RESEARCH IMPACT EVALUATION

Rabbit Biocontrol Case Study

October 2017

Contents

1 Executive Summary

The challenges

Rabbits were introduced in Australia in 1859 and spread rapidly and widely to become one of Australia's most destructive pests. Within 70 years they spread to 70 per cent of Australia's land mass, the fastest known invasion by a mammal anywhere in the world. They compete with livestock and native animals for food, affect tree plantings, and reduce ground water absorption. Less than two rabbits per hectare are sufficient to prevent the regeneration of native vegetation. Competition and land degradation by rabbits is listed as a key threatening process under the Environmental Protection & Biodiversity Conservation Act, and a Threat Abatement Plan is in place. Economic impacts include loss of agricultural productivity, control costs, land values, and national park management costs. Losses caused by rabbits to agriculture and horticulture in Australia are estimated to be about $239 million per year, not including environmental and social impacts.

The response

CSIRO's predecessor (CSIR), carried out initial trials that ultimately resulted in the successful release of the myxoma virus for the biological control of rabbits in 1950. This resulted in a dramatic reduction of Australia's rabbit population. It was the world's first successful biological control program of a mammalian pest. However, by the late 1950s, host-pathogen co-evolution led to development of genetic resistance in rabbits and the appearance of less virulent virus strains, and rabbit numbers increased again. In response to this challenge, CSIRO began a project to investigate the possibility of Rabbit Haemorrhagic Disease Virus (RHDV) as a potential biocontrol in 1989. The virus was brought to CSIRO at the Australian Animal Health Laboratory in 1991; and was assessed extensively for its suitability as Australia's second rabbit biocontrol agent. The releases of this virus began in late 1996. RHDV reduced rabbit numbers to very low levels, with the greatest impacts observed in arid zones, and lesser impact seen in high rainfall areas. A review of the economic benefits of the biological control of rabbits in Australia from 1950–2011 conservatively estimated that biological control of rabbits produced a benefit of A$70 billion (2011 A$ terms) for agricultural industries over the last 60 years (Cooke et al. 2013).

The current rabbit biocontrol program is based on 10-years of research into increasing the effectiveness of RHDV, and identifying factors limiting the effectiveness of RHDV in the field. CSIRO has worked with several national and international collaborators on a series of projects funded through the Invasive Animals Cooperative Research Centre (IACRC), the Department of Agriculture and Water Resources (DAWR; formerly Department of Agriculture, Fisheries and Forestry), and CSIRO.

For example, a collaborative research project funded by the IACRC, led by the New South Wales Department of Primary Industries (NSW DPI), evaluated overseas strains of RHDV for their ability to supplement Australia's existing biocontrol toolbox, resulting in the successful nationwide release of RHDV-K5 in 2017. The RHDV-K5 strain was selected due to its ability to better overcome partial protection from an endemic benign virus relative of RHDV that had been impeding successful RHDV mediated rabbit control since 1995, which the CSIRO-led team had identified and characterised. A second line of current research is developing a platform technology to accelerate and direct the natural evolution of the virus. The ultimate goal of this non-genetically modified organism approach is to repeatedly select tailored virus strains for subsequent virus releases, giving the virus the cutting edge to stay ahead in the co-evolutionary arms race with its host.

The impacts

CSIRO's recent (past ten years) biocontrol research is continually generating options and opportunities for impact for the future. Even where explicit social and economic outcomes are not yet evident, there can be value in outcomes such as enhanced capability, improved knowledge, better research infrastructure, and a clearer understanding of prospective areas for future research.

While CSIRO's rabbit biocontrol research program has been highly successful, there is as yet limited information that would allow separation of CSIRO's impact on actual gains for the farm communities and ecosystems over time. Most of this adoption takes place in the future, so impact analyses are associated with some uncertainty. For our analysis, we have relied on the Agtrans Research 2015 study and other analyses conducted in Australia. As such, our analysis is limited by the constraints within these studies. The 2015 report has been subject to sensitivity analysis and/or discretion explicitly advised in the report[1].

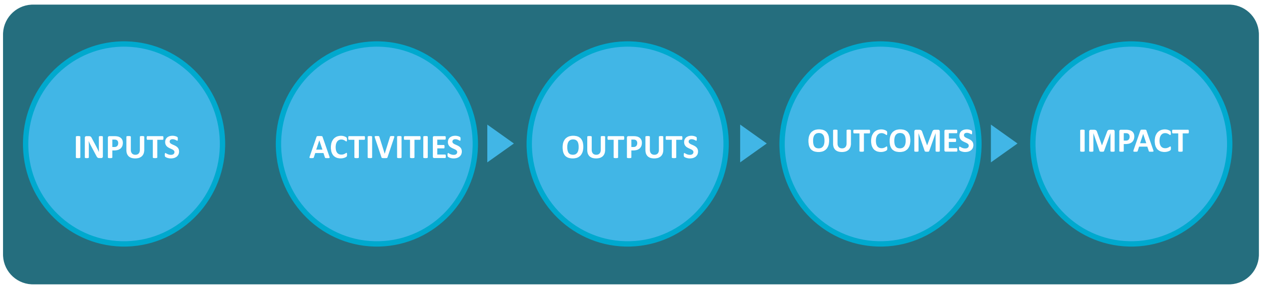
We acknowledge that the IACRC-led national rabbit biocontrol research and innovation program delivered the total impact; and that there are challenges associated with untangling precisely respective contributions among research agencies. CSIRO made essential contributions to most aspects, but only led some components.

Looking at a range of impacts, our conservative estimates suggest that the real research and development expenditure of $6.5 million per year will lead to ("CSIRO in context" not including extension and implementation costs):

- Total benefits (measured as avoided loss in agricultural production and savings in control costs, in real, present value terms) between $9.5 million and $230.6 million over the next 10 years, depending on the assumptions made;
- A benefit cost ratio between 2.5:1 and 36.3:1.

[1] The 2015 calculations were based on conservative assumptions (e.g. expected average reduction in rabbit control costs = 13%) that have subsequently been shown to be well below initial national average rabbit reduction of 42%.

This case study uses the evaluation framework outlined in the CSIRO Impact Evaluation Guide. The results of applying that framework to the Rabbit Biocontrol case study are summarised in Figure 1.1.



