented emergency quarantine measures to reduce the likelihood of entry of Xylella and strengthened the import requirements for several plant species considered to pose an increased risk of introducing Xylella.

Adding to the complexity of the system is that the external environment is dynamic and evolving rapidly over time. For example, the recent growth in new channels for trade such as e-commerce has been swift and has required the implementation of new rules and practices, including the development of new relationships, to manage the changing pathways of biosecurity risks. A further complicating factor is increasing incidents of deliberately non-compliant behaviour by importers, including those who are beneficiaries of the biosecurity system. Designing systems that incentivise compliant behaviour without imposing undue efficiency costs on system participants is an ongoing challenge.

The existence of complexity and the lack of clarity around the roles and responsibilities of participants mean that it is difficult to succinctly and clearly define the overall biosecurity system. However, developing a framework for evaluating the performance or measuring the value of the system requires an appropriate balance between the detail inherent in the system and the practical requirements of implementing a meaningful evaluation, or valuation, framework.

The following draws on the broad outline of the national biosecurity system in the IGAB, as well as the detailed descriptions contained in the Risk Return Resource Allocation model developed by the Department of Agriculture and Water Resources. It uses a program logic model to describe the key inputs to the system, the main activities that are performed and the outcomes that are derived from the operation of Australia's biosecurity system.

Figure 1: Program logic diagram outlining the relationships between inputs, activities/outputs and outcomes within Australia's biosecurity system



2.6 Activities

The Australian biosecurity system consists of a set of activities that are designed to:

- **anticipate** biosecurity risk;
- **prevent** the entry of exotic pests and diseases;
- **screen** goods, conveyances and people at the border to detect non-compliance;
- **prepare** for an outbreak or incursion of exotic pests and diseases;
- **detect** any pest and disease outbreaks or incursions within Australia;
- **respond** to an incursion of an exotic or established pest or disease; and
- **recover** from an incursion and **adapt** to the new circumstances created by an incursion.

Associated with each of these activities is a range of risk management interventions undertaken by various participants in the biosecurity system. These are outlined below and in Figure 1.

Anticipate biosecurity risk

Understanding the context in which Australia's biosecurity system operates, particularly the offshore environment, is important because it helps us anticipate biosecurity risk. This helps us identify the potential biosecurity risks facing Australia. Enhanced anticipation of these risks increases our capacity to prepare for and manage those risks in a timely and cost effective manner.

A key activity that contributes to this element of the biosecurity system is environmental scanning that systematically examines the external environment and detects early signs of emerging biosecurity risks. Environmental scanning involves understanding trends in global production, trade and travel and the risks arising from these, including changes in risk pathways for high risk species. It also includes tracking of global pest and disease spread and increasing our understanding of the pest and disease status in our near neighbours.

Another activity that enhances our capacity to anticipate biosecurity risk is participation in intelligence forums that contribute information and assessments of emerging risks. The Australian government conducts this type of activity across functional areas to identify changes in the external environment that might lead to changes in risk profiles.

Active surveillance for biosecurity risks in our near neighbours and trading partners is also designed to enhance our capacity to anticipate risk. Understanding the pest and disease status in our neighbouring countries contributes to identifying the potential for biosecurity risks to threaten Australia's animal and plant health. For example, the Australian government undertakes regular surveys of animal and plant health in Indonesia, Papua New Guinea and Timor Leste, in cooperation with the authorities in those countries.

These types of activities – environmental scanning, intelligence forums and offshore surveillance – generate considerable volumes of data and information. Ensuring that this translates to robust intelligence that can be used to manage risk effectively requires the capacity to analyse, report and provide timely access to the outputs of these activities to all relevant participants in the biosecurity system. Although most of the investment in anticipation activities is undertaken by the Australian government, the intelligence that is generated is highly valued by state and territory governments, industry and other players in the system.

Using its understanding of the biosecurity risk context facing Australia, the Australian government prioritises risks and undertakes biosecurity import risk analyses (BIRAs) or non-regulated risk

analyses (see Box 4). These are designed to assist the Australian government to consider the level of biosecurity risk associated with the importation of goods into Australia. If the biosecurity risks exceed the appropriate level of protection, then risk management measures are proposed to reduce the risks to an acceptable level. If the risks cannot be reduced to an acceptable level, the goods will not be imported into Australia until suitable measures are identified (DAWR, 2016d).

Box 4: Biosecurity import risk analyses and non-regulated risk analyses

A BIRA is generally undertaken in response to a new import proposal where risk management measures have not been established or where biosecurity risks could differ significantly from those associated with the import of similar goods. A BIRA is conducted through a regulated process under the *Biosecurity Act 2015* and Biosecurity Regulations. A non-regulated analysis is undertaken where the criteria for a BIRA are not met and can include reviews of existing policies or import conditions or reviews of biosecurity measures in response to new scientific information.

The risk measures proposed in import risk analyses must be compliant with Australia's international trade and biosecurity obligations and apply Australia's ALOP in a consistent manner.

The direct outcomes from the suite of activities that are designed to anticipate the biosecurity risks facing Australia are that the range and magnitude of risks are identified and understood, can be prioritised, and then analysed according to their priority. This increases the capacity to allocate investment across the biosecurity system more efficiently and to manage risk more effectively.

Prevent entry of risk material

Preventing pests and diseases from entering Australia on goods or conveyances is generally considered to be the most cost-effective approach to managing biosecurity risk. Along with anticipation activities, the returns on investment in prevention are believed to be higher than at other points on the biosecurity continuum (Biosecurity Victoria, 2009, 2010). The overarching aim of prevention activities is to manage biosecurity risk off shore in order to prevent threats to Australia's animal and plant health reaching the border.

Among the activities undertaken to prevent biosecurity threats reaching Australia are cooperation in international forums such as the World Organisation for Animal Health (OIE), the International Plant Protection Convention (IPPC) and Codex Alimentarius to develop science based standards, guidelines and codes of practice for the safe trade of animal, plant and food products. Australia has also ratified the International Convention for the Control and Management of Ships' Ballast Water and Sediments (the Ballast Water Management Convention), which came into effect in September 2017 and establishes global regulations to control the transfer of potentially invasive species. The Biosecurity Act 2015, as amended, establishes national domestic ballast water requirements that are consistent with the Convention to reduce the risk of spreading marine pests that establish in Australian seas. Other international arrangements between governments and importers to agree upon offshore risk mitigation measures can also be effective mechanisms for managing biosecurity threats. The Australian Fumigation Accreditation Scheme (AFAS), the Quarantine Regulators' Meeting (QRM), the International Cargo Cooperative Biosecurity Arrangement (ICCBA) and the Sea Container Hygiene Scheme (SHS) are examples of these mechanisms (Box 5).

Box 5: International risk mitigation arrangements

The Australian Fumigation Accreditation Scheme (AFAS) is a management system run by participating overseas government agencies to ensure compliance of fumigators with Australia's treatment requirements as well as a registration system for fumigation companies. The Quarantine Regulators' Meeting (QRM) is an annual forum that aims to connect government agencies responsible for, or involved in, biosecurity and border management. Its focus is to support a harmonised approach to biosecurity border management relating to cargo. The International Cargo Cooperative Biosecurity Arrangement (ICCBA) is a voluntary non-binding, multilateral arrangement that encourages international cooperation on the harmonisation and verification of international biosecurity activities

A further approach to preventing biosecurity risks arriving at the Australian border is the development of import protocols that define the conditions under which biosecurity risk material can be imported to Australia. These conditions are generally based on the BIRAs and non-regulated import risk analyses undertaken by the Australian government. They are implemented through the issuing of import permits to individual importers that specify the conditions under which a commodity is permitted to be imported. In 2015-16, 19,000 import permits were issued by the Australian government (DAWR, 2016b).

The Australian government conducts off-shore audit and verification activities to provide assurance that import conditions are met and that risks are mitigated prior to arriving at the border. Periodic audits are undertaken, for example, of pre-export quarantine facilities for horses and ornamental fish and of approved treatment facilities for imported plant material. The Australian government also certifies competent authorities in exporting countries to undertake some pre-export activities. In the case of live animal imports, for example, the government veterinary service in the country of export will certify that the animal complies with the requirements described in the import permit.

An additional measure that reduces the likelihood of risk material arriving at the Australian border is work undertaken in neighbouring countries to build their capacity to manage biosecurity risks. The Australian government supports a number of projects in Indonesia, Papua New Guinea and Timor Leste on issues such as strengthening the capacity of government veterinary services, enhancing poultry biosecurity, and establishing surveillance systems that provide early warning of pests and diseases that could potentially enter Australia. Some state and territory governments and other institutions also contribute to this area of activity.

The intended outcome of this suite of activities is that the majority of biosecurity risks are managed offshore, leading to a reduction in the number of priority pests and diseases that arrive at the Australian border.

Screen risk material at the border

Investments by governments and other participants in the biosecurity system to anticipate and prevent risk material arriving at the border will not be completely effective. This is consistent with the setting of Australia's risk tolerance or ALOP to a very low level but not to zero. As a result, the screening of passengers, cargo, plants, animals and mail at ports and airports and through mail centres to ensure that they meet import conditions is an important risk management intervention. The screening of conveyances – vessels and aircraft – is a further element of the biosecurity system designed to reduce the number of 'hitchhiker' pests entering Australia.

The Australian government is largely responsible for activities undertaken at the border. This includes the assessment of passengers, mail, cargo, vessels, live animals and plant material for biosecurity risk. Each year, millions of items are assessed at arrival ports (Table 2). Commercial goods are classified before their arrival according to their tariff code as well as characteristics such as country of origin, supplier and importer. This classification, called profiling, is used as a screening step to determine if further biosecurity management intervention, such as inspection, is necessary.

Many imported goods are not of biosecurity concern. For those that are, clearance without inspection, using declarations and information provided by the importer, is common. Goods may be released from biosecurity control or directed for further assessment. This could include inspection, diagnostic testing, and, where a biosecurity concern is identified, management such as treatment, export or destruction. Some goods that would not typically be directed for inspection will be randomly selected for inspection as part of the Cargo Compliance Verification Scheme.

The Department of Agriculture and Water Resources operates an 'approved arrangements' system that permits authorised entities to perform certain activities with goods under biosecurity control without the supervision of biosecurity officers. This involves using their own premises, facilities, equipment and people and is subject to periodic compliance monitoring and auditing.

Where assessment of goods is required, assessment regimes are designed that are based on sound science and statistics and targeted at highest priority risks. Inspections rely on investment in the quality and capacity of inspectorate staff supported by border biosecurity tools and infrastructure such as x-ray machines, detector dogs, and diagnostic capabilities that are capable of dealing with increasing passenger and goods volumes.

Goods may be cleared following inspection if they comply with import conditions. Alternatively, they may be directed for diagnostic testing to identify if biosecurity risk material is present. This relies on the availability and quality of diagnostic facilities, including laboratories, tests and trained staff. Following assessment, if the goods pose an unacceptable biosecurity risk then they may be directed for management, which may involve treatment such as fumigation, export or destruction to manage biosecurity risks.

In the case of imports of live animals, hatching eggs and plant material, import conditions require that they be quarantined in Australia's post arrival quarantine facility, or other approved facilities, for specified periods of time, where they will be observed and tested to ensure that they do not present a biosecurity threat on release.

Management at the border also involves a range of measures designed to target, assess and manage non-commodity risks. These are risks that are not specific to the imported goods but are facilitated through the movement of goods, people and conveyances. The pests and diseases in this category are commonly referred to as 'hitchhikers' and may be attached to a container carrying the goods, the packaging around the goods, or the vessel or aircraft. The types of hitchhikers are varied and can include tramp ants, reptiles, bees, beetles, snails, other animals and dirt. Programs are in place to manage these risks, including targeting at the border, and industry and community communication and reporting programs.

The outcome of these activities at the border is a reduction in the number of priority pests and diseases that enter Australia. Post arrival verification activities such as leakage surveys are undertaken at the border to estimate the success of these intervention strategies.

Table 2: Size of the import task, selected indicators, 2015-16 *(DAWR, 2016b)*

Indicator	Volume
Passenger clearances	19,000,000
International mail articles	138,000,000
Pratique visits – first ports	18,000
Wharf gate sea container inspections	250,000
Import permits issued	17,000
Live animal imports in Post Entry Quarantine	5,700

Collectively, the activities undertaken to anticipate biosecurity risk, prevent risk material arriving at the Australian border and to screen passengers, cargo, plants, animals and mail at the border to ensure they comply with import conditions contribute to meeting the first objective of the IGAB, that is, to 'reduce the likelihood of exotic pests and diseases, which have the potential to cause harm to the economy, the environment and the community (including people, animal and plants), from entering, becoming established and spreading in Australia'.

Prepare for an incursion

Given Australia's ALOP, it is not expected that pre-border and border activities will successfully intercept all threats to Australia's plant and animal health from exotic pests and diseases – some biosecurity risk material will inevitably cross the border. Across Australia, 18 outbreaks of pests and diseases were being managed in August 2017 (DAWR, 2017). Considerable investment is undertaken by a range of participants in the biosecurity system to ensure that Australia is well prepared to respond to incursions of pests and diseases in order to minimise the likelihood that they establish in Australia and to reduce or contain the harmful impacts on the economy, the environment and the community caused by those that do.

A major set of activities that helps participants in the biosecurity system prepare for an incursion of a potentially harmful exotic pest or disease is the development and maintenance of emergency response deeds and agreements and contingency plans. These define the nationally agreed approach that will be taken in an incursion response so that participants are able to respond quickly and effectively when one occurs.

Animal Health Australia is custodian of the Emergency Animal Disease Response Agreement (EADRA) and the Australian Veterinary Emergency Plan, or AUSVETPLAN. The EADRA is a contractual agreement between the Commonwealth, state and territory governments and livestock industry groups to increase Australia's capacity to prepare for and respond to emergency animal disease incursions. In particular, it defines how to manage the costs and responsibility for an emergency response to an animal disease outbreak. For all EADs listed in EADRA, there is an agreed initial approach to responding to an outbreak set out in AUSVETPLAN. AUSVETPLAN consists of a series of technical manuals and supporting documents that describe the proposed approach to an emergency animal disease incident, including roles, responsibilities and policy guidelines for agencies and organisations involved in the response to a disease outbreak (PIMC, 2008).

The equivalent arrangements for emergency plant pest incidents are the Emergency Plant Pest Response Deed (EPPRD) and PLANTPLAN, both of which are managed by Plant Health Australia (PHA, 2016, 2017a).

EMPPLAN and AQUAVETPLAN set out the preferred approach to diseases that affect marine and aquatic animals, respectively. The Department of Agriculture and Water Resources manages the development and maintenance of both plans.

The National Environmental Biosecurity Response Agreement (NEBRA) sets out emergency response arrangements, including cost sharing arrangements, for responses to biosecurity incidents that primarily affect the environment and/or social amenity and where the response is for the public good. It was delivered under the IGAB.

As well as formal agreements and contingency plans, training activities are used to help participants in the biosecurity system maintain their readiness for a response to an incursion of an emergency pest or disease. This includes emergency response simulation exercises that test the capacity of the biosecurity system to respond. Exercise Odysseus, for example, was a series of more than 40 simulated field activities and discussions in each Australian state and territory held throughout 2014 and 2015. It was designed to focus on the first week of a hypothetical outbreak of foot and mouth disease initially detected in Queensland. Exercise Haryana was conducted in 2015 and 2016 to test the preparedness for, and capacity to respond to a Karnal bunt detection in Australia. Simulation exercises typically involve government and industry representatives.

Other activities to prepare for an emergency animal disease (EAD) incursion include training for government officers, private veterinary practitioners and livestock industry managers in emergency response functions; the development of national scale modelling capability to capture complex disease epidemiology, regional variability in transmission, and different jurisdictional approaches to disease control; and membership in the International Animal Health Emergency reserve, an arrangement between Australia, Canada, Ireland, New Zealand, the United Kingdom and the United States to share personnel and resources in an EAD outbreak (AHA, 2017).

Good on-farm biosecurity practices can be a powerful means of reducing the risk that an exotic pest or disease present in Australia can establish and spread. While good farm biosecurity is the responsibility of land owners and managers, training programs are important for raising awareness and disseminating information about good practices. The Farm Biosecurity Program is a joint initiative of Animal Health Australia and Plant Health Australia that provides information and on-line resources on a range of farm level biosecurity issues.

The intended outcome of activities that increase our preparedness for an emergency pest or disease incursion is that participants in the biosecurity system are ready to respond to new incursions, with the appropriate arrangements, tools and training to maximise the effectiveness of the response action. In this way, the potential harm from newly detected pests and diseases is minimised.

Detect an incursion post border

Early detection of an exotic pest or disease incursion can significantly improve the outcomes of response activities. Targeted, or active, and general surveillance programs to ensure timely detection of pests and diseases are important components of the biosecurity system. Effective surveillance requires cooperative partnerships between the Australian and state and territory governments, industry and the community and is part of the shared responsibility concept described in the IGAB. The Australian government is responsible for reporting surveillance outcomes to the

OIE and the IPPC. State and territory governments run many surveillance programs targeting exotic pests and diseases, as well as extensive general surveillance activities. By underpinning Australia's claims to pest and disease freedom, surveillance activities facilitate access to international markets, as well as supporting the management of established pests and diseases.

