AN EVALUATION OF **THE IMPACT OF RHDV1-K5 IN AUSTRALIA**

TALIA HARDAKER AND PETER CHUDLEIGH AGTRANS RESEARCH, MARCH 2020

COLLABORATION INNOVATION IMPACT

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Building 22
University Drive South
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Bruce, ACT 2617

Mailing Address:

PO Box 5005,
University of Canberra LPO,
University of Canberra ACT 2617
Telephone: 02 6201 2887
Home Page: www.invasives.com.au

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Tanja Strive, Principal Research Scientist, CSIRO Health & Biosecurity

Patrick Taggart, Research Officer, Vertebrate Pest Research Unit, NSW Department of Primary Industries

Tarnya Cox, Research Officer, Vertebrate Pest Research Unit, NSW Department of Primary Industries

Richard Price, Portfolio Director (Research), Centre for Invasive Species Solutions

Andreas Glanznig, Chief Executive, Centre for Invasive Species Solutions

ABBREVIATIONS AND ACRONYMS

CBA	Cost Benefit Analysis
CISS	Centre for Invasive Species Solutions
DEWHA	Department of the Environment, Water, Heritage and the Arts
EPBC Act	Environment Protection and Biodiversity Conservation Act 1999
HRZ	High Rainfall Zone
IA CRC	Invasive Animals Cooperative Research Centre
NSW	New South Wales
PaZ	Pastural Zone
PVB	Present Value of Benefits
RD&E	Research, Development and Extension
RHDV	Rabbit Haemorrhagic Disease Virus
RHD	Rabbit Haemorrhagic Disease
SA	South Australia
VIC	Victoria
WSZ	Wheat Sheep Zone

EXECUTIVE SUMMARY

Significant past investment in the development and release of a new strain of Rabbit Haemorrhagic Disease Virus (RHDV), known as RHDV1-K5, in 2017 was predicated on the fact that no new rabbit biological control agents were likely to be introduced in Australia. However, in May 2015, a new variant of RHDV was detected in New South Wales. Serological studies showed that this new, highly virulent, exotic RHD virus, known as RHDV2, had been present in Australia since at least the Spring of 2014. RHDV2 spread rapidly across all Australian states and territories and had arrived in Western Australia by Spring 2016. Studies from Europe and Australia suggest that RHDV2 has a strong competitive advantage over the RHDV1 viruses and the arrival of RHDV2 in Australia coincided with reductions in average rabbit abundance of approximately 60%.

The appearance of RHDV2 in Australia was shown to have severely curtailed the potential benefits of the release of RHDV1-K5. Hence, the actual impact of K5 is uncertain. The Centre for Invasive Species Solutions (CISS), a significant stakeholder in Australia's rabbit biocontrol research, development and extension (RD&E) pipeline, required an evaluation of the impact of RHDV1-K5 for control of rabbits in Australia. The evaluation aimed to:

- Attempt to estimate the projected potential impact of RHDV1-K5 (without the emergence of RHDV2), based on available data for RHDV1-K5 and RHDV2 impacts.
- Estimate the current impact of RHDV1-Czech-351, RHDV1-K5 and RHDV2 together, and then assess the actual impact attributable to RHDV1-K5.

The current evaluation was conducted in line with prevailing impact assessment guidelines and was undertaken in three parts. First, an evaluation was completed for the estimated, potential impact of RHDV1-K5 based on an assumption that RHDV2 had not arrived in Australia. Second, a valuation was completed for the total current and future impact of all additional rabbit biocontrol introduced since 2014. Finally, an assessment of the actual impact of RHDV1-K5, given the presence of RHDV2 and other biological control agents, was conducted. The three analyses resulted in an estimate of the present value of benefits (PVB) for each of the scenarios investigated.

The analysis found that, without the incursion of exotic RHD variants including RHDV2, the predicted, potential impact of RHDV1-K5 was estimated to have a Present Value of Benefits (PVB) of $86.39 million (over 30 years using a 5% discount rate). However, due to the presence of RHDV2 and other RHD variants prior to 2017, the impact of RHDV1-K5 was curtailed. The actual impact of RHDV1-K5 was estimated to have a present value of benefits of $54.26 million (30 years, 5% discount rate). Table 1 shows the total PVB, estimated over 30 years using a 5% discount rate, for each scenario.

Table 1. Estimated present value of benefits for RHDV1-K5 under different scenarios regarding the presence of RHDV2

RHDV1-K5 Evaluation Scenario	Present Value of Benefits ($m, 30 years, 5% discount rate)
1) Potential impact of RHDV1-K5 in the ABSENCE of RHDV2	86.4
2) Combined impact of all additional biocontrol after 2014 (RHDV2, RHDVa and RHDV1-K5)	4,000.0
3) Estimated actual impact of RHDV1-K5 only given the presence of RHDV2	54.3

Compared to a situation where RHDV2 had not been present in Australia, the value of the impact of RHDV1-K5 was potentially reduced by about 37% based on the assumptions made in the current analysis. However, it is important to note that the analyses did not consider the significant rabbit biocontrol RD&E costs incurred to release RHDV1-K5 over the past 15 to 20 years. Agtrans (2011) reported an estimated total investment of $11.18 million (present value terms) for RD&E associated with the identification, testing, registration and release of a new RHDV variant through investment in a project known as RHD-Boost. Thus, the PVB results presented in the table above suggest that, regardless of the presence of other RHD variants, RHDV1-K5 was likely to have had a significantly positive net benefit. Further, it also has to be noted that inferring the potential impact of RHDV1-K5 in the absence of RHDV2 is extremely difficult, as the only data available for the actual impact of RHDV1-K5 are with the background of RHDV2 present.

The release of RHDV1-K5 in 2017 represented the culmination of almost 20 years of Australian investment in rabbit biocontrol RD&E. The RHDV1-K5 virus now contributes to the ongoing suppression of the Australian wild rabbit population and forms an integral part of landscape-scale integrated rabbit management practices. Also, the estimated benefits presented by the current analysis do not include the value of the positive environmental and social impacts of rabbit biocontrol. Therefore, the benefits reported may be an underestimate of the true value of the release of RHDV1-K5. The positive estimated benefits of rabbit biocontrol in Australia demonstrate the positive economic impact of new rabbit viral diseases and underpins the value of ongoing investment in rabbit biocontrol RD&E pipelines.

1. INTRODUCTION

This report presents the findings of an independent evaluation of the impacts of rabbit biocontrol in Australia for three different scenarios. First, the analysis investigated the predicted, potential impact of a new variant of Rabbit Haemorrhagic Disease Virus (RHDV) that was strategically released across Australia in 2017 (known as RHDV1-K5). This analysis explored the potential value of RHDV1-K5 without the incursion of new, exotic RHD variants. Next, the analysis estimated the current and future impact of all new forms of rabbit biocontrol introduced in Australia since 2014. Finally, the analysis examined the likely actual impact of RHDV1-K5 given the presence of other rabbit biocontrol agents in the form of the incursion of exotic RHDV variants (RHDV2 and, to a lesser extent, RHDVa) in Australia in 2014, after the investment in RHDV1-K5 had been made but before its release in 2017.

The report is structured as follows. Section 2 outlines the background, rationale and objectives of the evaluation. Section 3 provides summary of impact damage costs of rabbits and the potential benefits of rabbit biocontrol. Section 4 includes a brief overview of the current state of rabbit biocontrol in Australia. Section 5 presents an update of an impact assessment of RHD-Boost (the original RHDV1-K5 rabbit biocontrol investment funded through the Invasive Animals Cooperative Research Centre (IA CRC)). Section 6 describes a framework used to estimate the current and future impact of rabbit additional rabbit biocontrol in Australia since 2014. Section 7 provides an assessment of the actual impact of RHDV1-K5 after its release in 2017. Section 8 presents the key findings and conclusions of the evaluation.

2. BACKGROUND & RATIONALE

Background

European rabbits were introduced to Australia in the mid-nineteenth century. Wild rabbits now are one of Australia's most widely distributed pest species and cause damage to the environment as well as to the value of agricultural production. Rabbit Haemorrhagic Disease (RHD) is caused RHDV, a type of calicivirus that is fatal in non-immune rabbits. RHDV strains have been used as a form of biocontrol to control rabbit numbers across Australia since the mid-1990s. There currently exist three strains of RHDV in the Australian wild rabbit population.

The first virus (RHDV1, also known as the Czech-351 strain) escaped from quarantine in 1995 and then was officially released for rabbit biocontrol in 1996. RHDV1 was highly effective and killed up to 90% of the existing Australian wild rabbit population in some areas. Over time, rabbits developed population immunity as well as genetic resistance to RHDV1 and its effectiveness as a biocontrol agent began to decline.

To combat this resistance, the IA CRC (forerunner to the current Centre for Invasive Species Solutions (CISS)) funded further rabbit biocontrol research, development and extension (RD&E) projects aimed at identifying and developing strains of RHDV not already present in Australia, or novel biocontrol/biocide options, for improved rabbit control. As a result of these investments, a second strain of the virus, sourced from Korea (known as RHDV1-K5), was identified, developed as a new biocontrol agent, and registered and released into the wild rabbit population in March 2017.

However, in May 2015, a new variant of RHDV was detected in New South Wales. Serological studies showed that this new, highly virulent, exotic RHD virus, known as RHDV2, had been present in Australia since at least the Spring of 2014. RHDV2 spread rapidly across all Australian states and territories and had arrived in Western Australia by Spring 2016. Studies from Europe and Australia suggest that RHDV2 has a strong competitive advantage over the RHDV1 viruses and the arrival of RHDV2 in Australia coincided with reductions in average rabbit abundance of approximately 60% (Ramsey et al., 2020).

Rationale

Significant past investment in the development and release of RHDV1-K5 was predicated on RHDV2 not being present in Australia. Thus, the appearance of RHDV2 in Australia was perceived to have curtailed the expected benefits of the release of RHDV1-K5. Hence, the actual impact of K5 is uncertain. Thus, the CISS required an evaluation of the impact of the release of RHDV1-K5 for control of rabbits in Australia. The evaluation aimed to:

- estimate the projected potential impact of RHDV1-K5 (without the emergence of RHDV2)
- estimate the current impact of RHDV1-Czech-351, RHDV1-K5 and RHDV2 together, and then assess the actual impact attributable to RHDV1-K5.

Objectives

The aim of the project was to demonstrate the importance of long-term investment in rabbit biocontrol RD&E pipelines. Specific objectives of the project were to:

1. Update Agtrans' past impact assessment of the IA CRC's RHD-Boost investment, using recently available data on the actual release of RHDV1-K5, to estimate the projected, potential impact of RHDV1-K5 in Australia without the occurrence of RHDV2 in 2015.

2. Estimate the total, current impact of rabbit biocontrol using RHDV variants in Australia (including RHDV1-Czech-351, RHDV1-K5, and RHDV2).
3. Assess the actual impact of RHDV1-K5 given the presence of RHDV2 in Australia.

