The use of 1080 and other methods for controlling European Rabbits, Feral Pigs, Red Foxes and unprotected Dingoes and Wild Dogs in Victoria

April 2025

Arthur Rylah Institute for Environmental Research Unpublished Report

Arthur Rylah Institute for environmental research

VICTORIA State Government

Energy, Environment and Climate Action

Arthur Rylah Institute for Environmental Research
Department of Energy, Environment and Climate Action
PO Box 137, Heidelberg, Victoria 3084
Phone (03) 9450 8600
Website: www.ari.vic.gov.au

Citation: DEECA. (2025). The use of 1080 and other methods for controlling European Rabbits, Feral Pigs, Red Foxes and Dingoes and Wild Dogs in Victoria. Arthur Rylah Institute for Environmental Research Unpublished Report for Agriculture Victoria. Department of Energy, Environment and Climate Action, Heidelberg, Victoria.

Front cover photo: European Rabbit (Agriculture Victoria), Dingo (DEECA), Red Fox (Agriculture Victoria), mob of Feral Pigs (Stack and Land).

Edited by Fox Writing Services

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it.

We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

DEECA is committed to genuinely partnering with Victorian Traditional Owners and Victoria's Aboriginal community to progress their aspirations.

The use of 1080 and other methods for controlling European Rabbits, Feral Pigs, Red Foxes and Dingoes and Wild Dogs in Victoria

Arthur Rylah Institute for Environmental Research
Unpublished Report for Agriculture Victoria

Acknowledgements

This project was funded by Agriculture Victoria under the Victorian Governments *Backing Victorian Producers to Grow* election commitment

Glossary

ACTA	Animal Control Technologies Australia
ACUP	Agricultural Chemical Users Permit
APVMA	Australian Pesticides and Veterinary Medicines Authority
CE	Capture efficacy
CEA	Cost-effectiveness analysis
CPE	Canid pest ejector
LGA	Livestock guardian animal
LGD	Livestock guardian dog
LTD	Lethal trap device
PAPP	Para-aminopropiophenone
RHD	Rabbit haemorrhagic disease
RHDV	Rabbit haemorrhagic disease virus

Contents

OFFICIAL

Tables

Figures

Executive Summary

Introduced vertebrate pest species cause significant environmental and socio-economic impacts in Victoria and public and private land managers apply a variety of lethal and non-lethal control strategies to minimise their impacts. One of the most used poisons is sodium fluoroacetate, also known as 1080, which serves as the active (toxic) component in several pest bait products. 1080 is widely used and relied upon by land managers in Victoria for controlling populations of European Rabbits, Feral Pigs, Red Foxes, and Dingoes and Wild Dogs. However, there is ongoing community discourse on the non-target impacts and humaneness of 1080, and therefore a need to consider the use of other methods and their relative efficacy for controlling vertebrate pests. This report reviews alternative (lethal and non-lethal) control methods currently available in Victoria for the management of European Rabbits, Feral Pigs, Red Foxes, and Dingoes and Wild Dogs. The report summarises the advantages and disadvantages of each alternative control method and then synthesises the information for policy and land managers. The key findings are summarised for the four species.

For foxes, 1080 is currently the most cost-effective tool for managing their populations and mitigating their impacts on biodiversity. There is scope to reduce the reliance on 1080 for some of the other species, however this requires integration of multiple tools and increased costs. The optimal choice of lethal or non-lethal control method or combinations of both remains highly species- and context-specific, since none of the individual options are without issues relating to humaneness, animal welfare, environmental or social and cultural impacts, and/or cost-effectiveness. There are still major knowledge gaps in this area that, if addressed, could greatly enhance our understanding and the effectiveness of pest management in Victoria.

Key findings

Efficacy and cost-effectiveness of 1080 and other lethal methods

European Rabbits

European rabbit control methods vary in efficacy, cost, and environmental suitability. Carrot baits with 1080 can achieve up to 99% population reduction in dry conditions, though populations often recover within 8–15 months. Pindone performs comparably to 1080 and is safer for dogs, but it has poorer welfare outcomes, requires multiple feeds, and is less cost-effective, limiting its widespread use. Warren destruction via ripping achieves approximately 90% reduction and can be maintained effectively through re-ripping every 5–10 years, though outcomes depend on environmental factors and operator skill. Fumigation with phosphine or chloropicrin achieves 64–83% reduction and is ideal where ripping or baiting is impractical; however, phosphine's slow action underscores the need for improved fumigants. Combining methods — such as poisoning, ripping, and fumigation — significantly enhances control outcomes, particularly with ongoing maintenance efforts. Integrating Rabbit Haemorrhagic Disease Virus (i.e. biocontrol) with traditional techniques post-outbreak can improve cost-efficiency and reduce reliance on poisons like 1080 and pindone.

Feral Pigs

Feral pig control methods vary in effectiveness, cost, and practicality. PIGOUT (1080) baits demonstrate variable success, with the PIGOUT Econobait formulation achieving up to an 86% population reduction. Pre-feeding to train pigs to visit bait stations and baiting during food scarcity improve outcomes. HOGGONE® (sodium nitrite) bait paste offers a more humane alternative, achieving 63–99% population reduction when presented in bait boxes, which also mitigates non-target risks. Trapping methods, such as corral traps, drop nets, and Pig Brig traps, achieve 16–80% effectiveness depending on conditions and effort; while labour-intensive and costly, they are more humane than toxic baits. Ground shooting, often involving dogs, achieves 21–30% reduction in confined areas, while aerial shooting achieves up to 80% reduction but is less effective in rugged terrain or at low densities. Both shooting methods are labour-intensive and generally unsuitable for large-scale control in areas of dense vegetation in Victoria. Sustained population suppression typically requires integrated and targeted strategies.

Red Foxes

Red fox control in Victoria relies heavily on 1080 baiting, which is the most cost-effective method for broadscale population reduction. PAPP FOXECUTE®, a more humane alternative, has shown 65–80% reductions in fox activity, though research has focused on toxicity and environmental impact rather than operational efficiency. Canid pest ejectors (CPEs) using 1080 improve target specificity but have higher costs and lack comprehensive cost-effectiveness comparisons with traditional baiting. Ground shooting is highly selective but ineffective for sustained control due to uncoordinated efforts and rapid recolonisation, though it can complement other methods in targeted scenarios. Padded leghold and cage traps are labour-intensive, ineffective at scale, and perform poorly at low fox densities, with cage trapping efficacy remaining under-researched. Carbon monoxide fumigation of dens reduces fox cub activity by 80% but faces seasonal limitations, den detection challenges, and poorer welfare outcomes relative to 1080. Without den destruction, recolonisation occurs, highlighting the need for integrated control strategies.

Dingoes and Wild Dogs

We use the term Dingo and Wild Dog interchangeably throughout this report. Ground baiting for Dingoes and Wild Dogs in Victoria achieves variable success (10–76% reduction), with factors such as bait degradation and non-target removal affecting outcomes, though it remains a cost-effective method. Aerial baiting is more consistent, often exceeding 80% reduction. PAPP, delivered via DOGABAIT® or Canid Pest Ejectors (CPEs), offers improved humaneness and reduced non-target risks. While effective in CPEs, PAPP has a higher cost and to date, limited adoption in Victoria. Trapping, a key management tool in Victoria, is commonly employed where baiting is impractical or in response to stock losses; however, its effectiveness depends on trap type, operator experience, and environmental conditions. Foot-hold trapping is generally less humane than 1080 poisoning. Ground shooting, performed by farmers or government agents, lacks evidence of population-level impact or measurable influence on stock attack reduction. Research on the cost-effectiveness of Dingo and Wild Dog control in Victoria remains limited, with few studies addressing costs and none offering comparative analyses of various lethal and non-lethal methods.

Efficacy and cost-effectiveness non-lethal methods

Livestock guardian animals (LGAs) are widely used in predator control, with livestock guardian dogs (LGDs) being the most common. Their success depends on appropriate training, bonding, and livestock-to-dog ratios, as well as fencing to manage their tendency to wander. LGDs are rarely used in the absence of lethal control methods, complicating assessments of their standalone efficacy. Challenges include conflicts with neighbours, dog-specific issues, and potential harm to native wildlife. Alpacas and llamas are primarily employed to protect smaller livestock, with llamas showing some success internationally; however, alpacas are less effective against larger predators as they are vulnerable to predation. Donkeys offer a cost-effective alternative in dry environments but may be subject to health concerns in wetter conditions, with limited research on their effectiveness in different parts of Australia. While LGAs show promise in integrated management strategies, their efficacy across Australian environments remains under-researched, necessitating region-specific studies.

Exclusion fencing effectiveness varies by species and context. Its use for rabbits has declined due to costs and improved pest management approaches. Modern feral pig fencing is similarly limited to high-value areas. Fencing has proven effective for fox control in intensive agricultural zones, zoos, and conservation sanctuaries, contributing to ‘mainland islands’ that protect native species. However, costs and long-term maintenance present challenges. Linear and cell fencing are commonly used for Dingoes and Wild Dogs in Victoria, typically alongside lethal control methods rather than as standalone solutions. Despite its benefits, exclusion fencing is generally a secondary control method due to its expense, maintenance demands, and reliance on supplementary measures.

Behavioural modification strategies for pest animals shows mixed results. Deterrents like fladry tape offer brief success, while others, such as air horns and shotgun sounds, are less effective. Emerging approaches, including conditioned taste aversion and chemical deterrents like synthetic Dingo urine, demonstrate context-specific promise. Given their transient effectiveness, repellents are best suited for critical risk periods such as calving or lambing otherwise would require repeated applications to retain efficacy longer-term. For predators with large or seasonal ranges, targeted application in high-risk zones may prove more practical than comprehensive exclusion.

Impact on non-target species of lethal control methods

Research on the direct impacts of 1080, PAPP, sodium nitrite, and pindone on non-target species is limited, this is particularly true for rabbit control operations using pindone. While trials suggest that non-target species frequently consume rabbit baits, population-level effects on common birds and mammals appear minimal, though risks to specific non-target species remain a concern. Advances in bait design for feral pig control, such as PIGOUT (1080) and HOGGONE (sodium nitrite) formulations, alongside HogHopper™ bait dispensers, have reduced non-target consumption, though minor mortalities still occur. For the Red Fox, and the control of Dingoes and Wild Dogs, 1080 and PAPP present different levels of risk to native reptiles, marsupial carnivores, and some bird species, though burying baits has proven effective in reducing exposure. In some instances, PAPP presents a higher non-target risk than 1080, for example for the Spotted-tail Quoll. Notably, 1080-based predator control has improved prey species populations, highlighting its role in biodiversity conservation. The large-scale ecological impacts of PAPP remain underexplored due to its limited deployment.

Secondary poisoning risks vary by toxin and environmental factors. While 1080 presents risks to sensitive carnivores, sodium nitrite poses minimal secondary poisoning risk due to its rapid degradation and reduced vomiting in poisoned pigs. Limited data on pindone's non-target impacts indicate a need for further investigation.

Livestock guardian animals (LGAs), particularly LGDs, occasionally harm predators, non-target wildlife, and even livestock, raising welfare concerns. Llamas and donkeys have also been observed to injure or kill predators. LGDs can influence wildlife behaviour, with herbivores like grey kangaroos and Swamp Wallabies avoiding LGD-occupied areas. However, LGDs themselves face risks from predator encounters, complicating their deployment and necessitating careful evaluation of ecological and ethical trade-offs.

Shooting is generally target-specific but carries risks to non-target species, including livestock, and raises welfare concerns if dependent young are present. Lead-based ammunition poses an additional risk through fragment ingestion in carcasses.

The impact of den and warren fumigation on non-target species is poorly studied in Australia. When applied correctly, den fumigation appears target-specific, with minimal secondary poisoning risks. However, caution is advised where non-target species such as wombats, Dingoes, lizards, or snakes may occupy dens or warrens.

As a relatively new control method, research on Canid Pest Ejectors (CPEs) and their non-target impacts in field settings is limited. Efforts to improve CPE specificity, such as collar designs that exclude Dingoes and Wild Dogs while allowing fox access, show promise in reducing non-target risks.

Social and cultural considerations

The social and cultural aspects of pest control are distinct yet interconnected with concerns about humaneness, animal welfare, non-target effects and environmental impacts. Research on the social impacts of pest control tools in Australia is limited; however, existing studies suggest that pest control measures can create intracommunity conflicts, shaped by diverse rural land uses and differing stakeholder viewpoints. Dingoes are culturally significant to indigenous Australians and their perspectives on Dingoes are complex, though this review does not explore them in detail. The social implications of lethal control methods and the potential benefits of transitioning to non-lethal alternatives require further investigation to balance cultural values and community well-being.

Humaneness and animal welfare issues

1080 causes cardiac failure in herbivores and neurotoxic effects in carnivores, and is perceived to cause distress and pain as poisoning progresses. While alternatives such as PAPP and sodium nitrite have been developed as more humane alternatives to 1080, they also have welfare impacts. PAPP leads to a lag period before symptoms like lethargy and cyanosis emerge, followed by unconsciousness and death, but animals are vulnerable to predation and environmental harm during the transition. Sodium nitrite, used for feral pigs, induces rapid death after a brief onset of symptoms, but still causes distress. Pindone, an anticoagulant used for rabbits, causes prolonged suffering through internal bleeding, leading to death after a variable lag period.

Fumigation of warrens or dens with phosphine or carbon monoxide also carry welfare concerns, with phosphine causing rapid death at high concentrations, while chloropicrin results in respiratory distress and prolonged suffering before death. Ripping rabbit warrens leads to asphyxiation or crushing, while biological control via RHDV viruses can take up to 24 hours with internal haemorrhaging common.

Livestock guardian animals can cause significant welfare impacts on wildlife, and fencing can lead to animal entanglement and death. Shooting relies heavily on proper shot placement to minimise suffering. Trapping, whether using containment (cages or netted enclosures) or leghold traps (containment traps), also causes distress, with leghold traps raising welfare concerns despite improvements in design. Technological advancements like trap alert systems aim to reduce the duration animals spend in traps, improving welfare outcomes. Lastly, lethal trap devices (LTDs) utilising PAPP for foxes and Dingoes and Wild Dogs, while more humane than strychnine, still require further assessment for welfare impacts. Overall, while some control methods have shown improvements in reducing suffering, the welfare implications of each technique vary depending on species, method, and execution.

Environmental impacts

Toxic Baits

1080 is highly water-soluble so dilutes readily in water and biodegrades in water typically within days. The process of biodegradation in soil is primarily driven by temperature and soil microbes. When mammals experience sub-lethal exposure, rapid metabolism and excretion occur, such that 1080 is not considered to bio-accumulate in living animals.

PAPP is moderately water-soluble and mobile in sandy soils. It does not bioaccumulate but has been shown to slightly bioconcentrate. High residual concentrations of PAPP have been found in the stomachs of foxes, but it degrades quickly in carcasses and does not persist in the environment. Pindone degrades in wet conditions, though photodegradation remains unconfirmed. Residual concentrations in sub-lethally exposed rabbits clear in about 10 days.

Secondary poisoning risks are highest when predators consume multiple exposed rabbits, but pindone presents a lower risk to domestic pets when compared to 1080.

Sodium nitrite is highly mobile and does not bioaccumulate. It degrades in the environment through oxidation and microbial activity, integrating into the nitrogen cycle. Sub-lethal exposures are quickly eliminated in animals, which reduces the risk of secondary poisoning.

Den and Warren Fumigation
Phosphine gas reacts with water to release toxic gas, which is inherently degradable and not persistent in the environment. Chloropicrin, being volatile, moves through the soil with biodegradation and photolysis. It disperses more slowly in water. Carbon monoxide, when used in fumigation cartridges, poses no secondary poisoning risk, as it disperses through inhalation, microbial uptake, or integration into carbon cycles.

Rabbit Warren Ripping
Warren ripping disrupts soil but can promote stabilisation over time. It may reduce vegetation diversity, favouring exotic species.

Shooting
Lead ammunition poses environmental risks by contaminating soil and water. This contamination creates short-term environmental concerns and can influence scavenger populations. Although shooting disturbances are generally localised and temporary, they may still affect wildlife behaviour.

Livestock Guardian Animals (LGAs)
Proper containment of LGAs is essential to minimise environmental impacts. Livestock guardian dogs (LGDs) that roam excessively or exhibit aggression may pose a threat to non-target wildlife or neighbouring livestock. Similarly, donkeys used as guardians may contribute to environmental harm if they establish feral populations in new areas.