• CSIRO investment (FTE, in-kind contributions, equipment/facilities and background IP) • Investment from collaborators • Costs of adaptive development and extension by the industry • Background IP	• Rabbit research (Non pathogenic caliciviruses, RHD Boost, RHD Accelerator, development of diagnostic tools, and rabbit calicivirus field epidemiology studies) • Stakeholder engagement • Communication	• Identification of the non-pathogenic calicivirus RCV-A1, which proved to be a major factor limiting RHDV effectiveness in temperate Australia • Selection of rabbit biocontrol agents with enhanced efficacy in the presence of RCV-A1 for national release • New knowledge about the molecular epidemiology, evolution, and species-specificity of caliciviruses • New understanding into virulence evolution, experimental evolution platforms • Publications Development and optimisation of protocols for diagnostic testing of rabbit caliciviruses	***Uptake and adoption*** • Commonwealth and state government release of new RHDV strains • Research outputs used to develop future long term rabbit biocontrol pipeline strategy • More effective rabbit control methods	***Economic impact*** • Reduced cost of damage to the agricultural sector • Reduced rabbit control costs ***Environmental impact*** • Enhanced vegetation and native animal biodiversity • Reduced greenhouse gas emissions • Reduced land and soil damage ***Social impact*** • Regional community resilience through increased income and reduced stress

Figure 1.1: Impact Pathway for Rabbit biocontrol Project

2 Purpose and audience

This evaluation was undertaken to demonstrate to a range of stakeholders the likely future impacts arising from CSIRO's rabbit biocontrol research. This case study can be read as a standalone report or aggregated with other case studies to substantiate the impact and value of CSIRO's activities relative to the funds invested in these activities. Audiences for this report may include the Business Unit Review Panel, Members of Parliament, Commonwealth departments, CSIRO, and the general public.

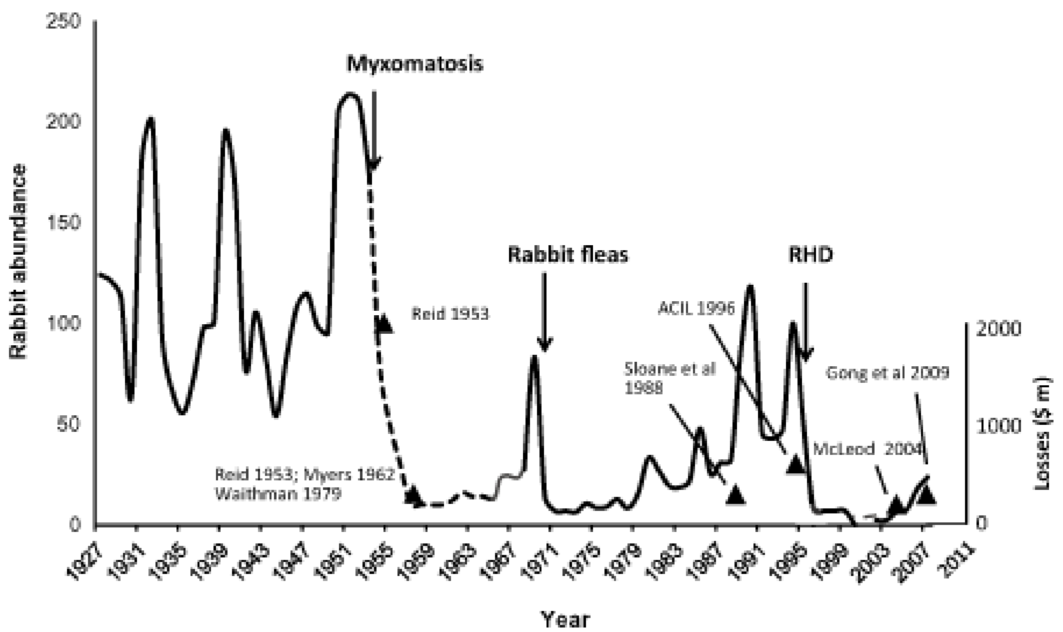
Dealing with evaluations where at least some of the impacts are difficult to quantify is not a new challenge. For this reason, mixed method (rather than mono-method) approaches have become firmly established as common practice in project evaluation. For the purpose stated above, the focus in this report is on summative evaluation, where the focus is on the outcome of a program, including predictions about future benefits (outcome focussed), rather than formative assessment, which evaluates a program at a cross-section in time (process focussed). Such evaluations are termed 'ex ante' if conducted before the project is carried out, and 'ex post' if conducted afterwards. Triple bottom line evaluation implies that judgements will be made across the three pillars of sustainable development: environment, economic, and social.

3 Background

Rabbits (*Oryctolagus cuniculus*) arrived with the first fleet in Australia; however, the main wild population is widely regarded as being descended from the introduction of wild rabbits into Victoria in 1859. Within 70 years, they had spread to 70 per cent of Australia's land mass, the fastest known invasion by a mammal anywhere in the world. They compete with livestock and native animals for feed, and occupy burrows that were once home to bilbies. They destroy tree seedlings destined for forestry, horticulture, or bush revegetation; and their eating habits change the types of plants that survive in bushland or in the outback. Ground degraded by rabbits is less able to absorb rain, sending water, nutrients, and sediment into river systems. The environmental impacts of rabbits can be devastating even at very low numbers – less than two rabbits per hectare are sufficient to prevent the regeneration of palatable native tree and shrub species by selective grazing. Competition and land degradation by rabbits is listed as a key threatening process under the *Environmental Protection & Biodiversity Conservation Act*; and a Threat Abatement Plan is in place. All of these impacts lead to higher land management costs, loss of agricultural productivity, and huge financial losses, impacting Australia's farmers as well as other land managers (e.g. national parks). The overall economic losses caused by rabbits to agriculture and horticulture in Australia was recently estimated to be approximately $239 million per year. Environmental impacts have not yet been quantified, and are not included in this assessment.

CSIRO's predecessor, Council for Scientific and Industrial Research (CSIR), in collaboration with Professor Frank Fenner's team at the Australian National University, carried out initial trials that ultimately resulted in the successful release of the myxoma virus for the biological control of rabbits in 1950. As a result, there was a dramatic reduction of Australia's rabbit population. It was the world's first successful biological control program of a mammalian pest. However, by the late 1950s, host-pathogen co-evolution led to less severe forms of the disease, and rabbit numbers increased again, although not to pre-1950 levels.