In 2016, the Animal Health Committee endorsed the National Animal Health Surveillance and Diagnostics Business Plan 2016-2019 (DAWR, 2016a), developed collaboratively by the Australian, state and territory governments and livestock industries. Under this business plan, Animal Health Australia coordinates several active or targeted surveillance programs, including the National Arbovirus Monitoring Program, the National Sheep Health Monitoring Program, the National Transmissible Spongiform Encephalopathies Surveillance Project and the Screw-worm Fly Freedom Assurance Program. Other programs use targeted and general surveillance activities to provide early detection of diseases, including the National Significant Disease Investigation Program and the National Avian Influenza in Wild Birds Surveillance Program (Box 6).

Surveillance activities are undertaken by jurisdictional veterinary authorities, private practitioners, industries and non-government organisations under a range of partnership agreements. Collectively, state and territory governments invest in more than 100 field veterinarians with district surveillance responsibilities, supported by seven government veterinary laboratories, veterinary pathology staff, abattoir veterinarians and inspectors and stock inspectors (Craik *et al.*, 2017).

In addition, the Australian Government funds the Northern Australia Quarantine Strategy (NAQS), which undertakes surveillance for targeted animal diseases in coastal areas of northern Australia from Broome to Cairns.

Box 6: National Avian Influenza in Wild Birds Surveillance Program

The National Avian Influenza in Wild Birds Surveillance Program is conducted Australia-wide and comprises two components: targeted surveillance via sampling of apparently healthy and hunter-killed birds, and general surveillance via investigation of significant unexplained morbidity and mortality events in wild birds, including captive and wild birds within zoo grounds. Sources for targeted wild bird surveillance data include state and territory government laboratories, universities and samples collected through the NAQS program. Samples from sick birds are sourced from members of the public, private practitioners, universities, zoos and wildlife sanctuaries. The program is managed by Wildlife Health Australia.

Plant pest surveillance activities are, similarly, undertaken on a collaborative basis between the Australian, state and territory governments, industry and the community. Current surveillance activities are outlined in the National Plant Biosecurity Surveillance Strategy 2013-2020 (PHA, 2013). They include the National Plant Health Surveillance Program (NPHSP) coordinated by the Australian Department of Agriculture and Water Resources. The objective of the NPHSP is to 'develop and implement a nationally consistent, multi-jurisdictional approach to plant pest surveillance that incorporates pest surveillance activities in the vicinity of ports as well as in urban areas that have a relatively high risk of pest presence based on pathway and host considerations' (PHA, 2013). Its three main components are ports of entry trapping, multiple pest surveillance and surveillance information management. The Australian government also undertakes surveillance for plant pests through the NAQS program.

State and territory governments run a number of surveillance programs targeting a range of exotic and established plant pests. General surveillance is also used, involving the development and dissemination of awareness information relating to pest threats, as well as maintaining systems for public reporting. Agricultural participants also invest in surveillance, either directly or through the purchase of services from private or government providers, primarily to manage established pests on an ongoing basis (PHA, 2013).

Early detection of exotic incursions also relies on having sound diagnostic capability and capacity available to support identification of pests and diseases. Diagnostic services (i) underpin the identification of exotic, emerging and nationally significant endemic pests and diseases; (ii) assist in assessing the magnitude of an incursion, which helps determine whether a pest or disease is eradicable; and (iii) provide evidence to support any claim that a pest or disease has been eradicated. They provide the necessary information to support pest and disease control programs and reporting requirements (Craik *et al.*, 2017).

Australia's animal disease diagnostic capacity is well developed. Facilities include the Australian Animal Health Laboratory, state and territory government veterinary laboratories and university and private veterinary laboratories. Institutional arrangements support the effective operation of the laboratory system. For example, the Laboratories for Emergency Animal Disease Diagnosis and Response (LEADDR) network plays an important role in ensuring quality assurance for targeted emergency animal diseases through standardising or harmonising the relevant testing performance in all member laboratories. All government laboratories and the major private laboratories in Australia are accredited by the National Association of Testing Authorities (NATA) for testing of various emergency animal diseases.

Plant pest diagnostic facilities are distributed across all states and territories, including in major agricultural and horticultural regions. Services are delivered by a range of agencies, including the Australian government, state and territory governments, private laboratories, museums, the CSIRO and universities. Services are provided on an ad hoc, commercial or nationally coordinated basis. Diagnostic operations are often performed as part of collaborative research activities that focus on specific pests of concern (PHA, 2017b).

The Subcommittee on Plant Health Diagnostics was established in 2004 by the Plant Health Committee to improve the quality and reliability of plant diagnostics in Australia. Its role includes to develop diagnostic policies, protocols and standards; to develop strategies to address national capability and capacity issues; to endorse national diagnostic protocols; and to drive the development and uptake of accreditation and quality management systems for diagnostic laboratories. Unlike the animal system, not all plant diagnostic laboratories are accredited by NATA to the appropriate international standard. The plant pest diagnostic system is underpinned by the National Plant Biosecurity Diagnostic Strategy (PHA, 2012) and a national network of diagnosticians. The latter improves capacity by facilitating communication between experts and sharing of diagnostic resources. Together these initiatives are designed to build an integrated national network that can provide efficient delivery of services, including the provision of surge capacity during incursions (PHA, 2017b).

Not all exotic pest and disease incursions are initially identified at source. A diseased animal, for example, might have been moved from its property before identification occurs at a saleyard or abattoir, or an infected plant might have been sold from an importer to a retail chain before detection occurs. The capacity to trace the source of an incursion is an important part of the detection element of the biosecurity system.

Animal traceability systems in Australia are well developed under the National Livestock Identification System (NLIS). The NLIS was developed to meet the National Livestock Traceability Performance Standards (NLTPS) endorsed in 2004 by the former Primary Industries Ministerial Council (PIMC). The NLTPS outline the requirements and timeframes for livestock to be traced quickly and reliably if needed (ABARES, 2014).

Under the NLIS all cattle, goat, pig and sheep producers must identify their stock and record their movements onto and off properties in the NLIS database. All movements to and from saleyards and abattoirs must also be recorded. When fully implemented for a type of livestock, NLIS is a permanent, whole-of-life system that allows animals to be identified – individually or by mob – and tracked from property of birth to slaughter, for the purposes of food safety, product integrity and market access (AHA, 2017). Box 7 summarises the status of animal traceability systems in Australia.

Box 7: Status of national animal traceability systems

NLIS (Cattle) is an electronic identification system for individual animals. NLIS (Sheep and Goats) is a mob-based system using visually readable ear tags labelled with property identification codes. Victoria is currently transitioning to an individual electronic identification system for sheep and goats. Australian Pork Limited is continuing to develop NLIS (Pigs), or PigPass, and voluntary movement reporting occurs through the PigPass portal. The development of legislation for NLIS (Pigs) is progressing. An NLIS (Alpaca and Llama) tracing system is also under development (AHA, 2017).

State and territory governments are responsible for the legislation governing animal movements, the implementation of NLIS and monitoring of compliance with NLIS requirements throughout the livestock supply chain. NLIS Limited administers the NLIS database on behalf of industry and government stakeholders (AHA, 2017).

Tracing the source of a plant pest incursion is a more ad-hoc process than occurs in the animal system, partly because plant pests move independently of their hosts. Hence there is no feasible equivalent of the NLIS and tracing activities are conducted on a case-by-case basis. An incursion of Mexican feather grass in Victoria in 2008 is an example of the types of actions undertaken to trace an incursion back to its source (see Box 8). The capacity to implement a successful tracing exercise in these circumstances relies on sound relationships between participants in the biosecurity system, the willingness of all participants to contribute to the tracing effort and effective communication.

Box 8: Tracing of a Mexican feather grass incursion in Victoria, May 2008

Following a detection of Mexican feather grass in a large retail chain, tracing was conducted by the state government back along the supply chain to the seed importer and forward through distribution channels to discover more than 10,000 plants for sale in Victorian retail outlets. Statewide product recalls were initiated, instructing retail chains to recover as many plants as possible. Sales information, including credit card transactions, was used to help assess where plants had been planted. New building-permit information from local governments provided locations for targeted public awareness campaigns. Community weed spotters were alerted to support the surveillance effort. *Source: Biosecurity Victoria (2009)*

The intended outcome of the surveillance activities, the provision of sound diagnostic services and the capacity to trace an incursion to its source is that the time taken to detect incursions of priority pests and diseases is reduced. This contributes to minimising the costs of response activities and maximising the effectiveness of eradication or containment efforts.

Respond to an incursion

Following the detection of an exotic pest or disease, response actions are implemented collaboratively between governments, industry and other stakeholders. Broad response actions are outlined in the response agreements and contingency plans discussed above – EADRA and AUSVETPLAN; EPPRD and PLANTPLAN; EMPPLAN and AQUAVETPLAN; and NEBRA. These are supported by detailed industry specific or pest/disease specific response plans. The agreements and plans are designed to ensure rapid and effective responses to detections and to provide certainty regarding the management and funding of the response.

Coordination of response activities is enhanced by the use of established management groups and consultative committees. The National Management Group (NMG) is responsible for making the key decisions in a response to an emergency pest or disease incursion. It is formed in response to a detection and comprises representatives from the Australian and state and territory governments, AHA/PHA, and affected industries. The NMG is responsible for approving a response plan, including the budget, if it is agreed that eradication is technically feasible and cost beneficial. The NMG is advised on technical matters by the relevant Consultative Committee (CC). The CC comprises the Australian Chief Plant Protection Officer/Chief Veterinary Officer, their state and territory counterparts, AHA/PHA, and industry representatives. It assesses the grounds for eradication and provides technical advice on which the NMG can base decisions. Operational responsibility for the response to an emergency incursion lies with the relevant state or territory.

Once a detection has been advised to a government party, the deeds require that the relevant government advises the CC within 24 hours. There follow sequential phases of response activities, as outlined in the relevant deeds. These are:

i) *The incident definition phase* where an initial investigation is undertaken by the relevant government authority. On the basis of a pest risk analysis, the CC advises the NMG if the incident relates to an emergency incursion and is capable of being eradicated or contained. In this case, an emergency response plan (ERP) is agreed by the NMG.

ii) *The emergency response phase* during which the ERP is implemented. The control measures used may evolve as new information about the outbreak becomes available. This phase continues until the NMG, on advice from the CC, determines that the incursion has been contained or eradicated, or cannot be contained or eradicated.

iii) *The proof of freedom phase* following a declaration by the NMG that an outbreak has been contained or eradicated. This period may include research and/or surveillance activities and will end when the NMG determines that the ERP has been successful.

iv) In the case of plant pests, where containment or eradication is not feasible, a *transition to management phase* may be determined by the NMG where it considers that transition to management is achievable within a reasonable timeframe not exceeding 12 months.

In the small number of cases where an exotic pest or disease incursion affects an industry that is not covered by a deed, the state or territory where the outbreak occurs is responsible for the response plan and the negotiation of funding arrangements. Currently, more than 90 per cent of the value of Australia's agricultural production is covered by the relevant deeds.

Having mechanisms in place that support rapid and effective responses to pest and disease incursions, including decisions about eradication and containment, ensures that the number of priority pests and diseases that establish and spread in Australia is reduced.

Collectively, the activities undertaken to prepare for an incursion, detect an incursion post-border and respond to an incursion once detected contribute to meeting the second objective of the IGAB, that is, to 'prepare and allow for effective response to, and management of, exotic and emerging pests and diseases that enter, establish or spread in Australia'.

Recover and/or Adapt to an incursion

A number of activities are undertaken as part of the biosecurity system are designed to manage and reduce any impacts of introduced pests or diseases on the environment, the economy and the community. These can be short term actions that occur immediately after an incursion as part of the recovery strategy or they may become long term activities that help the system adapt to changed circumstances. These activities are undertaken by a range of participants, including the Australian, state and territory governments, producers and industry and community groups.

Following pest or disease eradication or containment efforts, there is generally a need to provide evidence of success in order to underpin future interstate or international trade. Area freedom claims are based on surveillance activities and surveys that may be undertaken for a specific time or may become ongoing activities. Re-opening of international markets is a particularly important recovery strategy for trade dependent industries and requires certification by the Australian Department of Agriculture and Water Resources to verify that goods for export meet importing country requirements.

Part of the process of recovering from a pest or disease incursion is the provision of information and support to affected parties to facilitate their financial and non-financial recovery. These activities are provided by a range of participants in the biosecurity system and can be subject to agreements already in place, for example under the EADRA and the EPPRD.

Not all pests and diseases that enter Australia will be successfully eradicated. This might occur because the pest or disease was not detected sufficiently early or because it is technically infeasible to eradicate. Containment of pests and diseases to specific areas or regions can be used to minimise their negative impacts. In the case of plants, pests can be contained at a local, regional or state level, depending on their current distribution and the ability to implement cost beneficial measures for containment (PHA, 2017b). Domestic quarantine and movement restrictions on high risk material that are implemented under state and territory legislation are used to limit the spread of pests nationally. Interstate certification systems exist to govern the movement of plant products under the quarantine regulations in each state and territory.

In some cases, long-term management strategies will be implemented that seek to reduce the adverse impacts of the pest or disease. These plans might include changes in regional or local biosecurity practices to reduce the chance of a pest or disease spreading. The (Draft) National Fruit Fly Strategy is an example of a coordinated approach to managing the impacts of endemic fruit fly species on productivity and market access through the strategic use of containment, exclusion and other local management practices (PHA, 2008).

The biosecurity system also comprises a range of long term activities that are designed to manage pests and diseases that have become established and spread following incursions that occurred sometime in the past. These include community led programmes to manage weeds such as

blackberry and serrated tussock (for example, the Serrated Tussock Working Party) or pests such as rabbits (for example, Landcare).

A substantial proportion of the activity that occurs at the state and territory level – up to 60 per cent – is directed at ensuring that relevant participants in the biosecurity system comply with jurisdictional biosecurity regulations. One common example is the targeting of enforcement activities at landowners who fail to control noxious weeds on their property. These activities are often delivered in conjunction with local community led programs and are another example of 'shared responsibility'.

Part of recovering from and adapting to pest or disease incursions is evaluating outcomes of emergency response activities, including eradication and containment actions. Evaluation processes are used to update response tools, plans and procedures and to encourage the application of best practice across biosecurity sectors nationally.

The cumulative impact of activities in the national biosecurity system to recover from and adapt to incursions is that the realised impact on the economy, environment and community of pests and diseases that establish and spread in Australia is reduced and that disruptions to international market access are minimised. This contributes directly to meeting the third IGAB objective to 'ensure that, where appropriate, significant pests and diseases already in Australia are contained, suppressed or otherwise managed'.

2.7 Influencers and Enablers

In addition to the specific elements of the biosecurity system outlined above, there are activities undertaken as part of the system that are fundamental to its performance and the value it creates. These enablers and influencers underpin some, or all, of the biosecurity system's elements.

Governance arrangements define how each participant in the system will behave, including the relationships between participants. Key inter-governmental governance arrangements in the national biosecurity system are the IGAB and the National Biosecurity Committee and its sub-committees and working groups. At the jurisdictional level, biosecurity legislation provides the overarching framework for the operation of the system. Other important governance settings are provided in the emergency response deeds managed by Animal Health Australia, Plant Health Australia and the Department of Agriculture and Water Resources.

Because of the significant investment required to operate the biosecurity system, *funding arrangements* are important to the sustainability of each of its elements, as is ensuring the optimal *allocation of resources* across the system. This is particularly the case given the ongoing financial challenges faced by governments at all levels. The IGAB outlines principles for the funding of biosecurity activities and the prioritisation of resources to the areas of highest return. However, existing financial arrangements are complex and multi-faceted, and in some cases lack transparency (Craik *et al.*, 2017).

An effective biosecurity system requires a high level of skill and experience from its staff across all levels and areas of operation. A sustainable supply of relevant skills requires ongoing *capability development*, delivered through the general education system, specialist training and on-the-job experience.

Also critical to operations across the entire biosecurity system is the capacity for *information management and analysis*. Ready access to comprehensive and reliable data and information is

essential for anticipating, responding to and managing national biosecurity risks, substantiating Australia's claims to pest and disease free status, and for decision making, policy development, and performance measurement (Craik *et al.*, 2017). All jurisdictions, industries and relevant NGOs hold data of relevance to the national biosecurity system but these data holdings cannot easily be integrated to derive maximum benefit. Agreed data standards and formats are generally lacking as are interoperable technology platforms. However, recent developments across jurisdictions are addressing these issues. For example, the Victorian government's MAX system, which is designed to collect, manage and report data, is being used by five other jurisdictions for routine and emergency biosecurity activities. Plant Health Australia's AUSPestCheck is capable of providing and receiving national surveillance information on weeds and plant pests from a wide range of stakeholders. And the Australian government is investing significantly in sophisticated data capture, use and analysis through its Biosecurity Integrated Information System Analytics program (BIISA).