Fencing
Exclusion fencing requires ground access for installation and maintenance, which often involves vegetation clearance, earthworks, and vehicle traffic, all of which can have significant environmental effects. Environmental assessments of exclusion fencing in Australian agricultural contexts are rarely conducted.

Conclusion

Viable alternatives to the use of 1080 exist, however all require careful, context specific consideration and are generally less cost-effective with varying animal welfare and social impacts. Effective pest management requires the adoption of adaptive, evidence-based strategies that balance environmental, social, and welfare concerns. Tailored approaches, supported by careful monitoring and cost assessments, are necessary to mitigate negative impacts and ensure long-term control of pest populations.

1 Introduction

Since European settlement in 1788, between 70 and 80 introduced vertebrate pest species have established wild populations in Australia (West 2018). More than 30 of these species have been recognised as causing significant environmental, economic, and social harm (Bomford and Quentin 2002; Whisson and Ashman 2020). To minimise their impacts, both public and private land managers use a variety of control strategies, employing both lethal and non-lethal methods. Lethal tools include biological control agents, poisoning, shooting, and trapping, while non-lethal methods include fencing, livestock guardian animals (LGAs), on-farm practices, and deterrents (https://pestsmart.org.au/).

One of the most used poisons is sodium fluoroacetate, also known as 1080, which serves as the active (toxic) component in several pest bait products (Reddiex et al. 2006). Products containing 1080, intended for pest control, are registered with the Australian Pesticides and Veterinary Medicines Authority (APVMA). In Victoria, Agriculture Victoria regulates the use of 1080 and the toxin para-aminopropiophenone (PAPP), by restricting their supply and use to individuals holding an Agricultural Chemical Users Permit (ACUP) endorsed for the use of 1080 and PAPP, or other forms of authority. Victoria authorises the use of 1080 to control European Rabbits (*Oryctolagus cuniculus*; hereafter referred to as ‘rabbits’), Feral Pigs (*Sus scrofa*), Red Foxes (*Vulpes vulpes*; hereafter referred to as foxes) and Wild Dogs (see below for definition). These species are classified as established pest animals under the *Catchment and Land Protection Act* 1994 (CaLP Act), which obliges landowners to take reasonable steps to prevent the spread of, and attempt to eradicate, these pests from their properties.

Recent research (Weeks et al. 2025) has indicated that Dingoes are a distinct canid linage, with Jackson et al. (2021) describing the most appropriate taxonomic name as *Canis familiaris*, while the *Victorian Flora and Fauna Act 1988* (FFG Act) classifies *C. lupus dingo* as a threatened species that are protected as ‘threatened wildlife’ under the Wildlife Act 1975. The regulations for the use of 1080 and PAPP in Victoria and the APVMA approved labels of registered for 1080 and PAPP products refers to ‘Wild Dogs’. The meaning of ‘Wild Dogs’ under Victorian regulation for the use of 1080 and PAPP does not include Dingoes, except where Dingoes are unprotected by an Order under section 7A of the *Wildlife Act* 1975 or where the control of Dingoes by poisoning is otherwise permitted under the *Wildlife Act* 1975. A Governor-in-Council Order made in September 2018 and remade in September 2023 and again in October 2024 and expiring on 01 January 2028 unprotects Dingoes living in the wild allowing for their killing in specified areas in eastern Victoria. Wild dogs are also defined under the CaLP Act as established pet animals. For the purposes of this review when we refer to Dingo, we are referring to animals that are unprotected unless otherwise specified.

As part of coordinated, cross-tenure pest management programmes, 1080 plays an important role in combination with other control methods to reduce established pest species. It is routinely used to manage populations of European Rabbits, Feral Pigs, foxes, and Dingoes and Wild Dogs. A recent survey of 1080- and PAPP-endorsed ACUP holders found that most respondents (94% for foxes, 93% for Wild Dogs, 92% for rabbits, and 88% for Feral Pigs) consider it essential for effective pest control (Quantum Market Research 2024).

Stakeholder opinions on 1080 vary widely. Some advocate for its prohibition due to concerns about animal welfare and environmental impacts, while others consider it a vital tool for cost-effective, large-scale pest control. Numerous other methods are available for use in managing pest animals, which are often used in conjunction with 1080 as part of integrated control programmes, each with their own advantages and limitations. These other methods require thorough evaluation and comparison to guide best practices in pest management and determine the role of 1080 within this framework. According to the recent ACUP permit holder survey, the majority of 1080 users also employed other control methods over the past five years: 98% for rabbits, 96% for Feral Pigs, 89% for foxes, and 91% for Dingoes and Wild Dogs (Quantum Market Research 2024).

Vertebrate pest problems are foremost economic, political and social rather than purely biological problems or strictly technical in nature. Consequently, there needs to be consideration of the 'human dimensions’ that arise when implementing control actions. Assessing the efficacy of control actions does not explicitly consider the ethical issue of controlling pest species or the unintended consequences of potentially harming or killing some individuals to benefit populations of (in most cases) threatened native species, or to alleviate financial, psychological and social stress or cultural impacts. Resolving ethical and moral aspects of pest animal control is outside the scope of this review. However, it is an important consideration and drives a considerable amount of the debate surrounding the use of lethal and non-lethal control and the impact on non-target animals (De Ridder and Knight 2024; PETA 2024; RSPCA 2019).

In 2022, the Victorian Government committed to a two-year project (2023–2025) under the 'Backing Victoria's World-Class Producers to Grow' policy to assess the relative effectiveness of alternatives to 1080 for controlling European Rabbits, Feral Pigs, Red Foxes, and Dingoes and Wild Dogs. This literature review contributes to fulfilling the Government's commitment as part of a larger investigation.

2 Objectives

The objectives of this review were to:

- undertake a general literature review of the alternative (lethal and non-lethal) control methods currently available in Victoria for the management of European Rabbits, Feral Pigs, foxes and Dingoes and Wild Dogs.
- describe the 'pros and cons' of available alternative control methods currently available in Victoria for each of the four pest species, including
    - non-target species impacts
    - cultural and social considerations
    - health and safety of operators
    - humaneness and animal welfare (including welfare issues associated with 1080 and alternatives)
    - abiotic environmental impacts (water, soil and air – for all methods)
- evaluate the cost-effectiveness of alternative lethal control methods relative to the use of 1080 for the control of the selected pest species
- synthesise this information for policy and land managers.

3 Scope of the review

3.1 In scope

This review covers methods and approaches that are registered and currently permitted for use in Victoria for controlling the four pest species. Where no information is available, we may include Australian and overseas studies to provide context or examples.

We review the literature on the cost-effectiveness of each of the lethal management techniques, but do not formally model these, because there were insufficient data available in the literature or provided by land managers contacted as part of the review process, to build realistic models.

3.2 Out of scope

We do not review literature on new and emerging alternative tools, e.g. engineered synthetic gene drives using the CRISPR/Cas9 genome-editing system, which permits rapid, precise, and targeted genetic engineering in many organisms, including mammals (Grunwald et al. 2019). Nor do we review literature on the use of generative artificial intelligence to 'discover' new compounds (Gangwal et al. 2024) that may have the potential as vertebrate pest toxins.

We also do not present a detailed review on the impact each pest species has had in Victoria on either agriculture or biodiversity.

We do not review the literature relating to wider land or farm management practices that may assist in managing the impact of pest species.

A detailed cost-benefit analysis of 1080 and the lethal and non-lethal alternatives is outside the scope of the review. Where data are available from the published literature or are obtained from subject matter experts, we attempt to build models to compare the relative cost-effectiveness of different methods.

We do not provide a quantitative assessment (meta-analysis) of the likely size of the reduction in density of pest species from the application of the control tools applied to each species, nor do we consider the broader outcomes or benefits (economic or environmental) of reducing pest populations.

4 Methods

4.1 Literature search

We followed the general review approach as outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement to guide our methodology (Page et al. 2020). This approach aims to provide a repeatable and transparent review methodology. Our study search was conducted via the Victorian Government Library Services using database searches of BioOne, CSIRO, EBSCOhost, Policy Commons, ProQuest, Scopus, Science Direct, and Wiley Online searching for published journal articles, reports, conference proceedings, and information sheets. We also used Google Scholar, and State and Federal Government web sites, e.g. PestSmart (https://pestsmart.org.au/), and Agriculture Victoria https://agriculture.vic.gov.au/biosecurity/pest-animals. Based on the results from these searches, we were able to use citations to trace back to other appropriate studies.

We categorised findings by species and control method, or subject (e.g. animal welfare, social impact etc). We recorded details on the study location, dates, the control method(s), and the method used to assess changes in population densities (before and after) the control effort. We also grouped studies into those that had some element of experimental design (e.g. before-and-after, treatment control, replication and/or randomisation of treatments and controls) and those that did not have any of these elements to the study. If available, we recorded information on costs for implementing the control action. Where papers detailed multiple control tools, we reviewed and analysed each separately. Where a single paper detailed multiple control attempts (e.g. different years), we recorded these as separate control events.

Studies were initially collected covering the period 1980–2024; however, we expanded this criterion by dropping filters by date because many of the earlier studies provided critical data on effectiveness. We also contacted subject matter experts and researchers for unpublished data or advice on operational procedures and costs.

4.1.1 Selection and eligibility criteria

1080 and other lethal control effectiveness

We included studies that were published in peer-reviewed journals, technical reports, and government department publications and that included quantitative data from field-based research or that reported on the outcomes of monitoring to assess reductions in the pest species.

We included literature for review if the study met the set of criteria listed below:

1) The literature must have involved the attempted suppression or removal of the pest.
2) The literature must have used some elements of experimental design.
3) The literature must have reported some pre- and post-control abundances or an index of abundance, or the rate of removal.

The literature ideally would have reported efficiency of the control action (e.g. pest species removed per time unit), and/or the cost of control (e.g. cost per pest removed). Where this information was provided, we recorded it. Nonetheless, papers that did not include this information were not excluded from the review if they provided some insight into the general effectiveness of a control method.

When reviewing studies of efficacy, we focused on studies that measured population reductions in response to control actions. Except for studies that incorporated a comparative element, such as comparing different bait types or impacts on non-target species, we excluded research that used placebo or non-poisoned baits as a proxy for likely population reductions. Publications that met these criteria for lethal control tools were also used in the cost-effectiveness analysis if they had details of costs, the effort applied (e.g. hours flown and length of transect) and measures of pre- and post-densities of the pest species.

Cost-effectiveness analysis is one measure that can be used to compare the efficiency of different methods of control (Hone 1994). Rather than using cost-benefit analysis to quantify and subsequently assess the need to undertake an objective, cost-effectiveness analysis is used primarily to determine the least expensive way to meet the objective (Bicknell 1993). Given that control actions for the four species are commonly undertaken on agricultural and conservation land for the protection of susceptible prey, cost-effectiveness analysis would be a suitable means to compare the choice of strategy (Gentle 2005).

Literature on broader aspects of pest animal control

Literature searches on the remaining topics of the review (non-lethal control alternatives, humaneness, animal welfare, occupational health and safety, environmental impacts) were by the nature of the topics more generalised. We limited searches to the past 20 years and to those publications that were conducted in Australia and included the pest species and the topic as additional criteria for searches. However, where appropriate we included publications from overseas that had relevance to the Australian context.

Several reviews have been undertaken in the past two decades on the use of pesticides in Australia and the associated issues. The Australian Pesticides and Veterinary Medicines Authority (APVMA) has undertaken two major reviews of the use of 1080 in 2005 and 2008. Cooper et al. (2007) investigated the scientific and ethical issues of using 1080 on Australian mammals, and in 2013, McLeod and Saunders (2013) reviewed the use of pesticides for the management of vertebrate pests in Australia. In 2017, the Parliament of Victoria undertook an inquiry into the control of invasive animals on Crown Land, and Ross and Eason (2022) reviewed 1080 for conservation and protection of endangered species in New Zealand and Australia. Our review drew on these previous reviews as major sources of information.

4.2 Cost-effectiveness of lethal control

Cost-effectiveness analysis (CEA) offers a valuable framework for evaluating 1080 alongside other lethal control methods by comparing costs to measurable outcomes, such as reductions in pest populations or economic losses mitigated (Hone 1994). While 1080 is frequently viewed as cost-effective due to its capacity to cover extensive areas with minimal labour input, concerns persist regarding its potential negative effects on native wildlife and the suffering inflicted on poisoned animals (Saunders et al. 2010). Conversely, methods like trapping, ground shooting, and warren ripping are more selective but typically entail greater operational expenses and logistical difficulties, especially in remote or hard-to-access regions (McLeod 2004).

Recent technological advances, including aerial shooting supported by thermal imaging and the development of more humane toxins are gaining recognition. Evaluating these alternatives requires assessing cost-effectiveness in terms of effectiveness, scalability, ecological impact, and long-term sustainability (Eason et al. 2014). The primary value of CEA lies not in predicting exact costs, but in comparing relative costs across different scenarios to determine the most effective method under various conditions.

However, the cost-effectiveness of a particular pest management initiative does not necessarily mean it is the most efficient approach from a broader societal perspective, where more humane alternatives could provide comparable benefits at similar or even higher costs. CEA faces challenges common to other economic evaluations, such as cost-benefit analyses, including selecting appropriate discount rates, managing uncertainty, and accounting for the complexity of both ecological systems and associated management costs.

Additionally, evaluating non-lethal methods like LGAs or fencing is challenging within a CEA framework when outcomes are not directly tied to pest density reduction. Including such non-lethal tools in cost-effectiveness modelling is outside the scope of this review. However, there are available methods that can assess the effectiveness of non-lethal methods, for example, reduction in attack rates.

Conducting a comprehensive CEA requires detailed data on changes in pest density from before to after initiation of control, operational costs, including labour, travel, vehicle use, and machinery expenses (e.g. cost/hr for bulldozers, helicopters), as well as the costs of toxicants. Measures of the effort expended, such as hours spent shooting, distances travelled, number of baits laid, warrens destroyed, or animals culled are essential. Effectiveness should be measured against explicit management goals, such as reductions in population density or damage levels. While some studies and information provide total costs, they lack information on either effort or pre- and post-changes in density.

Understanding how management inputs, such as shooting, correlate with outputs like reduced pest densities is crucial (Choquenot et al. 1999). While decreased pest densities often lead to reduced impacts (Hone 1994), not all density reductions yield significant ecological or agricultural benefits. For instance, many pest populations have threshold densities above which impacts become unacceptable, such as the need to reduce rabbit densities to fewer than 100 individuals per km^2 to enable the regeneration of sensitive woody plant species (Bird et al. 2012; Mutze et al. 2008).

Outside of specialised research projects, operational data on lethal control costs across different regions and densities has not been systematically recorded. If available, such data could facilitate the calculation of kill-per-unit-effort metrics and cost comparisons between control methods.

To address these data gaps, modelling approaches can simulate population densities over time using species' life history data (Hone 1994) and generalised cost estimates. Simulations can incorporate expected density changes after control actions, helping estimate both effectiveness and associated costs. However, pest control cost assessments remain highly context-specific, because they are influenced by factors like operational area characteristics, logistical challenges, and management objectives (e.g. eradication versus sustained control).

While general operational activities have been recorded for some of the pest species under Victorian conditions, the requisite data are not available in sufficient detail to build useful cost-effective models.

Before applying any findings from this review to guide operational decisions, it is essential to prepare detailed, site-specific cost estimates, by carefully collecting the required data (Appendix A1). Additionally, sensitivity analyses should be performed to account for uncertainties in biological and economic parameters. These analyses can help determine whether varying assumptions would alter conclusions about a control method's cost-effectiveness (Bicknell 1993).

The current study reviewed available literature on the cost-effectiveness of control methods for each of the four pest species. The aim was to provide an insight into the relative differences in the cost-effectiveness of each method, rather than to determine the actual costs for each approach.

5 Summary of results from literature searches

After evaluating publications against the selection criteria, we reviewed 625 studies detailing control efforts for each of the four pest species and related topics (Table 1). However, only a small subset provided sufficient detail for inclusion in the CEA. Most studies describing control actions lacked key elements of experimental design, such as randomised treatments, control locations, or replication. While some studies included before-and-after measures, they typically relied on activity indices or relative abundance measures rather than actual density estimates. They rarely documented the level of effort or cost involved, or the level of reduction needed to prevent or reverse the damage caused.