In 1984, a new emerging disease of rabbits was first noticed in China, frequently referred to in Australia as Rabbit Calicivirus Disease (RCD). RCD was subsequently determined to be caused by the Rabbit Haemorrhagic Disease Virus (RHDV). RHDV resulted in widespread deaths in European rabbits overseas, and was therefore considered by CSIRO as a new rabbit control method for Australia's invasive wild rabbit populations as early as 1989. The virus was brought to CSIRO in 1991; and was assessed extensively for its suitability as Australia's second rabbit biocontrol agent inside the secure facilities at CSIRO's Australian Animal Health Laboratories. Laboratory testing cleared the way for restricted testing in the field; but the virus inadvertently escaped from the field site at Wardang Island in South Australia, transmitted to mainland Australia by blowflies in late 1995. Within seven months the virus had spread naturally (possibly assisted by deliberate translocations) to all mainland states and territories. Further controlled releases of the virus began in late 1996 after RHDV had been listed as a biological control agent under the *Biological Control Act*. RHDV reduced rabbit numbers to very low levels, with greatest impacts observed in arid zones. Figure 3.1 summarises how rabbit abundance has varied through time in response to the release of biological control agents. The estimated Australia-wide economic losses to rabbits (black triangles) are also shown.



Source: Cooke et al. (2013)

Figure 3.1: Rabbit abundance in semi-arid South Australia (1927-2011)

Subsequently, scientists observed that RHDV was not as effective in cool, high rainfall areas in Australia; and they suspected that a non-lethal calicivirus, closely related to RHDV and naturally circulating within the rabbit populations, was to blame. This virus, RCV-A1, was identified by CSIRO in 2007; and it was further demonstrated that RCV-A1 can indeed act like an incomplete vaccine, partially and transiently protecting rabbits from lethal RCD, and thereby likely contributing to the lack of effectiveness of RHDV observed in the more temperate areas where the benign virus is prevalent.

RHDV kept wild rabbit numbers low for over a decade and, in contrast to the myxoma virus, a reduction in virulence has so far not been observed. However, evidence of developing genetic resistance in some Australian wild rabbit populations has now been described; and this, in combination with immunity that develops in animals that survive RHDV infection, has resulted in recent increases in rabbit numbers. New strains that can better overcome RCV-A1-induced cross-protection or immunity to RHDV have been, and are currently being, studied in the effort to stop rabbits from further damaging Australia's agricultural and natural environment.

A review of the economic benefits of the biological control of rabbits in Australia, from 1950–2011 conservatively estimated that biological control of rabbits produced a benefit of A$70 billion (2011 A$ terms) for agricultural industries over the last 60 years (Cooke et al. 2013). This did not include the added indirect benefits following the illegal release of the same virus strain in New Zealand.

4 Impact Pathway

Project Inputs

The national rabbit biocontrol research and innovation program has been delivered through the IACRC, with major financial and in-kind resources provided by the Australian government, state governments, and industry and research agencies. Through IACRC, the national rabbit biocontrol research and innovation program has provided funding to CSIRO and NSW DPI since 2007. Key collaboration partners include:

- Department of Agriculture and Water Resources (Commonwealth)
- CSIRO
- Department of Primary Industries (New South Wales) (NSW DPI)
- Australian Wool Innovation Ltd (AWI)
- Meat & Livestock Australia (MLA)
- Rabbit Free Australia Inc. (RFA)
- Department of Environment, Land, Water and Planning (Victoria)
- Department of Agriculture, Fisheries and Forestry (Queensland)
- Department of Primary Industries & Regions (South Australia) (PIRSA)
- ACT Government Environment and Planning

- ACT Government Territory and Municipal Services
- Parks Victoria
- The University of Adelaide
- The University of Canberra
- The University of Sydney.
- The International OIE reference laboratory for lagomorph diseases at the Istituto Zooprofilattico Sperimentale della Lombardia e Dell'Emilia Romagna, Brescia, Italy.Landcare Research New Zealand

Table 4.1 shows the cash and in-kind support received for the project over time from both CSIRO and external organisations (e.g. IACRC), which total just over $4.94 million between 2007-08 and 2017-18. Other in-kind contributions from CSIRO and collaborators in terms of previously created skills and capabilities were significant, but are difficult to quantify due to measurement constraints.

Table 4.1: CASH AND IN-KIND SUPPORT FOR PROJECT ($ nominal)

Year	Collaborators(cash)	CSIRO (in-kind)	Total
2007-08	-	-	-
2008-09	211,920	221,942	433,862
2009-10	237,033	254,530	491,563
2010-11	41,047	57,926	98,973
2011-12	-	-	-
2012-13	295,502	295,785	591,287
2013-14	312,502	312,317	624,819
2014-15	347,991	293,159	641,150
2015-16	255,658	191,443	447,101
2016-17	359,687	376,344	736,031
2017-18	447,692	423,113	870,805
Total	**2,509,032**	**2,426,559**	**4,935,591**

Note: cash and in-kind contributions are based on four IACRC projects with CSIRO involvement: RHD Boost, RHD Boost Plus and RHD Accelerator Stage 1.

Activities

The IACRC's national rabbit biocontrol research and innovation program has been delivered through a large-scale collaboration between Commonwealth and state governments, industry, and research agencies. Through the IACRC, CSIRO has worked with key collaborators such as Department of Agriculture and Water Resources, NSW DPI, Landcare Research New Zealand, former DAFF, and University of Canberra since 2008, within four series of projects, as follows:

Series 1: (September 2007 – August 2010) – Enhancing RHDV Effectiveness

In the cooler, more humid areas of Australia's southeast, RHDV appears to be less effective in controlling rabbit numbers when compared to more arid regions. The presence of caliciviruses other than RHDV has been suggested as the underlying cause for this lack of effectiveness. In 2007, a two year field study was undertaken to identify and examine the prevalence of different rabbit caliciviruses in south-eastern Australia.

The first part of this project identified, isolated, and partially characterised this elusive benign virus, RCV-A1, in order to study its interactions with RHDV and the extent of their interference.

The second part of this project developed a specific diagnostic test (ELISA) that allows discrimination between the two viruses and facilitates epidemiological studies at a population level.

Series 2: (July 2010 – June 2012) – RHD Boost

The work described below was predominantly undertaken at the Elizabeth McArthur Agricultural Institute (EMAI), New South Wales by both NSW DPI and CSIRO researchers, with support from VIC-DPI and PIRSA. This research focussed on the selection and evaluation of new strains of RHDV for potential release into Australian wild rabbit populations. This research comprised a number of sequential activities, including:

- Identification of RHDV strains that can better overcome cross-protection induced by RCV-A1, and assessment of some aspects of the competitive advantage of the selected strain.
- Development of a model of RHDV and RCV-A1 interactions and a decision framework for optimizing the release of candidate viruses in terms of initial establishment and likely regional impact.

NSW DPI (EMAI) undertook the evaluation of new RHDV strains. CSIRO contributed the genetic analysis of the short-listed strains, and led a sub-project related to a competitive advantage study of the top-listed candidate.