Because Australia's biosecurity system is based on sound science, *research and innovation* is a critical element that enables technological solutions to be delivered to biosecurity problems and helps drive down the cost of many biosecurity operations. Biosecurity relevant research and innovation is funded principally by the Australian and state and territory governments, the Rural Research and Development Corporations (RDCs) and Cooperative Research Centres (CRCs), the latter two of which receive funding from both government and industry. Research is delivered by multiple providers, including the CSIRO, universities, state and territory research agencies and private consultants.

The allocation of investment in research and innovation is guided by several strategies that are framed within the national research priorities outlined in the National Science and Research Priorities and the National Rural R&D priorities. These include the Animal Biosecurity RD&E Strategy and the Plant Biosecurity RD&E Strategy that have been developed under the IGAB and the Invasive Plants and Animals Research and Development Strategy. There are also a few industry specific research and innovation strategies. In July 2017, the National Biosecurity Committee endorsed overarching national biosecurity Research, Development and Extension priorities that are intended to provide a strategic and unified guide to investment in high priority research activities (DAWR, 2016c).

Because of the many participants in the biosecurity system, the complex nature of their interactions, and the rapidly evolving nature of the system effective *communications and engagement* are important to achieve outcomes. Communication encompasses general strategies to inform and educate those who play a direct role in the biosecurity system such as producers and other landholders, as well as more peripheral participants such as travellers, traders and port workers. Communication between governments and industry is critical in an emergency response situation and can be central to building community resilience in the period following an outbreak.

There are numerous effective communication mechanisms in place in the Australian biosecurity system that facilitate communication at different levels. These include the Farm Biosecurity program operated by AHA and PHA to raise awareness of producers about on-farm biosecurity and prevention of animal diseases and plant pests. It uses many channels to communicate its messages about biosecurity, including electronic media, educational materials and direct stakeholder engagement. DAWR coordinates an annual Biosecurity Roundtable that provides biosecurity stakeholders and government agencies with a forum to exchange perspectives on priority biosecurity issues. DAWR also has a dedicated communications section that coordinates communication between governments and industry during biosecurity incidents. The Biosecurity

Incident National Communication Network produces nationally consistent public information in response to pest and disease outbreaks. It has members from the Australian and state and territory governments and from Animal Health Australia and Plant Health Australia. DAWR also produces a bi-monthly newsletter, *Biosecurity Matters*, as well as brochures on travel, biosecurity and citizens' awareness.

A further important element of the biosecurity system is the capacity to undertake *monitoring and evaluation* of its performance. This provides a basis on which all participants can identify what improvements in investment allocation can be made, either individually or on a collective, system-wide basis. Evaluation of components of the national biosecurity system occurs on a regular basis. The Australian and state and territory governments, for example, articulate performance measures in corporate plans, strategy documents and annual reports, though their coverage and sophistication vary widely (Craik *et al.*, 2017). Jurisdictional auditors-general undertake reviews of aspects of the biosecurity system from time to time and have been influential in driving system reform in some jurisdictions. However, there is no current framework for monitoring or evaluating the performance of the biosecurity system at the national level. This gap has been identified by the review into the IGAB, which notes that it is not possible to 'roll up' individual jurisdictional performance measures to capture the national system and assess national performance (Craik *et al.*, 2017).

3 A framework for valuing the biosecurity system

The overall objectives of our multi-year project are to:

(1) set out and design the methods that are needed to measure the value of the biosecurity system as a whole;
(2) develop or adapt a preferred approach for valuation and the aggregation of values specific to the Australian context;
(3) map value measures with risk-return trade-offs; and
(4) work towards providing an aggregate value measure of the biosecurity system across different biosecurity measures and threats, taking into account different desired outcomes.

In the absence of an equivalent analysis to use as a template, we have chosen the framework set out by Boardman *et al.* (2011) as the format for presenting our preferred approach (objective 2, above). Boardman *et al.* (2011) outline a nine step framework for estimating the net present value (NPV) of a generic investment. For each individual step we provide:

- ***Context:*** the background to a step – why it is important and what needs to be considered;
- ***Recommendations:*** our recommended approach;
- ***Rationale:*** the rationale for our recommendations and their implementation;
- ***Outstanding issues:*** any issues not yet resolved or requiring further consideration; and
- ***Actions arising:*** the actions arising from the step in year two of the project.

A strength of this framework is that it places the emphasis on the activity being evaluated [the biosecurity system], with the preferred choice of methods depending on the activity under evaluation (rather than nominating a 'best' method, and then trying to fit it to an activity). For example, if we were to decide in step two that we are interested in the benefits and costs to both producers and consumers (as discussed in the introduction) then economic surplus would be an appropriate measure of value at step five. Where the focus is on net returns, we would adjust our approach to allow for this possibility in step eight. Overall, the nine steps provide a global framework for the valuation of biosecurity measures and activities.

Adopting this framework will provide us with a template to review and standardise any existing market based estimates of value; extend these to include non-market values; refine methods to properly aggregate measures of value up to the system scale; and identify the influence of uncertainty on the overall value estimate (Objective 4, above). Through this work we will also better understand the importance, strengths and weaknesses of our investment in the biosecurity system (Objective 3, above) allowing us to guide improved investment in biosecurity risk management.

3.1 Specify the set of alternative projects

CONTEXT:
The first step in conducting any valuation is to specify the set of alternative projects / programs / policies requiring evaluation, including the counterfactual. In our case, we have just two possible states:

Alternative 1 – Current Biosecurity System (the *status quo*); or
Alternative 2 – No Biosecurity System (the counterfactual).

However, these descriptions on their own are insufficient to properly compare the two states, we need to be clear about exactly what we mean to be 'the biosecurity system' and 'no biosecurity system'; including the specific participants, resources and activities that comprise that system.

To this end, the CEBRA 'value' and 'health' project teams jointly developed the detailed description of Australia's biosecurity system outlined in section two as a consistent basis upon which any estimates of value (or health) will be made. This description is a project output in its own right.

Specifying the set of alternative projects in this way also gives us the opportunity to refine the scope of the project, allowing it to remain tractable within the allocated time and resources.

RECOMMENDATION(S):
- That the current biosecurity system be defined as per its description in the previous section.
- That the scope of the valuation be limited to activities that directly address a market failure.
- That the counterfactual be defined as the complete absence of all activities considered 'in scope'.

RATIONALE / PROPOSED APPROACH:
The biosecurity system set out in Section 2 was conceptualised from the principles outlined in the Intergovernmental Agreement on Biosecurity [IGAB] (COAG, 2012). This approach takes the broadest possible view of the biosecurity system, viewing it as the 'shared responsibility' of all sectors of the Australian community (see also Nairn *et al.*, 1996; Beale *et al.*, 2008). Whilst this makes sense as a guiding principle, estimating the benefits and costs of such a system is impractical.

Following the approach taken by the Australian Institute of Health and Welfare in their biennial review of the Australian health system (e.g. AIHW, 2016), we propose limiting the scope of our valuation to the activities delivered by either government or industry to directly address a market failure (e.g. excluding the influencers and enablers in the program logic; Figure 1). Consequently, those activities that indirectly add value (e.g. capability building or research and development) and activities aligned with biosecurity service delivery (e.g. animal welfare and chemical residue monitoring) are explicitly out of scope in the first iteration.

Within this framework, the activities delivered by land managers (private or public) to manage the impacts of widespread pests and diseases are the only 'biosecurity' activities that will continue in the 'no biosecurity' counterfactual. That is, land managers will act to maximise their private benefits, regardless of the presence (or not) of the biosecurity system (Hennessy, 2008; Ceddia *et al.*, 2009).

OUTSTANDING ISSUES:
System duration
An open question is the appropriate length of system operation for which to estimate the value generated by its presence. For example, are we estimating the value generated by a single year of investment in the biosecurity system? Or, the value generated by operating a biosecurity system over a multi-year period? The choice of timeframe is critical, because the value of the biosecurity system depends on its continued operation and the absence of high-priority pests, meaning the value of the system will inevitably (but somewhat unpredictably) decline over time.

ACTIONS ARISING:
- Confirm the description of the biosecurity system outlined in Section 2.
- Confirm which activities are considered 'in scope' for the biosecurity system.
- Confirm which activities (if any) are considered 'in scope' for the counterfactual state.
- Identify an appropriate time horizon (period of system operation) for the valuation.

3.2 Decide whose benefits and costs count (standing).

CONTEXT:
Once a project has been fully specified, the next step is to decide whose benefits and costs count. This step is typically referred to as determining 'standing'. Determining who has standing, and over what geographic scale, is of critical importance to a valuation as it can inadvertently create negative externalities. An externality is where losses are incurred (or avoided) by a third party not considered to have standing. Best practice is, therefore, to take the broadest possible view of benefits and costs in order to most accurately reflect impacts (James & Anderson, 1998; Boardman *et al.*, 2011).

It is important to note, however, that the World Trade Organisation (WTO), under Article 5 of the Agreement on the Application of Sanitary and Phytosanitary Measures, does not allow members to consider impacts on consumers when imposing trade regulations; any justification must rely solely on the direct impacts on producers (GATT, 1994). As such, the most common approach to standing in biosecurity valuations is to ignore consumers (see Buetre *et al.*, 2013; Cook *et al.*, 2013; Hafi *et al.*, 2015) although there are some exceptions (e.g. Cook *et al.*, 2011; Tozer & Marsh, 2012).

Consequently, impacts are often estimated in terms of changes in gross value of product (GVP) or gross domestic product (GDP). Though, this limits comparison with pests that cause impacts on consumers which are routinely estimated using [surplus] measures that have completely different theoretical justifications. This also leads to a logical inconsistency when we infer that a pest (Pest A) is important because it negatively impacts consumers, only to later ignore positive impacts on those same consumers where a different pest (Pest B) negatively affects producers (and vice versa).

Therefore, we have two alternative approaches:

Alternative 1 – Government; and Producers (the *status quo*); or
Alternative 2 – Government; Producers and Consumers (best practice).

RECOMMENDATION(S):
- That standing be inclusive of Australian 'society as a whole' (Alternative 2).

RATIONALE / PROPOSED APPROACH:
Our primary rationale for recommending that the analysis be inclusive of Australian society as a whole stems from the stated objective for conducting the analysis; that is, to identify the magnitude of the net benefit (value) created by the biosecurity system from its allocation of public funds. Given that government investments are typically conceived to provide a public good (usually by addressing a market failure) a meaningful comparison of programs is only possible if consumer's benefits and costs are included. This also avoids the logical inconsistencies associated with considering only the negative impacts on consumers, ignoring any positive impacts, as outlined above.

Finally, considering both consumers and producers in the analysis does not preclude a description of how costs and benefits are distributed between producers, consumers and government in order to justify a trade regulation. In contrast, any analysis that considers only government and producers would need to be re-done if consumers were later considered to be important.

OUTSTANDING ISSUES:
None.

ACTIONS ARISING:
- Confirm that standing be inclusive of Australian 'society as a whole'.

3.3 Identify the impact categories, catalogue them, and select measurement indicators.

CONTEXT:
The value of a biosecurity intervention is determined by its impacts (benefits and costs) on those with standing (Olson, 2006; Soliman *et al.*, 2010; Epanchin-Niell, 2017). Though, the main benefits of a biosecurity intervention arise from the avoidance of a future loss, rather than the receipt of a future gain (similar to a road safety project where benefits are a reduction in the number of deaths).

The two main forms of loss arising from a pest or disease incursion are control costs and damages. Control costs are the costs of activities undertaken to implement an intervention, such as monitoring and/or treatment activities. Damages are the losses that occur despite those control activities (also termed 'residual losses'). Examples of damages include production losses in agriculture, lost access to markets, adverse impacts on human health and lifestyle, and losses to native species (Pimentel *et al.*, 2005; Holmes *et al.*, 2009; Pejchar & Mooney, 2009; Vilà *et al.*, 2011). Of these, production losses are by far the most common form of damages estimated in the biosecurity literature.

However, not all of the impacts of biosecurity interventions are avoided losses. For example, complying with a biosecurity regulation may result in increased costs for producers, reducing their profitability (McAusland & Costello, 2004; DeAngelo *et al.*, 2007; Perrings, 2016). The widespread use of agricultural and/or veterinary chemicals may also cause off-target environmental and human health effects (Green *et al.*, 2004; Sexton *et al.*, 2007). Impacts of this kind are referred to as indirect, or second-round, effects and can have large [positive or negative] impacts on the overall value of an intervention (Finnoff & Tschirhart, 2008; Finnoff *et al.*, 2010; McDermott *et al.*, 2013).

Consequently, an important step in setting the scope for our analysis is to nominate which impacts we intend to value. Our decision then is whether, or not, to estimate indirect impacts:

Alternative 1 – Direct, first-round, impacts (the *status quo*); or
Alternative 2 – Direct and indirect, first- and second-round impacts (best practice).

RECOMMENDATION(S):
- That the scope be limited to direct, first-round, impacts (Alternative 1).

RATIONALE / PROPOSED APPROACH:
Any decision regarding the breadth of impacts requiring estimation is essentially an accuracy vs complexity trade-off. This is because the estimation of impacts requires an understanding of the cause and effect relationships between the organism, the biophysical environment and the activity. Consequently, as the number of relationships between these factors increases the complexity of the modelling task grows exponentially. Greater complexity can only be justified where it also improves the accuracy of the estimate, hence our need to consider this trade-off when setting the scope.

As indicated above, the baseline set of impacts typically estimated in the biosecurity literature are control costs and production losses (e.g. Sinden *et al.*, 2004; Pimentel *et al.*, 2005; Paini *et al.*, 2016) as these impacts are the most easily estimated. However, given the goals of our system (Section 3.1), it follows that we should also attempt to estimate the major social and environmental impacts of exotic pests and diseases, particularly given that we know that the magnitude of these impacts is likely to be large (Gutrich *et al.*, 2007; McIntosh *et al.*, 2010; Aukema *et al.*, 2011; Hafi *et al.*, 2013). A summary of the direct impacts with the strongest empirical evidence is shown in Table 3.

Table 3: Direct impacts (benefits and costs) attributable to biosecurity interventions.

Impact Category	Measurement Indicator
Benefits:	
Avoided production losses	Yield (count)
Saved control effort	Control activity (extent)
Avoided market access losses	Markets open (count)
Avoided infrastructure damage	Infrastructure repaired (count)
Avoided social amenity losses	Recreation activity (extent)
Avoided human health impacts	Morbidity (count)
Avoided species extinction	Extinction (probability)
Costs:	
Implementation cost	System activity (extent)

Indirect costs are typically more challenging to estimate than direct costs because an additional set of biophysical relationships will often need to be modelled; including the complex relationships that determine environmental damages and/or human health impacts. Additional market relationships may also need to be known in order to estimate indirect 'economy-wide' impacts. Unfortunately, without actually estimating these indirect impacts, it is very difficult to know whether their magnitude warrants the additional effort and complexity (discussed further in the RIFA case study).

Our proposal in this regard is to be pragmatic and restrict our scope to direct impacts. Indirect effects are rarely estimated in the biosecurity literature, and where they are, they have been estimated using bespoke computable general equilibrium (CGE) models (e.g. Finnoff & Tschirhart, 2008; Warziniack *et al.*, 2011; Liu & Piper, 2016). Locally, the Productivity Commission (PC, 2002) and ABARES (Buetre *et al.*, 2013) have both attempted to estimate the indirect effects arising from an outbreak of FMD, and both expressed concerns about the accuracy of their estimates. Hence, we are proposing to limit the scope for practical (rather than scientific) reasons (Aukema *et al.*, 2011).

OUTSTANDING ISSUES:
None.

ACTIONS ARISING:
- Confirm that impacts be limited to direct, first round, impacts.
- Confirm the proposed impact categories and measurement indicators.

3.4 Predict the impacts quantitatively over the life of the project

CONTEXT:
Estimating the avoided losses attributable to an existing biosecurity intervention requires a comparison between the impacts expected to occur with the intervention (the 'status quo') and the impacts expected to occur without the intervention (the 'counterfactual') (Ferraro & Pattanayak, 2006; Bull et al., 2014). Figure 2 illustrates a hypothetical case where an intervention (such as, risk assessment) reduces the number of exotic species incursions from 50 to 20 per year. The benefit (avoided loss) of the intervention is the impacts (damages and control costs) that are avoided by having 30 fewer species incursions each year (e.g.Keller et al., 2007; Springborn et al., 2011).

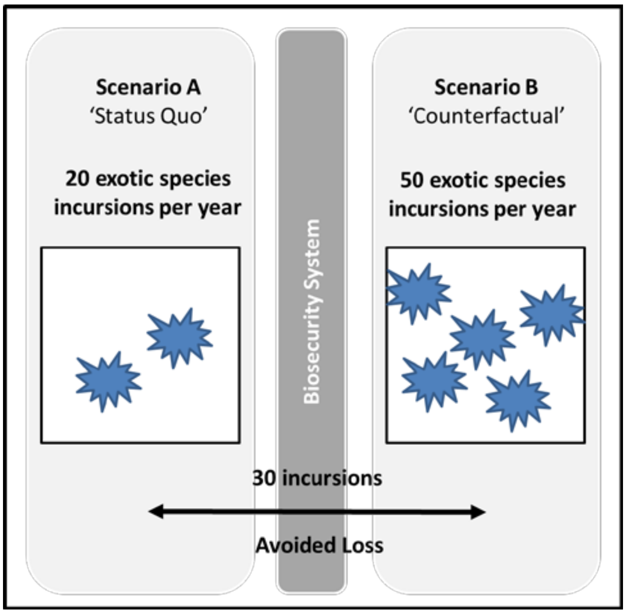


Figure 2: The relationship between the status quo, counterfactual state and avoided loss.