3. IMPACT COSTS OF RABBITS: HISTORICAL STUDIES

Rabbit grazing is known to lead to significant pasture degradation and a lack of regeneration or destruction of important fodder trees, shrubs and perennial grasses. Rabbits also damage cereal and horticultural crops and cause losses to forestry and tree plantations, preventing regeneration and damaging tree plantings. Further, rabbits threaten the survival of at least 17 native plants and many native animal species, particularly small mammals (Bomford & Hart, 2002).

Bomford and Hart (2002) noted:

> "The scale of the impact of the rabbit in Australia is considered to be unique in the history of exotic animal introductions."

A number of historical studies have attempted to quantify the impact costs of rabbits in Australia. There also exist some more recent studies that have updated or re-estimated the expected impact costs of rabbits give the release of RHDV1.

Bomford and Hart (2002) found that estimates of agricultural losses attributable to rabbits varied. Prior to the release of RHDV1 Czech-351 in Australia, annual crop losses in South Australia (SA) were estimated at $7.5 million, annual losses to sheep production were estimated at $130 million, and overall annual losses to agricultural production were estimated at $600 million (including $300 million for wool losses, $70 million for sheep meat, $150 million for beef cattle, and $80 million for crop industries). Bomford and Hart (2002) concluded that it was probable that the annual losses to agricultural production due to rabbits, given the 1995–96 release of RHDV1 Czech-351, were at least $200 million. Further, it was estimated that Australian governments were spending approximately $10 million per annum on rabbit control with landholders likely spending at least an equivalent amount ($10 million per annum) and that rabbit control research costs were approximately $5 million per annum.

McLeod (2004) undertook a desktop review of the economic, environmental and social impacts of 11 major introduced vertebrate pests of Australian agricultural industries and the environment. The study estimated the annual impact cost of rabbits at $113.1 million (assumed to be reported in 2003/04-dollar terms). This cost was made up of $25.0 million p.a. in management and research costs and $88.1 million in economic losses to agricultural industries (sheep and cattle production and cropping industries).

Gong, Sinden, Braysher, & Jones (2009) used a loss-expenditure framework and an economic surplus model to estimate the impact costs of rabbits for Australian agriculture. The 2009 study estimated economic losses of approximately $206.0 million per annum (2007/08-dollar terms). Gong et al. (2009) also estimated that $6.87 million per annum (2007/08-dollar terms) was spent on rabbit control and management activities by government and Australian landholders.

In 2016, Ross McLeod (eSYS Development Pty Ltd) completed a report for the NSW Natural Resources Commission that updated the estimates of impact costs for a number of pest species, including rabbits, largely based on the Gong et al. (2009) study. The updated study (2016) estimated that aggregate annual production losses associated with rabbits were between $108.3 million and $250.6 million (2013/14-dollar terms), with an average of $216.6 million (2013/14-dollar terms). In addition, the study reported that an estimated $20 million per year was spent on rabbit control.

The Potential Benefits of Rabbit Biocontrol

Reducing the Australian wild rabbit population through the implementation of biological control may lead to a number positive economic, environmental and social impacts. Such impacts may include:

Economic

- Increased livestock production because of reduced pasture/forage/vegetation degradation and reduced risk of disease. Bomford and Hart (2002) reported that about 12 to 16 rabbits eat as much as a single sheep. Prior to the release of RHDV1 Czech-351, average densities of rabbits annually consumed 10 tonnes of dry pasture per square kilometre and pastoralists were often unable to rest pastures due to rabbit abundance.
- Increased production for some cereal and horticulture crops from reduced rabbit feeding activity.
- Avoided losses for the forestry industry through reduced damage to new tree plantings/saplings.
- Reduced rabbit control costs for landholders and other agencies involved in the management of wild rabbits.

Environmental

- Improved biodiversity for both native plants and animals because of reduced rabbit feeding activity and reduced competition for resources (food and habitats).
- Improved biodiversity through reduced populations of introduced predators (such as foxes, cats and wild dogs) that rely on rabbits as a primary prey species (Pedler, et al., 2016). For example, McGregor, Moseby, Johnson and Legge (2019) found that reducing the rabbit population by approximately 80% (in an experimental enclosure) decreased feral cat activity by 40% in the short-term.
- Reduced erosion and dryland degradation.
- Improved water quality through reduced run-off because of increased vegetation.
- Increased carbon sequestration through improved regeneration of vegetation (however, this impact may be offset by increased greenhouse gas emissions from increased agricultural production).

Social

- Reduced risk to wildlife and domestic pets via reduced incidence of unintended impacts of trapping and poisoning rabbit control methods
- Improved wellbeing for primary producers and other people affected by rabbit impacts.
- Potentially, reduced risk of disease transmission to humans and/or other animals.
- Improved community wellbeing through spill-over benefits from increased productivity and profitability of primary producers.

4. AN OVERVIEW OF RABBIT BIOCONTROL IN AUSTRALIA

Myxomatosis (1950)

Myxoma virus is a poxvirus naturally found in two American leporid (rabbit) species where it causes an innocuous, localised growths/tumours (cutaneous fibroma). However, in European rabbits (*Oryctolagus cuniculus*), the same virus causes the lethal disease myxomatosis (Kerr, 2012).

In 1926 the Australian rabbit population was estimated to be in excess of 10 billion rabbits. As a means of combating their prolific spread, in 1950 Australia was credited with introducing the world's first vertebrate pest biocontrol in the form of the myxoma virus. The virus was extraordinarily effective and killed approximately 99% of infected rabbits (Cooke, Chudleigh, Simpson, & Saunders, 2013).

However, over time, it was observed that rabbits were becoming genetically resistant to the myxoma virus. Transmission of myxomatosis was mainly by mosquitoes so, in 1968 European rabbit fleas were released in New South Wales (NSW) to act as an additional vector for the virus in an attempt to combat resistance (Sobey & Conolly, 1971). The fleas had minimal impact and, by 1995, the rabbit population was estimated to be 300 million and climbing (Ward, 2011). Thus, given the initial success of myxomatosis, the Australian Government and researchers sought to find new ways to improve biocontrol of rabbits across Australia.

RHDV1 (Czech-351) (1995–96)

In 1991, a scientific research program was undertaken under quarantine measures at the Australian Animal Health Laboratory to assess the host specificity and efficacy of a strain of RHDV (RHDV1 Czech-351). After approval from relevant Australian authorities, RHDV1 Czech-351 was released on Wardang Island in the Spencer Gulf, SA, for further testing. In 1995, the virus escaped quarantine and spread to the Australian mainland, possibly transported by insects or air currents. In less than two years the virus became established across southern Australia and, in some areas, resulted in a reduction of more than 95% of the European rabbit population (particularly in more arid regions) (Abrantes, van der Loo, Le Pendu, & Esteves, 2012).

Once it was clear that RHD was unlikely to affect human health, formal release of the virus was approved and it was officially released in Wagga Wagga, NSW, in 1996 (Department of the Environment, Water, Heritage and the Arts (DEWHA), 2008). RHDV1 Czech-351 was initially very effective; however, following the virus's official release, scientists discovered that an endemic, non-pathogenic rabbit calicivirus (termed RCV-A1) also occurs in wild rabbits in Australia and provides partial and transient protection against lethal RHD infection (Liu, et al., 2014). RCV-A1 interferes with effective rabbit biocontrol particularly in rabbit populations in cool, high rainfall areas of the south-east and south-west of the Australian continent.

Increasing resistance to RHDV1 Czech-351 meant that, since 2003, rabbit numbers again began to rise. In addition to the presence of RCV-A1, research also indicated that rabbits have begun to develop genetic resistance to RHDV1 Czech-351 (Cox, Strive, Mutze, West, & Saunders, 2013). Thus, from 2009, new RD&E investments were funded to search for new and improved biological control agents through the IA CRC's integrated rabbit management RD&E platform.

RHDV1-K5 (2017)

A series of IA CRC rabbit biocontrol RD&E projects, known as RHD-Boost, were funded to identify new RHDV variants with superior lethality to rabbits with partial protection from endemic RCV-A1 and immunity or genetic resistance to infection with RHDV1 Czech-351 variants.

Thirty-eight different RHDV variants and one RHDV-like virus (RHDV2) were imported and evaluated as part of the IA CRC projects. RHD-Boost demonstrated that a South Korean strain (known as RHDV1-K5) had advantages over the original RHDV1 Czech-351 variant and warranted consideration as a biocontrol agent in Australia. In particular, the RHDV1-K5 virus was shown to overcome the partial protection offered by RCV-A1 (Cox, et al., 2014).

The project then was extended to facilitate the research necessary to obtain approval for the new RHDV1-K5 variant to be registered and released as a legal biocontrol agent in Australia. RHDV1-K5 was successfully registered with the Australia Pesticides and Veterinary Medicines Authority in April 2016 and was approved for release by the Department of the Environment (Commonwealth) in August 2016. In the following year, March 2017, RHDV1-K5 was strategically released at 361 sites across Australia alongside the launch of a comprehensive National Rabbit Biocontrol Monitoring Program. However, the impact of the release of RHDV1-K5 was confounded by the fact that, during the lengthy approval process (mid-2015), a new, highly virulent virus, RHDV2, had been detected in the Australian wild rabbit population.

Exotic RHD Viruses (RHDV2 and RHDVa)

In May 2015, another new variant of RHDV was formally detected in wild rabbit populations in the Australian Capital Territory (ACT). Studies in Europe showed that the new virus, known as RHDV2, had a strong competitive advantage over earlier RHD viruses and appeared to be replacing previous RHDV strains in parts of Europe. RHDV2 has the same mode of death as RHDV1 strains however, RHDV2 can cause death in young rabbit kittens (3-4 weeks) as well as adult rabbits vaccinated against RHDV1 strains. There now is evidence that RHDV2 was present in Australia as early as 2014 (Strive, et al., 2019) and has since been found in rabbit populations in all states and territories of Australia (Mahar, et al., 2018). The origin/cause of the RHDV2 incursion is not known, however, further serological studies showed that RHDV2 had been present in Australia from as early as Spring 2014 (Ramsey et al., 2020).

Also, in January 2014, another exotic RHDV was detected in Australia and eight additional outbreaks were reported in both domestic and wild rabbits in the following 15 months. Genomic analysis showed that the new virus was an RHD recombinant known as RHDVa. In some regions it was suggested that RHDVa had replaced previous enzootic[1] viruses (Mahar, et al., 2018) such as RHDV1 Czech-351. However, the significant impact of RHDV2 largely negated the potential impact of RHDVa post-2014.

Synergies

There is some evidence to suggest that positive interactions exist between myxomatosis and existing strains of RHDV (Barnett, et al., 2018). Such positive interactions, when and where they eventuate, bolster the effectiveness of ongoing rabbit biocontrol. To demonstrate, Figure 1 shows a diagram of

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1 Regularly affecting animals in a particular district or at a particular season. Non-human equivalent of endemic.

how rabbit abundance in semi-arid SA varied over time in response to the release of various biocontrol agents in Australia.