Series 3: (October 2012 – June 2018) – RHD Accelerator

This project is a logical extension of Series 2: RHD Boost. This research aims to use natural selection to produce strains of RHDV strains that are able to overcome immunity, and potentially genetic resistance, to existing Australian RHDV field strains. This non-GMO approach would provide a platform technology for the continuous supply of suitable calicivirus strains for subsequent release that would enable sustainable management of Australia's wild rabbit problem. A sub-project investigated the molecular virulence mechanisms of RHDV to gain a better understanding of the molecular traits defining a competitive field strain.

Series 4: (September 2014 – August 2018) – RHD Boost Rollout

The Series 2: RHD-Boost project identified a new strain of RHDV from South Korea (referred to as RHDV-K5) that is suitable for release into Australia's wild rabbit population. This project extended the coordinated nationwide release of RHDV-K5 into Australian wild rabbit populations and monitoring of the impacts to over 550 broad-scale release sites. During this time two exotic strains of RHDV arrived in Australia via unknown routes that had significant potential to interfere with the controlled release of RHDV-K5. CSIRO has been instrumental in the identification and characterisation of these viruses, including the development of discriminatory diagnostic tests as well as genetic and epidemiological studies.

Outputs

CSIRO's rabbit biocontrol research has significantly contributed to an integrated approach to wild rabbit management through four key initiatives, namely Enhancing RHDV Effectiveness, RHD Boost, RHD Accelerator, and RHD Boost Rollout. Specific output created through CSIRO's research are described below.

- *Identifying and characterising the endemic benign calicivirus*

Identifying and characterising the endemic benign calicivirus has made significant contributions to strategic knowledge of the effectiveness of RHDV in different regions of the country and helped to explain the lower mortality rates exhibited by the original Czech strain in temperate, higher-rainfall areas. The discovery of RCV-A1 has enabled the subsequent RHD Boost and Boost Rollout projects, the 'key' to unlocking the problem of reduced rabbit biocontrol effectiveness in temperate climate zones of Australia. In addition, the distribution map of this benign virus developed through the CSIRO project it was used to project the likely benefit of the RHDV-K5 strain in different areas of Australia, along with the development of serological diagnostic tools specific for the benign calicivirus, have been essential for ongoing epidemiological studies studying the interaction of different virus strains in Australia and New Zealand.

- *New biocontrol management products – RHD Boost (RHDV-K5 strain)*

The RHD Boost project found that the RHDV-K5 virus is able to better overcome the partial protection offered by RCV-A1 when compared to other strains; and the RHD Boost final report co-authored by CSIRO made recommendations that the RHDV-K5 variant be selected as an agent for release in Australia (Cox, et al., 2014).

- *Identification and characterisation of exotic RHDV strains in Australia*

The team at CSIRO was the first to identify an exotic variant of RHDV (termed RHDV2) that arrived in Australia via unknown routes. This virus, which can partially overcome immunity to existing field strains and also infects hares in addition to rabbits, has been replacing circulating field strains in parts of Europe over the past few years and has the potential to significantly impact on targeted rabbit biocontrol initiatives in Australia. By providing expert advice CSIRO contributed substantially to the media-communication and official investigations following these discoveries.

- *New biocontrol management products - RHD Accelerator (new tailored RHDV strains)*

Proof-of-concept for RHD Accelerator has been established, demonstrating a platform technology for the directed evolution of novel RHDV strains, and additional funding is being sought to take the platform technology through the final research phase and into development. Diagnostic tools that can discriminate between various calicivirus strains have also been developed during this project (Glanznig, 2015).

Publications

Impact area 1: Selection of rabbit biocontrol agents for national release. Liu 2012a,Liu 2012b, Liu 2014, Strive 2009, 2010, 2013, Mahar 2016, Nicholson 2017 describe the identification, characterisation, distribution and evolution of an endemic benign rabbit calicivirus (RCV-A1) that interferes with effective rabbit biocontrol in Australia and New Zealand, as well as the development of diagnostic tests to differentiate between RCV-A1 and RHDV. The outcomes of this work delivered one of the key criteria for the selection of the next rabbit biocontrol agent RHDV-K5 (selected to better overcome protection by RCV-A1) that was released nationwide in March 2017. Matthaei 2014 contributes an experimental characterisation of the infection dynamics and transmission aspects of RHDV-K5 in young rabbits.

Impact area 2: Studies about the molecular epidemiology, evolution, and species-specificity of caliciviruses naturally occurring in Australian rabbits – understanding the situation in the field is essential to inform the selection and application of new and existing calicivirus strains for biocontrol: Jahnke 2010, Kovaliski 2013, Eden 2015a, Eden 2015b, Hall 2015, Hall 2016, Mahar 2016, Hall 2017, Cox 2017.

Impact area 3: Studies into virulence evolution, experimental evolution platforms, as well as studies investigating host-pathogen interactions and virulence at a cellular/molecular level. This is fundamental science increasing our knowledge about the basic biology and host-pathogen co-evolution of biocontrol agents, underpinning future biocontrol strategies. Urakova et al 2015, 2016, 2017a, 2017b, Netzler 2017, Hall 2017, Nystrom 2011.

Outcomes

Key users of CSIRO's rabbit biocontrol research will encompass a broad range of enterprises (private and public lands), and a range of spatial scales. Beneficiaries will include farmers and pastoralists, biodiversity managers (e.g. Natural Resource Management Systems (NRMs)), government agencies, and regional networks (e.g. Landcare). Uptake has been accelerated by IACRC National Facilitators, using established and proven extension pathways (PestSmart, IACRC training programs, field days, FeralScan), public media, and national advisory groups (e.g. AWI Rabbit Advisory Group). Specific adoption and outcomes created through CSIRO's research are described below.

RHD Boost and Boost Rollout

The registration package to permit the release of RHDV-K5 was approved by Australian Veterinary Medicines Authority (APVMA) in 2016. The national release of RHDV-K5 by Commonwealth and state governments took place from the first week of March 2017 across Australia. This is the first time in 20 years that a new rabbit biocontrol agent has been released into Australia. More than 550 release sites were selected nationally.

The assessment of effectiveness of the new strains will be used as an input to future rabbit control strategies. In addition, information to more fully understand RHDV immunity, resistance, and changes in virulence will be used by scientists in the development of future vertebrate biocontrol strategies.

The probability of usage is very high based on past experiences with release of rabbit biocontrol agents, and the distribution channel capability of the output has been pilot-tested. The end-users of this distribution channel are also partners in IACRC; and there is a continued strong demand from industry for more effective rabbit control methods.

RHD Accelerator

New strains of RHDV are currently being generated through directed experimental evolution using the RHD Accelerator platform for which proof-of-concept has been demonstrated. New strains will be laboratory and field tested; and if suitable and approved, released by Commonwealth and state government authorities across Australia, under the auspices of the Invasive Plants and Animals Committee (IPAC).