Determining the biophysical impacts of an intervention requires information on pest or disease arrival rates, establishment and/or spread processes after arrival, and the capacity to influence arrival and spread processes with specific management actions (Epanchin-Niell *et al.*, 2014; Epanchin-Niell & Liebhold, 2015; Epanchin-Niell, 2017). However, this information can be difficult to obtain, especially where a pest or disease has not previously occurred in similar environments.

Estimation of the values of biosecurity interventions involves estimating biophysical impacts of the interventions and then monetising those impacts (covered in the next section) by applying market and/or non-market valuation techniques. These tasks can be achieved with a single bioeconomic model incorporating a biophysical component and a valuation component allowing feedback between the two (Yemshanov *et al.*, 2009; Cook & Fraser, 2015). Alternatively, separate economic and biophysical models can be applied, with the economic model used to estimate value parameters that are then incorporated within the biophysical model (Gutrich *et al.*, 2007; Aukema *et al.*, 2011). This choice between approaches is another complexity-accuracy trade-off (Soliman *et al.*, 2015).

RECOMMENDATION(S):
- That the Risk Return Resource Allocation (RRRA) model be used to estimate pest arrival rates.
- That integrated bio-economic [partial equilibrium] models be used to estimate impacts.
- That ABARES RRRA consequence method be extended to consider post-border interventions.
- That ABARES RRRA consequence method be extended to include modelling of non-market impacts.

RATIONALE / PROPOSED APPROACH:

The existing approach for estimating the reduction in impact attributable to the biosecurity system, used by DAWR, is the Risk Return Resource Allocation model. 'RRRA' is a probabilistic model that uses Bayes nets (Korb & Nicholson, 2003), parameterised using DAWR data and expert elicitation, to estimate the change in likelihood of about 60 pest and disease groups arriving in Australia. Following an expected value framework, this reduction in likelihood is then multiplied by the consequences of the pest or disease establishing to calculate a risk-adjusted net present value (Figure 3; Peterson, 2009).

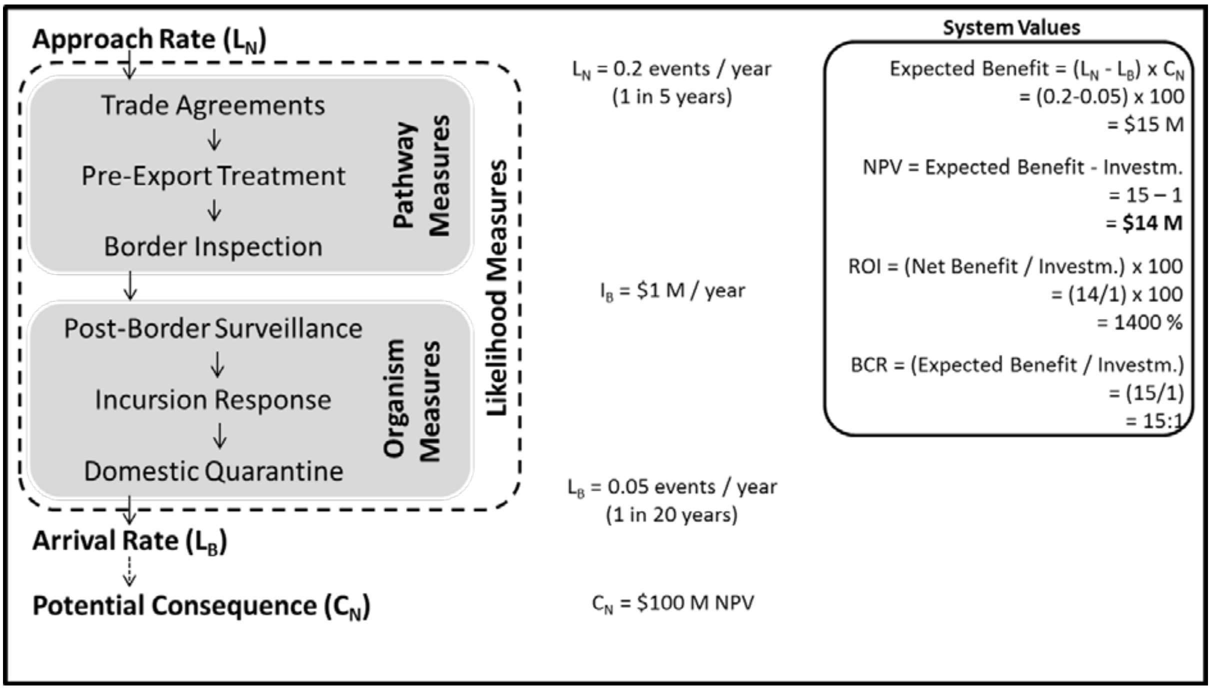


Figure 3: The existing approach utilised by the Risk Return Resource Allocation (RRRA) model.

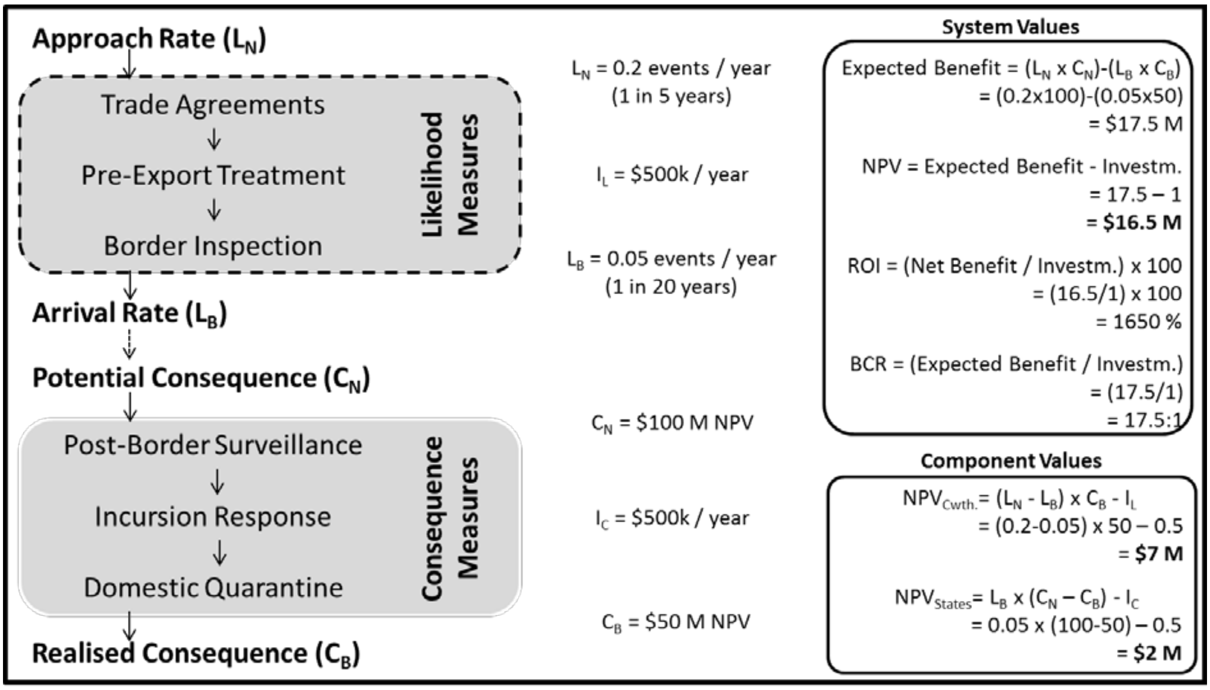


Figure 4: The proposed approach for extending RRRA to better account for consequences.

However, because RRRA was designed to estimate the value of activities delivered (or funded) by DAWR, several changes will need to be made to their approach in order to properly estimate the value of the broader system (Figure 4). Firstly, we propose estimating two separate consequence scenarios, one with the biosecurity system (realised consequence) and one without it (potential [counterfactual] consequence). This will allow us to model the effect of activities undertaken by both jurisdictions and industry to minimise the impacts of pests and diseases once they arrive.

Updates will also need to be made to the existing ABARES consequence estimates used within RRRA (Hafi & Addai, 2014; Hafi *et al.*, 2014) to reflect our recommendations regarding standing. Whilst the ABARES methodology already employs a partial equilibrium (PE) model (recommendation one), not all of the consequence estimates currently used in RRRA were estimated using this methodology. Rather, several existing impact estimates for were re-used where they were available, leading to some critical inconsistencies in the assumptions used to describe the counterfactual. Non-market impacts, such as changes in social amenity (Table 3), are also currently considered independently (using a scoring system); these will also need to be integrated in the final model estimate.

OUTSTANDING ISSUES:

Unaccounted consequences

One issue the project team has yet to unpack fully is the issue of consequences that occur when a pest enters and establishes, but does not spread [because it is eradicated]. Methods that calculate risk-adjusted values using conditional probabilities of entry, establishment and spread (such as the import risk assessment methodology; DAWR, 2016d) are susceptible to underestimating the impacts of pests, where this occurs, because they don't account for the damage done in the interim (Walshe *et al.*, 2012). Consequently, we need to review the potential for this error to occur in our approach.

Aggregation

Another critical issue requiring further consideration is aggregation. Aggregation issues can arise when estimating the value of a program with multiple interventions, or a program that addresses multiple biosecurity threats with the same intervention (see Aukema *et al.*, 2011; Epanchin-Niell *et al.*, 2014). Aggregation issues exist when the combined value of multiple interventions over- or under-estimates the true total value of those interventions. This occurs when the interventions do not have independent effects. A detailed discussion of aggregation issues is provided in the four tropical weeds case study.

Data deficiencies

Finally, it is almost certain that some of that data required to accurately estimate the nominated biophysical impacts, and their mitigation, will be unavailable. Given that we are at the beginning of a multi-year project, it would be prudent to identify areas where we think data is likely to be unavailable or incomplete, as soon as this framework is endorsed, in order to allow for data to be collected where the opportunity exists.

ACTIONS ARISING:

- Confirm the proposed use of RRRA for estimating approach and arrival rates.
- Confirm the proposed changes to the ABARES RRRA consequence methodology.
- Revise the ABARES RRRA consequence methodology to include non-market impacts.
- Review the pest groupings used in RRRA to identify non-market impacts and aggregation issues.
- Review the potential for uncounted consequences to be captured by the proposed changes.
- Identify any potential data deficiencies requiring corrective action.
- Predict the biophysical impacts with, and without, the biosecurity system.

Case Study: Four Tropical Weeds - Aggregation.

The National Four Tropical Weeds Eradication Program (NFTWEP) commenced in late 2002 with the aim of eradicating the incursions of six species of tropical weed: Koster's curse [*Clidemia hirta* (CH)], *Limnocharis flava* (LF), mikania vine [*Mikania micrantha* (MM)] and three miconia species [*Miconia calvescens* (MC), *Miconia nervosa* (MN) and *Miconia racemosa* (MR)]. Between 2002 and 2015, approximately $1-1.5 million was spent annually on controlling the six species, with contributions from Commonwealth, state and territory governments and in-kind contributions from local stakeholders. During this period, most of the species were contained within small areas, suggesting that eradication was still feasible. A subsequent discovery of an isolated large infestation of Koster's curse in in Wooroonooran National Park in 2015 led to this species being excluded from the program. Funding for the remaining 5 species until 2018 is conditional on progress being made towards eradication, relevant research being conducted to improve understanding of the weeds' biology and continuing community engagement to facilitate passive surveillance.

The six species are primarily environmental weeds but can also cause damage to pasture-based systems. Environmental impacts arise from changes in vegetation structure, including damage and displacement of overstorey and understorey vegetation. Canopy loss arises from species such as MC exploiting temporary canopy gaps and suppressing regeneration of overstorey (Meyer, 1998, 2008). In open woodland, the spread of weeds such as Koster's curse increases vegetation density and can increase fire risk, as well as causing harm to native species that require canopy gaps, such as gliders. Weeds such as Koster's curse also cause losses in pasture-based agriculture due to increased control costs and yield reductions (Burnett *et al.*, 2007; Conant, 2009; Day, 2012; Boyd *et al.*, 2015). Aquatic weeds such as LF can displace native aquatic plants and animals and damage aquatic ecosystems (Juraimi *et al.*, 2012). The ecological costs of the weeds can be severe when they invade species-rich biomes such as tropical forests. MC has replaced native vegetation over large areas in Tahiti, where it is one of the main threats to native biodiversity (Meyer, 1998; Kaiser, 2006; Meyer, 2008). Substantial damage to native forest ecosystems in Hawaii have been caused by Koster's curse (Bachrach, 1968; Smith, 1992).

The wet tropics bioregion of Queensland is the area most immediately threatened by the weeds in Australia. The region, which includes the Wet Tropics World Heritage Area (WTWHA), has a large tourism industry and many endemic species. Total visitor expenditures in the region are estimated to be in excess of $2 billion, with a gross economic value in excess of $400 million (Prideaux & Falco-Mammone, 2007). Of the region's 368 bird species, 11 are endemic, with 11 endemic mammal species, 24 endemic reptile species and 22 endemic amphibian species (Williams, 2006; Stork *et al.*, 2011; WTMA, 2014). These estimates of the region's economic value and endemic species richness do not indicate the magnitude of likely losses from uncontrolled spread of the weeds. For example, it is not known whether tourist visits to the region would decline if the weeds were present there or the extent to which weed control would reduce tourism losses. The locations most frequently visited by tourists are small relative to the total area of the WTWHA, implying these tourism sites could be maintained in a relatively undisturbed state by applying weed control programs. The weeds spread slowly in closed canopy forests (the slow spread rate of Koster's curse in closed forests is reported in (Lard *et al.*, 1999); Peters (2001)), which is a vegetation type prevalent in tourism areas. This implies that weed control would be highly effective in avoiding damages to tourism assets. In contrast, the large areas outside tourism sites imply that control efforts would probably not be applied to all areas that might be occupied by the weeds. The large number of endemic species in the bioregion imply that the weeds could potentially cause large losses from changes in vegetation structure. These losses are likely to be exacerbated by a projected increase in the frequency of natural disturbance events such as cyclones in North Queensland, which create canopy gaps that could be exploited by

Most Australian eradication programs are focused on a single species. In contrast, the NFTWEP is aimed at eradicating multiple species. The reasons for this have not been explicitly stated but this approach can be justified by interdependencies among the costs and benefits of eradicating the different species. Interdependencies among costs exist for different reasons, including sharing of operational and management costs between projects to eradicate the different weed species. Operational costs are shared because of spatial overlap between the weeds. The program's largest operational cost is the cost of monitoring the weeds. Sharing of monitoring costs occurs when monitoring of a specific area to confirm the presence of one of the species also confirms whether other species are present in the area. If more than one weed species is present in a location, cost sharing can arise from shared transportation costs to access the location for both monitoring and treatment purposes. In addition to operational costs, planning and management costs may also be shared. These include costs of gathering and analysing scientific evidence to improve the effectiveness of control efforts, which is a key element of the NFTWEP.

In addition to cost interdependencies there also are interdependencies between the benefits of eradicating the different weed species. These arise from the fact that different weed species may damage the same ecosystems or control actions to reduce the threat posed by one of the weeds simultaneously provides protection from other weeds. The counterfactual for determining benefits influences the magnitude of these benefit interdependencies. One reason for this is that the choice of counterfactual determines the rate of spread of the weeds in that scenario. In the counterfactual considered in the most recent benefit-cost analysis of the eradication program (Spring *et al.*, 2014) it was assumed that if eradication efforts cease the only remaining control efforts would be conducted by landowners and public land management agencies. These control efforts were assumed to have a relatively small impact on slowing the spread of the weeds and reducing weed abundance except in locations with tourism assets. In general terms, the benefits of eradicating a weed species can include avoided control costs, avoided damages, or both. Only avoided control costs were considered for tourism assets rather than damages such as reduced amenity benefits, based on an assumption that these assets can be kept free of the weeds at affordable cost. This assumption reflected the small area occupied by tourism assets and the slow rate of spread of the weeds.

Determining a realistic counterfactual for estimating biodiversity losses is more challenging than determining a counterfactual for estimating tourism losses. This primarily reflects the assumption made in the cost-benefit analysis that tourism losses will involve only avoided control costs. In contrast, estimating biodiversity losses requires an understanding of complex stochastic biophysical processes that govern the interactions between weed spread, native vegetation loss and native fauna species. The NFTWEP cost-benefit analysis (Spring *et al.*, 2014) considered a counterfactual in which ecological damages will occur over a large area. This scenario reflected an assumption that much of the WTWHA is inaccessible and/or too large for all infested locations to be monitored and treated. Low cost, highly sensitive methods for monitoring tropical weeds are not available, and available low cost monitoring methods such as remote sensing are likely to have low sensitivity because of visual obstructions in forested landscapes. Although passive monitoring by the community can potentially be effective in locations where people live or visit, much of the forested landscape within the WTWHA is uninhabited and not visited by tourists. In the absence of a low cost monitoring method, uncontrolled spread of weeds prior to detection could substantially increase the risk of ecological damages with long term adverse impacts on biodiversity.