For foxes and rabbits, the few publications that adequately addressed control efficacy and reported on effort primarily dated back to the 1950s and 60s. Recent developments, such as PAPP baits for foxes and Dingoes and Wild Dogs or sodium nitrite ($NaNO_2$) for Feral Pigs, have focused on testing different bait materials and dosing rates in laboratory settings. Additionally, some studies referenced the use of these methods while discussing aspects of species biology, management, or environmental and agricultural impacts, including non-lethal effects.

Table 1 summarises the number of publications included in the review for each pest species and control method. It also lists the number of publications addressing broader topics. The counts are presented as minimum values because some publications addressed multiple pest species. For instance, broader reviews of 1080 usage often included foxes and Dingoes or Wild Dogs. In such cases, publications were not double counted.

Table 1. The minimum number of publications reviewed for each pest species. Additional publications had references to multiple species and were not counted to avoid double counting.

Pest species	Review topic	Publications reviewed
European Rabbit	1080 carrot and oat baiting	16
	Pindone	11
	Warren ripping	16
	Fumigation	9
	Fencing	8
Feral Pig	Trapping	12
	Shooting (aerial)	10
	Hunting	5
	Ground baiting – PIGOUT	11
	Ground baiting – HOGGONE	13
	Ground shooting	1
	Fencing	8
	Non-target impacts	8
Red Fox	1080 ground-based baiting	34
	PAPP ground-based baiting	8
	Shooting	9
	Den fumigation	5
	Guardian animals	18
	Fencing	5
	Aversion devices	10

Pest species	Review topic	Publications reviewed
	Trapping (foothold and cage)	17
	Canid Pest Ejector	15
Dingo and Wild Dog	1080 ground-based baiting	11
	PAPP	5
	Aerial baiting – 1080	8
	Shooting	5
	Guardian animals (Livestock Guardian Dog (LGD), Llama, Alpaca, Donkey)	18
	Fencing	23
	Trapping	18
	Canid Pest Ejector	10
	Aversion devices	8
Reviews	Reviews of the use of pesticides for conservation and pest control in Australia	21
Social and cultural considerations	Papers detailing the social and cultural impact of pest control in Australia	17
Environmental impacts	Papers describing effects of a control method, or fate of an active pesticide, in natural environments (water, soil, air)	26
Humaneness	Across all four pest species and general ethical considerations	38
Non-lethal control	Publications reviewing or reporting general non-lethal control approaches but not quantifying outcomes	36
Non-target impact	Clinical or laboratory trials, field assessments, reviews	78
Biomarking	Use of chemicals to deter or change animal behaviour	6
Cost-effective modelling and assessment	Papers related to pest animals in Australia and where appropriate papers that have modelled cost-effectiveness in pest animal operations	39
Population ecology	Papers that relate population ecology to the management of pest species in Australia	9
Total publications included in the review		**625**

6 A brief description of the pest species

There is a significant body of literature that details the environmental and agricultural impacts of all four pest species in Victoria and more widely in Australia. We do not present a comprehensive review of each species and their impacts, because that is outside the scope of this review. However, we provide a brief description of each of the four pest species as background.

6.1 European Rabbits

European Rabbits were first unintentionally introduced to Australia in 1788 with the First Fleet, and then deliberately released in the 1800s for hunting. They quickly spread across the continent and are now considered Australia's most widespread and destructive environmental and agricultural pest. Agriculture losses from reduced crop and pasture yields, seedling loss, and feed competition are estimated at $197 million annually[1] (Hafi et al. 2023). Rabbits threaten at least 73 species of fauna in Australia, including 44 birds, 20 mammals, six reptiles, one invertebrate, one fish, and one amphibian, as well as 260 plant species and nine ecological communities (Commonwealth of Australia 2021). Impacts from grazing, competition, and land degradation are formally recognised as key threatening processes under the *Environmental Protection and Biodiversity Conservation Act of 1999* (EPBC Act) and are listed as potentially threatening processes under the Flora and Fauna Guarantee Act, 1988 (DELWP 2023). Indirect impacts are also recognised as threats, such as serving as a supplementary food source for predators that then increase predation on endangered small mammals and birds (Norbury and McGlinchy 1996; Fleming and Ballard 2019).

In Victoria, rabbits are widespread, with higher densities in central and western regions and lower densities in forested eastern areas. Even at moderate to low densities, rabbits can cause significant environmental damage. A study in southeastern Australia found that regeneration dropped sharply as rabbit densities neared five per hectare, and regeneration was nearly absent at sites with 10 rabbits per hectare (Cooke, Jones, and Gong 2010). Another study in the southeast observed that regeneration of a rabbit-sensitive shrub increased in areas where rabbit densities were reduced by about 90%, to 0.4 rabbits per hectare (Bird et al. 2012).

Land managers currently have several tools for controlling rabbit populations, including poison baiting with sodium fluoroacetate (1080) and Pindone® (a first-generation (multi-dose) anticoagulant). Warren fumigation using toxic gases to kill rabbits within warrens, either by generating the gas inside the burrow and allowing it to diffuse throughout (diffusion fumigation) or by forcing it into the warren under pressure (pressure fumigation) (Williams et al. 1995). Fumigation use either aluminium phosphide tablets, which liberate phosphine on exposure to atmospheric or soil moisture or chloropicrin gas generated from a liquid formulation and forced into a warren under pressure from a pump. Warren ripping which aims to destroy the warren and prevent re-invasion, not to kill large numbers of rabbits. Biological control through the rabbit haemorrhagic disease virus (RHDV) is also available. RHD is a severe illness affecting European rabbits and is caused by the rabbit haemorrhagic disease virus (RHDV), a calicivirus belonging to the Lagovirus genus (Cooke and Fenner 2002). Other methods include habitat removal, and exclusion fencing. Additional methods like shooting, trapping, and ferreting are available, but are generally ineffective for broad-scale control.

For detailed guidance on using these tools, visit the Agriculture Victoria website (https://agriculture.vic.gov.au/biosecurity/pest-animals/invasive-animal-management/integrated-rabbit-control) and the Centre for Invasive Species Solutions PestSmart website (https://pestsmart.org.au/wp-content/uploads/sites/3/2020/09/CISS-Glovebox-Guide-Rabbit-web.pdf).

6.2 Feral Pigs

Feral Pigs have been present in Australia since early European settlement. They initially concentrated near settlement areas but have since spread across 45% of the mainland and are now found in all states and territories. Feral Pigs rank among Australia's most damaging pest species due to their extensive impact on agriculture, the environment, and their ability to spread diseases that threaten human, wildlife, and livestock health. They are estimated to cost the Australian agricultural sector $153 million per year (Hafi et al. 2023)

[1] All costs in this review are presented in inflation-adjusted dollars where appropriate, https://www.rba.gov.au/calculator/annualDecimal.html

through direct predation on lambs, competition with livestock for food, and damage to fences, water sources, and crops.

Feral Pigs significantly harm natural habitats by rooting for food, wallowing in water sources, trampling and consuming native vegetation, and spreading weeds. They prey on ground-burrowing native species like frogs and turtles and endanger approximately 40 threatened species through predation, habitat degradation, competition, and disease transmission. They also pose risks to endangered plants, such as orchids, and protected ecological communities (EPBC Act 1999). Feral Pigs are carriers of over 45 different parasites and diseases, posing substantial threats to livestock, pets, native wildlife, and, occasionally, humans. An outbreak of Foot-and-Mouth Disease (FMD), which Feral Pigs can transmit, could reduce Australia's export revenue by over $10 billion. They also spread plant pathogens like *Phytophthora cinnamomi*, responsible for plant dieback. Currently, managing Feral Pigs nationally costs private landowners around $110 million per year (Hafi et al. 2023).

Feral Pigs have both positive and negative social impacts. They serve as a food source for recreational hunters and Aboriginal and Torres Strait Islander communities. However, they damage culturally significant sites, property, landscapes, and the amenity of national parks and reserves.

In Victoria, Feral Pigs are mainly found in the eastern half of the state and along the Murray River corridor, with isolated, deliberately translocated populations in the southwest, particularly in the Otway Ranges and around Portland. Their densities fluctuate with environmental conditions. During favourable years, when food, water, and shelter are abundant, their numbers can increase rapidly. In harsh conditions, such as drought, their populations decline due to reduced breeding and high mortality of young. Density also depends on habitat type and productivity. For example, in eucalypt woodlands, forests, and grazing lands, there may be one Feral Pig per square kilometre, while in wetlands and floodplains, densities can reach 10–20 pigs per square kilometre (https://agriculture.vic.gov.au/biosecurity/pest-animals/established-pest-animal-species). In the Budj Bim cultural landscape in southwest Victoria, Woodford et al. (2023) estimated a Feral Pig density of 5.4 pigs/km² (95% CI: 4.5–6.3).

Public and private land managers currently have several tools for controlling Feral Pigs, including poison baiting (1080 and sodium nitrate). Sodium nitrite induces methaemoglobinaemia in Feral Pigs, a condition characterised by elevated methemoglobin levels that inhibit oxygen from binding to haemoglobin (Cowled, Elsworth, and Lapidge 2008). Feral Pigs are particularly vulnerable to this condition due to their low levels of methemoglobin reductase, the enzyme responsible for reversing methemoglobin formation. Other methods include, trapping, ground and aerial shooting, exclusion fencing, property hygiene, and harbor removal. Detailed information on these tools is available on the Agriculture Victoria website (https://agriculture.vic.gov.au/biosecurity/pest-animals/invasive-animal-management/integrated-feral-pig-control) and the Centre for Invasive Species Solutions PestSmart website (https://pestsmart.org.au/wp-content/uploads/sites/3/2020/09/CISS-Glovebox-Guide-Pig-web.pdf).

6.3 Red Foxes

Foxes rank among Australia's most destructive agricultural pest animals, capable of rapidly injuring or killing significant numbers of livestock, including lambs (*Ovis aries*), Goats (*Capra hircus*), and poultry, as well as domestic pets (Saunders et al. 2010). They can introduce diseases like distemper, parvovirus, and mange, which have costly and distressing effects on both humans and animals. Indeed, it was estimated that foxes caused $51 million in lost production in Australia, in 2023 alone (Hafi et al. 2023).

Foxes are a major cause of the decline of many small to medium-sized mammal species, especially those within the critical weight range of 35 to 5,500 grams (Burbidge and McKenzie 1989). They also prey on native birds and reptiles. Due to their impact, fox predation is classified as a key threatening process under the EPBC Act 1999. In Victoria, an evaluation of 893 species based on various life history traits identified 293 species as highly vulnerable to fox predation (Kennedy and Ferns 2015).

In Victoria, foxes are the most widespread of all the four major pest species, found in urban areas and in every biome, from coastal habitats to alpine environments. Fox density has been measured in only a few areas in Victoria. For instance, densities are estimated at 0.28 foxes km² in wet forests in southwest Victoria (Le Pla et al. 2022) and range between 0.69 (95% CI: 0.47–1.0) and 1.06 (95% CI: 0.74–1.51) foxes/km² in the Wimmera/Mallee region (Keem et al. 2023). In temperate agricultural areas of Australia, fox densities typically range between 4 and 8 foxes/km² (Saunders et al. 1995), while in urban areas of Victoria, densities as high as 16–30 foxes/km² have been recorded (Marks and Bloomfield 2006).

The tools available to public and private land managers for fox control include poison baiting (1080 and PAPP). Concerns about non-target risks associated with broad-scale baiting—using 1080 or any other toxins—along with issues related to humaneness and the absence of an antidote, have driven research into alternative toxins. PAPP has been developed over the past 24 years as a toxin for pest animal control in both

New Zealand (Eason et al. 2014) and Australia (APVMA 2015; Gentle et al. 2017; Marks et al. 2004; Meek et al. 2019). The toxic effects of PAPP result from the clinical condition methaemoglobinaemia, which occurs when excessive haemoglobin is converted to methaemoglobin. This conversion causes a lethal oxygen deficit in the heart and brain (Vandenbelt et al.1944). Early pharmaceutical trials have indicated that PAPP is highly specific to eutherian carnivores, particularly canids, with much lower toxicity to rodents, birds, and especially humans (Savarie et al. 1983). Den fumigation using carbon monoxide is sometimes used. When inhaled, carbon monoxide binds to haemoglobin in the red blood cells, with an affinity 250 times that of oxygen. This results in reduced oxygen-carrying capacity and reduction of oxygen supply to the tissues (hypoxia), eventually leading to failure of the respiratory centre and unconsciousness followed by death from cardiac arrest. Other methods include ground shooting, above-ground harbour removal, exclusion fencing, guardian animals, and property hygiene. Detailed information on these tools can be found on the Agriculture Victoria website (https://agriculture.vic.gov.au/biosecurity/pest-animals/invasive-animal-management/integrated-fox-control) and the Centre for Invasive Species Solutions PestSmart website (https://pestsmart.org.au/wp-content/uploads/sites/3/2021/03/CISS-Glovebox-Guide-Fox-web.pdf).

6.4 Dingoes and Wild Dogs

Dingoes have been present in Australia for approximately 3,200–3,500 years (Jackson et al. 2021) and hold a significant place in Aboriginal and Torres Strait Islander culture.

In Victoria, Dingoes (*Canis lupus dingo*) are classified as native wildlife under the Wildlife Act 1975, while feral and wild populations of dogs and dingo-dog hybrids (*Canis familiaris*; referred to as Wild Dogs) are designated as established pest animals under the CaLP Act. Recent research (Weeks et al. 2025) suggests that animals previously identified as Wild Dogs or Dingo-dog hybrids are, in fact, likely to be Dingoes, noting that DNA testing is more reliable than physical appearance for distinguishing between the two. Recently, Jackson et al. (2017) reviewed to taxonomy of Dingoes and concluded that they are an ancient dog, and the most appropriate taxonomic name to use for the Dingo is *Canis familiaris*. In 2024, The Australasian Mammal Taxonomy Consortium (AMTC 2024) concluded that the "weight of evidence strongly suggests that Dingoes should not be considered as a different species from domestic dogs and are a distinct population of wild canid. They also note that future research will continue to inform the taxonomic status of dingoes, and that the Dingo has important cultural, ecological and management value. The taxonomic placement of the Dingo in no way diminishes the importance of conserving them as an ecologically important animal in Australian ecosystems. We use the term Dingo and Wild Dog interchangeably throughout this review.

The Victorian government acknowledges that livestock predation is a significant challenge for Victorian farmers and declared the Dingo as unprotected under the Wildlife Ac 1975 on private land and within a 3 km buffer zone along the boundaries of public land in eastern Victoria. The Order revokes and replaces the order made in March 2024 and will have effect until 1 January 2028.

Dingoes and Wild Dogs significantly impact agriculture and cause emotional stress to livestock producers, with agricultural and horticultural losses across Australia reportedly reaching $73 million (Hafi et al. 2023). Their effect on wildlife, however, is complex. While top predators play essential roles in ecosystems, Dingoes are relatively recent in evolutionary terms, potentially contributing to the extinction of the thylacine (*Thylacinus cynocephalus*) and the Tasmanian devil (*Sarcophilus harrisii*) on the Australian mainland (Corbett 1995). Their role in limiting fox and feral cat (*Felis catus*) populations and regulating herbivore numbers remains debated in scientific literature (Castle et al. 2023; Glen, et al. 2007; Hayward and Marlow 2014; Letnic et al.2013).

In Victoria, Dingoes and Wild Dogs primarily inhabit the eastern forested areas and exist in small, isolated populations in the Big Desert and Wyperfeld landscape in the west. A 2022 assessment of Dingo density on public land in Victoria estimated an average density of 0.08 Dingoes per km². The estimated Dingo population in eastern Victoria is approximately 4,900 (90% CL: 2,640–8,880), while in western Victoria, the population was estimated at 110 (90% CL: 40–230) (https://www.wildlife.vic.gov.au/__data/assets/pdf_file/0028/722971/wild-dog-program-summaries.pdf).

Where Dingoes are unprotected, public and private land managers may employ control measures to safeguard livestock. Available methods include poison baiting with 1080 or PAPP, with pen trials confirmed that canids are highly susceptible to the toxin, showing no clinical signs of vomiting or physical distress after exposure (Lapidge 2004). Other methods such as trapping using leg-hold traps (smooth jawed, spring-operated traps designed to capture an animal by the leg), exclusion fencing, shooting, and audio-visual deterrents are also used. Land managers may also implement on-farm strategies, such as carcass removal, shepherding vulnerable young (lambs/calves), and managing grazing (Smith, Appleby, and Jordan 2021). Further details on these tools are available on the Centre for Invasive Species Solutions PestSmart website.