The outputs from this project will rely on a number of external factors, including the success of the RHD Boost project and the rate of decline of the effectiveness of RHDV-K5.

At this stage there are no competing technologies being developed to reduce the impact of rabbits on the same scale as RHD Boost and RHD Accelerator. However, as it will take time to produce, characterise, and register any new RHDV strains, there is still potential for an alternative to become available during that time. For example, *Eimeria intestinalis* and *Eimeria flavescens* are infectious rabbit parasites that have been detected in south-west Western Australia, but not elsewhere on mainland Australia, and are currently being discussed as potential biocides to be relocated, provided they are absent in eastern Australia. A project to be funded through the new Centre for Invasive Species Solutions will use genetic testing to sample a wider range of rabbit populations to determine if the parasites' occurrence is restricted to Western Australia, as it currently appears.

In the interim, there may be scope to assess the naturally circulating RHDV2 for its usefulness to become a registered product for targeted application in certain areas to complement RHDV-K5. It is envisaged that any RHD Accelerator outputs will be rolled out after the effectiveness of RHDV-K5 starts to decline (likely within 10 to 15 years of release). The co-investment of CSIRO and industry in this project, combined with the in-principle support of IPAC, highlights the strong support and demand for this project's outputs.

Impacts

The table below summarises, in a triple bottom line framework, the broad impacts that may be delivered from CSIRO's investment in the rabbit biocontrol program. The principal economic impact will be reduced rabbit impacts on agriculture and rabbit control costs incurred compared to the situation where the new biocontrol investment is not made.

Positive environmental impacts from reduced rabbit populations will also result, in the form of:

- enhanced biodiversity of native vegetation from reduced impacts of rabbits on native tree and shrub regeneration
- enhanced biodiversity of small to medium sized mammals by reduction of rabbit favouring exotic predator populations such as foxes and cats (Pedler 2016, Mutze 2017)
- reduced greenhouse gas emissions from increased regeneration of young trees and shrubs and biomass in general
- reduced landscape damage and soil erosion from reduced impact of rabbits due to overgrazing and burrowing.

Social impacts will include the regional community impacts from maintained or increased farm productivity and income from increased grazing opportunities for livestock.

It is also important to acknowledge that there are potential negative impacts arising from the introduction of the biocontrol approaches. These negative impacts include:

- reduced wild rabbit industry and deaths or costs of protective vaccination of pet and farmed rabbits
- possible short term increased pressure on alternative prey species and increased methane production by increased stocking rates of livestock species
- social adjustment for families in wild rabbit industry and loss of bush tucker for indigenous people.

The impacts (both positive and negative) are summarised in Table 4.2. The impacts identified but not valued include the impact on natural resources, landscapes, vegetation, soils, and greenhouse gas emissions, and the community impacts from a healthier farm economy.

Table 4.2: Summary of rabbit biocontrol project impacts

TYPE	CATEGORY	INDICATOR	DESCRIPTION
Economic			
Benefits	Productivity and efficiency	Production loss	Reduced cost of damage caused by rabbits to the agricultural sector and associated increase in farm profits and land values due to improved productivity because of increased grazing resources.
	Productivity and efficiency	Management cost	Reduced rabbit control costs.
Costs	Productivity and efficiency	Production loss	Reduced domestic trade and exports for the wild rabbit industry.
	Productivity and efficiency	Costs of death and vaccination of farmed and pet rabbits	Non-vaccinated rabbits are susceptible to RHDV, which results in loss of the non-vaccinated population.

Environmental			
Benefits	Ecosystem health and integrity	Biodiversity	Enhanced fauna and flora biodiversity.
	Air quality	Emissions	Reduced greenhouse gas emissions from increased regeneration of young trees and shrubs.
	Land quality	Soil quality	Reduced land and soil damage from overgrazing and burrowing.
Cost	Ecosystem health and integrity	Short term pressure on alternative prey	As well as providing food for foxes and feral cats, rabbits are eaten by native predators. The decline in rabbit numbers may increase pressure on alternative prey, at least temporarily.
	Air quality	Methane production	The additional sheep and cattle emit greenhouse gases, although this is a relatively small amount.
Social			
Benefits	Resilience	Income	Regional community impacts from maintained or increased grower incomes and less anxiety and income related stress.
Costs	Resilience	Income	Social adjustment for families in wild rabbit industry.
	Indigenous	Not quantified	Loss of bush tucker for indigenous people.

5 Clarifying the Impacts

Counterfactual

The counterfactual scenario describes what happens if rabbit biocontrol technology is not implemented and the status quo or extension of current trends prevails. For example, scientists observed that RHDV was not as effective in controlling wild rabbit populations in cool, high rainfall areas of Australia.

Conventional controls, along with biocontrol agents, are routinely used in Australia to control rabbits. Conventional methods include destroying rabbit burrows by warren ripping, warren fumigation using poison baits, exclusion fencing, and/or shooting. However, conventional controls are labour intensive and time consuming; and, faced with the rate at which rabbits breed, cannot suppress numbers on their own. In addition, not all methods are universally suitable for any situation, for example sodium fluoroacetate (1080 poison) is not suitable near built up areas due to possible non-target effects. For continental landscape-scale control in more remote areas, biological control with the self-disseminating viral agents RHDV and the myxoma virus has been the only reliable means of sustainably reducing rabbit numbers. However, biocontrol is never a silver bullet and cannot solely be relied upon, but has to be used as part of tailored, integrated rabbit management strategies.

Overall, the counterfactual scenario includes the following two broad key elements:

- Conventional approach to rabbit biocontrol (relying on original myxoma virus and RHDV biocontrol strain and other non-biocontrol methods) resulting in less effective rabbit control management over time. As a result, annual rabbit damage and control costs increased steadily from 2008-09 (capped at 150% of 2008/09 level).
- No successful research investment similar to RHD Boost or RHD Accelerator undertaken by other research organisation or government agencies, reflecting ongoing biocontrol funding uncertainty, lack of capability, and lack of coordination of resources for delivering effective biocontrol methods. Extensive research on rabbit biocontrol in Australia at a national scale and working across state and jurisdictional boundaries can therefore only be performed by large collaborative projects involving CSIRO in its role as a national agency, as well as universities, industry, state, and federal government agencies.
- The impact on the wild and farmed rabbit industry will remain at 2008-09 levels.