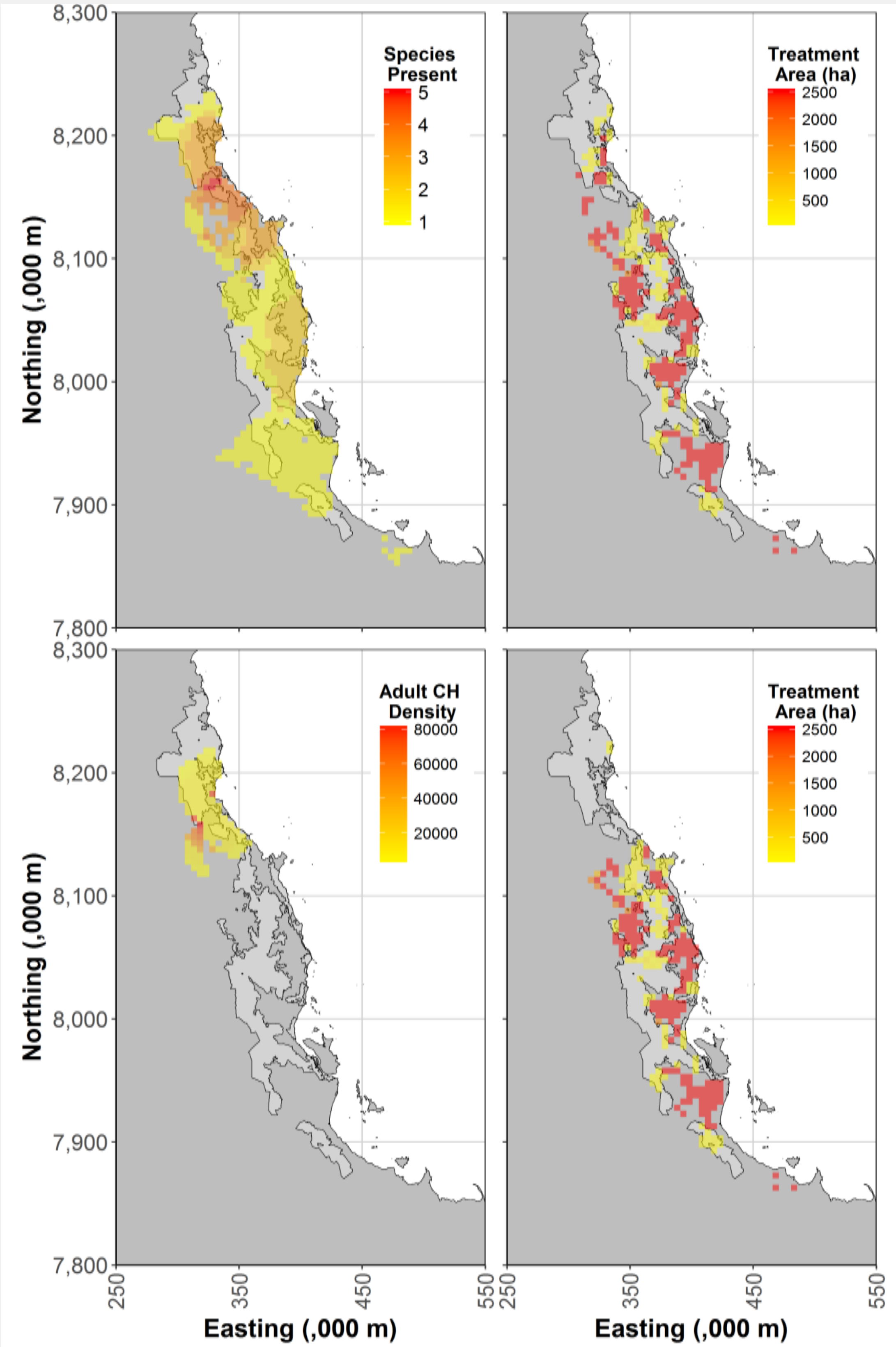


Figure 5: Map of the Wet Tropics area of northern Queensland: (a) the number of 4TW species present after 100 years of spread; (b) the area that would require treatment if the eradication program failed; (c) the density of *Clidemia hirta* after 100 years; and (d) the area that would require treatment if CH was abandoned.

The magnitude of damages is difficult to estimate because of uncertainty about weed spread rates, rates of displacement of native vegetation and resulting impacts on native species. The five weed species targeted in the NFTWEP are primarily environmental weeds that have direct and indirect impacts on native species, including species that require a closed canopy forest structure and species that require a more open woodland structure. Both of these forms of vegetation structure are threatened by the weeds but there is substantial uncertainty about when these changes will occur and the magnitude of these changes. Interdependence of benefits from controlling the weeds in natural areas outside tourism assets arises primarily because once an ecological asset is damaged by one of the weed species, there is reduced scope for further damage by other weed species.

The most commonly applied approach for estimating the benefits of biosecurity interventions is to estimate the benefits of individual interventions in isolation and then aggregate the benefits. An alternative approach is to group similar pests and diseases together and estimate their impact as a group. If the former approach were applied to estimate the total value of the NFTWEP, estimated based on weed presence data in 2014, the present value of the avoided losses at a 3% discount rate would increase by $50.4M, from $200.3M to $250.7M. This value includes only the avoided control costs required to maintain tourism assets in a largely weed-free state and does not include the avoided impact of the weeds on native species. The value relates to the program in 2014 prior to the exclusion of Koster's curse, which occurred in 2015. The $50M increase in estimated program value when values of individual weed eradications are considered in isolation and then summed reflects double counting of benefits that occurs when different weeds occupy the same land units. This spatial overlap of the weeds is not considered when benefits of eradicating the different weed species are estimated in isolation of each other. The smaller benefit estimate explicitly accounts for spatial overlap through specifying that benefits are obtained by preventing weeds affecting locations where at least one of the weeds is present in the absence of the eradication program.

If Koster's curse is excluded from the valuation of program benefits and its spatial overlap with other weed species is ignored, the total value of protecting tourism assets by eradicating the remaining four species is estimated to be $177.8M. This value, which reflects avoided control costs to maintain tourism sites in a weed free state, falls considerably when Koster's curse is considered because the latter species will eventually overlap substantially with the four remaining species (Figure 5). In locations where Koster's curse is present, eradicating the other four weed species would not have a benefit in terms of avoided control costs in tourism areas, because land managers would not incur an additional treatment cost. The total value of eradicating the remaining four weed species falls by approximately 10%, from $177.8M to $160.7M if the large new infestation of Koster's curse in the Wooroonooran National Park is not considered. If the latter infestation were considered, the reduction in program benefits would be much larger for several reasons, including:

- This infestation is large, comprising many thousands of mature individuals.
- The infestation occurs near tourism assets.
- The new infestation does not overlap with the original infestation of Koster's curse.
- The new infestation overlaps with at least one of the other four species by the end of the modelled time horizon (Figure 5).

If the reduction in total program value arising from the exclusion of Koster's curse is sufficiently large, it may potentially be cost-beneficial to reinstate the species in the eradication program despite the larger area requiring control efforts. The exclusion of Koster's curse from the eradication program has reduced the total program value in protecting tourism assets by tens of millions of dollars.

This foregone value should be compared with a revised estimate of the cost of eradicating Koster's curse that accounts for its larger area of infestation and the high likelihood that the species has established a large seedbank over this area. More generally, invasive species eradication programs often are terminated when new infestations of the species are discovered in unexpected locations. Under these circumstances, excluding the species from a multi-species eradication program can substantially reduce the value of the remaining species in the program. In the case of Koster's curse, its exclusion not only reflected the discovery of a large remote infestation of the species but also the fact that much of the land near that infestation is inaccessible and has not been monitored. It also reflects that if the species is found so far from the previously known area of infestation, it is possible that it exists in other locations that have not been monitored. If the entire WTWHA were monitored, it is likely that other satellite infestations would be discovered, increasing the degree of overlap of the species. These considerations imply there could be a much larger aggregation error than estimated in the most recent cost-benefit analysis of the NFTWEP if the benefits of eradicating each weed species is estimated separately and then summed.

The value of a national biosecurity system is an aggregate of the values of the interventions made in the system. When these values are independent, summing them is the correct approach for estimating the value of the system as a whole. When the values of different interventions are interdependent, summing them will over- or under-estimate the total value of the system. This is an important issue because interdependence is likely to be ubiquitous in national biosecurity systems. The value of eradicating a pest depends on whether other similar pests will be eradicated or effectively controlled. Development of a control method for a specific pest may have less value if similar alternative control methods will be developed, which is a potentially significant influence on the value of publicly funded research. Increased expenditure on prevention can influence the value of expenditures on post-border eradication, containment and asset protection.

In general terms, interdependence between values of different projects can arise from biophysical, management and market factors. Many pests and diseases have similar impacts and/or can be controlled with similar methods, with application of one method often providing simultaneous protection against multiple threats. The NFTWEP is a program aimed at eradicating multiple invasive species of similar type in terms of impacts and control costs, involving highly valued ecological and tourism assets. Importantly, the invasive species considered are sufficiently different from other non-indigenous species that their collective removal would make a substantial difference to ecological and tourism outcomes. This would not be the case if other invasive species with similar impacts were already established and widespread across the region of interest. In those circumstances, removal of the weeds may have a much smaller effect in avoiding ecological damages. This raises the important issue that economic assessments of biosecurity programs should consider the difference that can be made by the program, which depends on whether other invasive species with similar impacts are already present. We recommend that economic assessments of biosecurity programs that are focused on particular invasive pests or diseases consider whether other biological invasions with similar effects are already present in relevant geographic regions.

3.5 Monetize (attach dollar values to) all impacts.

CONTEXT:
Once we have estimated the biophysical impacts of a pest (say, a reduction in crop yield), the next step in the framework is to convert that biophysical impact into monetary units (in our case, dollars). As we discussed in the interim report, there are numerous theoretical approaches for quantifying the monetary [dollar] value of these changes including economic surplus, gross product and several different fixed-price measures (Soliman *et al.*, 2010; McDermott *et al.*, 2013). Given our recommendation in the previous section to use integrated bio-economic models, such as partial equilibrium models, to estimate biophysical impacts it follows that our preferred approach to monetising those impacts is via changes in economic surplus.

The concept of economic surplus is derived from welfare economics, a branch of economics based on utilitarianism (Riley, 2008). The primary utilitarian goal is to maximize happiness and wellbeing ('welfare') within society and to minimise pain and suffering. Economic surplus can be estimated for both marketed and non-marketed goods. The value of marketed goods can be derived directly from market data by estimating the supply and demand for the goods. Monetising these market impacts in terms of changes in economic surplus involves first estimating changes in consumer and producer surplus (Figure 6):

- ***Consumer surplus*** is the difference between what consumers are willing to pay for a good or service and what they actually pay (the market price).
- ***Producer surplus*** is the difference between the amount that a producer of a good receives and the minimum amount he/she would be willing to accept for the good.

The sum of benefits obtained by all those who supply or consume a good is the 'economic surplus'.

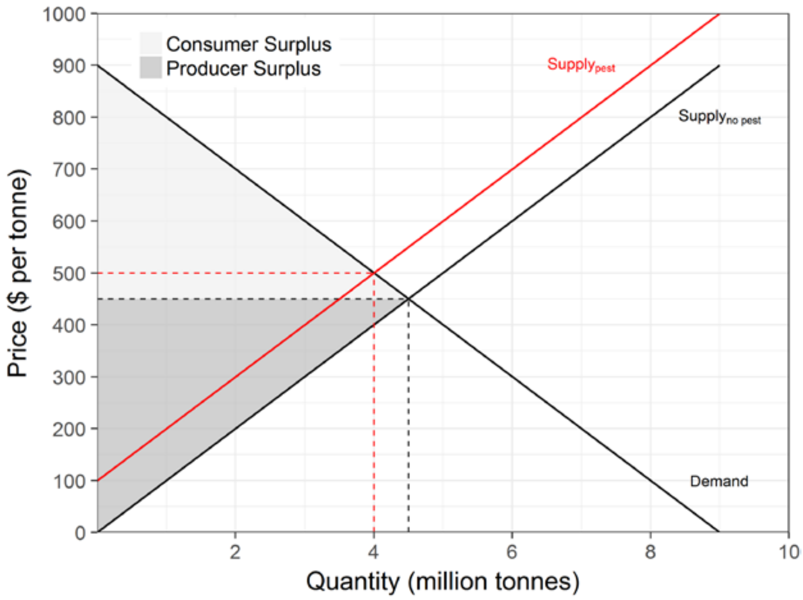


Figure 6: Supply and demand curves for a theoretical commodity showing the effect of an upward shift in the cost of production (supply) due to the presence of a pest.

Any change in either the supply of or demand for a good due to the presence of a pest will result in changes in the size of the economic surplus (Tozer & Marsh, 2012; Cairns *et al.*, 2017). Avoiding changes in surplus by preventing supply and/or demand shifts are the benefits of the intervention.

However, some pests and diseases affect the availability of goods not traded in markets. These include goods supplied by government, such as national park recreation opportunities, and goods that are 'self-supplied' by households, such as specific forms of recreation. Like marketed goods, the benefits of non-market goods can be measured in terms of economic surplus. A biosecurity intervention that prevents a loss of a specific amount of a particular non-market good can be monetised in two different ways: (1) peoples' willingness to pay (WTP) to maintain the additional availability of that good, or (2) the amount people are willing to accept (WTA) as compensation for the loss of that amount of the good. Either measure of value can be used in practice, but the most appropriate measure depends on the individual's presumed rights to a pest free environment.

For a non-marketed good, peoples' WTP for more of it cannot be directly observed by their market purchases. Two approaches for estimating WTP for non-marketed goods are to use indirect market-based valuation methods or to conduct surveys of people affected or potentially affected by a biosecurity program. Indirect market-based methods are forms of revealed preference methods in the sense that the estimated values are derived from peoples' observed economic behaviour (e.g. their purchases in markets or sacrifice of time; Holmes *et al.*, 2009; Aukema *et al.*, 2011). Survey based methods are referred to as stated preference methods because values are based on peoples' responses to survey questionnaires (e.g. Akter *et al.*, 2011, 2015). Finally, benefit transfer methods can be used to extrapolate either stated or revealed preferences made in other contexts to estimate the value of a specific biosecurity program (e.g. Kaiser, 2006; Gutrich *et al.*, 2007).

RECOMMENDATION(S):

- That impacts are monetised using economic surplus measures (producer and consumer surplus).
- That ABARES revised consequence method be used exclusively to monetise impacts.

RATIONALE / PROPOSED APPROACH:

As discussed in the previous section, although fixed-price models are the most commonly used in the biosecurity economics literature, [more detailed] partial (or even general) equilibrium models are the appropriate choice for a detailed, system level, analysis such as ours (Soliman *et al.*, 2015). We propose using ABARES' agriculture sector partial equilibrium model to estimate the market-based economic surplus measures. Model capability will be enhanced by ABARES to improve the representation of horticultural crops, import supply relationships for all commodities and crop specific land availability constraints based on a land capability assessment. Consumer surpluses will also be estimated and reported as part of the revised RRRA consequence methodology.

In contrast, monetisation of the impacts on non-marketed goods will be achieved using five separate methods, informed by their suitability for the impact being monetised and the availability of existing value data. Indirect market-based valuation methods (travel cost, averting behaviour and hedonic pricing), will primarily be used for impacts on 'use' values such as social amenity. Conversely, stated preference methods (contingent valuation and choice modelling) will likely be used for 'non-use' values such as species extinction. Wherever possible, benefit transfer will be used to reduce costs.

OUTSTANDING ISSUES:

None.

ACTIONS ARISING:

- Confirm that impacts are monetised using economic surplus measures.
- Revise the ABARES RRRA consequence methodology to include consumer surplus.
- Review the availability of existing non-market value data for each pest group.
- Monetize (attach dollar values to) the biophysical impacts.

Case Study: Red Imported Fire Ants – Non Market Valuation.

The red imported fire ant eradication program began in September 2001 after the species was detected at two locations in Brisbane. Fire ants inflict losses on agricultural producers, households, and the environment. Avoiding these losses through an eradication program provides market benefits to producers and non-market benefits to households. Household health and amenity benefits from avoiding fire ant stings were the two forms of non-market benefit considered in the most recent cost-benefit analysis of the eradication program (Hafi *et al.*, 2013). The value of these benefits was estimated to be almost half the program's total value ($3.9b of $8.5b), demonstrating the importance of considering non-market benefits when evaluating biosecurity programs that affect human health and lifestyle. The large magnitude of these benefits reflects that fact that fire ants inflict painful stings and are predicted to affect large numbers of people because of rapid spread through a large metropolitan area with almost 2.5 million people. The estimated rapid spread rate if eradication efforts cease reflects the invasion's large current size (>400,000 ha), the low estimated effectiveness of control efforts by private landowners, and the assumption that all government control efforts will cease in the counterfactual considered in the program's cost-benefit analysis.