7 Effective pest animal control and population ecology

All methods used to control the four pest species – including non-lethal techniques – have the potential to affect both target and non-target animals (Allen et al. 2019; Jenkins 2003). The impact of lethal and non-lethal control on these populations depends on whether the removal rate from control actions exceeds the population growth rate, denoted as *r* (Krebs 1999). When $r = 0$, the population remains stable; when $r > 0$, it grows; and when $r < 0$, it declines. For control measures to be effective, they must reduce populations to the point where growth ceases, and numbers decline (Caughley 1980; Hone 1999; Hone et al. 2010). The maximum proportion of a population that must be removed annually to halt growth is termed *p* and is calculated using the formula $p = 1-(1/e^{r_m})$, where r_m is the maximum annual growth rate under unlimited resources (Caughley 1980; Hone et al. 2010).

For instance, Hone (1999) estimated that reducing fox populations by 65% and rabbit populations by 87% annually is required to prevent their growth. Similarly, (Hone et al. 2010) used demographic data for various Australian native species to calculate r_m and the proportion of a population that needs annual removal to drive it to extinction. For the Spotted-tailed Quoll (*Dasyurus maculatus*), with an estimated mean annual growth rate of 1.21 (95% CI: 0.1–4.84), the required annual reduction is 52% (95% CI: 9–99%). For Long-footed Potoroos (*Potorous longipes*), the required reduction is 29% (95% CI: 9–63%), and for Eastern Barred Bandicoots (*Perameles gunnii*), it is 89% (95% CI: 37–100%).

These figures provide examples of the level of removal needed to cause pest or non-target population declines, but the wide confidence intervals for native species underscore the need for more field-based data to refine these estimates. Nevertheless, the framework of applying population ecology outlined by (Hone 1994, Hone 2012; Hone et al. 2010) provides a quantitative approach to assessing level of effort to manage pest species and the risks to non-target species.

In addition to direct impacts, lethal and non-lethal control methods can have other sublethal population level effects on both pest and native species. A modest reduction in pest density might trigger compensatory demographic responses, such as enhanced survival, increased reproduction, or immigration, due to reduced competition for resources (Choquenot and Ruscoe 1999; Lieury et al. 2015). However, in socially complex pest species, the loss of individuals may disrupt social organisation. For example, controlling wolf populations can fragment their social structure, potentially altering age composition, group size, survival rates, hunting efficiency, territory dynamics, behaviour, and genetic diversity (Haber 1996). Wallach et al. (2009) suggest that lethal control of Dingoes could have similar effects.

The relationship between pest damage and density remains unclear. It is often assumed that reducing pest populations will reduce the damage, halt declines or boost the abundance of at-risk species. However, the extent to which pest densities need to be reduced to alleviate predation pressure, allow vegetation recovery, or enhance farm productivity remains largely unknown. An example of this is if dominant male predators are responsible for most of the killing, removing sub-dominant individuals from the population may result in a decline in overall density but not reduce the damage caused.

Understanding population ecology provides valuable insights into the effectiveness of pest control measures, particularly in reducing pest populations, preventing damage, and minimising impacts on native species and the environment. It also highlights the ecological complexities of pest management and underscores the risks of unintended consequences. Without linking our understanding of population ecology to measurable outcomes from control actions, there is a risk of misallocating scarce public resources to ineffective strategies that fail to achieve the desired benefits.

This review assumes that 1080 products, when applied according to label conditions and in adherence to best practice methods, are effective in controlling the target species. This section provides a brief overview of 1080 usage and summarises its efficacy in reducing populations of the target species. The broader economic, social, and environmental benefits that may flow from reducing pest populations fall outside the scope of this review.

8 Lethal methods for managing rabbits

8.1 1080

Research into the efficacy of 1080 as a toxin for rabbit control in Australia began extensively in the early 1950s (Lazarus 1956; Meldrum et al. 1957; Rowley 1960). By the 1950s and 1960s, 1080 had become a primary method for managing rabbit populations. Early studies aimed to determine the minimum effective concentration of 1080 required to kill rabbits, identify the most effective bait types, and optimise delivery methods. Meldrum et al. (1957) were among the first to report a significant reduction in rabbit populations, recording a 95% decrease in parts of Tasmania.

These foundational studies established two standardised baiting methods, using: (1) oat baits and (2) carrot baits, both treated with 1080 at concentrations between 0.01% and 0.02%. Rowley (1960) compared the effectiveness of these bait types under various climatic conditions in Western Australia and the New South Wales tablelands. During winter, both oat and carrot baits were readily consumed by rabbits. However, in the hot and dry summer months, oat baits were less palatable. In this study, rabbit populations were reduced by 98.9% with carrot baits and 83.6% with oat baits. Other research has demonstrated variability in effectiveness, with oat baits achieving reductions between 45% and 100%, and carrot baits resulting in reductions between 33% and 99% (Burley 1986; Meldrum et al. 1957; Oliver et al. 1982; Rowley 1968; Wheeler 1984).

Subsequent studies examined the durability of 1080's impact on rabbit populations. Rowley (1968) found that 1080-treated carrots or oats reduced rabbit numbers by 93–99% across five sites. However, these reductions were temporary, lasting only 8–15 months. The rapid recovery of rabbit populations was attributed to high reproductive rates among surviving individuals and immigration from neighbouring untreated areas supported by the fact that warrens were left untreated and intact (Myers and Poole 1962; Mykytowcyz 1960).

Table 2 details the reported percentage reductions in rabbit populations from the application of lethal control measures used to control rabbits.

A recent survey of ACUP holders revealed that one-third of land managers actively engaged in rabbit control had used 1080 baiting within the past five years. Of these, 98% reported incorporating 1080 baiting into an integrated rabbit management strategy (Quantum Market Research 2024). Additionally, 73% of respondents who used 1080 during this period favoured carrots as the preferred bait medium.

8.2 Pindone

Pindone is effective in reducing rabbit populations, achieving reduction rates comparable to those of 1080-treated oat and carrot baits. Unlike 1080 carrot or oat baits, which are affected by rainfall, pindone can be used year-round (Robinson and Wheeler 1983). Pindone is also less toxic to dogs than 1080, and an antidote is available (Williams et al. 1995). However, it is more expensive, requires multiple feedings to achieve efficacy, and poses a higher risk to non-target species such as Southern Brown Bandicoots (*Isoodon obesulus*), Western Grey Kangaroos (*Macropus fuliginosus*), and Australian Ringneck Parrots (*Barnardius zonarius*) (Twigg et al. 2001). Fisher et al. (2015) detected residual pindone concentrations in the fat and liver of poisoned rabbits, highlighting the potential for secondary poisoning in some non-target predators and scavengers. The lack of comprehensive field studies on pindone's non-target impacts remains a significant information gap. Consequently, pindone is recommended for use only in situations where 1080 or other control tools are unsuitable, such as in urban or peri-urban areas.

Few studies (n = 4) have specifically examined changes in rabbit populations following pindone application. Oliver et al. (1982) compared the effectiveness of 1080 and pindone oat baits in reducing rabbit populations in southwest Western Australia. Their study found no significant difference in summer kill rates between the two poisons (1080: 59% ± 2.02; pindone: 63% ± 3.80). However, while 1080 was less effective during the wet winter months, pindone's seasonal performance did not vary significantly, likely because 1080 is highly water-soluble, whereas pindone is not. Robinson and Wheeler (1983) and Wheeler (1984) used radio-tracking methods in Esperance, Western Australia, to assess the impacts of pindone and 1080 oat baits, reporting kill rates exceeding 86% for both methods.

Patel et al. (2023) explored the integration of pindone baiting with RHDV-K5 virus release at 13 sites in South Australia. While the K5 virus alone had little impact on rabbit populations, pindone baiting led to an average population reduction of 36.6% (ranging from a 92.3% decrease to a 22.7% increase) across all sites within 23 days. The increase at one site was attributed to a combination of a low dose rate during bait preparation and inconsistent bait deployment by participating private landholders.

A recent survey of ACUP holders revealed that 10% of respondents identified pindone as their primary rabbit control tool, (compared to 18% that used 1080) and 33% reported using pindone within the past five years. Among those who used 1080 during this period, 47% indicated they would increase their use of pindone if 1080 were no longer available (Quantum Market Research 2024).

8.3 Warren ripping

The destruction of warrens has been employed as a rabbit control method since the mid-1970s when Myers and Parker (1975) proposed its use during drier periods, coinciding with natural declines in rabbit populations. Since then, several studies have demonstrated the effectiveness of warren ripping in reducing rabbit numbers (Berman et al. 2011; Martin and Eveleigh 1979; Mutze 1991, 1991; Parer and Milkovits 1994; Ramsey et al. 2014; Wood 1985). For instance, McPhee and Butler (2010) reported results from 14 sites in Victoria over a 10-year period, providing strong evidence for warren ripping as a viable control method. Across these studies, rabbit abundance or indices of abundance were reduced by an average of 90.4% (range: 36–99%).

Warren ripping has shown long-lasting impacts on rabbit populations. Warren reopening rates of 14–25% have been reported after 14 months (Martin and Eveleigh 1979), and only 2% after 10 years without follow-up treatment (Mutze 1991). Ramsey et al. (2014) further investigated factors influencing recolonisation rates and the long-term effectiveness of warren ripping in Victoria, using data from McPhee and Butler (2010). They found that recolonisation rates increased rapidly within 2–3 years post-ripping, then stabilised at a slower rate, with a ~40% chance of a warren reopening 10 years after ripping. Reopening rates were highest within 1 km of an active warren and increased by 22% for every additional 10 rabbits per km recorded during spotlight counts. The study highlighted the importance of considering warren size and spatial relationships when planning monitoring and maintenance activities.

Best practice involves reducing rabbit numbers through poison baiting before ripping warrens, typically in summer or early autumn. Follow-up treatments include fumigation or re-ripping reopened or non-ripped warrens, combined with routine baiting of areas inaccessible to machinery in subsequent years (Williams et al. 1995). Pre-RHDV studies established that combining warren ripping with maintenance control was highly effective and cost-efficient (Williams and Moore 1995). In some cases, re-ripping warrens proved more economical than fumigation as a follow-up treatment (Williams et al. 1995). In Victoria, pre-RHDV rabbit population declines due to ripping were not significantly affected by rainfall, soil type, landform, or land use, suggesting that well-coordinated rabbit control programme based on warren ripping can achieve consistent and sustained reductions (McPhee and Butler 2010).

In a post-RHDV context, McPhee and Butler (2010) recommend re-ripping active warrens at 5–10 year intervals, based on monitoring reopening rates. This approach could be more cost-effective than fumigation for maintaining low rabbit numbers of at large scales. However, when protecting sensitive environmental assets, such as native vegetation regeneration, even small rabbit populations can be detrimental. In such cases, follow-up treatments of active warrens are likely necessary to maintain numbers below thresholds that cause ecological damage (Denham and Auld 2004; Lange and Graham 1983).

The success of ripping can be influenced by rainfall, soil type, landform, land use, rabbit carrying capacity, operator skill, and the type of machinery used. However, steep slopes, rocky landscapes, and areas where rabbits primarily live above ground, such as in southern Western Australia and Tasmania, are unsuitable for ripping (Williams et al. 1995).

In a recent ACUP survey, 15% of respondents identified warren ripping as their primary rabbit control tool, and 54% reported using it in the past five years (Quantum Market Research 2024). Among those who used 1080 in the same period, 62% indicated they would increase warren ripping activities if 1080 were unavailable.

8.4 Warren fumigation

This method is commonly employed as a follow-up technique to address warrens discovered after baiting and ripping, in areas where ripping or baiting is impractical or undesirable, or to control small, isolated infestations (Williams et al. 1995).

According to a recent ACUP user survey, 11% of respondents identified fumigation as their primary rabbit control method, while 39% reported using it in the past five years. Among those who employed 1080 for rabbit control during the same period, 45% indicated they would increase fumigation activities if 1080 were no longer available (Quantum Market Research 2024).

Several fumigants are available, including chloropicrin (CLPN; no longer available in Victoria), phosphine (PH_3) produced by aluminium phosphide tablets (e.g. Phostoxin and Gastion), and magnesium phosphide tablets (e.g. Magtoxin). Among these, aluminium phosphide pellets are the most commonly used fumigants in Victoria. These pellets release phosphine gas upon activation by moisture. However, as aluminium phosphide is classified as a Schedule 7 poison, only individuals holding an ACUP or those under their direct supervision are authorised to purchase and apply it.

Studies on fumigation's effectiveness in Australia report reductions in rabbit populations ranging from 64–83% (Gigliotti et al. 2009; Ross 1986). Concerns regarding the humaneness and efficiency of chloropicrin and phosphine have driven the development of carbon monoxide (CO) as an alternative fumigant (Gigliotti et al. 2009). Comparative trials indicated that phosphine gas killed 10–12 rabbits within an average of 225.3 minutes, though this slow action was attributed to the gas's low production rate and limited diffusion throughout the warren. Conversely, carbon monoxide at a concentration of 6% caused the death of 8 of 10 rabbits in an average of 28.3 minutes—2.9 and 8 times faster than chloropicrin and phosphine, respectively (Gigliotti et al. 2009). This research suggests carbon monoxide is a promising alternative, offering a humane, rapid-acting, and effective solution for rabbit control.

Alternative fumigants

Carbon dioxide (CO_2), although commonly used to euthanise other species, is ineffective and uneconomical for rabbit warren fumigation. Wild rabbits exhibit a high tolerance to CO_2, requiring a sustained concentration of 45% for at least one hour to be lethal. Additionally, CO_2 disperses poorly within warrens, limiting its efficacy (Page 1994; Ross et al. 1998).

8.5 Biocontrol (RHDV-K5)

The unintentional release of RHDV in September–October 1995 had an immediate and significant effect on rabbit populations. Mutze et al. (1998) estimated that approximately 1 million rabbits died above ground in the Flinders Ranges National Park, with over 30 million rabbits likely succumbing in surrounding areas during the November outbreak. RHDV's introduction led to long-term reductions in rabbit populations, particularly in arid regions, where populations decreased by around 85%. However, its success was more limited in cooler, wetter regions of southern Australia (Henzell et al. 2002). RHDV has since become endemic in Australia (Abrantes et al. 2012). Despite its initial effectiveness, the impact of RHDV diminished over time, with rabbit populations beginning to recover within 8–9 years of the initial epidemics (Mutze et al. 2014).

In 2015, a novel strain, RHDV2, emerged in Australia. Unlike its predecessor, RHDV2 can cause fatal infections in juvenile rabbits under five weeks old (Neave et al. 2018) and infect rabbits that have either recovered from RHDV or been vaccinated against it (Neave et al. 2018; Williams et al. 2011a). Initial estimates of the impact of RHDV2 on wild populations from two sites in South Australia indicated a reduction in rabbit abundance of around 80% (Mutze et al. 2018), likely leading to significant economic benefits to Australian agriculture (Cooke et al. 2013). Monitoring 18 sites across five States in Australia reported an initial decline of 60% with a 64% reduction 8-years later across six sites, overall RHDV2 was shown to have reduced rabbit population between 52 and 82% (Ramsy et al. 2023).

8.5.1 Development and release of RHDV-K5

To enhance rabbit biocontrol efforts, research began in 2009 to identify new strains of RHDV that could complement the now-endemic RHDV (IACRC 2014). A strain originating from Korea, known as RHDV-K5 (hereafter K5), was selected for its potential to overcome the benign calicivirus (RCV-A1), which can diminish the efficacy of classical RHDV (Strive et al. 2013; Strive et al. 2009). Following rigorous testing, K5 was approved and registered as a biocontrol agent in April 2016. In autumn 2017, it was released at 322 sites across Australia in a coordinated effort (Ramsey et al. 2020).

At 22 release sites the impact of K5 was monitored by professional ecologists; rabbit abundances ranged from 612–1.5 rabbits/km. Four of the K5 release sites exhibited declines in rabbit abundances following the release relative to their pre-release abundances. However, only one of these declines was significant.

Conversely, three K5 release sites showed evidence of increases between pre- and post-release survey periods with one of these being significant. Overall estimates of the finite monthly growth rates were approximately equal for both K5 release sites and non-release sites, indicating no substantial changes occurred between pre- and post-release survey periods (Cox et al. 2019). However, research by Ramsey et al. (2020) found that while K5 and RHDV2 were coexisting at the time of their study, the effectiveness of K5 had been compromised by the presence of the competing strain, RHDV2, which has the competitive advantage of causing fatality in juvenile rabbits.