6 Evaluating the Impacts

Cost Benefit Analysis

Modelling approach

We calculated the rabbit biocontrol research program outcome deployment and counterfactual scenarios to determine the value of the entire research program benefits (where quantification is possible). The counterfactual scenario represents the pathway where CSIRO's rabbit biocontrol research is not implemented, and a 'status quo' or extension of current trends prevails. The benefits calculated in the analysis are the net benefits from the program, that is, the difference between the 'with program' and 'without program' scenarios. The analysis is equivalent to carrying out separate analyses for the 'with program' and 'without program' scenarios and calculating the difference between them.

There are a number of past studies that have addressed the economic impacts of rabbits on Australian rural industries (e.g. Gong et al. 2009, Agtrans research 2011 and 2015, Cooke et al. 2013). Other analyses have updated these expected costs given the recent impacts observed with the original RHD strain and the potential cost reductions due to the release of RHDV-K5. Studies examining the impact of the IACRC's RHD Accelerator investment also exist. All of these studies have predicted future rabbit damage and control cost levels, thus providing a baseline for costs in the 'without new investment in biocontrol agents' that represents the counterfactual scenario.

If RHD Accelerator is successful in producing a continuous supply of new RHDV variants suitable for registration and nationwide release, the industry and environmental cost-savings assumed for RHD Boost is extended indefinitely, rather than rabbit numbers increasing again after eight years as is assumed in the RHD Boost analysis. As current data for the RHD Boost analysis was not available at the time of preparing this report, consideration of the impact is limited to RHD Boost based on assumptions sourced from Gong et al. 2009, and Agtrans research 2011, 2015.

Box 1: Method for valuing rabbit biocontrol impacts

Rabbit distribution

- Include data about densities of rabbits by climatic zone, particularly in agricultural areas.
- Scientific literature summarized in relation to distribution and potential for impact.

Agricultural production

- Include data for the value of agricultural industries at risk from rabbit impacts e.g. livestock numbers and areas cropped by ABARE region.
- Gross margin data summarised for different states and average derived for Australia across sheep, cattle, and broad acre industries.

Valuation of impact

- Rabbit distributions are superimposed over values of agricultural production in each region.
- Estimates made of reduced carrying capacities, yield losses, and rabbit management costs.
- Aggregate rabbit-related costs are calculated.
- Biodiversity impacts valued where possible.
- Total costs (control and losses) calculated.

Source: CIE 2004.

Due to limited information on the actual gains of the social, environmental, and economic impacts, many of the assumptions required to value the impacts for each biocontrol investment are uncertain. While reasonable and conservative assumptions have been made in the analyses, the results should be viewed with some caution. This valuation provides a ball-park estimate of the potential net benefits; and therefore requires the need for a follow-up revision of the valuation once the results of the actual uptake/adoption become available.

The steps in quantifying the gains from the program are as follows:

1. Estimate the benefits for farmers in the counterfactual case (without CSIRO's rabbit biocontrol research) and the case with CSIRO's rabbit biocontrol research.
2. Estimate the costs of research and adoption of the technology.
3. Aggregate the costs and benefits to obtain a net benefit. All past benefit flows are compounded forward to 2016-17 and future benefits are discounted back to 2016-17 at a real discount rate of 7 per cent to convert to a present value in 2016-17.

The assumptions and sources for this benefit are outlined in Table 6.1. As illustrated, the baseline level of rabbit impacts to Australian agriculture is $92.4 million/year in the high rainfall zone, $69.6 million/year in the wheat-sheep zone, and $77.3 million/year in the pastoral zone. These are the impacts on beef, lamb, and wool enterprises. Without RHD Boost (i.e. the release of RHDV-K5) the baseline impact will increase by 10 per cent per annum in the high rainfall, and 5 per cent per annum in the wheat-sheep and pastoral zones. This continues until a maximum level of impact of 150 per cent of the base level of impact is reached. In contrast, with RHD Boost (i.e. the release of RHDV-K5), in 2017-18 (the first year after releasing RHDV-K5) the impact of rabbits is reduced by

20 per cent in the high rainfall, 15 per cent in the wheat-sheep zone, and 5 per cent in the pastoral zone. After eight years, the impacts of rabbits begins to increase again by 10 per cent per annum in the high-rainfall zone, and 5 per cent per annum in the wheat-sheep and pastoral zones, as the efficacy of RHDV-K5 reduces.

Table 6.1: Costs benefits from the rabbit biocontrol project

Measures		**Value^**	**Source**
Counterfactual (without RHD Boost)			
$\mathbf{A}_R$	Costs of rabbits to industry by agricultural zone per year ($m as of 2008/09)	$92.35 (HRZ); $69.61(WSZ); $77.32 (PaZ)	Gong et al. (2009)
$\mathbf{B}_R$	Expected increase in industry costs by agricultural zone per year (%)	10% (HRZ); 5% (WSZ); 5%(PaZ)	Agtrans Research (2015)
$\mathbf{C}_R$	Rabbit control costs per year ($m)	$7.98	Agtrans Research (2015)
$\mathbf{D}_R$	Expected increase in rabbit control costs per year (7%)	10%	Agtrans Research (2015)
$\mathbf{E}_R$	Total industry and control cost ($m)	$= \mathbf{A}_R * (1+ \mathbf{B}_R) + C_R (1+D_R)$	
	Maximum level of industry and control cost impacts (%)	150% of 2008/09 level	Agtrans Research (2015)
	Proportion of Australia applicable for biocontrol use (%)	70%	Agtrans Research (2015)
With research collaboration involving CSIRO (with RHD Boost)			
$\mathbf{A}_c$	Costs of rabbits to industry by agricultural zone per year ($m as of 2008/09)	$92.35 (HRZ); $69.61(WSZ); $77.32 (PaZ)	Gong et al. (2009)
$\mathbf{B}_c$	Expected decrease in industry costs by agricultural zone per year (%)	20% (HRZ); 15% (WSZ); 5%(PaZ)	Agtrans Research (2015)
$\mathbf{C}_c$	Rabbit control costs per year ($m)	$7.98	Agtrans Research (2015)
$\mathbf{D}_c$	Expected decrease in rabbit control costs per year (%)	13%	Agtrans Research (2015)
$\mathbf{E}_c$	Total industry and control cost under adoption ($m)	$= \mathbf{A}_c * (1- \mathbf{B}_c) + C_c (1-D_c)$	
	Duration of stable impact (years)	8 years (until 2023/24)	Agtrans Research (2015)
	Maximum level of industry and control cost impacts (%)	100% of 2016/17 level	Agtrans Research (2015)
	Proportion of Australia applicable for biocontrol use (%)	70%	Agtrans Research (2015)
Impacts			
	Counterfactual – with CSIRO rabbit biocontrol research		
	Cost savings per year ($m)	$=E_R - E_c$	

HRZ: high-rainfall zone; WSZ: wheat-sheep zone; PaZ: pastoral zone.