The fire ant program illustrates circumstances where the benefits of eradication are much larger than costs (>20:1), irrespective of the method used to estimate benefits. For example, a previous cost-benefit analysis (Kompas & Che, 2001) estimated broadly similar eradication benefits to those estimated by Hafi *et al.* (2013) despite substantially different valuation methods being applied in the two studies. Although changed assumptions on the counterfactual in Hafi *et al.* (2013) and the use of a different non-market valuation method would potentially result in different eradication values, the values would still be large. An implication is that even though a different valuation method may produce a different estimated value of eradication, this change is unlikely to influence the decision whether to continue the eradication program. The reason for this is that benefits are likely to be large enough with any valuation method, provided that eradication success is likely (this is because the value is risk-adjusted for the probability of a payoff and is hence, an expected net present value). When the choice of valuation method is of lesser importance than accurately estimating eradication likelihood, there is flexibility in choosing the valuation method based on pragmatic considerations such as the cost of applying the method. The remainder of this discussion focuses on options for reducing the cost of estimating non-market values whilst achieving acceptable level of accuracy, focusing on the Australian fire ant program. The discussion includes background information on the main valuation methods, including their most important advantages and disadvantages.

The first step in choosing a valuation method is to determine the forms of benefit to be valued. The two main benefits considered in the most recent cost-benefit analysis of the Australian fire ant program were avoided harm to household health and avoided urban amenity losses. These benefits can be valued using both revealed and stated preference methods. Revealed preference methods are based on peoples' observable behaviour in markets. Fire ants trigger observable behaviour by households, including expenditures on medical treatment and pesticides. These expenditures provide a basis for applying the 'averting behaviour' approach to valuing avoided fire ant losses, in which values are estimated based on observed expenditures and behavioural changes (including time costs) to prevent or mitigate losses. Several applications have been made of the averting behaviour approach to estimating fire ant impacts on household health and lifestyle in the United States, where the species has affected large numbers of people (Lard *et al.*, 1999; Miller *et al.*, 2000). The data on household expenditures required to apply this approach typically are obtained through a survey of people who have experienced losses. Many fewer people have experienced fire ant losses in Australian than in the USA because the invasion is much newer in Australia. This implies that a USA survey could potentially form the basis for valuing Australian eradication benefits.

An alternate option is to base averting costs on expert opinion, such as minimum required frequencies of pesticide bait applications to prevent fire ants establishing in a backyard. This option may provide realistic estimates of avoided control costs if expert-recommended standards will ultimately be adopted in Australia. This approach would also avoid the need for a more costly household survey. The main disadvantage of all averting cost approaches is that they do not consider utility losses arising from peoples' concerns about being stung or having to apply pesticides in their homes. If these utility losses are large, averting cost methods may substantially underestimate true losses from fire ants. In these circumstances, it may be preferable to apply a stated preference method such as the choice modelling approaches of (Akter *et al.*, 2011, 2015) and Rolfe and Windle (2014). Stated preference methods estimate non-market values based on peoples' responses to survey questions. As noted above, the analysis of Akter *et al.* (2011) provided the per-household non-market value estimates used in the fire ant program cost-benefit analysis. The two main disadvantages of stated preference methods are their large cost and vulnerability to biases. Their large costs ($00,000's per survey) reflect the need to gather information to understand the relevant non-market impacts, formulate survey questions in the light of this information, survey enough people to represent the broader community, and analyse survey data. Biases associated with stated preference methods include information bias when survey respondents have little understanding of what they are being asked to value. Australians with no experience of fire ants may have difficulty in expressing a value for avoiding the potential losses that might be caused by the species because most Australians have never had contact with the species.

Given these cost and accuracy disadvantages of valuation methods based on averting costs and stated preferences, alternative methods should be considered for valuing avoided fire ant impacts on health and urban amenities. The high cost of household surveys for averting behaviour and stated preference methods can be addressed by applying the benefit transfer approach. This involves taking values estimated from a previous survey and applying it to biosecurity programs for which the survey results are relevant. This was the approach taken in the latest cost-benefit analysis of Australia's fire ant program, in which benefits were based on a previous survey of households' willingness to pay to avoid contact with biting insects. The capacity to apply a previously estimated value to different contexts was made possible by the focus of the survey on a functional group of insects (biting insects) instead of a single species. This also is a potential source of inaccuracy, reflecting that if fire ants are substantially worse than other biting insects, estimates made in the Akter *et al.* (2011) survey would underestimate households' willingness to pay to avoid contact with fire ants.

Although the benefit transfer approach can avoid substantial survey costs, it does not address any of the inaccuracies and biases that may exist in the original survey. If information bias is one of the main sources of bias in applying stated preference methods, there may be scope to reduce this by adequately informing survey respondents of the potential damages that can be caused by biting insects and control options. Care should be taken to avoid overwhelming households with too much information as this would defeat the purpose of providing the information, which is to minimise information bias. In this regard, it can be noted that the Akter *et al.* (2011) survey elicited households' WTP for two levels of risk reduction. A simpler approach which is worth investigating is to elicit households' WTP for one level of risk reduction, from certain contact with a biting insect to certain avoidance of the insect. This risk reduction would be larger than the reduction that can realistically be expected with fire ant control, however it could be adjusted in estimating eradication program benefits using risk weighting. This could involve adjusting the WTP estimate by the actual reduction in fire ant contact probability estimated in a spread simulation model. An advantage of this approach is that it would avoid the arbitrary definitions of low, medium and high that are necessary when applying the results of stated preference surveys that elicit values for qualitative categories.

The fire ant program illustrates circumstances in which an invasive species causes large non-market losses relative to total losses caused by the species, implying that the benefit of avoiding these non-market losses should be estimated. However, perhaps counter-intuitively, achieving a high degree of precision in non-market benefit estimates may not be important when these benefits substantially exceed program costs because incremental improvements in accuracy are unlikely to change program decisions. In circumstances where the accuracy of program benefit estimates is of secondary importance, there is more flexibility to choose a lower cost valuation method that achieves an acceptable degree of accuracy. There is substantial scope to reduce the cost of valuation methods that involve large household surveys by conducting a relatively small number of surveys of general relevance instead of conducting a new survey for each biosecurity program. Applying a small number of valuation surveys to a larger number of biosecurity programs requires a benefit transfer method that adjusts the original WTP estimate to allow it to be 'transferred' to an evaluation of a different biosecurity program. This approach was taken in the most recent fire ant program cost-benefit analysis. In particular, the analysis considered an estimate of households' WTP to avoid contact with biting insects in general rather than fire ants in particular. If this approach is to be applied more widely in Australian biosecurity evaluations, careful consideration should be given to options for increasing the generality of the original household valuation surveys to ensure the resulting WTP estimates can be applied to many potential programs of interest.

A promising approach for increasing the generality of a set of household valuation surveys is to consider different functional groups of pests/diseases relevant for non-market valuation. For example, these groups could include terrestrial environmental weeds, specific forms of livestock diseases, and biting insect pests (following Akter *et al.*, 's approach). Consideration should be given not only to the functional groups for estimating households' non-market values but also whether a stated preference or revealed preference approach should be taken for each of the functional groups. A third option is to apply a hybrid approach that addresses key limitations of stated and revealed preference valuation methods. If a stated preference survey is conducted, it should address key biases such as information bias which can be substantial if survey respondents are unfamiliar with the pest of interest. A revealed preference survey of averting behaviour is most likely to be suitable if the pest of interest does not impose substantial psychological harm on people affected by the pest. For example, if fire ants cause significant distress to people in addition to expenditures on medical treatment and pesticides, a stated preference survey may be more appropriate.

3.6 Discount benefits and costs to obtain present values.

CONTEXT:

Once our biophysical impacts have been monetised, those impacts that occur in the future then need to be 'discounted' to reflect the decline in the value of money over time (OBPR, 2007; Harrison, 2010). The choice of discount rate, how fast the value of money declines, is important as it can influence the relative profitability of alternative response strategies within a biosecurity investment project, and between different projects, because their costs and benefits may occur over different time frames. Consequently, the appropriate discount rate to apply to evaluate biosecurity (and other long-term public policy) interventions is actively debated (Weitzman, 1998b, 2001).

A higher discount rate favours strategies that yield benefit early over others that yield most benefit later. For example, RIFA could take 70 years to spread across Australia and most of the damage is likely to be realised towards the end of this time horizon (Hafi *et al.*, 2013). The use of a high discount rate in this case will heavily discount (reduce) the impact. A low rate near zero has been recommended for projects that have long term effects on the environment or human health and amenity services (Weitzman, 1998b) and where the discount rate itself is uncertain (Weitzman, 2001).

The choice of discount rate not only affects the value of individual interventions and the biosecurity system as a whole, it also influences the optimal allocation of resources across interventions (e.g. Kompas *et al.*, 2015; Kompas *et al.*, 2016). This is because the timing of the impacts prevented by the system are highly variable – some impacts occur immediately, whereas others may take decades to be realised. If values associated with optimal interventions are to be estimated in this project (Objective 3; Section 3.0), the choice of discount rate could have substantial implications.

A related problem is the selection of a time horizon for assessing intervention benefits and costs. Many interventions have long term effects and it is not known how long effects will persist after the intervention has ended. For example, a successful eradication program can prevent people coming into contact with the eradicated pest over an indefinite future. This raises the question of whether to consider a finite or infinite horizon, and for the former option, how long a horizon to consider. The horizon to consider can have important implications for performance assessment. For example, performance may be enhanced by considering a longer horizon for species that spread slowly.

RECOMMENDATION(S):

- That the discount rate be set at 7 percent, with sensitivity analyses at 3 and 11 percent.
- That benefits be calculated over a sufficiently long and variable horizon, such that their discounted value at a point in the future is zero.

RATIONALE / PROPOSED APPROACH:

According to Harrison (2010), there are two options in choosing a discount rate: a 'descriptive' approach and prescriptive or 'normative' approach. Adopting the descriptive approach means choosing a discount rate based on the opportunity cost of funds sourced from the private sector. This approach recognises that market rates reflect the opportunity cost of investing in both public and private projects. Conversely, the prescriptive approach involves considering various ethical issues (such as intergenerational equity) and, therefore, favours using lower discount rates to balance equity and efficiency considerations (Weitzman, 1998b, 2001). However, using low discount rates when market rates of returns are relatively high could make future generations worse off.

The default discount rate recommended in both the Best Practice Regulation Handbook (OBPR, 2007) and Harrison (2010) is an average discount rate based on the weighted average long term marginal rates of return to capital. The marginal return to capital over the four decades to 2010 averaged approximately 9 % in real terms (Harrison, 2010). Consequently, Harrison (2010), recommended a real discount rate of 8 per cent be used with sensitivity tests done at 3 and 10%, while the Best Practice Regulation Handbook (OBPR, 2007) recommends a real discount rate of 7% with sensitivity tests done at 3 and 11%.

Market rates of return include a market risk premium; therefore, a discount rate based on the weighted average market rate of return is the appropriate discount rate for a publicly funded biosecurity investment project (which generally has a similar level of risk to the average private sector investment). The recommendation to conduct sensitivity analysis at both a lower and higher discount rate is because there is considerable imprecision in the estimated weighted average market rate of returns. The low and high discount rates are based on the average rate of return for risk free and riskier assets, respectively (Harrison, 2010).

OUTSTANDING ISSUES:

None.

ACTIONS ARISING:

- Confirm that the discount rate be set to 7%, with sensitivity analyses at 3 and 11%.
- Confirm that benefits be calculated until their discounted value is zero.
- Discount the monetised benefits and costs to obtain present values.

3.7 Compute the net present value of each alternative.

CONTEXT:

Estimates of the benefits and costs of biosecurity interventions can be combined and/or adjusted in different ways to report the value of those interventions and inform decisions on how to operate the biosecurity system to increase or maximise its social value. These alternative ways of combining benefit and cost information to report value are defined here as value ‘indicators’. The most commonly applied value indicators are net present value (NPV) and return on investment (ROI).

NPV is a ‘net’ value because it involves subtraction of intervention costs from intervention benefits. It is a ‘present’ value because most benefits and costs resulting from biosecurity interventions occur in the future and are diminished in value by the passage of time (OBPR, 2007; Harrison, 2010). Converting future values to a present value by applying a discount rate to future benefits and costs (see section 3.6) allows those values to be aggregated to estimate a net present value. Our review of previous studies found that biosecurity program values are most commonly expressed as NPVs.

The ROI of investing in an individual intervention is the net benefit from the investment divided by the investment’s cost, properly expressed as a percentage, but also often times as a ratio.

Both NPV and ROI can be estimated for individual biosecurity interventions, sets of interventions, or the biosecurity system as a whole. Both indicators can also be expressed as marginal values, which are values of changed scales (amounts) of intervention arising from changed expenditure on individual programs. Expenditure changes can occur as a result of the reallocation of spending between programs or additional funding made available to the system as a whole.

The most appropriate indicator of value (NPV or ROI) and its most appropriate form (i.e., whether it is applied to individual interventions or sets of interventions, and whether marginal or total values are considered) depends on the intended use of the indicator.

RECOMMENDATION(S):

- That expected [risk-adjusted] net present value (eNPV) be the nominated indicator of value.

RATIONALE / PROPOSED APPROACH:

NPV is one of the most commonly applied indicators of value used in biosecurity evaluations (e.g. Alston *et al.*, 2013; Bourdôt *et al.*, 2015; Cook & Fraser, 2015; Susaeta *et al.*, 2016), so our proposal to use NPV here is uncontroversial. As described above, NPV is the discounted benefit of an intervention or set of interventions less the discounted cost of that intervention/s. It is a suitable measure of value when the aim is to estimate the net benefits of current interventions (our aim).

Though, particularly in the biosecurity context, we are often uncertain about the likelihood that a particular cost or benefit will be incurred in the period under consideration (i.e., the probability of an event / outbreak occurring in the next financial year / budget cycle is usually less than 100%). In this circumstance, we need to account for this uncertainty when calculating our NPV by multiplying the impact of an outbreak by the likelihood that it will occur (Table 1; Figure 4). An NPV that has been risk-adjusted in this way is known as an expected (or risk-adjusted) net present value (eNPV).

However, NPV / eNPV is not the only indicator of value that has been applied in biosecurity and natural resource management programs. Programs in these areas are increasingly being evaluated on the basis of their return on investment (ROI; Boyd *et al.*, 2015) and benefit-cost ratio (benefits divided by costs, BCR). A number of papers reviewed for this report estimated ROI or BCR (Turner *et al.*, 2004; de Lange & van Wilgen, 2010; Fasina *et al.*, 2012; Faccoli & Gatto, 2016).

We recommend against the use of ratio indicators of value, including the benefit-cost ratio (BCR) and return on investment (ROI), for estimating values at the system level. When applied to the system as a whole by adding up the discounted net benefits of all biosecurity programs and dividing this by total discounted system costs, ROI is a misleading indicator of value, or more specifically, the potential returns from increased investment within the system. This issue is discussed further, in the context of making recommendations, in Section 3.9.

Lastly, ROI is also highly sensitive to subjective accounting decisions, including whether to define indirect losses arising as side effects of interventions, such as losses to consumers from higher prices of regulated goods, as negative benefits or costs. NPV are not susceptible to this subjectivity and are, consequently, our recommended indicator of value.

OUTSTANDING ISSUES:

None.

ACTIONS ARISING:

- Confirm that net present value (NPV) be the agreed indicator of value.
- Calculate the agreed indicator(s) of value (e.g. NPV).

3.8 Perform sensitivity analysis.

CONTEXT:
Most biosecurity interventions have uncertain impacts due to the existence of multiple sources of uncertainty relating to pest and disease arrival rates, spread rates, detectability and/or susceptibility to treatment (Epanchin-Niell *et al.*, 2014; Epanchin-Niell, 2017). For example, uncertainty about a program's treatment effectiveness translates into uncertainty whether the program will succeed, or if does succeed, how long it will take (Hester *et al.*, 2013; Keith & Spring, 2013). A program that fails will usually provide smaller benefits than a successful program (Hafi *et al.*, 2013). A program that takes longer than expected to achieve its aims will typically cost more than a program that achieves its aims within the expected planning horizon (Dodd *et al.*, 2017). This implies that uncertainty can affect value in different ways and result in a specific program having a range of possible values.

Uncertainty across the biosecurity system can be classified into different forms. Following the framework set out by Regan *et al.* (2002), uncertainty may arise from several sources:

- ***Natural (aleatory) variation:*** arising from naturally occurring heterogeneity / chance events;
- ***Knowledge based (epistemic) uncertainty:*** arising from limitations in our knowledge; and
- ***Language based (linguistic) uncertainty:*** arising from vague or imprecise use of language.

How we choose to incorporate, and ultimately minimise, uncertainty in our final estimate depends on the specific form of uncertainty that we are dealing with (Burgman, 2005; Burgman, 2015).