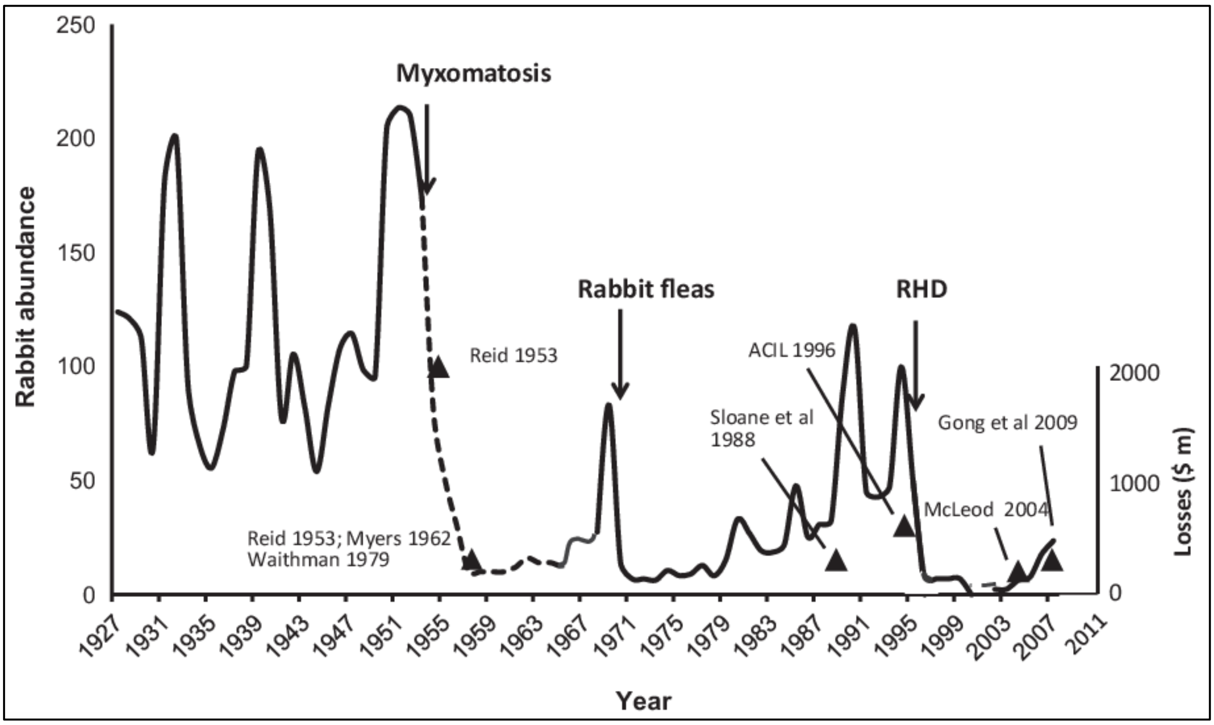

Figure 1. Rabbit abundance in semi-arid South Australia over time with the release of various biocontrol agents

Source: (Cooke, Chudleigh, Simpson, & Saunders, 2013)

5. RHD-BOOST: UPDATED IMPACT ASSESSMENT

Past Evaluations of the RHD-Boost Investment

In 2011, Agtrans Research conducted an ex-ante economic analysis of the IA CRC investment in RHD-Boost. The evaluation used a logical framework approach that described the research in terms of its expected inputs, objectives and activities, outputs, outcomes and potential impacts. Some of the impacts identified then were valued in monetary terms through a cost-benefit analysis (CBA). The CBA assumed that that RHD-Boost (resulting in the prospective release of RHDV1-K5) would have a differing impact on rabbit populations depending on rainfall zone (high rainfall zone, wheat-sheep zone, and pastoral zone) and that, in the absence of the RHD-Boost investment, rabbit impact costs would increase from the post-RHDV1 (Czech-351 strain) levels due to increasing resistance to the then existing biocontrol agents.

The 2011 evaluation estimated that the present value of expected benefits (PVB) for the proposed RHD-Boost investment was $1,401.06 million (over 30 years at a 5% discount rate, 2010/11-dollar terms) with total investment costs of $11.18 million (present value terms). This gave an estimated net present value of $1,389.89 million (present value terms), a benefit-cost ratio of 125.4 to 1, and an internal rate of return of 191.2%. Impacts valued included productivity improvements for some primary producers due to reduced rabbit numbers, reduced rabbit control costs for government and landholders, and increased carbon sequestration. The 2011 impact assessment was largely prospective and conducted prior to the identification and selection of suitable new strains of RHD. At the time, it was thought originally that a new RHD virus may have a similar impact to the original RHDV1 Czech Strain resulting in high, positive estimated ex-ante benefits.

In 2015, Agtrans Research was contracted by the IA CRC to complete an end-of-term impact assessment to measure, describe, and report on the long-term economic, environmental and social impacts of the overall investment in the IA CRC (2005 to 2017) (Agtrans Research, 2015). As part of the 2015 impact assessment, the 2011 ex-ante RHD-Boost evaluation was updated based on new data for the selected release strain RHDV1-K5. New assumptions regarding the potential impact of RHDV1-K5 were therefore more conservative than those originally used in the 2011 assessment as K5 was expected to have the greatest impact in high rainfall areas where resistance to RHDV1 Czech Strain was highest. The updated assessment estimated that the PVB for the RHD-Boost investment was $294.42 million (over 30 years at a 5% discount rate, 2013/14-dollar terms).

Update of the 2015 RHD-Boost Evaluation

As described in Section 4, RHDV1-K5 was released across Australia in March 2017. However, the potential impact of the new RHDV1 strain was curtailed by the arrival of RHDV2 in Australia in late 2014 and subsequent spread across the continent within the following two years (Ramsey, et al., 2020). As part of the current evaluation of RHDV1-K5, CISS required that the 2015 RHD-Boost impact assessments be revisited to estimate the projected, potential impact of RHDV1-K5 in Australia without the occurrence of RHDV2 in 2015.

Original, 2015 RHD-Boost Valuation Assumptions

The assumptions used in the IA CRC 2015 valuation of RHD-Boost (note, the term RHD-Boost has been used interchangeably with the term RHDV1-K5 in later sections of this report), prior to the detection of RHDV2, are reproduced in Table 2.

Table 2. Assumptions used in the 2015 IA CRC valuation for RHD-Boost

Source of RHD-Boost (RHDV1-K5 strain) Original Valuation Assumptions		
Agtrans Research (2011). *Prospective Economic Assessment of Investment in Activities to Manage the Impact of Rabbits up to and Beyond 2020*. Canberra: Invasive Animals CRC.		
Counterfactual (Without RHD-Boost Investment)		
Variable	**Value/Assumption**	**Source/Update**
Cost of Rabbits to Industry	$239.28m as of 2008/09	Gong et al. (2009)
Cost of Rabbits to Industry by Agricultural Zone		
- High Rainfall Zone (HRZ)	$92.35m as of 2008/09	Agtrans Research (2011)
- Wheat-Sheep Zone (WSZ)	$69.61m as of 2008/09	Agtrans Research (2011)
- Pastoral Zone (PaZ)	$77.32m as of 2008/09	Agtrans Research (2011)
Rabbit Control Costs	$7.98m as of 2008/09	Gong et al. (2009)
Expected Increase in Industry Costs by Zone		
- HRZ	10% p.a.	Based on the prevalence of the benign strain of RHDV in the HRZ, Agtrans Research
- WSZ	5% p.a.	Agtrans Research
- PaZ	5% p.a.	Agtrans Research
Expected Increase in Rabbit Control Costs	10% p.a.	Agtrans Research (2011)
Maximum Level of Industry and Control Cost Impacts	150% of 2008/09 level	Agtrans Research (2011)
With RHD-Boost (RHDV1-K5 strain) Investment		
Variable	**Value/Assumption**	**Source/Update**
New Strain Released	RHDV1-K5	Cox, et al. (2014)
Release Year	2015/16	Andreas Glanznig, pers. comm. 2015
First Year of Impact	2016/17	Agtrans Research
Expected Reduction in Industry Impacts by Zone		
- HRZ	20%	Andreas Glanznig after consultation with Tarnya Cox, John Tracey, and Glen Saunders
- WSZ	15%	Andreas Glanznig after consultation with Tarnya Cox, John Tracey, and Glen Saunders

- PaZ	5%	Andreas Glanznig after consultation with Tarnya Cox, John Tracey, and Glen Saunders
Expected Reduction in Rabbit Control Costs	13%	Average of expected industry impact reductions (20%, 15%, and 5%)
Duration of Stable Impact	8 years from 2016/17 to 2023/24	Agtrans Research (2011)
Rate of Increase in Rabbit Costs by Zone (beginning 2024/25) assuming resistance to new strain begins to develop		
- HRZ	10% p.a.	Based on evidence of genetic resistance in more arid areas and the fact that RHDV K5 is expected to be most effective in the HRZ, Agtrans Research
- WSZ	5% p.a.	Agtrans Research
- PaZ	5% p.a.	Agtrans Research
Maximum Level of Industry and Control Cost Impacts	100% of 2015/16 level	Based on growing evidence of positive seasonal synergies between RHD viruses and the Myxoma virus (Cox et al., 2013) and after consultation with David Peacock of Biosecurity SA.
Environmental Impact — Increased carbon sequestration: method as in *Prospective Economic Assessment of Investment in Activities to Manage the Impact of Rabbits up to and Beyond 2020*, Agtrans Research, 2011.		
Additional Carbon Sequestered in Southern PaZ after removal of 85% of Rabbits	0.14 tonnes / hectare	Ryan (undated)
Adjustment to Carbon Sequestration in Southern PaZ by Removal of 5% of Rabbits (RHDV K5 Strain Expected Reduction in PaZ)	0.008 tonnes / hectare	0.14t/ha x 5%/85% (previous row)
Area with Additional Carbon Sequestration due to the Removal of Rabbits	1.5 million square km (1,500,000,000 ha)	Ryan (undated)
Conversion Factor for Carbon (C) to Carbon Dioxide (CO_2) Equivalent	Atomic weight of CO_2 is 44 and atomic weight of C is 12	44/12 = 3.67
Value of CO_2 Equivalent	€10.79 per metric tonne	Expected average of the European Carbon price for 2013–2020 (Chestney, 2015)
AUD ($) / EUR (€) Exchange Rate	0.657 $ / €	Average buy rate on 29th September, Commonwealth Bank of Australia, 2015
Price in Australian Dollars	$16.42 per metric tonne	€10.79 / 0.657
Additional Usage Costs and Risk Factors — With RHD-Boost (RHDV1-K5 strain) Investment		

Cost of Initial Virus Release	$1.55m (one-off in 2015/16)	Agtrans Research (2011)
Ongoing Cost of Continued Virus Spread	$0.26m p.a. from 2016/17 onward	Agtrans Research (2011)
Probability of Output Success	100%	IA CRC (2015)
Probability of Usage Given Output Success	100%	IA CRC (2015)
Probability of Impact	90%	IA CRC (2015)

Revised Valuation Assumptions — RHDV1-K5 (RHD-Boost)

The 2015 assumptions presented in Table 1 were revisited for the current evaluation in 2020. Key research personnel associated with the RHD-Boost investment were consulted to provide input into the updated assumptions. The assumptions were made under the premise of estimating the predicted, potential impact of the release of RHDV1-K5 in the absence of RHDV2 in Australia.