Time period

While CSIRO's rabbit biocontrol program is an ongoing activity, it is necessary to define a particular period for the cost-benefit analysis (CBA). Given the history of the project, the analysis is based on research activity since 2008-09.

In the program, there are lags between the scientific discovery, and the realisation of benefits after adoption by government agencies and other end users. In recent years, the lag has averaged

10 years[2]. On that basis, the benefits are only measured from 2017/18 onwards. In the analysis, the costs from 2008-09 are included.

Given the costs are measured until 2017-18, the benefit must be estimated for the future, since the RHD Boost outputs developed and released in 2017-18 provide a foundation for biocontrol impacts for many years. The duration of stable impact of a new biocontrol agent is typically around eight years, with a life span ranging from 15-30 years (Agtrans Research 2015). In this analysis, a conservative approach of 10 years is adopted and it is assumed that benefits are measured to 2026-27.

Thus the analysis involves a small component of ex post analysis (relating to the costs in the period 2008-09 to 2017-18), but also a large component of ex ante analysis forecasting the benefits flowing from the research activities over the period to 2026-27.

Costs

Research, development and implementation costs

In principle, establishing the costs involved throughout the entire 'inputs to impact' pathway is an important exercise of a CBA. This includes both the input costs incurred by CSIRO and its collaborators, as well as any usage and adoption costs borne by clients, external stakeholders, intermediaries, and end users. CSIRO and its research partners contributed $15.6 million respectively to the rabbit biocontrol research ("RHD boost in context") between 2008-09 and 2017-18 in real terms.

Table 6.2: Summary of CSIRO and industry adjusted project costs ($m) (discounted @7%)

	PV of NSW DPI costs (2008-09- 2017-18)	PV of CSIRO costs (2008-09- 2017-18)	PV of other costs (2008-09- 2017-18)	PV of implementation costs (2017-18 to 2026-27)
Total ($m)	5.6	6.5	3.4	3.5
% of total cost	29%	34%	18%	19%

Note: PV=present value. Others include IZS, IAL, UC, PIRSA, DAFWA, ACT Government, UOA, MLA, AWI, and DAFF QLD

Source: CSIRO based on four IACRC projects: RHD Boost, RHD Boost Plus and RHD Accelerator Stage 1.

For RHD Boost, there were some costs associated with disseminating RHDV-K5. The cost was $1.54 million in the first year of release, and an estimated $0.26 million per annum thereafter (IACRC 2016). Table 6.3 summarises all costs, adjusted for inflation and discounted at 7 per cent.

Other costs arising from the negative impacts

As identified in Table 4.1, there are also social, environmental, and economic costs (negative impacts) arising from the biocontrol program. The discussion below is based only on the economic

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[2] Author's analysis based on the CSIRO example.

costs from the reduced wild rabbit industry and deaths and vaccinations of pet and farmed rabbits.

Reduced wild rabbit industry

In the past, the Australian rabbit industry was based on harvesting wild rabbits. With the release of RHDV, the number of harvested rabbits fell from about 2.7 million wild rabbits per year in 1990 to about 100,000 in 1999 (NSW DPI 2006). The domestic trade was at around $7.8 million in 1995, of which about $1.7 million came from farmed rabbits (Saunders and Kay 1999), leaving $6.1 million attributable to harvested wild rabbits. The export market was worth about $0.1 million p.a. prior to RHDV, leading to a total of $6.2 million in 1995, or $10.2 million in 2017-18 dollars.

Most rabbits for this trade was taken from pastoral regions because the densities of rabbits have to be high to make harvesting economically worthwhile. Assuming RHDV caused an 85 per cent reduction in this industry, the economic cost is about $8.7 million in 2017-18 dollars.

The industry claimed compensation for this loss of earnings but settled out of court for an undisclosed amount. Given the limited information, the economic loss of the wild rabbit industry was not taken into account in the CBA.

Vaccination costs for pet and farmed rabbits

There were about 337,000 pet rabbits in Australia in 1994 (ABS 2002). Assuming the numbers grow at the same rate as the Australian human population growth of 1.2 per cent, this equals about 443,386 in 2017. About half of the pet rabbits are vaccinated once against RHDV (Ryan 2003). Allowing an average life span of pet rabbits of four years, this accounts for about 110,000 annual vaccinations. At an average cost of $80, this amounts to $8.8 million per year.

Breeding stock in rabbit farms are more likely to be vaccinated against RHDV. There are currently about 119,000 to 132,000 breeding stock on rabbit farms (NSW DPI 2006). Although small, the industry is growing rapidly; and 10 per cent growth per year from 2003 has been assumed (NSW DPI 2006). Immunising these rabbits cost about $15 each (mostly done by the farmer), accounting from $6.9 million to $7.5 million per year in 2017-18 dollars.

Dead weight costs of government taxation

Given that the national rabbit biocontrol research is mainly funded by the Australian and state governments, the cost of the funds that it has used for the biocontrol program should reflect on the rest of the economy. Assuming that it is realistic to assume that CSIRO biocontrol funding has been obtained through income taxation, there will have been negative effects on the private sector in the form of deadweight loss. It has been argued by a number of authors that program costs should be increased by about 20 per cent to reflect the deadweight loss of income tax-based funding, although many Australian cost-benefit studies omit it.

Contribution of CSIRO

The evaluation has been undertaken by CSIRO to both understand the payoff from the technology, as identified above, and to identify specifically the potential net benefit (and success) of CSIRO’s research programs. It is therefore necessary to tease out CSIRO’s benefits, requiring a disaggregation of the benefits back to either CSIRO or other research agencies, such as NSW DPI. In practice, this requires that we make a judgement about the value of CSIRO's contribution to the project outcomes, distinct from CSIRO's contribution to the technology (RHDV-K5), which has facilitated the uptake.