The purpose of a sensitivity analysis is to acknowledge this uncertainty in order to understand how robust our estimate of value is to changes in our underlying assumptions. Put another way, what would happen to our value estimate if a species spread more quickly than we assumed [estimated] it would? Does the value of our program increase, decrease, or barely change? Where we identify that a small change in a particular assumption, or input, results in a large change in our estimate we consider that input to be 'sensitive'. Identifying the input variables to which our final value estimate is most sensitive is important as it allows us to validate (check) those inputs, or collect more data to justify our assumptions. Undertaking a detailed sensitivity analysis is, therefore, an important step in ensuring our estimate is both accurate and robust to any assumptions (Boardman *et al.*, 2011).

RECOMMENDATION(S):
- That a sensitivity analysis be considered to be 'in scope'.
- That value of information principles be used to guide any additional data collection/analysis.

RATIONALE / PROPOSED APPROACH:
Given the size and complexity of the biosecurity system, and the relatively limited time available to undertake our valuation, a detailed analysis of every aspect of the biosecurity system is impractical. Instead, the framework we have proposed throughout this report has sought to balance any gains in accuracy against the cost of additional detail and complexity (see Sections 3.3-3.5; RIFA Case Study). Sensitivity analysis assists us to determine which elements of the system would benefit from a more detailed assessment by identifying the inputs to which our final estimate of value is most sensitive.

Because the typical aim of a benefit cost analysis is simply to determine whether benefits exceed costs, many sensitivity analyses focus on ensuring that 'break-even values' of input parameters have been exceeded. For example, the economic evaluation of weed risk assessment referred to in Section 3.4 identified that the accuracy of the Australian weed risk assessment (AWRA) tool needed to be greater than 70% for the benefits of preventing new weed species establishing to exceed the costs of restricting trade (Keller *et al.*, 2007; Springborn *et al.*, 2011). The accuracy of the AWRA tool is estimated to be close to (but above) 70%, however, this estimate depends on the underlying base

rate of introduced species becoming invasive (Caley *et al.*, 2006; Hulme, 2012). Because a small change in the base rate could (theoretically) result in the weed risk assessment no longer being cost-beneficial, the outcome of a sensitivity analysis would be to check (validate) that our estimate of the base rate was correct or collect more data if we had low confidence in the input.

In contrast, our project is focused solely on the magnitude of the net benefit; therefore, the focus of our sensitivity analysis will be to identify inputs with high leverage. That is, identifying those inputs that when varied across their ranges substantially vary the magnitude of the value estimate. With the remaining available time in the project we will then use value of information principles (Ward & Kompas, 2010; Runge *et al.*, 2017) to identify where additional data could be collected to most effectively minimise our exposure to high-sensitivity, low-confidence inputs. This approach should maximise our final accuracy, given the available resources.

OUTSTANDING ISSUES:

Reporting of uncertainty

One issue that we haven't yet discussed, but that nevertheless needs to be considered, is the most appropriate way to report on uncertainty when the final estimate of value is ultimately derived. By following an expected value framework (see Section 3.4), uncertainty about pest arrival rates will be explicitly reported in our final report (see Hafi *et al.*, 2015), however, the extent to which any other forms of uncertainty will be described remains unclear. Our preference is that, where possible, uncertainty intervals and break-even values be reported, particularly where they have relevance to the assessment of 'health'. Consequently, the specific format will ultimately depend on our findings.

ACTIONS ARISING:

- Confirm that sensitivity analysis, including any subsequent validation / data collection, is 'in scope'.
- Identify a preferred approach for reporting uncertainty in the final value estimate.
- Perform a sensitivity analysis, including any subsequent validation / data collection.

Case Study: Foot and Mouth Disease – Sensitivity and Uncertainty.

An outbreak of foot and mouth disease (FMD) is considered to be the most significant biosecurity risk faced by Australia's livestock industries (Matthews, 2011; Buetre *et al.*, 2013). Consequently, it follows that the value of Australia's biosecurity system will be highly dependent on the extent to which the likelihood and consequences of an outbreak of FMD are reduced by the system (Table 1). Stated another way, this dependency means that the accuracy of our estimate of the system's value is likely to be highly '*sensitive*' to the accuracy of our estimate of the impact of an FMD outbreak, should one occur. Where an input parameter is shown to have a large influence on the final estimate, it is prudent to validate that input to confirm its accuracy (Ward & Kompas, 2010; Runge *et al.*, 2017). At this point, we expect that most readers will be of the opinion that the impact of an FMD outbreak is well understood; therefore, the purpose of this case study is to discuss what we know, what we don't know, and what that means for accurately estimating the value of Australia's biosecurity system.

Foot and mouth disease is a highly contagious viral disease that is capable of spreading rapidly via a wide range of vectors (Bachrach, 1968; Grubman & Baxt, 2004). This ability to spread rapidly means that random 'chance' events, such as a farmer sending some livestock to market, can result in large differences in the final size of the outbreak (McLaws & Ribble, 2007; Garner *et al.*, 2016). Variability, or natural variation, of this kind is an unavoidable and irreducible source of '*uncertainty*' in complex systems (Burgman, 2005; Burgman, 2015). Accurately estimating the impacts of an FMD outbreak, therefore, requires large number of simulations to be run so that a general trend can emerge [converge]. Figure 7 illustrates this approach using 1000 simulations of two different FMD scenarios (the details of which are unimportant) modelled as part of the recent CEBRA 1604D project. In both cases, a wide range of possible outcomes emerged despite the identical initial starting conditions, revealing a skewed distribution of potential impacts (Figure 7; top).

Most of the existing estimates of the impact of an FMD outbreak have used variants of this approach (e.g. PC, 2002; CIE, 2010; Buetre *et al.*, 2013). Typically, a small, medium and large outbreak have been simulated from specific starting conditions, with the most likely (mean) prediction from each set of disease simulations used as an input into a separate economic model. In total, these three studies have modelled ten different scenarios, the results of which are shown in Figure 8. Like the within scenario variability illustrated in Figure 7, what is immediately apparent in Figure 8 (bottom) is the large, order of magnitude, differences both between scenarios and across studies. The latter difference arises primarily from differences in assumptions regarding the time required to regain full market share (Matthews, 2011; Buetre *et al.*, 2013). Here, we are faced with a lack of knowledge, or incertitude, as our source of uncertainty – we simply don't know how long it will take to return to full market share. Fortunately, unlike variability, uncertainty due to a lack of knowledge can often (but not always) be reduced through the collection of additional information.

Similarly, our understanding of the variation between scenarios (but within studies) is also limited by a lack of knowledge. As we discussed above, the initial starting conditions for each of the scenarios have been specifically selected to model outbreaks of a particular size. Consequently, we don't currently have a good understanding of the relative likelihoods (frequency) of each of those respective scenarios occurring. This means that whilst we may know the range of possible impacts (range: $5-52bn), we don't know which of those impacts is most likely. One possible solution to this issue would be to run a large number of scenarios (>5,000) based on plausible combinations of starting conditions, similar to the approach of Garner *et al.* (2016), in order to better understand the distribution of possible impacts (Figure 8; top). Fortunately, our ability to run large numbers of national scale simulations has improved substantially in recent years with the development of the AADIS platform (Bradhurst *et al.*, 2015; Bradhurst *et al.*, 2016), potentially resolving this limitation.

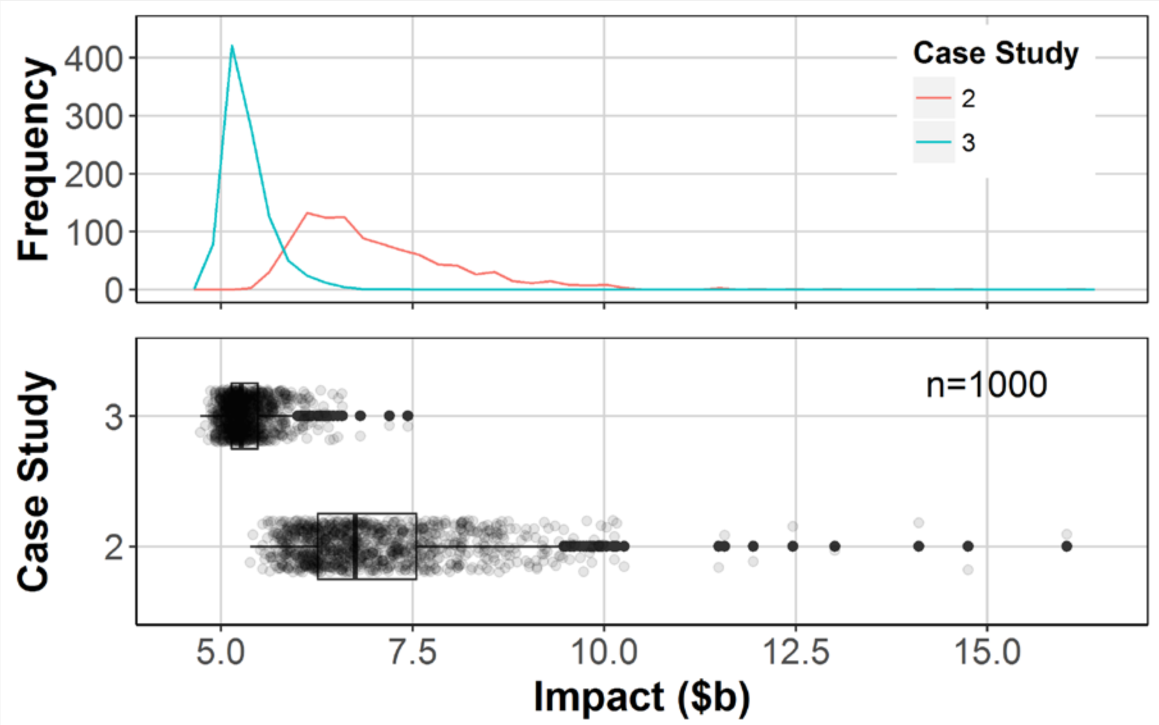


Figure 7: Empirical frequency distributions, and equivalent boxplots summarising the impact of two small foot and mouth disease outbreaks across 1000 simulations.

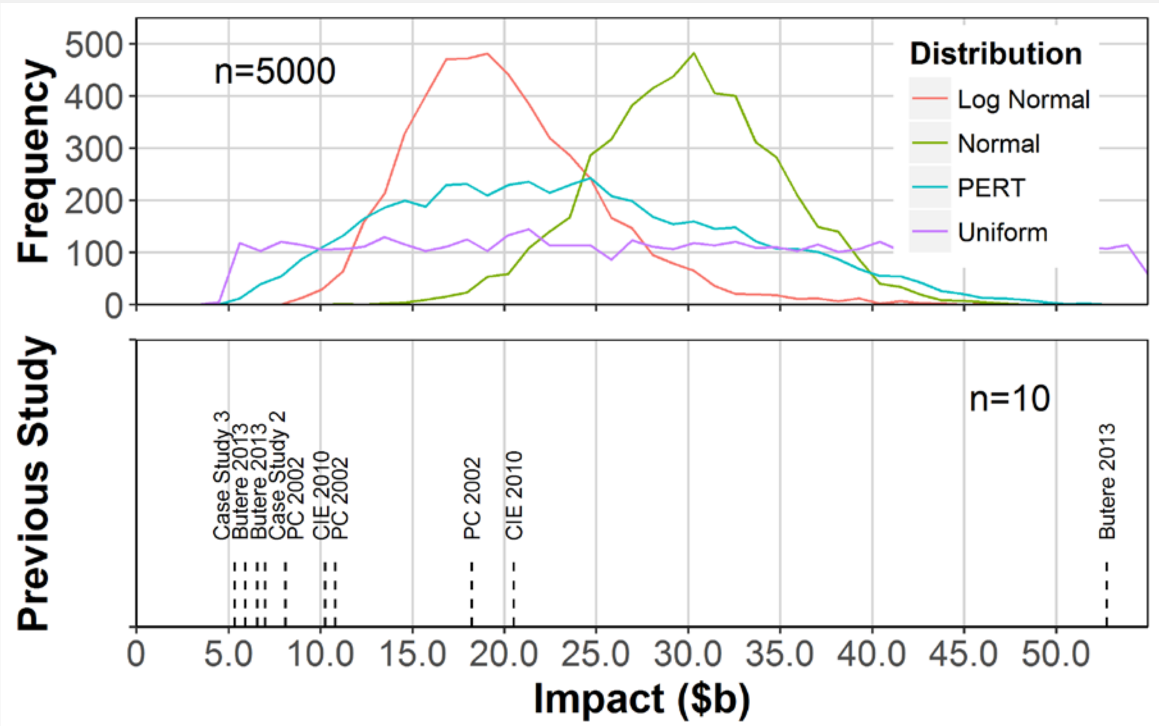


Figure 8: Theoretical frequency distributions that could plausibly explain the ten previous estimates of the impact of a foot and mouth disease outbreak.

However, the most important gap in our knowledge is a lack of understanding as to what the impact of FMD would be in the absence of a biosecurity system (our counterfactual). As we discussed in the introduction, of the major economic analyses of FMD conducted to date (e.g. PC, 2002; CIE, 2010; Buetre *et al.*, 2013), none have estimated a counterfactual. Each have instead estimated the impacts that would occur in the event of a government coordinated disease eradication program. However, the *value* of that program is the difference between the impacts that would have occurred without the intervention (the potential consequences), and those that occurred despite it (the realised consequences) minus costs (Table 1; Figure 4). Hafi *et al.* (2015) assumed (for simplicity) that the impacts in these two scenarios would be the same, arguing that government would likely be compelled to eradicate FMD even in a 'no biosecurity' scenario. Though, this assumption is untested. Because our final estimate of value is likely to be highly sensitive to the accuracy of this scenario, collecting additional information to validate or strengthen our assumptions may be justified.

This case study highlights the importance of sensitivity analysis, uncertainty and validation when estimating the value of a biosecurity intervention. Although many would consider the impacts of FMD to be well understood, because our estimate of value is likely to be highly sensitive to these impacts, it is important that (where possible) assumptions are validated and uncertainty is minimised. Moving beyond FMD, this principle applies to any other inputs to which our estimate of value is highly sensitive. This may include (but is not limited to) estimates of arrival rates, spread rates, treatment efficacy, eradication feasibility or even the behaviour of private individuals (see the RIFA case study). For example, the benefits of the RIFA eradication program are highly sensitive to the feasibility of eradication. Consequently, the latest review of the program (Magee *et al.*, 2016) focused only on estimating the cost of eradication and the likelihood of program success without considering new estimates of the benefits of eradication. This is a clear example of sensitivity analysis in practice.

3.9 Make a recommendation.

CONTEXT:
The final stage of the Boardman *et al.* (2011) framework is to make a recommendation regarding the best course of action. Typically, two (or more) alternative projects will have been evaluated, and the outcome of the analysis will be a recommendation about which of the alternatives generates the most value. However, in our case, we are effectively identifying the value of just a single scenario; the value of Australia's biosecurity system. Provided the net present value of the system is greater than zero (and this is almost certain), a recommendation at this point will be somewhat redundant.

Rather than omitting this section, we have instead included a short discussion on the suitability of NPVs for the various potential uses of our final estimate of the system's value, so that its limitations are clearly understood. For example, indicators of value are commonly used in three ways:

1. Estimating the value of current interventions;
2. Estimating the value of potential changes in interventions; or
3. Determining optimal values of interventions.

Given that the primary aim of the value project is to estimate the value of the current biosecurity system in Australia, 'total NPV' (total benefits less total costs) is the most appropriate performance indicator. However, if the aim were to determine whether there is scope to increase value above the current level, or to determine largest possible values (optimal NPV), 'marginal' values need to be estimated.

Estimates of the NPV of the current biosecurity system as a whole (total NPV) are not informative for decisions aimed at increasing or maximising the value of the system. This reflects that total NPV provides no information on whether biosecurity system resources are used efficiently or whether those resources provide higher or lower returns than other potential uses of those resources in other government activities (e.g. Akter *et al.*, 2015; Kompas *et al.*, 2015).

This arises because biosecurity interventions operate at a specific scale. Increasing the scale (amount) of an intervention can increase benefits by increasing avoided losses. For example, spending more on an eradication program may achieve eradication sooner (or make it more likely), reducing risk-adjusted losses caused by the pest or disease (Hester *et al.*, 2013; Dodd *et al.*, 2017).

Estimating the rate of return on an additional investment in the biosecurity system requires information on which activities within the system would receive the investment and the marginal returns from those activities. This is substantially more information than is required to estimate NPV of current levels of intervention in the biosecurity system.

RECOMMENDATION(S):
- That the limitations of the final value estimates be considered prior to their use in other contexts.

RATIONALE / PROPOSED APPROACH:
The benefits of changed scales of intervention can be estimated by developing a model of the intervention and the process it influences. An example of such a process model is a model of pest spread and removal during an eradication program. The biophysical impacts of different levels of intervention in the spread process can be assessed with such a model and these impacts can be monetised to estimate the benefits of changing intervention scale (e.g. Cacho & Hester, 2011; Dodd *et al.*, 2017).

The marginal benefit of a small change in project scale can be contrasted with the average benefit of the project as a whole. The latter benefit is the total benefit of the project divided by total spending.

Consider an example where an existing budget has been allocated to the inspection of all high- and medium-risk containers and the cost of inspecting a container is fixed. The marginal benefit arising from additional investment is the benefit arising from the inspection of the remaining low risk containers, rather than the average benefit arising from the previously inspected medium and high risk containers. This scenario is illustrated in Figure 9a.