The valuation of the potential impact of RHDV1-K5 in the absence of RHDV2 assumes that no other rabbit biocontrol agents would be released for the Australian wild rabbit population (in both the with, and without, RHDV1-K5 scenarios). Specific assumptions for the updated 2019/20 RHDV1-K5 evaluation are shown in Table 2.

Table 3. Assumptions for the revised valuation of impacts for RHDV-K5 (RHD-Boost) in the absence of RHDV2 — nationally coordinated release

Counterfactual (without release of RHDV1-K5 and no RHDV2)		
Variable	**Value/Assumption**	**Source/Update**
Cost of Rabbits to Industry	Average of $216.6 million p.a. in 2013/14	eSYS Development Pty Ltd (2016) – 2013/14 $ terms
Cost of Rabbits to Industry by Agricultural Zone		
- High Rainfall Zone (HRZ)	$83.61m as of 2013/14	2013/14 $ terms. Approximately 38.6% based on Agtrans Research (2011)
- Wheat-Sheep Zone (WSZ)	$63.03m as of 2013/14	2013/14 $ terms. Approximately 29.1% based on Agtrans Research (2011)
- Pastoral Zone (PaZ)	$69.96m as of 2013/14	2013/14 $ terms. Approximately 32.3% based on Agtrans Research (2011)
Rabbit Control Costs	$20.0m as of 2013/14	eSYS Development Pty Ltd (2016) from Bomford and Hart (2002) – assumed to be 2001/02 $ terms
Expected Increase in Industry Costs by Zone without RHDV1-K5		
- HRZ	5.0% p.a.	Based on Agtrans Research (2015) and consultation with RHDV1-K5 researchers
- WSZ	2.5% p.a.	
- PaZ	2.5% p.a.	

Expected Increase in Rabbit Control Costs	3.33% p.a.	
Maximum Level of Future Industry and Control Cost Impacts	150% of 2013/14 level	
The counterfactual assumes no release of RHDV1-K5 or other rabbit biocontrol agent and that RHDV2 is not present in Australia.		
With RHDV1-K5 release (no RHDV2)		
Variable	**Value/Assumption**	**Source/Update**
New Strain Released	RHDV1-K5	Cox, et al. (2014)
Release Year	2016/17 (March 2017)	Cox & Strive (2019)
First Year of Impact	2016/17	
Expected Average Reduction in Industry Impact and Rabbit Control Costs Across Affected Regions	34%	Based on the average decline in rabbit abundance one month after the release of RHDV1-K5 in 2017 at the release sites (Cox et al., 2019)
Proportion of Rabbit Affected Regions Impacted by Release of RHDV1-K5 Initial Release	5.0%	Agtrans Research – based on the distribution of release sites for RHDV1-K5 2017 (Cox & Strive, 2019) and consultation with RHDV1-K5 research personnel
Duration of Impact of National Release of RHDV1-K5	1 year	Data post-release of RHDV1-K5 in March 2017 indicated that the virus appeared to work as a biocide. That is, it was effective at a local scale, but generally does not self-disseminate beyond the release sites (Cox et al., 2019; Ramsey et al., 2020)
Rate of Increase in Rabbit Impact Costs (industry and control costs) post-release of RHDV1-K5	2.5% p.a. beginning 2019/20	Based on Agtrans Research (2015) and consultation with RHDV1-K5 researchers indicating increasing rabbit abundance over time
Maximum Level of Future Industry and Control Cost Impacts	150% of 2013/14 level [(b)]	As for 'without' RHDV1-K5 scenario and based on the assumption that RHDV1-K5 does not self-disseminate
Environmental Impact — unlike in the 2011 and 2015 evaluations, it was assumed that no increased carbon sequestration would occur. This was because the impact of the initial, national release of RHDV1-K5 was localised to release sites and, without tactical use of the virus as a biocide (see note 'a' below) prolonged impact/ improvements would not be likely to occur.		
Risk Factors — With RHD-Boost (RHDV K5 strain) Investment		
Probability of Output Success	100%	RHDV1-K5 successfully registered (Cox & Strive, 2019)
Probability of Usage Given Output Success	100%	RHDV1-K5 successfully released across Australia (Cox & Strive, 2019)

Probability of Impact	80%	Agtrans Research – allows for exogenous factors that may affect realisation of impact

a) For prolonged/ ongoing impact, it was assumed that periodic re-release of the RHDV1-K5 by landholders (in appropriate conditions) would be required. Ongoing, tactical use of RHDV1-K5 and the costs associated with such use in the absence of RHDV2 were uncertain and therefore not included in the current valuation.

b) Assumes no RHDV2 present in Australia.

Results of Updated Valuation

The impact of the national release of RHDV1-K5 is reduced rabbit abundance resulting in avoided rabbit impact costs for affected regions (including industry productivity losses and rabbit management and control costs). Therefore, the estimated, potential benefit of the release of RHDV1-K5 (in the absence of RHDV2) is the difference between the impact damage costs of rabbits without the RHDV1-K5 release and the costs with the RHDV1-K5 virus release. Figure 2 shows the estimated, annual impact costs of rabbits for relevant areas, with and without the release of RHDV1-K5 (in the absence of RHDV2), based on the assumptions described in Table 2 above.

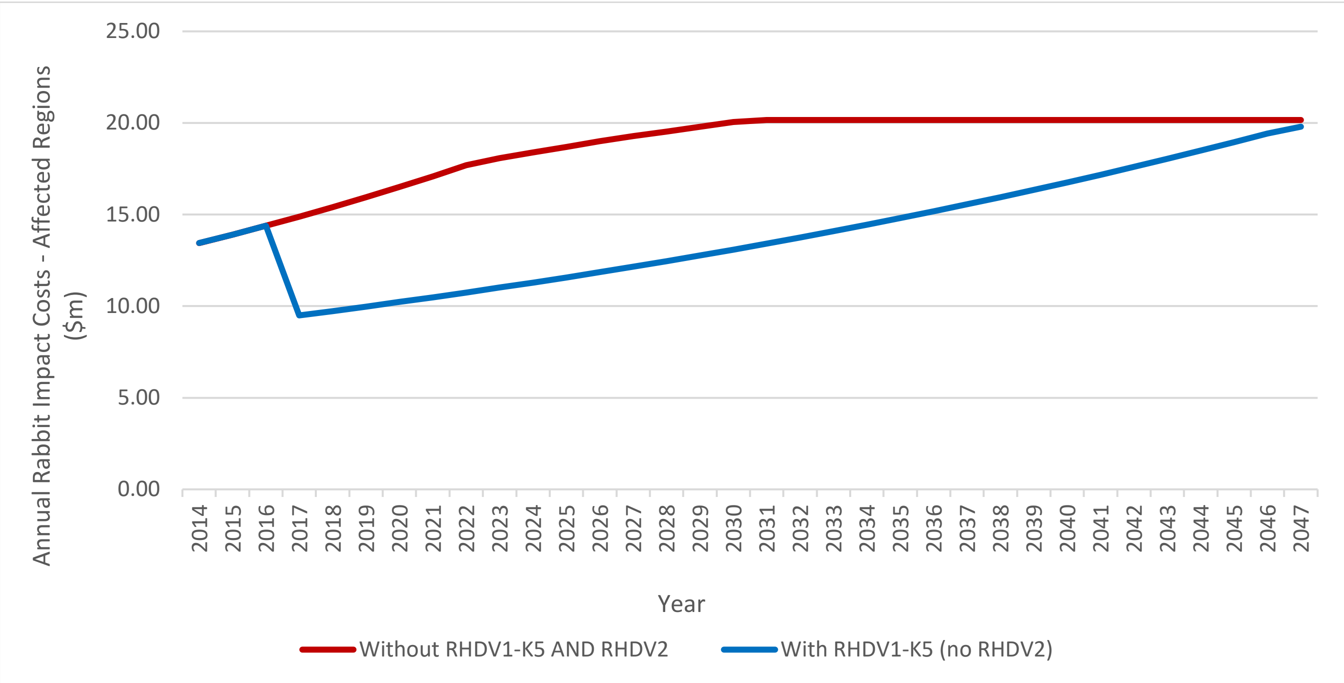

Figure 2. Estimated predicted annual rabbit impact costs in the absence of RHDV2. With and without release of RHDV1-K5 (RHDV1-K5 affected regions only).

All benefit cash flows were discounted to 2019/20 using a discount rate of 5%. The base analysis used the best available estimates for each variable, notwithstanding a level of uncertainty for many of the estimates. The analyses ran 30 years from the year that RHDV1-K5 was released in Australia (2016/17). Table 4 shows the estimated PVB for different time periods after the year of virus release.

Table 4. Estimated, potential present value of benefits for the release of RHDV1-K5 in the absence of RHDV2

Investment Criteria	Years after RHDV1-K5 Release						
	0	5	10	15	20	25	30
Present Value of Benefits ($m)	4.99	30.11	52.45	69.33	79.70	84.90	86.39

Discussion

Compared to the 2015 impact assessment results for the RHD-Boost investment (estimated PVB of approximately $294.42 million), the results of the current, updated analysis (PVB of $86.39 million) were driven by more conservative assumptions about the potential impact of RHDV1-K5 based on actual data and the fact that, after its strategic release in 2017, RHDV1-K5 did not self-disseminate in the Australian environment.

It is important to note that this analysis does not take into account the significant rabbit biocontrol RD&E costs incurred to identify, develop, and release the RHDV1-K5 virus over the past 15 to 20 years. Agtrans (2011) reported an estimated total investment of $11.18 million (nominal dollars) for RD&E associated with the identification, testing, registration and release of a new RHDV variant for the RHD-Boost project. Thus, the PVB results presented in Table 3 suggest that, in the absence of RHDV2, RHDV1-K5 was likely to have had a positive net benefit, even assuming some increase in the $11.18 million due to additional investment and/or correction for dollar terms.

However, it also has to be noted that inferring the potential impact of RHDV1-K5 in the absence of RHDV2 is extremely difficult, as the only data available for the actual impact of RHDV1-K5 are with the background of RHDV2 present. For example, it is not possible to predict if RHDV1-K5 would have established and spread in Australian rabbit populations rather than just spreading locally. If it had become established, the impacts would likely have been higher (Tanja Strive, pers. comm., 2020).