8.5.2 Limitations of RHDV-K5

Currently, K5 is the only strain of RHDV available to land managers for strategic release in rabbit control efforts. Patel et al. (2023) assessed the impact of integrating K5 release with pindone baiting in South Australia. Their findings showed rabbit population reductions at only two of eight sites (16.7% and 8.3%) within 14 days post-release. Conversely, rabbit numbers significantly increased by an average of 66% (ranging from a 16.7% decrease to a 250% increase) across all sites. This variability was attributed to factors such as pre-existing RHDV2 immunity in the rabbit population and the presence of juvenile rabbits, which possess innate resistance to lethal RHDV. These findings align with Ramsey et al. (2020), who demonstrated that RHDV2 reduced the effectiveness of K5 as a biocontrol agent.

To optimise the outcomes of K5 releases, it is essential to consider the prevalence of RHDV2 in the population and the timing of young rabbit emergence. Patel et al. (2023) recommend releasing K5 during summer or early autumn when juvenile numbers are low and combining the release with conventional control measures for better outcomes. Further research is needed to refine strategies for integrating K5 with traditional control methods across different regions of Australia.

The recent ACUP survey revealed that 9% of respondents had used RHDV as their primary rabbit control method, while 25% had employed it within the past five years (Quantum Market Research 2024). Among those who had utilised 1080 for rabbit control during the same period, 35% indicated they would rely more heavily on RHDV if 1080 were unavailable.

This highlights the ongoing need to understand and improve the strategic deployment of RHDV strains in conjunction with other rabbit management practices.

8.6 Cost-effectiveness

8.6.1 Conventional control methods

Three studies provided a comprehensive assessment of the cost-effectiveness of conventional rabbit control (Cooke 1981; Cooke et al. 2010; Williams and Moore 1995), while Cooke (2012) summarised cost-effective approaches to planning rabbit control using conventional tools.

Cooke (1981) assessed the effectiveness of rabbit control methods, including poisoning with 1080 oat bait (P), warren ripping (R), phosphine-diffusion fumigation (F), and combinations of these methods (P+R, P+F, R+F, and P+R+F), to prevent crop damage. The study was conducted in mallee vegetation along 1-km lengths of road reserve near Pinnaroo, South Australia. The results showed that none of the individual treatments were cost-effective for protecting crops, although poisoning with 1080 oats was included in all effective combinations. The most cost-effective treatment ($12.04 per warren entrance for a 1-km road reserve) was the combination of P+R+F. This approach became even more cost-effective with follow-up control, as the number of warrens requiring treatment decreased over time, reducing the cost of subsequent fumigation.

Williams and Moore (1995) experimentally compared the effectiveness, cost, and cost-efficiency of factorial combinations of four commonly used rabbit control methods on grazing properties in the Southern Tablelands of eastern Australia. Initial control treatments were applied over four months, followed by maintenance control on half the replicates at intervals of 2, 6, and 12 months. Initial treatments included no treatment, poisoning (P) with 1080 oats, warren ripping (R), chloropicrin pressure fumigation (F), or combinations of these methods (P+R, P+F, R+F, P+R+F). Maintenance control consisted of phosphine-diffusion fumigation (M).

Their results showed that initial treatment using P or F alone did not reduce the number of active entrances, while warren ripping alone was effective (94%) at a cost of $2.91 per entrance. Combining treatments had an additive impact, with the triple treatment (P+R+F) being highly effective (>98%), with warren ripping as the only common element across all successful combinations. Cost-effectiveness further improved with maintenance control applied 6 and 9 months after the initial treatment. The combination P+R+F+M was the most cost-efficient, achieving 99.4% effectiveness after three rounds of maintenance treatment over two years, at a cost of $6.61 per warren entrance. Costs declined by about half with each subsequent maintenance application, despite the increasing intervals between applications.

Cooke et al. (2010) used an economic decision model to evaluate the cost-efficiency of poisoning with 1080 oats, warren ripping, and phosphine-diffusion fumigation, either individually or in combinations, to protect regenerating native vegetation. They used data from the above two studies. Depending on the vegetation's capacity to regenerate, the most cost-effective treatment varied with rabbit density. At densities above 1.25 rabbits ha^{-1}, P+R+F was most effective for vegetation with a medium to high regenerative capacity. At these densities or higher, no treatment or treatment combinations were effective. At densities between >0.25 and 1.00 rabbits ha^{-1}, the R+F or F treatment was effective, depending on the vegetation's regenerative capacity, while at densities below 0.25 rabbits ha^{-1}, fumigation alone was sufficient.

In addition, Mutze (1991) investigated the effectiveness of long-term warren ripping and poisoning at Manunda Station, Yunta, South Australia 10-years after control. He showed that poisoning had an initial knockdown but no lasting effect, while ripping was able to maintain very low numbers. After nearly 10 years without follow-up control work, ripped warrens had only two per cent of the pre-control number of active entrances. They assumed one rabbit for every two active entrances, 12 rabbits as equivalent to one Sheep, and that grazing pressure of rabbits was equal to one Sheep/warren – which meant that one Sheep could have been grazed per ripped warren for 10 years with no extra cost, at a gross margin of $12 (in 1990 dollars) per Sheep. This meant that the cost of control would have been recovered in the first year following treatment.

These studies underscored the importance of integrating multiple control methods to achieve effective outcomes, with the most cost-effective combinations depending on the underlying rabbit density and the vulnerability of the resources being protected. They also confirmed that rabbit numbers must be reduced to fewer than one rabbit per hectare to protect the most vulnerable plant species, as indicated by (Mutze et al. 2008).

Table 3 compares the cost-effectiveness, non-target impacts, and pros and cons for each of the lethal control methods used to manage rabbits in Victoria.

8.6.2 Pindone as an alternative to 1080

The use of 1080-poisoned baits in combination with other methods is a key component in the cost-effective management of rabbits at moderate to high densities. However, at low densities, combinations of treatments not involving the use of 1080 appear to be effective. No studies were found that assessed the cost-effectiveness of using Pindone in combination with warren ripping and fumigation. While Pindone was found to be as effective in reducing rabbit densities (Oliver et al. 1982), it was assessed to be more expensive, required multiple feedings to achieve efficacy, and posed a localised higher risk to non-target species (Twigg et al. 2001). Therefore, substituting Pindone for 1080 where poisoning was necessary to reduce rabbit populations was unlikely to be cost-effective.

8.6.3 Integrating biocontrol and conventional methods

In situations where RHDV outbreaks are isolated events in a local rabbit population, recurring at an unknown frequency, the use of conventional control tools depends on the recovery rate of the rabbit population (which, in turn, is dependent on the pre-epidemic density).

Specifically, low-density populations would recover more rapidly than high-density populations because the RHDV epidemic would be less intense. In this respect, single RHD epidemics, whether natural or the result of the deliberate release of K5, behave differently from conventional one-off controls such as poisoning, in that the mortality they cause is density-dependent rather than constant. The presence of other sustained controls, such as fumigation, inhibited rather than promoted the recovery of populations, despite the lower density that results. This is because the control affects the rate of increase as well as the density. Therefore, even if RHDV did not persist, the synergy between its effect and that of other controls suggests a valuable potential role for the disease in an integrated pest management programme (Barlow and Kean 1998).

Mutze et al. (2010) investigated the impact of conventional control on the prevalence of RHDV at eight sites across South Australia and Victoria. They found that conventional control (1080 poisoning, warren ripping, removal of surface harbour, and fumigation) did not impact the effectiveness of RHDV transmission, and the timing of conventional control was important to maximising the effectiveness of the integration of biological and conventional control. In their study, populations reduced by 70% or more had lower RHDV antibody prevalence in juvenile rabbits but not in adult rabbits, indicating that reducing rabbit density slowed but did not stop RHDV transmission. They also found that in the cooler, higher-rainfall districts of southern and central Victoria, RHDV activity often occurred in summer. To make the best use of the seasonal reduction of rabbit populations by RHDV, rabbit control should be delayed and conducted in late summer or early autumn, after RHDV outbreaks but before the seasonal increase in plant growth that follows autumn rains.

As noted above, the optimal combination of control tools to implement could depend on the density of the rabbit population. Where RHDV had reduced the population, it would be feasible to implement follow-up control using ripping and fumigation, and maintenance control using fumigation, making the operation more cost-effective and reducing the need to use poison.

Increasingly, any circulating field strain in Australia was likely to be RHDV2 rather than RHDV1 (including K5 and RHDVa) (Mahar et al. 2018). However, when used strategically in conjunction with other control methods and where RHDV2 has been absent for two or more years or when seropositivity is low, planned K5 virus releases could potentially reduce rabbit populations above and beyond what is achieved by naturally circulating viruses in combination with conventional control methods (Strive and Cox 2019).

While these studies indicate that the main potential for RHDV may be as an initial reduction agent that should be complemented by conventional control methods, research has yet to establish the most cost-effective combinations of tools and the conditions under which they are best applied.

Table 2. Comparisons of reported changes in European Rabbit abundance using different lethal control methods in Australia.

Method	Percentage reduction	Region	Method used to measure change	Reference
1080 carrot/oats	86	Gibson, WA	No. killed radio tracked	Robinson and Wheeler 1983; Wheeler 1984
1080 oats	74–100	Meningie, SA	Rabbits per spotlight km	Burley 1986
	91–98	south-east NSW	Standard walk counts	Rowley 1968
	45–70	south-west WA	Rabbits per spotlight km	Oliver et al. 1982
	85–90	Esperence, WA	No. killed radio tracked	Wheeler 1984
1080 carrots	79 –100	Meningie, SA	Rabbits per spotlight km	Burley 1986
	80	Esperence, WA	No. killed radio tracked	Wheeler 1984
	33	Tasmania	Standard walk counts	Meldrum 1957
Pindone	60–63	South-west WA	Rabbits per spotlight km	Oliver et al. 1982
	100	Gibson, WA	No. killed radio tracked	Robinson and Wheeler 1983; Wheeler 1984
	-92.3 – +22.7	Adelaide Hills, SA	Walked random survey	Patel et al. 2023
Warren ripping	39–99	Manunda Station, SA	Active entrances/warren	Mutze 1991
	37–98.5	12 sites across Victoria	Rabbits per spotlight km	Ramsey et al. 2014; McPhee and Butler 2010
	87	Calindary Station, NSW	Active entrances/warren	Wood 1985
	96	Bulloo Downs, QLD	Rabbits per spotlight km	Berman et al. 2011
	98	Shannon Flats, NSW	Rabbits/ha	Parer and Milkovits 1994
	65	Kinchega NP, NSW	Rabbits per spotlight km	Martin and Eveleigh 1979
	93	Central Australia	Rabbits/spotlight km	NHT 2003
	100	Western NSW	Rabbits/warren	
	98	South-western NSW	Rabbits/spotlight km	
	99	Western District, Victoria	Rabbits/spotlight km	
Fumigation	48–80	Ballan, Vic	Count of bodies	Giggliotti et al. 2009

Method	Percentage reduction	Region	Method used to measure change	Reference
	40–78	Adaminaby, NSW	Rabbits /ha	Parer and Milkovits 1994
RHDV2	Given an epidemic of RHDV2 occurs the average reduction reported ranges between 52-82%			
RHDV-K5	RHDV K5/RHDVa co-circulates with RHDV2, with the latter thought to be the dominant strain. Seropositivity to K5 remains at low levels and it is unlikely to play a major role in regulating rabbit abundance.			Ramsey et al. 2020; 2023

Table 3. Summary of cost-effectiveness, target specificity advantages and disadvantages of lethal European Rabbit control methods used in Victoria. Adapted from the State and National Codes of Practices and updated using outcomes from this literature review.

Control technique	Cost-effectiveness	Target specificity	Advantages	Disadvantages
Ground baiting with 1080 oats or carrots	Cost-effective	Potential risk of poisoning and secondary poisoning non-target animals	Effective for reducing rabbit populations prior to warren destruction.	1080 ingestion can also kill non-target animals including native species, cats, dogs and livestock. 1080 is toxic to humans; operators need to take precautions to safeguard against exposure.
Pindone baiting	Relatively expensive (compared to 1080). Effective.	Potential risk of poisoning and secondary poisoning non-target animals	Used in areas where it is impractical or unsuitable to use 1080 e.g. urban/residential and semi-rural areas. Veterinary administered antidote available. Low risk to cats and dogs.	Generally, not used for large-scale open areas. Slow acting – requires multiple feeds. High risk to kangaroos, wallabies. Degradation rates and process not well understood.
Warren destruction by ripping	Cost-effective when integrated with poisoning or fumigation and follow up control	Non-target wildlife using warrens are vulnerable	Where warrens are the principal shelter for rabbits, ripping is the most cost-effective and most long-lasting method of control.	Cannot be used in inaccessible, rocky or environmentally and culturally sensitive areas.
Diffusion fumigation of warrens using phosphine	Expensive – variable effectiveness. Effective as a follow up control option in an integrated operation.	Non-target wildlife using warrens are vulnerable	Can be used near settled areas. Can be used in steep slopes. Little equipment needed.	Labour-intensive, slow and expensive. Unsuitable for large areas.
Biological control with RHDV – K5	No costs reported – variable effectiveness, can depend on habitat.	Target specific	Easily applied, commercially available, no special permits or training required.	Needs to be followed up with conventional control methods Bait delivery of the virus is a more humane technique because it does not require live capture and handling of rabbits for inoculation. Less effective in the presence of RHDV2.

Control technique	Cost-effectiveness	Target specificity	Advantages	Disadvantages
Ground shooting	Not cost-effective. May be effective to control small, isolated rabbit populations.	Target specific	Can be effective over small, isolated areas.	Is inefficient for general control. Is time consuming and labour intensive and not suitable in certain situations e.g. where dense cover is available, inaccessible or rough terrain, near human habitation.

9 Lethal methods for managing Feral Pigs

9.1 1080

Sodium fluoroacetate (1080) is the primary toxicant used for controlling Feral Pigs in Australia (Sharp 2012a). Alternative toxicants, such as warfarin and yellow phosphorus, have also been employed; however, both have been deemed inhumane as control methods (pestSMART 2024a). Neither are available for use in Victoria so are not discussed further in this review. More recently, sodium nitrite (HOGGONE) has been developed as a Feral Pig toxicant (see Section 9.2). Table 4 details the reported percentage reductions in Feral Pig populations from the application of various lethal control measures.

Historically, 1080 was delivered to Feral Pigs via poisoned grain, compressed bran/pollard pellets, fresh or dried meat, offal, carcasses, lupin seeds, fruits, or vegetables (Twigg et al. 2007). These traditional bait types are no longer permitted in Victoria. Rather, only specific manufactured baits—PIGOUT® (1080) and HOGGONE® (sodium nitrite)—are authorised for use (Agriculture Victoria 2024).

Traditional bait substrates, and delivery methods, posed significant risks to non-target species, as grain, fruits, vegetables, and meat often attracted animals other than Feral Pigs. The high doses of 1080 required for effective pig control were also lethal to some non-target species (Fleming et al. 2000; Gentle et al. 2005; Millar et al. 2015; O'Brien et al. 1986). To address these risks, Animal Control Technologies Australia (ACTA) and the Pest Animal Control Cooperative Research Centre developed PIGOUT as a pig-specific bait (Smith et al. 2005). PIGOUT baits are designed to appeal to pigs through specific odour, size, and appearance, and have 1080 in their cores to reduce the chance of non-target consumption by birds and other non-target species (Smith et al. 2005). Although PIGOUT baits reduce non-target impacts compared to traditional methods, several studies (Bengsen et al. 2010; Bengsen et al. 2011a; Campbell and Long 2009) have found that non-target species continue to consume PIGOUT baits, with uptake varying depending on region and delivery strategy. Techniques to minimise non-target impacts are discussed further in Section 1.

PIGOUT baits were tested in Welford National Park, Queensland, where conservative population reductions of 73% were recorded using multiple abundance index methods (Cowled et al. 2006). In contrast, later studies found no significant reductions in Feral Pig populations when comparing treatment and control areas. These discrepancies were attributed to factors such as differing habitat conditions, initial pig densities, and an inadequate programme scale. For example, Adams et al. (2019) noted that deploying only 60 PIGOUT baits in a region with an estimated population of ~9440 pigs was insufficient to produce measurable reductions.