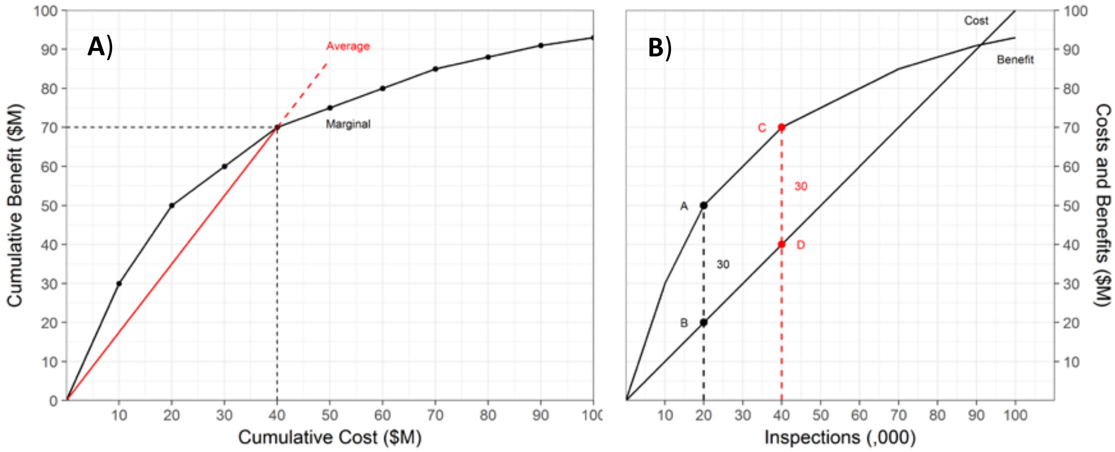


Figure 9: The relationship between a) the average and marginal benefit; and b) the value and value added of a hypothetical container inspection program.

A reliance on average benefit as a performance indicator can be misleading if a project's marginal benefits change substantially with project scale. It is possible to have a high average benefit and low marginal benefit or vice versa. For example, in the case illustrated in Figure 9, the average benefit of a $40 million budget is 1.75:1, whereas the marginal benefit at that point is only 0.5:1 (a destruction of value). In this [hypothetical] scenario, the additional benefit arising from each additional dollar spent on the program is only fifty cents.

An alternative way of visualising the impact of changes in program scale is to plot the costs and benefits on the same axis (Figure 9b). In this situation we can see how the net present value of the program (benefits minus costs) changes as the scale of the program increases; this is referred to as the 'value added'. Following our container example, we can see in Figure 9 that the value (net benefit) of inspecting 40,000 containers generates $30M of value, but that the same amount of value could have been generated by inspecting only 20,000 containers as the 'value added' by these additional inspections was equal to the cost of inspecting them (the BCR was 1:1).

Thus, whilst understanding the value of a biosecurity intervention is useful for evaluating the health of our existing biosecurity system, if we are to improve (or even maximise) that value we also need to understand how value is added across the system. A detailed discussion of value and value added is included in the following case study.

OUTSTANDING ISSUES:

None.

ACTIONS ARISING:

- Report the final value estimate, including any limitations and uncertainties.

Case Study: Fruit Flies – Value and Value Added

Biosecurity agencies face challenging decisions of how best to allocate scarce resources when they attempt to prevent, detect, eradicate and suppress exotic and established pests and diseases. In this regard, there is a key difference between the value of biosecurity measures and the extra value, or value-added, of investments in biosecurity. The question, in other words, is not how valuable a given biosecurity measure (or set of measures) is, but how to allocate resources across different biosecurity measures and threats to get the best possible rate of return.

While resource allocation in biosecurity may be approached as a standard portfolio problem (Akter *et al.*, 2015), allocating resources to address biosecurity threats may pose two key additional challenges. First, policy makers are often faced with a (possibly large) number of pests, and each of those can be associated with a range of biosecurity measures. A measure to control or prevent a particular pest likely influences the effectiveness of other measures, and the overall cost-effectiveness of the money spent to address that problem (Epanchin-Niell, 2017). Consequently, a biosecurity portfolio must allocate a budget not only across different pests, but also across different measures to detect and control them. Second, invasive species are diverse in terms of how they spread, how they cause damage and how they are controlled, so evaluating cost-effectiveness across measures and species, as well as making them comparable, is complicated.

A proper portfolio allocation in biosecurity differs from the common principle which ranks alternative projects by their benefit-cost ratios (Weitzman, 1998a; Boyd *et al.*, 2015) and picks the one that generates the highest benefit-to-cost ratio (BCR). This principle is sometimes referred to as 'the winner takes all' because the projects with highest average BCRs will be allocated at full scale while others may have no budget. This may result in misallocation of resources because the average BCR of a biosecurity project can be highly sensitive to its scale (size). Instead, it's best to allocate each (small) block of budget to the measure that it is most cost-effective, and consequently determine the optimal scale of the program for each threat with different levels of budget constraints. The cost-effectiveness of each block of budget spent on a threat is determined by minimising its expected total cost, including the damages it inflicts and the control expenditures incurred in preventing or mitigating damages. In this way, rates of return from a given biosecurity measure are maximised. BCRs can be positive at different scales, but the key is to find the largest difference between benefit and costs (Figure 9).

This case study illustrates this point. Drawing on the CEBRA Project Report, *Defensible Resource Allocation for Plant Health Surveillance (1608A)*, it illustrates both: (a) the optimal trade-off between border and post-border biosecurity expenditures, and (b) the optimal level of 'early detection' post-border for an exotic pest – in this case papaya fruit fly (PPF) through the Torres Strait pathway, although the principles apply broadly. Both elements illustrate the fundamental difference between value and value-added for biosecurity.

Allocations between the border and post-border surveillance depend on a host of complicated issues, and a set of parameters that drive a computational outcome. That said, the idea is simple: we need to find a set of measures, at the border and post-border, which maximise rates of returns by minimising the sum of all potential damages and the cost of the biosecurity measures themselves. This is equivalent to finding an allocation that ensures that the extra benefits of combined biosecurity measures, border and post-border, in terms of all the avoided losses that go with these measures, exactly equal the extra costs of providing the measures themselves.

In this part of Project 1606A, the key parameters are average arrival rates, spread rates, eradications costs, the discount rate, and the effectiveness of quarantine and surveillance measures. Using these (and other) baseline parameter values we can calculate optimal border quarantine and post-border surveillance measures. The results from the PFF case are illustrated in Figure 10. At all points on the surface of the diagram the BCRs of different border and post-border measures are positive and often large. The optimal portfolio allocation, however, occurs at a ratio of 1:4 for border and post-border measures. Given parameter values, in other words, and although both activities are valuable, it pays to invest more in post-border surveillance than at the border.

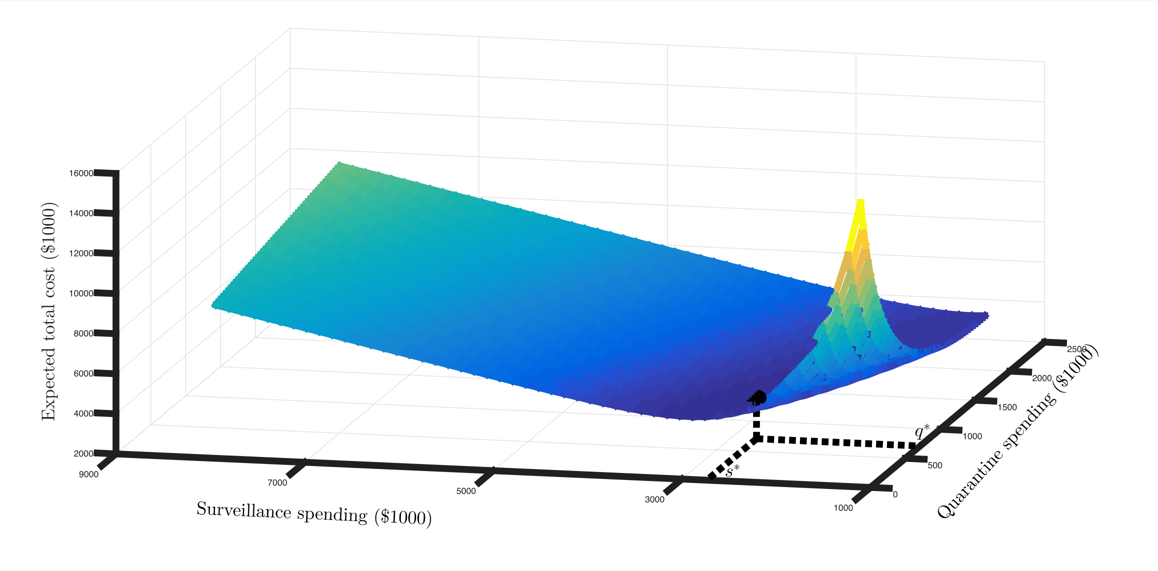


Figure 10: Optimal border quarantine and post-border surveillance expenditures.

Allocating resources for post-border surveillance, given existing border quarantine measures, also generates an issue about value added or rates of return. For example, the key question of a trapping network for the early detection of fruit flies is 'how early' to detect a possible incursion. A trapping grid that is very 'tight', with many traps placed in host-suitable areas will detect very early, but then the cost of the program, with a large number of traps is very expensive. Having less traps means the cost of the surveillance program is lower, but then detection will be later and thus potential avoided losses will be higher. In total, if the extra benefits of adding more traps exceed the extra costs, that investment should take place – and continue to take place until extra benefits exactly equal extra costs.

The second part of Project 1606A illustrates this through the use of a fairly complicated spatial model, over-layered with an optimization routine that ensures an optimal point of early detection. The parameter set is further complicated with control costs, production losses, the costs of trapping, probability of a given fruit fly to find a nearby host, among other things. Figure 11 illustrates the best outcome.

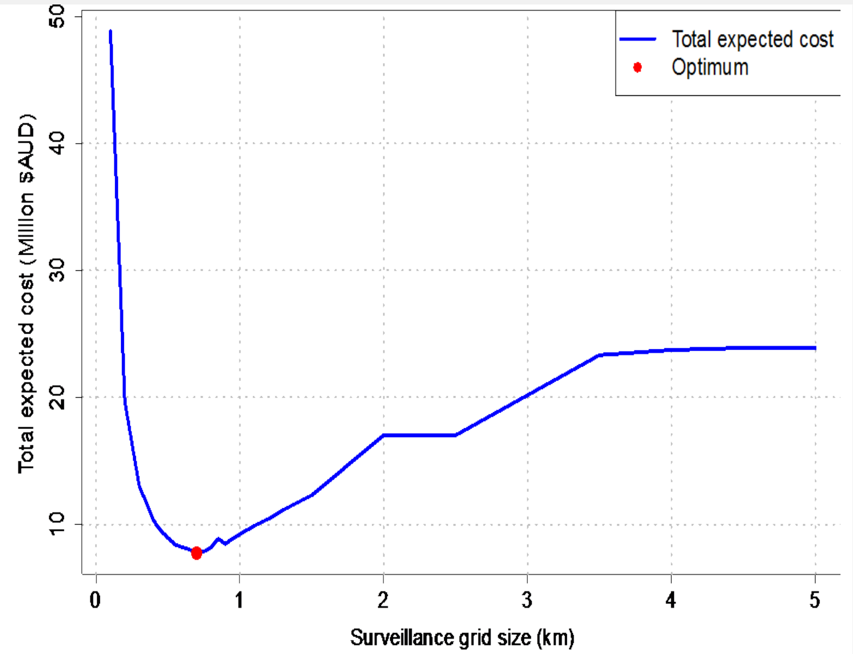


Figure 11: Optimal surveillance grid for PFF post-border.

As expected, a grid size that is too small, or tight, implies that the cost of the program is too large relative to the extra benefits in terms of the smaller avoided losses that go with early detection. A grid size that is too large generates just the opposite result. The best grid size is illustrated by the minimum of all losses and expenditures.

This case study illustrates the importance of making a distinction between value and value-added, and indicates where and how it is important to pursue optimal allocations for biosecurity resources across various biosecurity measures, in this case border and post-border surveillance measures. Going forward in the Value of Biosecurity Project it will important to identify cases where rates of return and optimal allocations can be determined. This will assist the department in allocating its scarce resources across various threats and control measures.

4 Implementing the framework

Year one of *CEBRA Project 1607A - Value of Australia's biosecurity system* has delivered:

- a comprehensive review of the biosecurity economics literature;
- a detailed description of Australia's biosecurity system;
- four small case studies highlighting critical issues identified by the project team; and
- a framework for accurately estimating the value of Australia's biosecurity system.

In short, 1607A has developed a scope for a multi-year project to estimate *value* at the system level.

Within the framework set out above, future years of the project will, therefore, be to:

- review and standardise any existing estimates of value;
- extend these estimates to include non-market values;
- update/refine methods to properly aggregate measures of value up to the system scale; and
- identify the influence of uncertainty on the overall value estimate.

We expect that the successful completion of these activities will deliver a transparent, repeatable and robust estimate of the value of Australia's biosecurity system through a multi-year project.

4.1 Next steps

In order to progress with the project, we first need to *confirm* the recommendations that comprise the project scope, then we need to *review* and revise several existing methods (to reflect the scope) before we ultimately, commence [*do*] the valuation. Activities and target dates are shown below.

***Confirm** the project scope (Target: end of Q1 2017/18)*

- Confirm the description of the biosecurity system outlined in Section 2 (3.1)
- Confirm which activities are considered 'in scope' for the biosecurity system (3.1)
- Confirm which activities (if any) are considered 'in scope' for the counterfactual state (3.1)
- Confirm that standing be inclusive of Australian 'society as a whole' (3.2)
- Confirm that impacts be limited to direct, first round, impacts (3.3)
- Confirm the proposed impact categories and measurement indicators (3.3)
- Confirm the proposed use of RRRA for estimating approach and arrival rates (3.4)
- Confirm the proposed changes to the ABARES RRRA consequence methodology (3.4)
- Confirm that impacts are monetised using economic surplus measures (3.5)
- Confirm that the discount rate be set to 7 %, with sensitivity analyses at 3 and 11 % (3.6)
- Confirm that benefits be calculated until their discounted value is zero (3.6)
- Confirm that net present value (NPV) be the nominated indicator of value (3.7)
- Confirm that sensitivity analysis, incl. any subsequent validation / data collection, is 'in scope' (3.8)

***Review**, identify and revise existing methods (Target: end of Q2 2017/18)*

- Identify an appropriate time horizon (period of system operation) for the valuation (3.1)
- Review the potential for uncounted consequences to be captured by the proposed changes (3.4)
- Review the pest groupings used in RRRA to identify non-market impacts & aggregation issues (3.4)
- Identify any potential data deficiencies requiring corrective action (3.4)
- Revise the ABARES RRRA consequence methodology to include non-market impacts (3.4)
- Revise the ABARES RRRA consequence methodology to include estimates of consumer surplus (3.5)
- Review the availability of existing non-market value data for each pest group (3.5)
- Identify a preferred approach for reporting uncertainty in the final value estimate (3.8)

***Do** the valuation (Target: end of Q4 2017/18 [3.4 & 3.5 only])*

- Predict the biophysical impacts with, and without, the biosecurity system (3.4)
- Monetize (attach dollar values to) the biophysical impacts (3.5)
- Discount the monetised benefits and costs to obtain present values (3.6)
- Calculate the agreed indicator(s) of value (e.g. net present value) (3.7)
- Perform a sensitivity analysis, including any subsequent validation / data collection (3.8)
- Report the final value estimate, including any limitations and uncertainties (3.9)

4.2 Milestones and Deliverables

The CEBRA Advisory Board (CAB) and DAWR Biosecurity Research Standing Committee (BRSC) have agreed to a schedule of milestones and deliverables for the second phase of the 'value' project (to be delivered as CEBRA Project 1707-13). Table 4 provides a synopsis of these milestones and how they contribute to the delivery of the steps identified in the previous section.

Table 4: Agreed project milestones and deliverables for 2017/18

Milestone	Timeframe
Project start and planning meeting. **Format:** Workshop **Desired outcome:** To confirm the project scope with the project sponsor / participants.	August 2017
Meeting and documentation of ABARES planned work and agreed deliverables for this phase of the project. **Format:** Workshop **Desired outcome:** To confirm the 'review' and 'do' activities to be delivered by ABARES.	October 2017
Extended work on non-market values and interim report, with recommendations on what further measures are needed. **Format:** Status Report (<20 pages) **Desired outcome:** To report on progress revising / standardising methodologies.	January 2018
Draft final report. **Format:** Technical Report (>20 pages) **Desired outcome:** To report on progress with the first phase of valuation (draft).	May 2018
Final report. **Format:** Technical Report (>20 pages) **Desired outcome:** To report on progress with the first phase of valuation (final).	June 2018

Following this schedule, we expect that by the end of the 17/18 project we will have valued most of the constituent pieces of the biosecurity system (using our standardised framework). This will leave the third year (18/19) to properly aggregate these values together, conduct uncertainty / sensitivity / validation analyses, and iron out any final bugs / gaps / issues. The final estimate of value will be delivered at the end of the 18/19 financial year, *ceteris paribus*.

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