It is important to note that the rabbit biocontrol program is a large national collaborative initiative, which is greater than the sum of its parts. IACRC, Commonwealth, and state governments provided important co-financing, capability, and infrastructure from 2008-09 to 2016-17. Industries have also played an important role by providing access to trial sites and facilities, without which the research could not have been undertaken. To attribute a portion of the impact of this program to date to CSIRO, it is useful to delineate the major outputs from the IACRC national rabbit biocontrol research and innovation program, and the attribution between research agencies:

- Discovery and characterisation of RCV-A1 (100% CSIRO) in collaboration with Istituto Zooprofilattico Sperimentale (IZS) Universities of Sydney and Adelaide
- Evaluation of overseas RHDV strains to select K5 (95% NSW DPI and EMAI, 5% CSIRO)
- RHDV-K5 competitive advantage study (95% CSIRO, 5% EMAI)
- RHDV Accelerator (CSIRO 100%) in collaboration with the University of Canberra and IZS.
- Future biocontrol agents – 20 year biocontrol pipeline strategy (80% CSIRO)
- CSIRO contributions to the Boost Rollout project:
    - Identification and characterisation of exotic strains – (80% CSIRO overall (RHDV2/RHDVa-Aus strain), >95% for RHDV2)
    - Advice prior to Boost release, input into media releases, and web based information (70% CSIRO)
    - Registration package – feedback & advice regarding genetic diversity, species-specificity etc. (40% CSIRO)
    - Development and implementation of differential molecular diagnostics pre- and post-Boost rollout (100% CSIRO)
    - Serology (development of RHDV2 ELISA) (50% CSIRO and 50% IZS), serology implementation for rollout (RCV-A1, RHDV2) (30% CSIRO and 70% PIRSA)
    - Spread, epidemiology, and evolution of RHDV strains (80% CSIRO with input from the University of Sydney and EMAI, Landcare, and PIRSA).

Since CSIRO and collaborators were necessary to achieve the ultimate objective of developing an effective rabbit biocontrol technology, it was appropriate to attribute benefits by defining the major outputs from the national program and estimating a CSIRO attribution to each major output. Based on the above descriptions (on a cost-sharing approach), in this analysis it is assumed that **40 per cent of research impacts arising from IACRC's national rabbit biocontrol research program can be attributed to CSIRO**. The other 60 per cent being split between NSW DPI (40%) and other parties (20%) Based on the above, this case study will attribute total impacts as follows:

- CSIRO – 40 per cent
- Others including IACRC, governments, and industry – 60 per cent.

Results

Table 6.4 summarises the present value of the benefits resulting from reduced agricultural losses and rabbit control costs. Benefits ranges from $276.6 million (‘program in context’) to $77.5 million (‘CSIRO in context’). Assuming total costs of $51 million and $6.5 million respectively, then benefit-cost ratios (BCRs) from the research range from 5.4:1 (‘program in context’) to 11.9:1 (‘CSIRO in context’). Despite the conservative estimates of the potential benefits that might be delivered by the rabbit biocontrol program, the total estimated benefits comfortably exceed the costs of the research.

Table 6.4: Results of cost-benefit analysis

Criteria	CSIRO	Program
Present value of costs ($ m)	6.5	51.0
Present value of benefits ($ m)	77.5	276.6
Net Present Value (NPV)	70.9	225.6
Benefit-cost Ratio (BCR)	11.9	5.4

7 Sensitivity analysis

While CSIRO’s biological control of rabbits has been an Australian success story, the effectiveness of individual biocontrol agents is not yet certain (i.e. if it is doing the job and was a good choice for biocontrol).

In addition, the overall benefits of the biocontrol project depend crucially on the adoption profile and actual achievement of social, economic, and environmental benefits. Most of this adoption takes place in the future, so impact analysis outcomes are associated with some uncertainty. Revisiting this analysis when more recent data is available is highly recommended.

Given these uncertainties, it would be useful to look at results under different discount, adoption, and attribution rates. For example, our base-case calculations were based on conservative assumptions. The expected average reduction in rabbit control costs was assumed to be 13 per cent, which has subsequently been shown to be well below the initial average rabbit reduction of 42 per cent at RHDV-K5 release sites. Table 7.1 presents the sensitivity analysis results for selected key variables on Present Value (PV) of benefits and BCR at 4 and 10 per cent discount rates. Overall, all scenarios analyses proved that this project consistently generates more benefits than costs, even with some assumptions and uncertainty.

While the parameters used in the base-case scenario seem reasonable in the light of current realities on the ground, it is nevertheless important to test the robustness of our conclusions to variations in these assumptions. The low and high alternative assumptions used in the above sensitivity analysis were brought together to estimate the benefit and cost streams under pessimistic and optimistic scenarios by combining changes across all variables jointly. The results under these different assumptions are summarised in Table 7.1. Based on this analysis, we estimate that the total benefits (measured as avoided loss in agricultural production and savings in control costs, in real, present value terms) between $9.5 million and $230.6 million over the next 10 years with BCRs ranging from 2.5 to 36.3 ("CSIRO in Context").

Table 7.1: Alternative assumptions for sensitivity analysis.

Scenario	Variables	Description	NPV ($m)	BCR
Optimistic scenario	Discount rate = 7% Expected decrease in industry costs by agricultural zone = 20%, 15% and 5% Expected decrease in rabbit control costs = 43% Proportion of Australia applicable for biocontrol use =100% Benefits of the program attributable to CSIRO =60%	Program	$330.8	6.1
		CSIRO	$230.6	36.3
Pessimistic scenario	Discount rate = 7% Expected decrease in industry costs by agricultural zone = 15%, 10% and 5% Expected decrease in rabbit control costs = 13% Proportion of Australia applicable for biocontrol use =50% Benefits of the program attributable to CSIRO =20%	Program	$117.9	3.8
		CSIRO	$9.5	2.5

8 Limitations and Future Directions

This evaluation uses a mixed methodology to evaluate the research impacts arising from CSIRO's rabbit biocontrol technology. It combines quantitative and qualitative methods to illustrate the nature of the technology's economic, environmental, and social impacts. In cases where the impacts can be assessed in monetary terms, a CBA is used as a primary tool for evaluation. As a methodology for impact assessment, CBA relies on the use of assumptions and judgments made by the authors. This relates primarily to the economic indicators for impact contribution, attribution, and the counterfactual scenario. These limitations should be considered when interpreting the results presented in this case study.

Given the scope and budget for the analysis, we acknowledge that there are some limitations with regard to the evidence base of impacts. For our analysis, we have relied on the Agtrans Research 2015 study and other analysis conducted in Australia (e.g. Gong et al 2009). As such, our analysis is limited by the constraints within these studies. For instance, due to data limitations, the distribution of biocontrol agents and the actual effectiveness of the agent post-release across the country was based on estimates only as limited information was available about the actual gains on the farm communities, pastures, and ecosystems over time. Results from the 2015 report have been subject to sensitivity analysis and/or discretion explicitly advised in the report. In addition, social and environmental benefits were not quantified, but are clearly additional (but treated here as potential impacts) owing to a lack of reliable data.

It is important to note that, in addition to its financial investment, CSIRO provides a range of contributions into these projects that help deliver the impact beyond the scale of its financial investment (intangible contributions like background IP, knowhow, key staff capabilities), which were not able to be taken into account in this analysis, but without which financial investment could not provide the same level of realised public benefit.

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