Recently, ACTA introduced PIGOUT Econobait, a more cost-effective and long-lasting alternative to the original PIGOUT bait, which has been approved for use in Victoria (ACTA 2024). Econobaits are smaller and designed to reduce spillage from pig-specific feeders. A manufacturer-run trial reported an 86% reduction in Feral Pig populations, with minimal non-target impacts (ACTA, unpublished data). However, as this study had not been peer-reviewed, further research is required to validate these results.

Both types of PIGOUT baits should be dispensed using HogHoppers™ wherever possible to reduce non-target exposure. Where this is not possible, a thorough risk assessment should be undertaken beforehand using non-toxic free-feeds and/or monitoring techniques to detect presence or absence of non-target species. HogHoppers are metal cubes with internal dividers that allow Feral Pigs to access bait through gravity-activated guillotine doors (Figure 1). These bait stations exploit the size, reach, and feeding behaviours of Feral Pigs, thereby minimising access by non-target species (Campbell et al. 2012).

Figure 1. HogHopper dispenser used to allow Feral Pigs access and reduce non-target bait take.
(Photo Jason Wishart).

Several design elements have been shown to improve bait uptake by Feral Pigs. Pre-feeding during the initial 3–7 days of a baiting programme significantly increases subsequent poison bait uptake (Cowled et al. 2006; Pachauri et al. 2024; Saunders et al. 1993). Additionally, bait uptake improves when alternative food sources are seasonally scarce (Choquenot and Lukins 1996; Hone et al. 1985; McIlroy et al. 1993; Snow et al. 2022) or when Feral Pig body condition deteriorates (Bengsen et al. 2011a; Saunders et al. 1993). Placing baiting in areas frequented by Feral Pigs may also improve bait station discovery. These findings suggest that seasonal or climatic factors should be considered when designing baiting programmes for maximum efficacy.

A recent survey of ACUP holders revealed that 10% of land managers actively engaged in Feral Pig control had used 1080 baiting as the primary control tool, and 23% used it in the last 5-years. Of those, 96% reported incorporating 1080 baiting into an integrated management strategy, with 42% using more than four methods in the past 5-years. Ground shooting (77% of respondents) and trapping (55%) were the most used tools in the past five years (Quantum Market Research 2024).

Notably, no studies have reported population reductions from 1080 aerial baiting, a method commonly employed in some parts of Australia but currently prohibited in Victoria. This represents a significant gap in the literature and a priority area for future research.

9.2 Sodium nitrite

Due to concerns regarding the humaneness of 1080 (see Section15; Green and Rohan, 2012; Sherley, 2007), researchers initiated a search for alternative chemicals better suited for Feral Pig management. This research identified sodium nitrite as the most promising option (Cowled et al. 2008). Subsequently, ACTA developed the HOGGONE® bait matrix specifically to deliver sodium nitrite to Feral Pigs (pestSMART 2024b). HOGGONE is supplied as a dense solid paste bait and is offered to Feral Pigs in trays. The sodium nitrite is in a microencapsulated form (meSN®) that is spread throughout the paste. It is presented in bait boxes (e.g. HOGGONE Paste Bait Hopper, Figure 2).

Despite its benefits, sodium nitrite can affect non-target species, including mammals and birds, in both the United States and Australia (Lapidge and Eason 2010; Snow et al. 2021). To mitigate these risks, it is a regulatory requirement for HOGGONE to be used in conjunction with bait boxes in Australia (ACTA 2024). Further discussion on non-target impacts and mitigation strategies are provided in Section1.

Figure 2. HOGGONE Paste Bait Hopper used to present HOGONE to Feral Pigs and to reduce non-target species access (image – Leschenault Landscape Group, WA).

Field trials across New South Wales, the Australian Capital Territory, and Queensland demonstrated that HOGGONE baiting achieved Feral Pig population reductions of 63–91.7% (Lapidge et al. 2012; Shapiro et al. 2016). Later studies incorporating pig-specific bait stations recorded average population declines of 90.4% in Queensland and 76.3–99% at trial sites in the United States, as measured by visitation rates to bait stations before and after baiting (Snow et al. 2021, 2024).

While effective, HOGGONE is more expensive than 1080 baits due to the higher bait cost, and the regulatory requirement to use bait stations to minimise impacts on non-target species (Wilson and Gentle 2022). As with 1080-based control methods, HOGGONE's efficacy can be enhanced by programme design factors such as training Feral Pigs to use the feeders by pre-feeding and optimal seasonal timing (Lapidge et al. 2012). Results from the ACUP survey indicated that 6% of land managers had used HOGOGNE as the primary tool, and of those, 20% indicated they had used HOOGONE in the past 5 years. In addition, 58% said they would do more HOGGONE baiting if 1080 were no longer available.

9.3 Trapping

Trapping is a commonly used method for controlling Feral Pig populations and involves repeated pre-feeding, daily trap-setting and checking, humane destruction, and removal of captured pigs (Sharp 2012b). While labour-intensive, trapping remains an effective control technique in specific circumstances. In contrast to toxins such as 1080 and sodium nitrite, which face regulatory restrictions concerning deployment, safety, and bait delivery, trapping is subject to fewer regulations (which are stipulated in the *Prevention of Cruelty to Animals Act 1986* (POCTA Act) regulations). This makes it a more viable option where baiting is not suitable (i.e. e.g. in peri-urban areas), or where aerial shooting is impractical due to poor visibility and limited access or not allowed due to aviation regulations. For instance, McCann and Garcelon (2008) documented the eradication of Feral Pigs in a fenced section of Pinnacle National Park, USA, where baiting and aerial shooting were constrained. Trapping proved more effective than ground shooting, although a combination of methods was ultimately necessary for eradication.

Various trap types have been developed for Feral Pig management. The most commonly used are box or corral traps (which use manual gates which are triggered by the animals themselves) or remote activated gates (which are triggered by the operator via cell phone and remote camera technology to confine pigs within a fenced enclosure) (Williams et al. 2011b). Innovations in trap design aim to enhance portability, increase capture rates, reduce trap-shyness, or eliminate the need for manual triggers. Examples include drop nets, where weighted nets are triggered to fall over pigs (Conejero et al. 2022); suspended traps, which enclose pigs by lowering the entire trap around them (Gaskamp et al. 2021); and proprietary 'Pig Brig' traps, netted one-way systems that allow pigs to enter for bait but prevent escape (Pig Brig Trap Systems 2024) (Figure 3). Gaskamp et al. (2021) compared the effectiveness of three trap types—corral traps, drop nets, and suspended traps—finding they achieved reductions of 88.1%, 85.7%, and 48.7% in estimated Feral Pig populations, respectively. The authors highlighted the ability of drop nets and suspended traps to capture entire sounders as a significant advantage.

Figure 3. The range of traps available to capture Feral Pigs in Victoria: a) box or corral style trap; b) suspended style trap; and c) a Pig Brig Trap System.

Numerous studies have assessed the effectiveness of trapping for population control, yielding varied outcomes. For example, Mitchell (1998) reported only a 16% reduction in Feral Pig populations in North Queensland, likely due to the limited deployment of four traps over six days and the absence of pre-feeding. Similarly, Saunders et al. (1993a) documented a 28% reduction in Kosciuszko National Park, which was attributed to minimal pre-feeding (three days), abundant alternative food sources, individual differences in pigs' ‘trapability,’ and suboptimal trap placement. In contrast, Choquenot et al. (1993) achieved population reductions of 81–83% in the central tablelands of New South Wales by trapping for 14–16 days following pre-feeding until bait consumption reached a stable level (~four days). Bengsen et al. (2011b) used camera traps in Daintree National Park, Queensland, to estimate Feral Pig abundance, reporting a 57% decrease after trapping. More recently, a US study recorded an initial reduction of 54–68% in Feral Pig density following a trapping programme, although the population recovered rapidly within 3–5 months (Garabedian and Kilgo 2024).

As with poison baiting, pre-feeding is strongly recommended to mitigate pigs' wariness and encourage repeated trap visits. Studies indicate that limited or no pre-feeding often leads to poor success rates (Mitchell 1998). Additionally, using bait aligned with local dietary preferences and deploying traps during periods of food scarcity can improve trapping efficiency and overall success (Caley 1994).

9.4 Shooting

9.4.1 Ground shooting (with and without dogs)

Shooting by trained sharpshooters is considered one of the most humane methods of managing Feral Pig populations (Section 15; Sharp, 2012c). However, ground shooting is labour-intensive and is typically insufficient for significant population reductions or damage control unless applied intensively. Its effectiveness is heightened when used on small populations, within confined areas, or as part of an integrated strategy alongside aerial shooting, trapping, or baiting (Bengsen et al. 2020). The use of thermal technology to increase detection of pest species such as kangaroos and Sambar Deer (*Rusa unicolor*) has been used successfully in ground-based shooting operations (Comte et al. 2022; Hampton and Forsyth 2016) and in aerial shooting programs (Cox et al. 2023). However, we could find no published accounts of its use on Feral Pigs in Australia.

In jurisdictions where permitted, dogs are often employed during ground shooting to flush, chase, bail, or hold pigs, ostensibly improving efficiency. In Victoria, however, dogs are limited to flushing, chasing, and bailing, with regulations prohibiting direct contact, such as attacking or holding pigs (DEECA 2024). Despite its prevalence, no studies have directly compared ground shooting with and without dogs. The practice remains controversial due to concerns over animal welfare, its effects on pig behaviour, and the potential for non-target impacts on livestock or native species (Hampton et al. 2023; Keuling and Massei 2021; Mori 2017; Orr et al. 2019).

Studies from Australia and New Zealand have reported population reductions of 27–30% from ground hunting campaigns involving dogs (Caley and Ottley 1995; Krull et al. 2016; Mcilroy and Saillard 1989). In contrast, a Swiss study of ground hunting without dogs recorded a slightly lower reduction of 21% over a three-year period (Hebeisen et al. 2008). Both Hebeisen et al. (2008) and Krull et al. (2016) observed declining kill rates over time, likely due to lower pig densities, increased search times between kills, or pigs moving away from disturbances.

Recreational hunting is sometimes proposed as a means of controlling invasive vertebrates in areas where it is legally permitted (Baur and English 2011). Similarly, commercial harvesting by accredited operators to supply the game meat industry is occasionally perceived as a ‘free’ method of Feral Pig control (Gentle et al. 2022). However, evidence suggests these approaches are insufficient for effective population control. Bengsen and Sparkes (2016) found no substantial evidence that recreational hunting effectively reduces invasive mammal populations in Australia, while Gentle and Pople (2013) reported that commercial harvesting in Queensland fails to achieve meaningful reductions in Feral Pig abundance. Moreover, in Europe, recreational hunting has been shown to undermine the success of trapping and baiting programme. Disturbances caused by hunters often result in more cautious pigs retreating to inaccessible refuges, further complicating control efforts (Calenge et al. 2002; Sodeikat and Pohlmeyer 2003).

9.4.2 Aerial shooting

During aerial shooting campaigns, accredited marksmen use high-powered semi-automatic firearms or shotguns to target Feral Pigs from helicopters. In regions where permitted, the use of thermal imaging has been shown to enhance aerial shooting efficiency, particularly in areas with dense vegetation or low pig densities (Cox et al. 2023).

Several studies have reported aerial shooting to be effective at reducing populations (Cowled et al. 2006; Davis et al. 2018; Ferris 2010; Hone 1983; Hone 1990; Saunders 1993; Saunders and Bryant 1988). In a study conducted at the Macquarie Marshes in western NSW, Saunders and Bryant (1988b) demonstrated that aerial shooting could reduce a Feral Pig population by 80%. In a follow-up study at the same location, Saunders (1993) reported that aerial shooting over two years achieved population reductions of 80% and 65%, respectively. However, the Feral Pig population recovered to 77% of its original size within one year, highlighting the necessity for annual control measures to counteract immigration and reproduction.

Choquenot et al. (1999) utilised data from three aerial shooting programmes (Hone 1987; Hone 1990; Saunders and Bryant 1988) to develop predictive models assessing the effectiveness of aerial shooting. Their models demonstrated that kill rates approached a constant maximum at high Feral Pig densities, but declined toward zero at densities below a certain threshold. While maximum kill rates were comparable across the three programmes (average 60.49 pigs per hour, range 49.64–76.28), the minimum densities at which no Feral Pigs would theoretically be killed varied considerably (average 2.79 pigs per km², range 1.34–5.02). These findings suggest the existence of a threshold density below which the hourly kill rate for helicopter shooting becomes negligible. This may be attributed to refugial habitats where Feral Pigs are effectively concealed from aerial view. The Choquenot et al. (1999) model implies that the return on investment diminishes as shooting effort increases at very low Feral Pig densities, because additional effort does not proportionally increase the number of Feral Pigs killed. This underscores the importance of considering habitat characteristics and Feral Pig density when planning and executing aerial shooting operations for population control. There are concerns that aerial shooting could cause Feral Pigs to alter their home ranges or movement patterns (Saunders and Bryant 1988). However, two studies concluded that aerial shooting did not affect home range location or size, suggesting the method is unlikely to impact Feral Pig behaviour (Campbell et al. 2010; Dexter 1996).

One study, conducted on pastoral land in south-western Queensland, found no significant changes in population size, demographics, or genetics after a two-year aerial control programme. The researchers attributed this to the programme's failure to encompass the full range of a large, well-connected pig population, leading to rapid reinvasion and population recovery within the control area (Cowled et al. 2006). Ramsey (2021) analysed the results of an aerial shooting operations in the Eastern Alps and Snowy River Corridor in eastern Victoria. There was no evidence that aerial shooting resulted in population reductions in either of the areas. Estimates of population densities of Feral Pigs before the commencement of aerial shooting ranged from 0.2–1.7 pigs/km^2. However, these estimates were highly uncertain because of the very low removal rates. These low rates were attributed to the aerial shooting teams avoiding some areas where ground control of Feral Pigs was being undertaken. It is also possible that Feral Pigs increased their avoidance behaviour to the helicopter, or that the removal rate was insufficient to overcome natural additions to the population from reproduction or immigration.

Judas pig technique

The Judas pig technique exploits the social behaviour of Feral Pigs to enhance search efficiency during control programmes. Adapted from its initial use with Goats, the technique involves fitting a captured pig with a radio transmitter, releasing it, and allowing it time to rejoin other pigs. The Judas pig is then tracked using radio telemetry, and all associated pigs are culled. The Judas pig may be released again to locate additional groups, repeating the process (McIlroy 1995).

Studies suggest that sows trapped locally are the most effective Judas pigs due to their higher sociability compared to males and their familiarity with the area, which aids in locating nearby sounders (McIlroy and Gifford 1997; Wilcox et al. 2004). Wilcox et al. (2004) demonstrated that the technique significantly reduces search times during ground hunting campaigns. Without the Judas technique, the average time to locate pigs was approximately 4.1 hours, compared to less than one hour when using a Judas pig.

The Judas pig method is versatile and can assist ground or aerial shooters in locating pigs, as well as identifying core areas or home ranges where traps or bait stations may be most effective (McIlroy and Gifford 1997). However, the approach is time- and resource-intensive, requiring significant effort to trap, collar, and track Judas pigs, followed by the culling of associated groups. It is particularly valuable in eradication programmes, where it can expedite the elimination of the final, elusive individuals. If, however, the individual slips its collar, it can confuse sign in low density populations, making eradication of the last few individuals challenging. Additionally, data collected during the process can be used to estimate the likelihood of detecting remaining pigs, aiding in the objective decision-making regarding when to conclude control efforts (Ramsey et al. 2022).

9.5 Cost-effectiveness

Few studies have investigated the cost-effectiveness of individual control methods or compared multiple methods for managing Feral Pigs. Among the available management techniques, shooting from helicopters and trapping have received the most attention concerning cost-effectiveness assessments. AgEcon (2020) investigated the cost: benefits of baiting, exclusion fencing, trapping, and ground and aerial shooting across multiple cropping and livestock enterprises in north-west NSW. Across all cropping enterprises baiting and aerial shooting returned the highest results, followed by trapping. Ground shooting (as the least effective method) returned the lowest results. Exclusion fencing was analysed separately in consideration of the long-term investment. Even when the cost was annualised, exclusion fencing was the highest cost control method per hectare; however, it was also modelled as the most effective option. These two factors meant that the economic outcome from exclusion fencing was highly variable. Exclusion fencing was best suited to high value enterprises that experience year on year damage from feral pigs for example, lambing paddocks. However, documented evaluations of the cost-effectiveness of integrated Feral Pig control programmes are scarce.