6. ESTIMATING THE CURRENT AND FUTURE IMPACT OF RABBIT BIOCONTROL IN AUSTRALIA SINCE 2014

Introduction

European Rabbits are considered a pest species throughout Australia. Competition and land degradation by feral rabbits is listed as a key threatening process under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). Under the EPBC Act, the Australian Government, in consultation with the states and territories, developed the 'Threat Abatement Plan for Competition and Land Degradation by Rabbits' (Department of Sustainability, Environment, Water, Population and Communities, 2011). The plan aims to reduce the impact of feral rabbits by:

- Preventing rabbits from occupying new areas in Australia and eradicating rabbits from high-conservation-value 'islands',
- Promoting the maintenance and recovery of native species and ecological communities that are affected by rabbit competition and land degradation,
- Improving knowledge and understanding of rabbit impacts and interactions with other species and other ecological processes,
- Improving the effectiveness, target specificity, integration and humaneness of control options for rabbits, and
- Increasing awareness of all stakeholders of the objectives and actions of the threat abatement plan, and of the need to control and manage rabbits.

Effective rabbit control involves the integration of various management methods. Current control methods can broadly be categorised as biological, chemical, and mechanical. Chemical and mechanical options include ground baiting — for example 1080 — warren fumigation, warren destruction (ripping or explosives), trapping, shooting, exclusion fencing and/or removal of surface habitats for rabbits (Invasive Animals Ltd, 2020).

Estimating the Value of Additional Rabbit Biocontrol

Ongoing biological control of wild rabbits aims to reduce rabbit abundance and achieve ongoing suppression of wild rabbit populations throughout Australia to minimise rabbit impact costs including productivity losses and rabbit management and control costs. Currently, biocontrol of the Australian wild rabbit population includes the impact of the myxoma virus, RHDV1 (Czech-351 Strain), RHDV1-K5, RHDV2 and RHDVa (as described previously in Section 4) as well as the ongoing use of freeze dried RHDV1 strains as tactical biocides for localised rabbit populations in appropriate conditions and regions. RHDV1-K5 represents the first nationally coordinated release of a rabbit biocontrol since the introduction of the myxoma virus in Australia.

Valuation Scope and Relevant Timeframe

The most recent information available on the national, average annual impact costs of rabbits was produced in 2016 by Ross McLeod (eSYS Development Pty Ltd). The 2016 report to the NSW Natural Resources Commission estimated that aggregate annual production losses associated with rabbits were between $108.3 million and $250.6 million in 2013/14, with an average of $216.6 million (see Section 3 for further detail). In addition, the study reported that an estimated $20 million per year was spent on rabbit control. This estimate was taken directly from Bomford and Hart (2002) and was therefore assumed to be reported in 2001/02-dollar terms.

The estimate of the average annual impact costs of rabbits ($216.6 million p.a.) was made after the release of RHDV1 Czech-351 (1995/96) but prior to the incursion of RHDV2 (2014/15), and also prior to the release of RHDV1-K5 in 2017. Further, evaluations of the impact of early rabbit biocontrol in Australia have previously demonstrated the expected value of the myxoma virus and RHDV1 Czech-351. A 2013 study of the economic benefits of biological control of rabbits in Australia between 1950 and 2011 (Cooke, Chudleigh, Simpson, & Saunders, 2013) conservatively estimated that rabbit biocontrol had produced a benefit of $70 billion (2010/11-dollar terms) for Australian agricultural industries.

Therefore, the following analysis estimates the value of the impact of the additional rabbit biocontrol introduced to the Australian wild rabbit population since 2014. Prior to 2014, the myxoma virus and RHDV1 Czech-351 were the only two endemic virulent rabbit biocontrol agents in Australia. Since 2014, RHDV2, RHDVa and RHDV1-K5 have been added, by incursion and strategic release, to the suite of rabbit biocontrol agents now active within the Australian wild rabbit population. The analysis assumes 2014/15 (year of RHDV2 incursion) as year zero with benefits estimated for a period of 30 years from year zero.

Relationship between Rabbit Abundance and Rabbit Impact Costs

Estimation of the current and future value of the impact of rabbit biocontrol in Australia relies on an assumed relationship between reductions in rabbit abundance (reduced rabbit numbers) and reduced rabbit impact costs. For the purpose of the current evaluation, it was assumed that there is a one-to-one relationship between reduced rabbit numbers and reduced rabbit impact costs. That is, a 1% reduction in rabbit abundance would lead to a 1% reduction in total, annual rabbit impact costs. Specific assumptions used in the valuation are described in Table 4.

Other Key Assumptions

<u>Ongoing use of RHDV1-K5</u>

The evaluation assumes that, after the nationally coordinated release of RHDV1-K5 in 2017, landholders and agencies responsible for rabbit control will continue to use RHDV1-K5 tactically in appropriate seasons and regions as a localised rabbit biocide.

<u>Other Rabbit Biocontrol</u>

The valuation of the current and future impact of additional rabbit biocontrol in Australia assumes that no other rabbit biocontrol agents would be released/occur for the Australian wild rabbit population. That is, after 2014/15 (year zero) only RHDV2, RHDVa and RHDV1-K5 would be active for rabbit biocontrol in addition to RHDV1 Czech-351 and the myxoma virus. Specific assumptions for valuation are shown in Table 4.

<u>Rabbit Population Growth Given Existing Biocontrol as of 2013/14</u>

The valuation of the impact of rabbit biocontrol from 2013/14 (year zero) assumes that after the release of RHDV1-K5 (2017), given evidence of positive seasonal interactions between RHD viruses and the myxoma virus, the Australian wild rabbit population would never recover to 100% of the pre-2014/15 rabbit population and therefore rabbit impact costs would similarly remain below 100% of the pre-RHDV2 2013/14 impact costs. Specific assumptions for valuation are shown in Table 4.

The Counterfactual

The current analysis assumed that, from 2014/15, without the incursion/release of additional biocontrol through RHDV2, RHDVa and RHDV1-K5, the Australian wild rabbit population would continue to be affected by existing rabbit biocontrol in the form of the myxoma virus and RHDV1 Czech-351. However, due to increasing resistance, biocontrol of rabbits would gradually become less effective over time and the wild rabbit population, and associated rabbit impact costs, would increase. Specific assumptions for valuation are shown in Table 5.

Valuation Assumptions

Table 5. Assumptions for the Valuation of the Impact of Additional Rabbit Biocontrol in Australia since 2013/14

Counterfactual (without additional biocontrol – Myxomatosis and RHDV1 Czech-351 only)		
Variable	**Value/Assumption**	**Source/Update**
Average, Annual Cost of Rabbits to Industry	$216.6 million p.a. in 2013/14	eSYS Development Pty Ltd (2016) — 2013/14 $ terms
Average, Annual Cost of Rabbits to Industry by Agricultural Zone		
- High Rainfall Zone (HRZ)	$83.61m as of 2013/14	2013/14 $ terms. Approximately 38.6% based on Agtrans Research (2011)
- Wheat-Sheep Zone (WSZ)	$63.03m as of 2013/14	2013/14 $ terms. Approximately 29.1% based on Agtrans Research (2011)
- Pastoral Zone (PaZ)	$69.96m as of 2013/14	2013/14 $ terms. Approximately 32.3% based on Agtrans Research (2011)
Average, Annual Rabbit Control Costs	$20.0m as of 2013/14	eSYS Development Pty Ltd (2016) from Bomford and Hart (2002) – assumed to be 2001/02 $ terms
Expected Increase in Industry Costs by Zone as Biocontrol Efficacy Decreases Over Time		
- HRZ	5% p.a.	Based on the prevalence of the benign strain of RHDV in the HRZ, Agtrans Research
- WSZ	2.5% p.a.	Agtrans Research
- PaZ	2.5% p.a.	
Expected Increase in Rabbit Control Costs	3.33% p.a.	Average of increases in impact costs by zone
Maximum Level of Industry and Control Cost Impacts	150% of 2013/14 level	Agtrans Research
With Additional Biocontrol (RHDV2, RHDVa and RHDV1-K5)		
Variable	Value/Assumption	Source/Update
First year of impact of additional rabbit biocontrol	2014/15	Based on the evidence that RHDV2 arrived in Australia in Spring of 2014
Expected Average Reduction in Industry Impacts and Rabbit Control Costs Across Australia	2014/15: 30% (preliminary impact of RHDV2)	Agtrans Research - based on Ramsey et al. (2020) and Cox et al. (2019) plus consultation with key RHDV research personnel
	2015/16: 60% (RHDV2 spread to all states/territories)	

	2016/17: 60% across Australia plus 20% (of the remaining 40%) in regions impacted by the coordinated release of RHDV1-K5 2017/18 to 2026/27: 60% across Australia plus 10% (of the remaining 40%) in regions where RHDV1-K5 is used as a tactical biocide 2027/28 and beyond: reduced rabbit impacts assumed to decline as rabbit abundance begins to increase	
Proportion of Rabbit Affected Regions Impacted by Release of RHDV1-K5 Initial Release	5.0%	Agtrans Research – based on the distribution of release sites for RHDV1-K5 2017 (Cox & Strive, 2019) and consultation with RHDV1-K5 research personnel
Rate of Increase in Rabbit Impact Costs (productivity and control costs) assuming efficacy of biocontrol decreases over time (e.g. due to increasing resistance)	2.5% p.a. from 2027/28 (whole of Australia)	Agtrans Researched – based on initial reductions in rabbit abundance after additional biocontrol occurs
Maximum Level of Industry and Control Cost Impacts	99.0% of 2013/14 level	Based on growing evidence of positive seasonal synergies between RHD viruses and the myxoma virus (Cox et al., 2013)
Environmental Impact — carbon sequestration Though reduced rabbit abundance has likely led to improved environmental outcomes such as regeneration of native vegetation and reduced threats to native animal species, the primary impact costs of wild rabbits in Australia are incurred by primary producers through degradation of pasture, lack of regeneration or destruction of key fodder trees, shrubs and perennial grasses, and damage to cereal and horticultural crops and forestry plantations. It was assumed that any increased carbon sequestration from reduced damage to plants (both native and cultivated) would be offset by increased greenhouse gas emissions (e.g. methane, estimated to have 28 times more warming potential than carbon dioxide (Borunda, 2019)) resulting from increased production by primary producers involved in industries that rely on grazing (e.g. dairy, beef cattle, sheep and wool, etc.).		
Additional Costs and Risk Factors		
Cost of Nationally Coordinated Release of RHDV1-K5	$1.6m (one-off in 2016/17)	Agtrans Research (2015)
Additional average cost of ongoing tactical use of RHDV1-K5 as a rabbit biocide	$0.25m p.a. from 2017/18 onward	Agtrans Research — based on estimates of the cost of ongoing release of RHDV1 Czech-351 as a biocide in Agtrans (2015)

Probability of Output Success	100%	Based on the incursion of RHDVa and RHDV2 and the successful, national release of RHDV1-K5
Probability of Usage Given Output Success	100%	
Probability of Impact	80%	Accommodates exogenous factors that may affect the realisation of impacts

Results

The introduction of additional rabbit biocontrol agents has led to reduced rabbit abundance across Australia resulting in avoided rabbit impact costs (including industry productivity losses and rabbit management and control costs). Figure 3 shows the estimated, annual impact costs of rabbits for Australia, with and without the additional biocontrol, based on the assumptions described in Table 5 above.