Table 5 summarises the reported cost-effectiveness, non-target impacts and the advantages and disadvantages for the lethal control methods used to manage Feral Pigs.

9.5.1 Baiting

Baiting using either PIGOUT or HOGGONE has been shown to reduce Feral Pig populations by as much as 73 and 91.7% (Cowled et al. 2006b, Lapidge et al. 2012a; Shapiro et al. 2016). However, we were not able to locate any papers or reports that compared the relative costs, or cost-effectiveness of these bait types. Prices per bait produce average $290.00 for a 12-tray box of HOGGONE compared to 346.00 for a 64-bait pail of 1080 bait. Operational costs will vary depending on several factors, such as the number of bait stations (boxes) used, the replacement rate of the bait, the underlying density of the feral pig population, the duration of the baiting operations etc.

9.5.2 Trapping

While trapping has been reported to be effective in reducing Feral Pig populations (Choquenot et al. 1993, Gaskamp et al. 2021), only one study detailing the associated costs was identified. (Saunders et al.1993) evaluated the rate and extent of population reduction achieved through trapping Feral Pigs in Kosciusko National Park, New South Wales. Over 330 trap-nights, a total of 142 pigs, including 12 of 17 (71%) previously fitted with transmitters and confirmed to be still on the study site, were captured at a cost of $356.41 per pig. A model applied to the number of pigs caught estimated a population reduction of 62% among animals exposed to traps, but only 28% of the entire population.

9.5.3 Ground-based shooting (from vehicles)

We were not able to source any studies or reports that describe the costs of ground shooting from vehicles. Mitchell (1988) removed 49 pigs through ground shooting, which resulted in an estimated reduction in density of 16%. However, they did not report costs (Mitchell 1988).

9.5.4 Aerial shooting

In a study conducted at the Macquarie Marshes in western NSW, Saunders and Bryant (1988) reported that shooting from a helicopter resulted in the removal of 946 Feral Pigs at a rate of 39.2 pigs per hour, with a cost of $40.34 per pig. In a follow-up study at the same location, Saunders (1993) reported that aerial shooting over two years achieved population reductions of 80% and 65%, respectively. However, the Feral Pig population recovered to 77% of its original size within one year, highlighting the necessity for annual control measures to counteract immigration and reproduction.

In a study conducted in the woodlands of the Mary and Adelaide rivers in the Northern Territory, Hone (1990b) reported a cost of $A22.97 per Feral Pig shot, including helicopter charter, fuel, and ammunition, though excluding salaries. The operational cost per square kilometre was $A111.66. Costs per kill were lowest ($9.43), and kills per hour were highest (93) when the number of Feral Pigs killed per square kilometre was greatest (35). Conversely, costs per square kilometre ($358.26) were highest when shooting time per square kilometre was maximised.

Choquenot et al. (1999) utilised data from three aerial shooting programmes (Hone 1987; Hone 1990; Saunders and Bryant 1988) to develop predictive models assessing the effectiveness of aerial shooting. The findings from their models were consistent with those found by Choquenot et al. (1999) in implying that additional effort does not proportionally increase the number of Feral Pigs killed.

9.5.5 Integrating control methods

McIlroy and Saillard (1989) compared the relative costs of hunting Feral Pigs with dogs and using poison baiting with warfarin in Namadgi National Park, ACT. They found that hunting was ineffective as a method for reducing the Feral Pig population, removing only 13% of the pigs known to inhabit the area. In contrast, poison baiting was more effective across several projects conducted in the same region, with reductions ranging from 29–100%. Additionally, hunting proved more costly, at $783.57 per pig, compared to the $595.21 per pig cost of poison baiting using warfarin. The authors noted that Feral Pigs had been regularly subjected to predation by Wild Dogs, Dingoes, and unauthorised hunters, which appeared to have influenced their behaviour. They also highlighted several factors affecting the success of poisoning efforts, including seasonal and individual movements, habitat use, inadequate distribution and abundance of baits, and variation in bait consumption by the pigs.

Hone (1983) employed 1080 poisoning, followed by ground and aerial shooting, to eradicate Feral Pigs from a 50 km² area in south-western New South Wales. His study revealed that poisoning with 1080 killed 73% of the Feral Pigs. After the poisoning, 95 of the 98 Feral Pigs seen in the area were subsequently shot. The total operational cost of the eradication attempt was $19,950.69, or $399.01 per km². The cost of poisoning was $7,388.01, while the cost of shooting amounted to $12,562.68, or $132.25 per pig killed.

Hamnett et al. (2023) used stochastic population models to determine the most cost-effective strategy for eradicating Feral Pigs from Kangaroo Island, South Australia. They used effort and cost data collected over 17 months to derive functional-response relationships between control effort (hours per pig) and Feral Pig abundance for four control methods: (i) ground-based shooting; (ii) trapping with remote triggers; (iii) poison baiting (HOGGONE); and (iv) thermal-assisted aerial culling. They also simulated combinations of control methods, using an equal-proportion harvest scenario (where each method removed 25% of the annual harvest quota), and a relative cost-proportional allocation scenario (which utilised all four methods in varying proportions, with a greater emphasis on the most cost-effective method).

Hamnett et al. (2023) found that the Feral Pig population was successfully reduced to 10% of its initial size in all culling scenarios, with annual harvest rates of 70% over three years, or 50% over ten years. They suggested that using a combination of methods, proportional to their cost-effectiveness, is the most realistic strategy for eradicating Feral Pigs on Kangaroo Island. In contrast to previous studies, they found that while thermal-assisted aerial culling required the least effort to achieve the reduction targets, it was the least cost-effective method. An important consideration in the integration of methods for controlling Feral Pigs is the sequencing of the methods used. Parkes et al (2010) found that in their eradication attempt on Santa Cruz Island using the most effective methods first (i.e., methods that do not teach Feral Pigs to avoid persecution) was the most productive approach.

Table 4. Comparisons of reported changes in Feral Pig abundance using different lethal control methods in Australia.

Method	Percentage reduction	Region	Methods used to measure change	Reference
PIGOUT (1080)	73–100	Welford NP, Queensland	Proportion bait removed number Known To Be Alive (KTBA) Proportion of radio collared pigs killed	Cowled et al. 2006
	92	Macquarie Marshes, NSW	Camera activity index	Wishart 2013
HOGGONE (sodium nitrite)	90	South central Queensland	Pre- and post-visitation rates to bait stations	Snow et al. 2021
	63–89	Glenrock Station, NSW Namadgi NP, NSW Eaglebar Station, Queensland Harmar Station, Queensland Lassie Creek Station, Queensland	Activity index from camera trap monitoring pre- and post-baiting	Lapidge et al. 2012
	92	Ingelwood, Queensland	Number of radio collared pigs killed	Shapiro 2016
	64–84	Mt Hope, NSW St. George, Queensland	Count of individuals pe-post from camera traps Activity index from camera traps Visitation rate to bait station pre- and post-baiting	Staples and Wishart 2019
Trapping	38–57	Daintree NP, Queensland	Camera trap index	Bengsen et al. 2011
	65–66	Douglas Daly, NT	Known-to-be-alive Mark-recapture	Caley and Ottley 1995
	81–100	Sunny Corner, NSW	Bait takes Spotlight counts	Choquenot et al. 1993
	18	Lakefield NP, Cape York, Queensland	Proportion trapped of marked population	Mitchell 1988
	62–71	Yarrangobilly Caves, NSW	Change in population estimated from cumulative kills of pigs at bait stations Proportion of radio collared pigs killed	Saunders et al. 1993
	60–80	Edmund Kennedy NP, Queensland	Activity transects	Vernes et al. 2001

Method	Percentage reduction	Region	Methods used to measure change	Reference
Aerial shooting	73–96	Hillston, NSW	Line transects pre- and post-control	Hone 1983
	79	Woolner Station, NT	Line transects pre- and post-control	Hone 1990
	65–80	Macquarie Marshes, NSW	Aerial surveys pre- and post-control	Saunders 1993
	75	Macquarie Marshes, NSW	Aerial surveys pre- and post-control	Saunders and Bryant 1988
	86	Barnard/Hunter River catchment, NSW	Aerial surveys pre- and post-control	Ferris 2010
Ground-based shooting (with and without dogs)	22	Douglas Daily, NT	Effort-removal estimate	Caley and Otley 1995
	13	Namadgi NP, ACT	Proportion killed of KBTA at time of hunting	McIlroy and Saillard 1989

Table 5. Summary of efficacy, cost-effectiveness, target specificity, and advantages and disadvantages of lethal Feral Pig control methods used in Victoria. Adapted from the State and National Codes of Practices and updated using outcomes from the literature review.

Control technique	Cost-effectiveness	Target specificity and non-target impacts	Advantages	Disadvantages
Ground baiting with 1080	Cost-effective	Relatively large amounts of 1080 are required to kill pigs; therefore, there is a risk of poisoning non-target animals. Strategic ground baiting uses fewer baits than aerial baiting programmes. Uneaten baits can be collected and destroyed. Potential risk to non-target species if stomach contents, stomach, gastrointestinal tract, and/or any vomit is consumed. To minimise non-target impacts, remove livestock from paddocks, lock gates to paddocks, and use a HogHopper™ and exclusion fencing. All canids can die if they consume vomit, eat a meat bait (where allowable for use) or feed on a poisoned carcase.	Currently the most cost-effective technique available. Highly palatable even after prolonged storage and proven to effectively knockdown pigs. Very little non-target interest. Stays attractive and palatable in hot and dry conditions.	1080 ingestion can kill non-target animals including native species, cats, dogs and livestock.
Ground baiting with sodium nitrite	Cost-effective	NaN is highly target specific. Minimal non-target risks managed by bait box (APVMA/label requirement). Poses little potential risk to non-target species. Minimise non-target impacts by removing livestock from paddocks and locking gates to paddocks.	Available through re-seller network. No special permits are required. Uneaten baits can be collected and destroyed.	More expensive than 1080.
Ground shooting	Not cost-effective	Target specific. No non-target impacts.	Can be useful to clean up small populations in conjunction with baiting and/or trapping.	Labour intensive, only suitable for smaller-scale operations.

Control technique	Cost-effectiveness	Target specificity and non-target impacts	Advantages	Disadvantages
Aerial shooting	Relatively expensive. Can be cost-effective when pig density is high.	Target specific. No non-target impacts.	Provides high level medium- to long-term control of Feral Pig populations.	Relatively expensive. Is habitat-dependant and operationally complex to implement.
Trapping	Can be cost-effective in certain situations	May catch non-target animals. No non-target impacts.	Important control technique in areas where baiting or aerial shooting is not possible.	Not practical for large-scale control.

10 Lethal methods for managing foxes

10.1 1080

1080 baiting is the most widely utilised tool for managing fox populations across Australia (Reddiex et al. 2006; Saunders et al. 2010). In Victoria, 68% of public land managers and 48% of commercial farms authorised to use 1080 employ 1080 baiting as their primary method for controlling foxes (Quantum Market Research 2024). This method is considered the most cost-effective and efficient approach currently available for reducing fox numbers, thereby protecting biodiversity and agricultural values (Saunders et al. 2010).

In Victoria, three types of 1080 bait products are registered for fox control:

1. Shelf-stable baits (FOXOFF®, FOXSHIELD, ACTA 1080 Dried Meat Fox Baits and DeFox®) made from dried, manufactured meat.
2. Perishable baits (short-life or fresh liver baits) that must be used within three days of production.
3. Capsules containing 1080, designed for use in canid pest ejectors (CPEs).

Shelf-stable and perishable bait types must be buried to a depth of 8 – 10 cm to reduce uptake by non-target species (Allen et al. 1989; Bloomfield 1999). Aerial baiting for foxes in Victoria is not permitted.

More than 30 studies have examined the effectiveness of 1080 baiting in reducing fox populations and aiding native species recovery since Kinnear et al. (1988) described the response of Brush-tailed Rock Wallabies (*Petrogale penicillata*) in Western Australia to a 1080 baiting campaign. Reported reductions in fox populations range between 0–99%. Dexter and Meek (1998) recorded a 97% reduction in fox populations in southern NSW coastal habitats with a bait density of 0.14 baits km^{-2}. While Berry et al. (2012) documented a 99% reduction in a fox eradication programme, decreasing the density from 0.73 km^{-2} to 0.004/km^2. Similarly, Marlow et al. (2015a) reported an 81% reduction over 25 years in south-west Western Australia woodlands. More moderate reductions have been reported. Thompson and Fleming (1994) achieved a 70% reduction in agricultural areas of NSW with a bait density of 12 baits km^{-2}. While Fleming (1997) reported a 50% reduction on farmland also in NSW at a bait density of 4.4 baits km^{-2} for a density of 1.3–1.9 foxes km^{-2}. In some cases, 1080 baiting appears to have limited effectiveness. For example, in south-west Victoria, Le Pla et al. (2022) observed densities of 0.21 foxes km^{-2} during baited periods compared to 0.28 foxes/km^2 during unbaited periods, and in semi-arid regions in Victoria, Keem et al. (2023) observed densities of between 0.69 and 1.06 foxes km^{-2}, with no differences between baiting periods or regions, possibly due to the limited spatial and temporal distribution of baits in their study.

Foxes significantly impact animal agriculture. Studies have consistently reported predation on viable lambs, with estimated losses of 1–3% of lambs born annually (Dennis 1965; Mann 1968; Rowley 1970; Greentree et al. 2000). This equates to approximately 1.58 million lambs lost annually across Australia (MLA 2024). Fox predation also affects piglets in commercial piggeries (Fleming et al. 2016) and kid Goats (Long et al. 1988), although studies assessing the effectiveness of control measures in these contexts are lacking.

In New South Wales, Greentree et al. (2000) found that applying fox control three times per year reduced lamb carcass predation from 10% to less than 4%. McLeod et al. (2010) demonstrated that biannual fox control—once in autumn and again in late winter or early spring—significantly reduced lamb predation, with farms participating in coordinated efforts experiencing fewer losses.

However, it remains a challenge to coordinate efforts across multiple properties due to the rapid recolonisation of foxes. For example, in central-western NSW, private landholders across two sites encompassing multiple properties in a coordinated baiting program failed to achieve any detectable reduction in foxes, with a survival rate of 69% among foxes, largely due to bait location and consumption failures (Bengsen 2014).

The effectiveness of ground-based 1080 baiting depends on several interacting factors. Francis et al. (2020) used a spatially explicit population model (FoxNet; Hradsky et al. 2019) to evaluate 14 Victorian fox control projects across areas ranging from 200–800,000 hectares. Their findings highlighted the importance of several factors, including bait density, the spatial layout of bait stations, the frequency and duration of the baiting programme, and the bait replacement rates. The study also revealed that interactions among these factors significantly influence the success of fox control operations, underscoring the need for tailored approaches to maximise efficacy.

Table 6 compares the reported percentage reductions in fox populations achieved using the various lethal control methods available for managing them.

Table 6. Comparisons of reported changes in fox abundance using different lethal control methods in Australia.