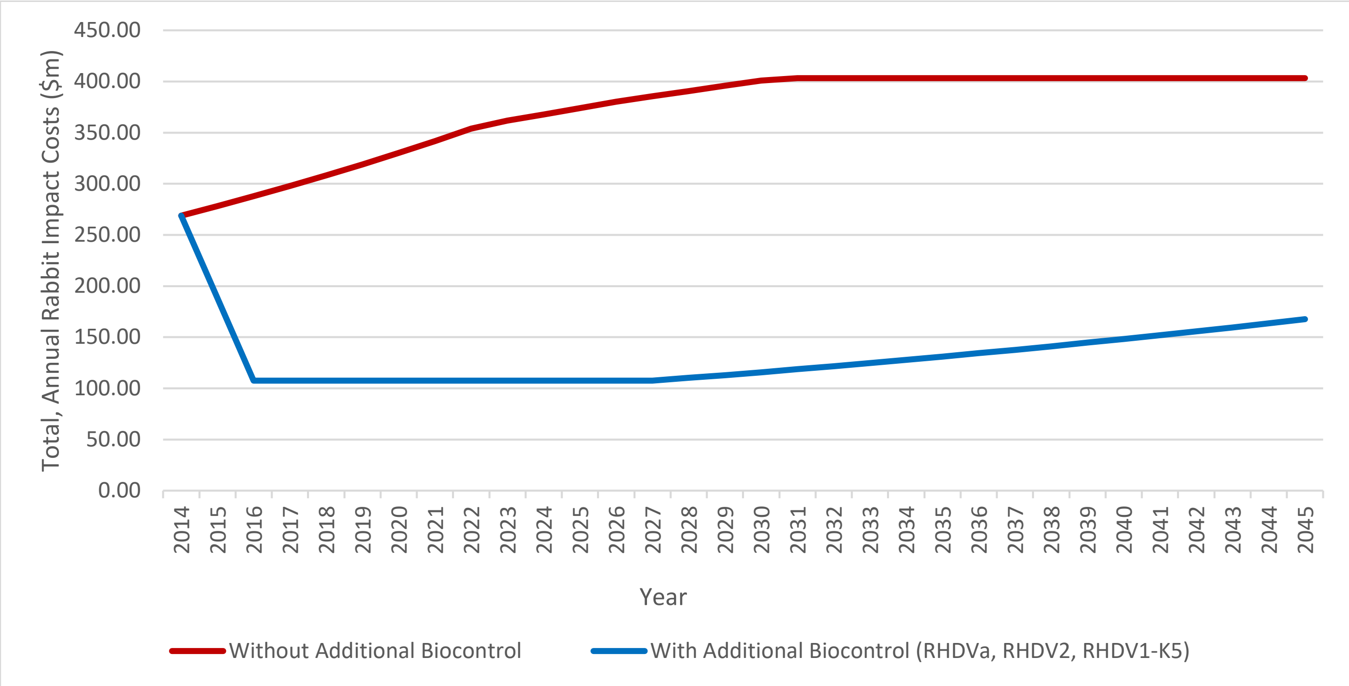

Figure 3. Estimated annual rabbit impact costs with and without additional biocontrol from 2014 (RHDV2, RHDVa and RHDV1-K5)

All benefit cash flows were discounted to 2019/20 using a discount rate of 5%. The base analysis used the best available estimates for each variable, notwithstanding a level of uncertainty for many of the estimates. The analyses ran 30 years from 2014/15 (the year prior to the incursion of additional rabbit biocontrol in the form of RHDV2). Table 6 shows the PVB for different time periods after the first year of additional biocontrol.

Table 6. Estimated Present Value of Benefits for the Additional Biocontrol of Rabbits in Australia (RHDV2, RHDV1-K5, and RHDVa)

Investment Criteria	Years after 2013/14						
	0	5	10	15	20	25	30
Present Value of Benefits ($m)	91.81	984.66	1,865.66	2,632.27	3,232.24	3,675.88	4,000.03

Discussion

Additional biocontrol of Australian wild rabbits since 2014 is expected to deliver significant benefits with an estimated PVB of $4.0 billion over 30 years. RHDV2 was highly virulent and spread through the Australian wild rabbit population without specific human intervention or investment, thus minimising the costs associated with current biocontrol efforts. Further, use of RHDV1-K5 as a tactical biocontrol is likely to complement the impact of RHDV2 in the medium-term, keeping rabbit numbers lower than they would have been otherwise thus minimising rabbit impact costs.

7. ASSESSING AND ESTIMATING THE ACTUAL IMPACT OF RHDV1-K5

Overview

As described previously, the actual impact of the release of RHDV1-K5 was confounded by the presence of RHDV2. RHDV2 has been shown to be highly virulent and preliminary data from professionally monitored sites suggested that, overall, rabbit population declines from RHDV2 were 60% on average. Based on antibody monitoring, RHDV2 was estimated to have arrived in NSW in Spring of 2014 and had spread across the country to WA by Spring of 2016 (Cox & Strive, 2019). Therefore, to estimate the impact of RHDV1-K5 after its release in March 2017, it was necessary to estimate the initial impact of RHDV2 prior to 2017 and then estimate the impact of RHDV1-K5 given the reduced rabbit population in 2017.

Valuation Scope

The valuation of the actual impact of RHDV1-K5, given the presence of RHDV2 (and, to a lesser extent, RHDVa), is predicated on evidence that RHDV2 was present in Australia in 2014 and spread across the country within two years. Further, the valuation is based on the rabbit impact cost data described in Ross McLeod's 2016 report to the NSW Natural Resources Commission where it was estimated that rabbit impact costs in 2013/14 were, on average, $216.6 million per annum. RHDV1-K5 was released in March of 2017, therefore, 2016/17 is taken as year zero and impacts were estimated for a period of 30 years.

Counterfactual

The analysis assumed that, in the absence of RHDV1-K5, the highly virulent RHDV2 would still have been present in Australia but that no other significant biocontrol agents would be introduced. Further, the efficacy of rabbit biocontrol (including myxomatosis, RHDV1 Czech strain, RHDVa and RHDV2) would gradually decrease over time.

Valuation Assumptions

Similar to the valuation of the impact of all additional rabbit biocontrol introduced since 2013/14 described in Section 6, the following analysis for the actual impact of RHDV1-K5 alone assumes that:

1. There is a one-to-one relationship between reduced rabbit abundance and reduced rabbit impact costs,
2. RHDV2, and to a lesser degree, RHDVa, were present and widespread by the time RHDV1-K5 was released in March of 2017,
3. No other rabbit biocontrol agents would be introduced into the Australian population after 2017 (with or without the release of RHDV1-K5),
4. RHDV1-K5 would continue to be used in appropriate seasons and regions as a tactical biocide for localised rabbit control, and
5. Given the adaptive nature and reproductive rate of the wild rabbit population, the efficacy of all forms of rabbit biocontrol will gradually decrease over time.

The key difference between the impact of RHDV1-K5 in the valuation of all new biocontrol post-2014 (Section 6) and the valuation of the actual impact of RHDV1-K5 alone (described here) is that the current analysis assumed that the medium- to long-term impact of RHDV2 would be reduced without the complementary impacts of the national release and ongoing tactical use of RHDV1-K5.

Specific assumptions used in the valuation of the actual impact of RHDV1-K5 given the presence of RHDV2 are described in Table 7.

Table 7. Assumptions for the valuation of the impact of RHDV1-K5 with RHDV2

<table>
<tr><th colspan="3">Counterfactual (Without RHDV1-K5, given presence of RHDV2)</th></tr>
<tr><th>Variable</th><th>Value/Assumption</th><th>Source/Update</th></tr>
<tr><td>Average, Annual Cost of Rabbits to Industry</td><td>$216.6 million p.a. in 2013/14</td><td>eSYS Development Pty Ltd (2016) — 2013/14 $ terms</td></tr>
<tr><td colspan="3">Average, Annual Cost of Rabbits to Industry by Agricultural Zone</td></tr>
<tr><td>- High Rainfall Zone (HRZ)</td><td>$83.61m as of 2013/14</td><td>2013/14 $ terms. Approximately 38.6% based on Agtrans Research (2011)</td></tr>
<tr><td>- Wheat-Sheep Zone (WSZ)</td><td>$63.03m as of 2013/14</td><td>2013/14 $ terms. Approximately 29.1% based on Agtrans Research (2011)</td></tr>
<tr><td>- Pastoral Zone (PaZ)</td><td>$69.96m as of 2013/14</td><td>2013/14 $ terms. Approximately 32.3% based on Agtrans Research (2011)</td></tr>
<tr><td>Average, Annual Rabbit Control Costs</td><td>$20.0m as of 2013/14</td><td>eSYS Development Pty Ltd (2016) from Bomford and Hart (2002) — assumed to be 2001/02 $ terms</td></tr>
<tr><td>Incursion of RHDV2</td><td>2014/15</td><td>Ramsey et al. (2020)</td></tr>
<tr><td rowspan="2">Expected Average Reduction in Industry Impacts and Rabbit Control Costs Across Australia</td><td>2014/15: 30% (preliminary impact of RHDV2)</td><td rowspan="2">Agtrans Research — based on Ramsey et al. (2020) and Cox et al. (2019) plus consultation with key RHDV research personnel</td></tr>
<tr><td>2015/16: 60% (RHDV2 spread to all states/territories)</td></tr>
<tr><td>Duration of Stable Impact</td><td>8 years
from 2015/16 to 2022/23</td><td>Agtrans Research (2015)</td></tr>
<tr><td>Expected Increase in Industry Costs by Zone as Biocontrol Efficacy Decreases Over Time</td><td>2.5% p.a.</td><td>Agtrans Research</td></tr>
<tr><td>Maximum Level of Industry and Control Cost Impacts</td><td>99% of 2013/14 level</td><td>Agtrans Research</td></tr>
<tr><th colspan="3">With RHDV1-K5 given presence of RHDV2</th></tr>
<tr><th>Variable</th><th>Value/Assumption</th><th>Source/Update</th></tr>
<tr><td>First year of impact</td><td>2016/17</td><td>Based on national release of RHDV1-K5 in March 2017 and subsequent impact within one month of release</td></tr>
<tr><td>Expected Average Reduction in Industry Impacts and Rabbit Control Costs Across Australia</td><td>2016/17: 20% in regions impacted by the coordinated release of RHDV1-K5</td><td>Agtrans Research — based on Ramsey et al. (2020) and Cox et al. (2019) plus consultation with key RHDV research personnel</td></tr>
</table>

	2017/18 to 2026/27: 10% in regions where RHDV1-K5 is used as a tactical biocide	
	2027/28 and beyond: reduced rabbit impacts assumed to decline as rabbit abundance begins to increase	
Proportion of Rabbit Affected Regions Impacted by Release of RHDV1-K5 Initial Release	5.0%	Agtrans Research — based on the distribution of release sites for RHDV1-K5 2017 (Cox & Strive, 2019) and consultation with RHDV1-K5 research personnel
Rate of Increase in Rabbit Impact Costs in RHDV1-K5 regions (productivity and control costs) assuming efficacy of biocontrol decreases over time (e.g. due to increasing resistance)	2.0% p.a. from 2023/24 (whole of Australia)	Agtrans Researched — based on initial reductions in rabbit abundance after additional biocontrol occurs
Maximum Level of Industry and Control Cost Impacts	99.0% of 2013/14 level	Based on growing evidence of positive seasonal synergies between RHD viruses and the myxoma virus (Cox et al., 2013)
Environmental Impact — carbon sequestration Though reduced rabbit abundance has likely led to improved environmental outcomes such as regeneration of native vegetation and reduced threats to native animal species, the primary impact costs of wild rabbits in Australia are incurred by primary producers through degradation of pasture, lack of regeneration or destruction of key fodder trees, shrubs and perennial grasses, and damage to cereal and horticultural crops and forestry plantations. It was assumed that any increased carbon sequestration from reduced damage to plants (both native and cultivated) would be offset by increased greenhouse gas emissions (e.g. methane, estimated to have 28 times more warming potential than carbon dioxide (Borunda, 2019)) resulting from increased production by primary producers involved in industries that rely on grazing (e.g. dairy, beef cattle, sheep and wool, etc.).		
Additional Costs and Risk Factors		
Cost of Nationally Coordinated Release of RHDV1-K5	$1.6m (one-off in 2016/17)	Agtrans Research (2015)
Additional average cost of ongoing tactical use of RHDV1-K5 as a rabbit biocide	$0.25m p.a. from 2017/18 onward	Agtrans Research – based on estimates of the cost of ongoing release of RHDV1 Czech-351 as a biocide in Agtrans (2015)
Probability of Output Success	100%	Based on the incursion of RHDVa and RHDV2 and the successful, national release of RHDV1-K5
Probability of Usage Given Output Success	100%	
Probability of Impact	80%	Accommodates exogenous factors that may affect the realisation of impacts

Results

Figure 4 provides a graphical representation of the actual impact of RHDV1-K5 given the presence of RHDV2 in Australia from 2014 (based on the assumptions described in Table 7 above). The graph shows the significant effect of RHDV2 on rabbit abundance prior to the release of RHDV1-K5 in 2017. Further, comparing the with and without scenarios to the information presented in Figure 2 (Section 5 — impact of RHDV1-K5 in the absence of RHDV2) gives some indication of how the impact of RHDV1-K5 was curtailed by the incursion of RHDV2.

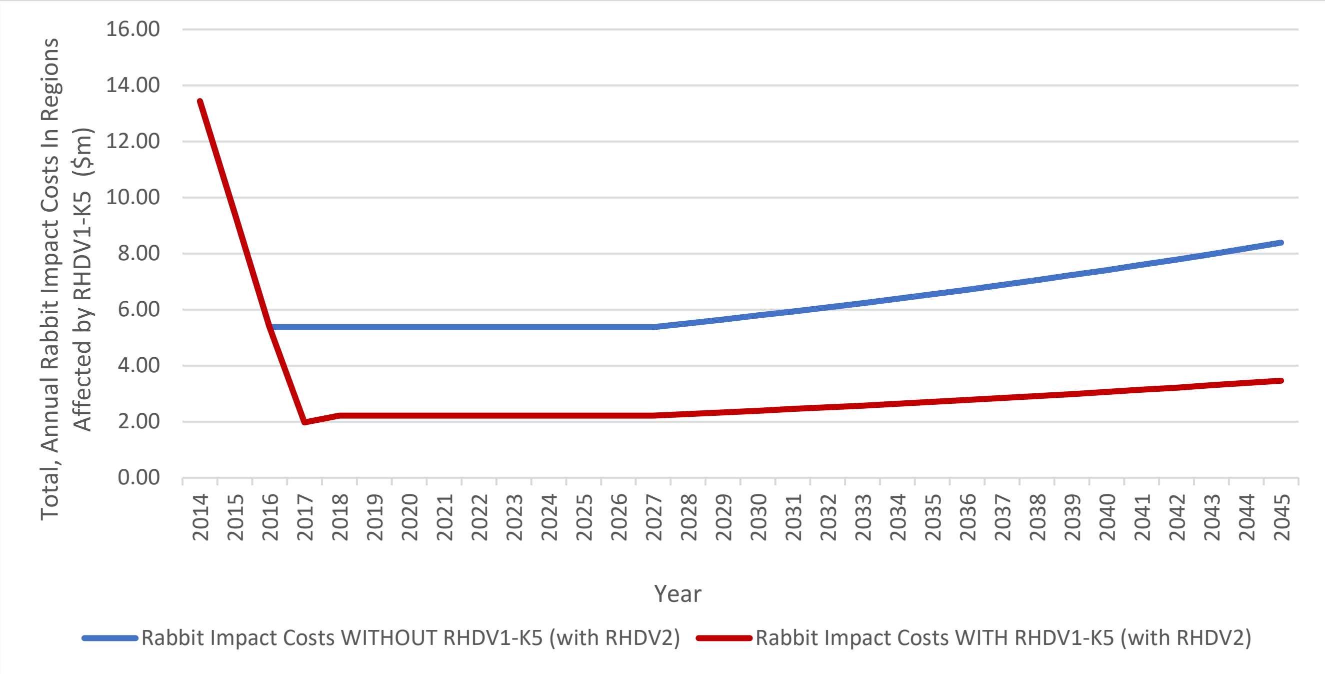

Figure 4. Estimated annual rabbit Impact costs with and without RHDV1-K5 given the presence of RHDV2 in Australia from 2014 (for regions affected by RHDV1-K5 only)

All benefit cash flows were discounted to 2019/20 using a discount rate of 5%. The base analysis used the best available estimates for each variable, notwithstanding a level of uncertainty for many of the estimates. The analyses ran 30 years from 2016/17 (the year RHDV1-K5 was released). Table 8 shows the PVB for different time periods after the first year of additional biocontrol.

Table 8. Estimated Present Value of Benefits for the Impact of RHDV1-K5 Given the presence of RHDV2 in Australia

Investment Criteria	Years after 2013/14						
	0	5	10	15	20	25	30
Present Value of Benefits ($m)	1.67	13.32	23.18	32.11	40.22	47.59	54.26

Discussion

Compared to a situation where RHDV2 had not been present in Australia, the value of the impact of RHDV1-K5 was potentially reduced by about 37% given the assumptions made in the current analysis. In the absence of RHDV2 the current analysis estimated a PVB for RHDV1-K5 of $86.39 million (over 30 years using a 5% discount rate) whereas the PVB for RHDV1-K5 with RHDV2 presence was estimated at $54.26 million (30 years, 5% discount rate). However, this comparison should be made with caution as the assumptions underpinning each valuation, and the counterfactual scenarios differ. Also, as noted in Section 5, inferring the potential impact of RHDV1-K5 in the absence of RHDV2 is extremely difficult, as the only data available for the actual impact of RHDV1-K5 are with the background of RHDV2 present.

The results of the current RHDV1-K5 analyses, based on actual data from the incursion of RHDV2 and release of RHDV1-K5, represent a more realistic estimation of the potential and actual impacts of RHDV1-K5 when compared to the results in previous, 2015 and 2011 RHD-Boost analyses. The current evaluation demonstrates that, though the total potential impact of RHDV1-K5 was curtailed by the incursion of RHDV2, RHDV1-K5 has provided positive benefits (in present value terms) for Australia and represents a positive contribution to the ongoing investment in integrated rabbit control methods used across Australia.

8. KEY FINDINGS AND CONCLUSION

Key Findings

The current analysis aimed to demonstrate the value of long-term investment in rabbit biocontrol RD&E pipelines, exemplified by the release of RHDV1-K5 in 2017. The project objectives were to:

- Estimate the projected, potential impact of RHDV1-K5 in Australia without the occurrence of RHDV2.
- Estimate the total, current impact of rabbit biocontrol using RHDV variants in Australia (including RHDV1-Czech-351, RHDV1-K5, and RHDV2), and
- Assess the actual impact of RHDV1-K5 given the presence of RHDV2 in Australia.

Section 5 described the estimation of the potential impact of RHDV1-K5 without the presence of RHDV2. Section 6 evaluated the total, current and future impact of additional rabbit biocontrol (RHDV2, RHDVa and RHDV1-K5) since 2014. Section 7 assessed the actual impact of RHDV1-K5 given the presence of other, exotic RHD variants in Australia. Table 9 summarises the PVBs estimated for each of the three RHDV1-K5 biocontrol impact scenarios.

Table 9. Estimated present value of benefits for RHDV1-K5 under different scenarios regarding the presence of RHDV2

RHDV1-K5 Evaluation Scenario	Potential value of benefits ($m, 30 years, 5% discount rate)
1) Potential impact of RHDV1-K5 in the ABSENCE of RHDV2	86.4
2) Combined impact of all additional biocontrol after 2014 (RHDVa, RHDV2 and RHDV1-K5)	4,000.0
3) Estimated actual impact of RHDV1-K5 only, given the presence of RHDV2	54.3

The results support the scientific evidence that suggests that the exotic RHDV2 has had, and will continue to have, the most significant impact on Australian wild rabbit populations of the three new biocontrol agents introduced in Australia since 2014. However, such assertions should be made with caution as each analysis was underpinned by different assumptions and counterfactual scenarios.

The impacts valued in the three valuation scenarios include reduced productivity losses and reduced rabbit control costs because of reduced rabbit abundance. However, rabbit biocontrol also contributes to a number of positive impacts that were not valued in monetary terms, including:

- Improved biodiversity for both native plants and animals.
- Reduced erosion and dryland degradation.
- Improved water quality through improved vegetation.
- Increased carbon sequestration through improved regeneration of vegetation (however, this impact may be offset by increased greenhouse gas emissions from increased agricultural production).

Improved wellbeing for primary producers and other people affected by rabbit impacts.

- Reduced risk of disease transmission to humans and/or other animals.
- Improved community wellbeing through spill-over benefits from increased productivity and profitability of primary producers.

Discussion

In 2011, prior to the identification and selection of RHDV1-K5 as a biocontrol agent for European rabbits in Australia, an ex-ante analysis of the potential impact of the RHD-Boost (RHDV1-K5) investment optimistically estimated expected benefits of approximately $1,401.06 million (over 30 years at a 5% discount rate, 2010/11-dollar terms). At the time, expert opinion suggested that introduction of a novel biocontrol agent could have a similar impact on rabbit abundance as that of the original RHDV1 Czech Strain. In 2015, an update of an earlier ex-ante analysis of the RHD-Boost investment (2011), based on new data for the selected release strain RHDV1-K5, was undertaken. Assumptions regarding the potential impact of RHDV1-K5 in the 2015 assessment were therefore more conservative than those originally used in the 2011 assessment as RHDV1-K5 was still expected to self-disseminate but to have the greatest impact only in high rainfall areas where resistance to RHDV1 Czech Strain was highest. The updated 2015 assessment estimated that the PVB for the RHD-Boost investment was $294.42 million (over 30 years at a 5% discount rate, 2013/14-dollar terms).

The current analyses, based on actual data from the incursion of RHDV2 in 2014 and the strategic national release of RHDV1-K5 in 2017, estimated the present value of benefits for RHDV1-K5 at $54.26 million. This result represents a more realistic estimation of the actual impacts of RHDV1-K5 when compared to the results in previous RHD-Boost (RHDV1-K5) analyses. The current evaluation demonstrates that, though the total potential impact of RHDV1-K5 was curtailed by the incursion of RHDV2 and RHDV1-K5 did not self-disseminate, RHDV1-K5 has provided positive benefits for Australia and continues to contribute to ongoing suppression of rabbit numbers.

Conclusion

The release of RHDV1-K5 in 2017 represented the culmination of almost 20 years of investment in rabbit biocontrol RD&E. However, during the regulatory approval phase to coordinate a strategic national release of RHDV1-K5, RHDV2 was detected in Australia. RHDV2 spread rapidly across all Australian states and territories and the arrival of RHDV2 in Australia coincided with reductions in average rabbit abundance of approximately 60% prior to the release of RHDV1-K5, thus curtailing the potential benefits of the K5 release.

The evaluation estimated that the benefit of all rabbit biocontrol introduced both strategically and by incursion since 2014 (including RHDV2, RHDVa, and RHDV1-K5) was approximately $4.0 billion over 30 years (present value terms, 5% discount rate). Further, the current analysis found that, given the incursion of RHDV2 in Australia in 2014, the potential impacts of RHDV1-K5 were curtailed. The actual impact of RHDV1-K5 was estimated to have a present value of benefits of $54.26 million (30 years, 5% discount rate). These results were estimated against a baseline that included the ongoing expected impacts of the myxoma virus and RHDV1 Czech 351.

The RHDV1-K5 virus now contributes to the ongoing suppression of the Australian wild rabbit population and forms an integral part of landscape-scale integrated rabbit management practices. Also, the estimated benefits presented by the current analysis do not include the value of the positive environmental and social impacts of rabbit biocontrol. Therefore, the benefits reported may be an underestimate of the true value of the release of RHDV1-K5.

The positive estimated benefits of rabbit biocontrol in Australia demonstrate the positive economic impact of new rabbit viral diseases and underpins the value of ongoing investment in rabbit biocontrol RD&E pipelines.

REFERENCES

Abrantes, J., van der Loo, W., Le Pendu, J., & Esteves, P. J. (2012). Rabbit haemorrhagic disease (RHD) and rabbit haemorrhagic disease virus: a review. *Veterinary Research, 43*.

Agtrans Research. (2011). Prospective Economic Assessment of Investment in Activities to Manage the Impact of Rabbits Up To and Beyond 2020. Brisbane, QLD: unpublished client report.

Agtrans Research. (2015). *Invasive Animals CRC Impact Assessment.* Canberra, ACT: unpublished client report.

Barnett, L. K., Prowse, T. A., Peacock, D. E., Mutze, G. J., Sinclair, R. G., Kovaliski, J., Cooke, B.D. & Bradshaw, C. J. (2018). Previous exposure to myxoma virus reduces survival of European rabbits during outbreaks of rabbit haemorrhagic disease. *Journal of Applied Ecology, 55*(6), 2954-62.

Bomford, M., & Hart, Q. (2002). *Non-Indigenous Vertebrates in Australia.* Retrieved from Pestsmart: https://www.pestsmart.org.au/wp-content/uploads/2010/03/00026.pdf

Borunda, A. (2019). *Methane, explained*. Retrieved from National Geographic: https://www.nationalgeographic.com/environment/global-warming/methane/

Chestney, N. (2015). *EU carbon market expects price rise for first time in four years*. Retrieved from Reuters: http://uk.reuters.com/article/2015/05/26/us-europe-carbon-survey-idUKKBN0OB0YI20150526

Cooke, B., Chudleigh, P., Simpson, S., & Saunders, G. (2013). The Economic Benefits of the Biological Control of Rabbits in Australia, 1950-2011. *Australian Economic History Review, 53*(1), 91–107.

Cox, T. E., Ramsey, D. S., Sawyers, E., Campbell, S., Matthews, J., & Elsworth, P. (2019). The impact of RHDV-K5 on rabbit populations in Australia: an evaluation of citizen science surveys to monitor rabbit abundance. *Scientific Reports, 9*(1), 1–1.

Cox, T., & Strive, T. (2019). *RHD Boost Plus & Serology.* Canberra, ACT: Invasive Animals Ltd.

Cox, T., Kovaliski, J., Mutze, G., Peacock, D., Pople, T., Sinclair, R., Strive, T., Tracey, J., Read, A & Cooke, B. (2014). *RHD-Boost: Import and evaluate new rabbit haemorrhagic disease virus (RHDV) variants to strengthen rabbit biocontrol.* Canberra: Invasive Animals Cooperative Research Centre.

Cox, T., Strive, T., Mutze, G., West, P., & Saunders, G. (2013). *Benefits of Rabbit Biocontrol in Australia.* Canberra, ACT: Invasive Animals Cooperative Research Centre. Retrieved from https://www.researchgate.net/publication/281419596_Benefits_of_rabbit_biocontrol_in_Australia

Department of Sustainability, Environment, Water, Population and Communities. (2011). *European wild rabbit (Oryctolagus cuniculus).* Retrieved from Australian Goverment Department of the Environment and Energy: https://www.environment.gov.au/system/files/resources/7ba1c152-7eba-4dc0-a635-2a2c17bcd794/files/rabbit.pdf

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

eSYS Development Pty Ltd. (2016). *Cost of Pest Animals in NSW and Australia, 2013–14.* Sydney, NSW: NSW Natural Resources Commission.

Gong, W., Sinden, J., Braysher, M., & Jones, R. (2009). *The economic impacts of vertebrate pests in Australia.* Canberra, ACT: Invasive Animals Cooperative Research Centre.

Invasive Animals Cooperative Research Centre. (2015). Performance Review IA CRC Impact Tool Companion Document. Canberra, ACT: unpublished.

Invasive Animals Ltd. (2020). *Control techniques and best practice*. Retrieved from Rabbit Scan: https://www.feralscan.org.au/rabbitscan/pagecontent.aspx?page=rabbit_techniquesandmanuals

Kerr, P. J. (2012). Myxomatosis in Australia and Europe: a model for emerging infectious diseases. *Antiviral Research, 93*(3). Retrieved from https://publications.csiro.au/rpr/download?pid=csiro:EP118112&dsid=DS4

Liu, J., Fordham, D. A., Cooke, B. D., Cox, T., Mutze, G., & Strive, T. (2014). Distribution and Prevalence of the Australian Non-Pathogenic Rabbit Calicivirus Is Correlated with Rainfall and Temperature. *PLoS ONE, 9*(12), e113976. Retrieved from https://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0113976&type=printable

Mahar, J. E., Hall, R. N., Peacock, D., Kovaliski, J., Piper, M., Mourant, R., Huang, N., Campbell, S., Gu, X., Read, A., Urakova, N., Cox, T., Holmes, E.C. & Strive, T. (2018). Rabbit hemorrhagic disease virus 2 (RHDV2; GI. 2) is replacing endemic strains of RHDV in the Australian landscape within 18 months of its arrival. *Journal of Virology, 92*(2), e01374-17.

Mahar, J. E., Read, A. J., Gu, X., Urakova, N., Mourant, R., Piper, M., Haboury, S., Holmes, E.C., Strive, T. & Hall, R. N. (2018). Detection and Circulation of a Novel Rabbit Hemorrhagic Disease Virus in Australia. *Emerging Infectious Diseases, 24*(1), 22-31. Retrieved January 2020, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5749467/

McGregor, H., Moseby, K., Johnson, C. N., & Legge, S. (2019). The short-term reponse of geral cats to rabbit population decline: Are alternative native prey more at risk? *Biological Invasions*. doi:https://doi.org/10.1007/s10530-019-02131-5

McLeod, R. (2004). *Counting the Cost: Impact of Invasive Animals in Australia, 2004.* Canberra, ACT: Pest Animal Control Cooperative Research Centre.

Pedler, R. D., Brandle, R., Read, J. L., Southgate, R., Bird, P., & Moseby, K. E. (2016). Rabbit biocontrol and landscape-scale recovery of threatened desert mammals. *Conservation Biology, 30*(4), 774–785.

Rabbit Biocontrol Scientific Committee. (2016). *Factsheet: RHDV-2 in Australia and implications for current rabbit biocontrol initiatives*. Retrieved from Pestsmart: https://www.pestsmart.org.au/the-arrival-of-rhdv2-in-australia-and-implications-for-current-rabbit-biocontrol-initiatives/

Ramsey, D. S., Cox, T., Strive, T., Forsyth, D. M., Stuart, I., Hall, R., Elsworth, P. & Campbell, S. (2020). Emerging RHDV2 supresses the impact of endemic and novel strains of RHDV on wild rabbit populations. *Journal of Applied Ecology, 57*, 630-641.

Ryan, S. (undated). Rabbit Control - Rabbit Haemorrhagic Disease (RHD) and Virally Vecotred Immunocontraception (VVIC), in Evaluating the Triple Bottom Line Impact of R&D Projects - Draft Framework and Five Case Studies. mimeo paper, pers. comm. CSIRO Sustainable Ecosystems.

Sobey, W. R., & Conolly, D. (1971). Myxomatosis: the introduction of the European rabbit flea Spilopsyllus cuniculi (Dale) into wild rabbit populations in Australia. *The Journal of Hygiene, 69*, 331–346.

Strive, T., Piper, M., Huang, N., Mourant, R., Kovaliski, J., Capucci, L., Cox, T. & Smith, I. (2019). Retrospective serological analysis reveals presence of the emerging lagovirus RHDV2 in Australia in wild rabbits at least five months prior to its first detection. *Transboundary and emerging diseases*.

Ward, C. (2011). *Myxomatosis to control rabbits*. Retrieved from CSIROpedia: https://csiropedia.csiro.au/myxomatosis-to-control-rabbits/

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