Method	Reduction (%) or efficacy	Region	Method used to measure change	Reference
FOXOFF (1080)	66–73	Glen Innes, NSW	Index-removal index pre- and post-control	Thompson and Fleming 1994
	58	Glen Innes, NSW	Index-removal index pre- and post-control	Fleming 1997
	97–100	Beecroft Peninsula, NSW	Proportion of radio-collared foxes killed Pre-post bait take	Dexter and Meek 1998
	64–88	Ben Boyd, NSW Genoa, NSW	Sand pad activity index	Claridge et al. 2010
	58	Goonoo SF, NSW	Camera trap activity index	Towerton, et al. 2011
	83	SW Victoria	Bait take index	Robley et al. 2014
	80	WA Wheatbelt	Mark-recapture DNA genotyping scats pre-post control	Marlow et al. 2015
	41	Mallee, Victoria	Change in occupancy pre- and post-control	Robley et al. 2016
	73	Southwest Victoria	Spatially modelled changes in density	Hradsky et al. 2018
FOXECUTE (PAPP)	65–80	Dubbo, NSW Werribee, Victoria Phillip Island, Victoria	Not reported	APVMA 2015
CPE (1080)	0.016/trap night	5 sites across Victoria	No. killed	Marks et al. 2003
	42 foxes/1000 person hours	Phillip Island, Victoria	Catch per unit effort	van Polen Petel et al. 2004
	Mean 78, max 98	Seven sites across NSW	Pre- and post-control sand plot activity	Hunt 2010
Ground-based shooting	31–92	Milton/Ulladulla Region, NSW	Change in spotlight index pre- and post-control	McLeod et al. 2011
	22	Arthursleigh Farm, NSW	Density estimates from distance sampling	Newsome et al. 2014
	1 fox/36 trap nights	Jervis Bay, NSW	Catch per unit effort	Meek et al. 1995

Method	Reduction (%) or efficacy	Region	Method used to measure change	Reference
Trapping (foot-hold traps)	7–57 1 fox/36 trap nights–1/320 trap nights	Three sites across NSW	Change in spotlight index (foxes/km)	Kay et al. 2000
	1 fox/42 trap nights	Seven sites across NSW	Catch per unit effort	Flemming et al. 1998
	1 fox/150 trap nights	NSW	Catch per unit effort	McIlroy et al. 1994
	1 fox/129 trap nights	NSW	Catch per unit effort	Saunders et al. 2000
	1 fox/12 trap nights	Central Victoria	Catch per unit effort	Carter et al. 2012
Den fumigation	80 (of cubs)	Not reported	Cub activity at dens compared to untreated dens	Hart et al. 1996

10.1.1 Canid pest ejectors for controlling foxes

CPEs are a mechanical device loaded with a small capsule (~ 400 mg capacity) containing either 1080 powder or PAPP. The CPEs are ejected or expelled into the mouth of the target species that bites, tugs or pulls on them, requiring a pull force of 1.6–2.7 kg to be triggered (Figure 4). To achieve this level of force, the animals must have a body mass of at least 1.55–2.7 kg (Connolly and Simmons 1984; Marks and Wilson 2005).

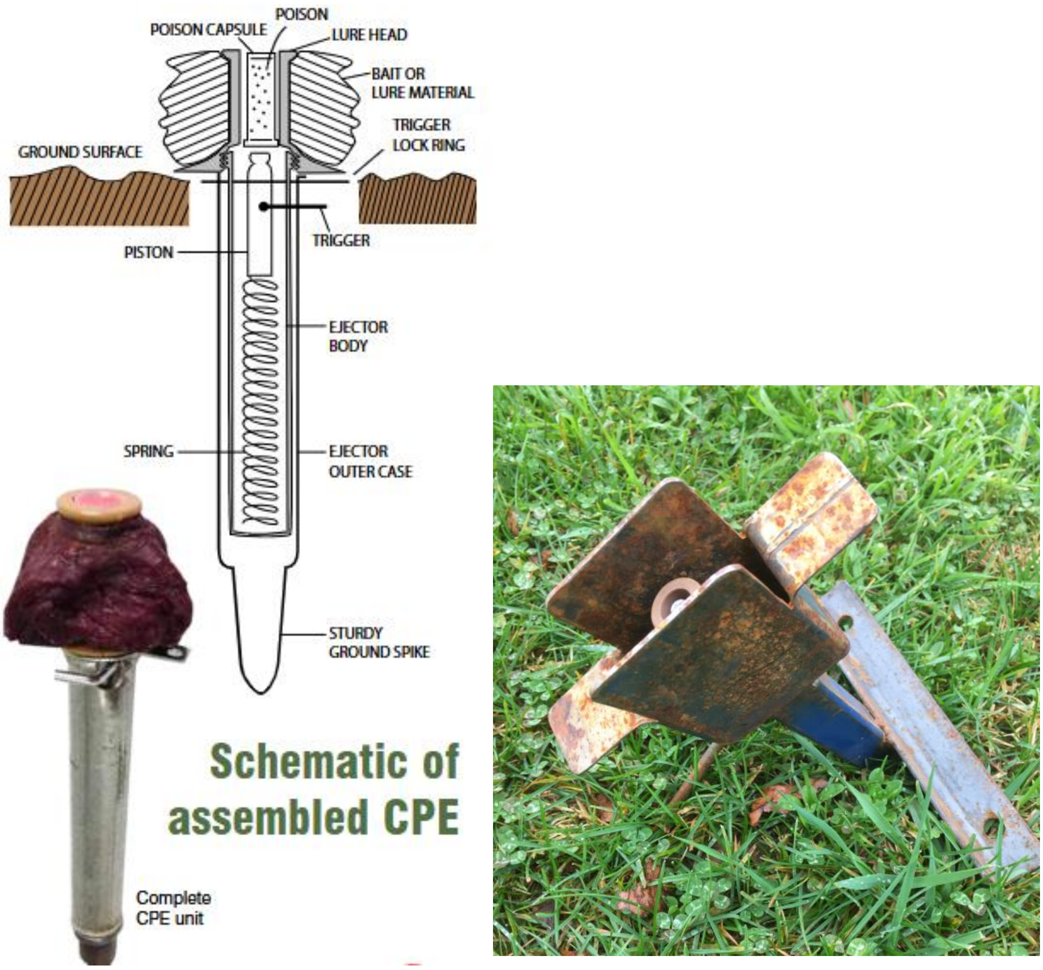

Figure 4. Canid Pest Ejector, a) from an ACTA brochure without a collar to restrict access by non-target species;https://static1.squarespace.com/static/5a5ebfbed74cff30017f4e32/t/5b04e0998a922da81bbffc6b/1527046315060/CPE+DL+Booklet-Email.compressed.pdf, and b) with a collar modification (image supplied by G. Malgaard (DEECA), design following (Young et al. 2024).

CPEs are a derivative of the M-44 device used in the United States for the control of foxes, Grey Foxes (*Urocyon cinereoagenteus*), Coyotes (*Canis latrans*) (Connolly and Simmons 1984) and Feral Dogs (*Canis familiaris*) (Connolly 1988). The devices have been researched in Australia for the control of foxes, using cyanide (Busana et al. 1998), 1080 (Marks et al. 1999; Marks et al. 2002, 2003) and PAPP (Allen 2019; Harriott et al. 2021; Kreplins et al. 2021; Marks et al. 2004). While CPEs have been used to manage Dingoes and Wild Dogs in other states, they have not yet been used in Victoria for that purpose.

There have been several trials assessing the effectiveness of CPEs to control foxes using either strychnine, 1080 or more recently PAPP. Field trials using either 1080 or strychnine have shown that CPEs can be an effective tool. Over a six-week period in the central highlands of Victoria, 160 foxes were removed, with the age of foxes recovered declining from summer to winter in each year and the ratio of yearlings to adults systematically increasing over time (Marks et al. 2003). On Phillip Island in Victoria, van Polanen Petel et al. (2004) compared catch per unit effort (number of foxes killed per 1000 person-hours) of M-44s with other control techniques (spotlight shooting [30 foxes 1000 person-hours], treadle snaring [15 foxes 1000 person hours] and hunting with fox hounds [12 foxes 1000 person-hours]) and found that ejectors (42 foxes 1000 person hours) could be a more time-effective control option.

Results from field research undertaken by Department of Environment, Climate Change and Water, NSW (DECCW) Pest Management Unit using unmodified devices confirmed the effectiveness of the (CPEs (M-44 ejector device) for the reduction of foxes across seven study sites. Monitoring of 98,299 lethal ejector nights across seven sampling periods between 2005 and 2010 identified consistent reductions in sand-plot activity for foxes of up to 93%, with an average reduction of 78% across all sites (Hunt 2010).

CPEs have several advantages over baiting, including target specificity. Capsules containing 1080 or PAPP are sealed and protected from the elements. This allows 1080 solution to remain viable for extended periods in the field. CPEs can be set and left in the field for extended periods and remain lethal until activated. The limiting factor for long-term field sets is the longevity of the attractiveness of the lure head. Once the ejector head is no longer attractive the ejector is far less likely to be triggered so considered. CPEs are difficult to move, unlike buried baits that can be moved and cached (Thomson and Kok 2002; Van Polanen Petel et al. 2001). In some instances, foxes have been known to dig out and remove untriggered ejectors. However, as 1080 has an extended period before the onset of symptoms, foxes may stay and dig at a site even after activating an ejector. Non-target issues have been described in Section 13.5.

10.2 PAPP baits

PAPP was registered for fox control in Australia in 2016 and is currently available in the commercially produced bait, FOXECUTE. As PAPP has been incorporated into an existing bait product, limited literature addresses the efficacy of baiting foxes. Much of the research instead focuses on the mode of action, toxicity levels in both target and non-target species, humaneness, and environmental impact (Eason et al. 2014; Marks et al. 2004:20; Marks and Trought 2023; Shapiro et al. 2010).

The trial data submitted to the Australian Pesticides and Veterinary Medicines Authority (APVMA) in 2015 to support the registration of FOXECUTE included seven pen trials and three field trials (APVMA 2015). The pen trials were conducted to develop the baits, including determining the appropriate dose of PAPP to effectively kill foxes and the optimal way to disperse PAPP within the bait. An optimal dose of 400 mg per 35 g of FOXECUTE was selected, and proof of concept was established, with all test foxes succumbing to the 400 mg dose. Three field trials demonstrated the efficacy of FOXECUTE using indices correlated with population size. One trial conducted near Phillip Island in Victoria showed a reduction of more than 80% in fox activity following baiting. A second trial at Werribee showed a 65% decline in a large fox population. A third trial near Dubbo, NSW across a large study area, recorded a reduction of over 70% (APVMA 2015).

We found no other literature assessing the efficacy of FOXECUTE under operational field conditions, including pre- and post-control population densities or counterfactual scenarios.

Results from a 2024 survey of ACUP users indicated that public land managers are more likely to replace 1080 with PAPP (54%), while pest controllers and contractors are more inclined to choose PAPP (66%). In contrast, commercial farm owners, employees, and hobby farmers tended to select other tools as the main alternative to 1080 (Quantum Market Research 2024).

10.3 Shooting

Shooting has been used as a method of hunting and controlling fox populations in Australia since foxes became a recognised pest. By 1893, the shires of Euroa, Benalla, and Shepparton had introduced a bounty scheme for fox heads (Saunders et al. 1995). In Victoria, a survey of ACUP users revealed that while 1080 is the primary control method for most land managers, shooting is still regarded as the main tool by 47% of respondents, with 87% having used it in the past five years (Quantum Market Research 2024).

Although shooting is considered a selective and humane control method (Sharp and Saunders 2011), many Australian studies have shown it to be ineffective for long-term fox population management. Shooting operations are often uncoordinated, and conducted at small spatial and temporal scales, which leads to rapid recolonisation and minimal long-term impacts on population densities (Harding et al. 2001; Newsome et al. 2014). Furthermore, such operations tend to target younger individuals and may inadvertently cause an increase in breeding by survivors, higher immigration rates, and reduced dispersal (Caughley 1977; Coman 1988; Fairbridge and Marks 2005; Fleming 1997; Harding et al. 2001; Hone 1999; McLeod et al. 2007). For example, during the 2002 Victorian Fox Bounty Trial, which culled 150,822 foxes statewide, the lack of landscape- or region-wide coordination meant that the scheme resulted in only a temporary and marginal reduction in local fox populations (Fairbridge and Marks 2005).

In contrast, McLeod et al. (2011) evaluated a coordinated fox shooting operation conducted by professional shooters over five years on private land. The study showed a significant reduction in fox populations across two areas, with marked reductions in pre- and post-control counts each year. These results indicate that coordinated shooting can achieve lasting impacts on fox populations. However, the trial did not assess the relationship between the population reduction and the damage caused by fox predation.

Intensive shooting during the lambing season may provide short-term protection against predation, similar to the protection offered by baiting. However, unless shooting costs are subsidised, for instance, by involving recreational hunters rather than paying professional shooters, baiting is likely to remain the more cost-effective option (Saunders and McLeod 2007). Detailed economic analyses would be required to confirm this.

Fox hunting for conservation purposes has also been promoted in Australia. However, studies to date have only reported the number of foxes shot as evidence of effectiveness, with no research linking fox shooting to measurable environmental recovery (Mcleod et al.2008).

10.4 Trapping

In Victoria, the two trap types authorised for use are padded leghold and cage-style traps. Padded leghold traps feature offset jaws with rubber-like inserts designed to cushion the impact on the animal’s limb (Fleming et al. 1998). Cage traps are typically box-style traps made from wire mesh, which close when an animal enters (Figure 5).

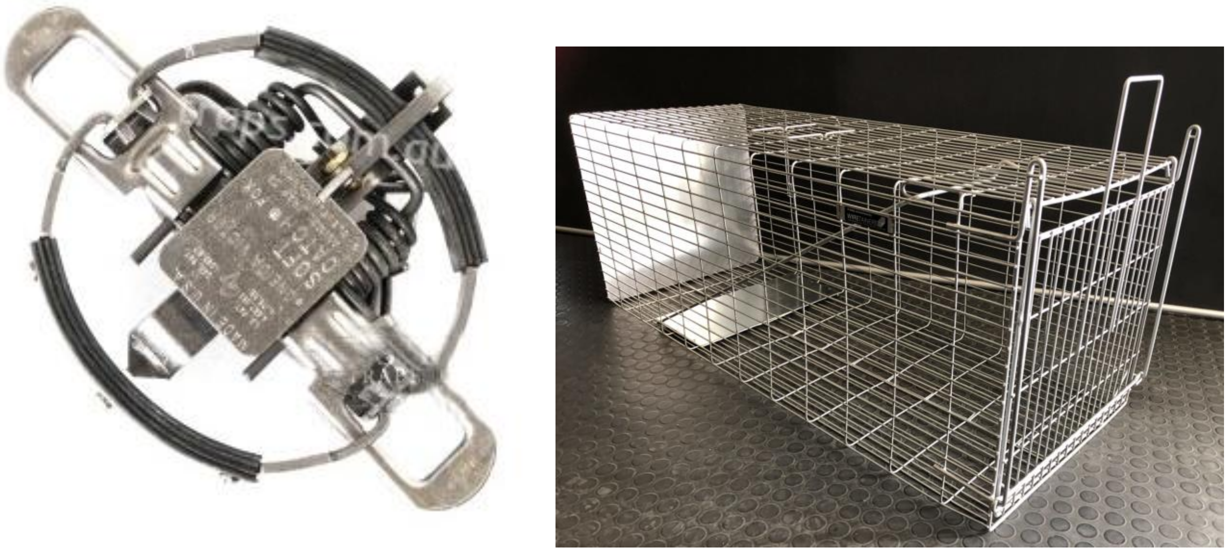

Figure 5. Padded leghold (Victor Soft Catch Trap® 1.5) and cage-style traps used to capture foxes.

Despite the widespread use of padded leghold and cage-style traps (Saunders et al. 1995), there is limited published research on their effectiveness. Trapping is a labour-intensive and skilled activity, and the need to check traps daily for animal welfare reasons makes it an inefficient method for large-scale control (Gentle 2006; Saunders and McLeod 2007). Consequently, trapping is generally reserved for research purposes or situations where other methods are unsuitable or ineffective (Fleming et al. 1998). A recent survey of ACUP users in Victoria revealed that only 1% of respondents would consider trapping as their primary method if 1080 were no longer available, and 13% of land managers had used trapping in the past five years (Quantum Market Research 2024).

Studies that have assessed the efficiency of fox trapping (Bubela et al. 1998; Fleming et al. 1998; Meek et al. 1995), did not directly correlate trapping success with fox abundance. Fleming et al. (1998) reported an overall trapping efficiency of one target animal per 41 trap-nights using Victor Soft Catch® traps. This figure was derived from data collected across seven different sites, including captures of Red Foxes, Wild Dogs, Dingoes, and feral cats. In one study, over a continuous seven-month period, approximately 14,000 trap-nights resulted in a capture rate of one fox per 150 trap-nights (McIlroy 1994). Meek et al. (1995) achieved a capture efficiency of one fox per 36 trap-nights at Jervis Bay in New South Wales, where fox densities typically range from 2–3 km^2. Kay et al. (2000) reported trapping efficiencies ranging from one fox per 63 trap-nights to one per 320 trap-nights. In a study investigating fertility control, trapping foxes with Victor Soft Catch traps over three years resulted in a capture rate of one fox per 129 trap-nights (Saunders et al. 2002). Additionally, a study examining fox home ranges in northern Victoria captured 20 foxes (eight adult males, three adult females, three subadult males, two subadult females, and two cubs of each sex) over 2,516 trap-nights, yielding a rate of one fox per 11.7 trap-nights (Carter et al. 2012). Two foxes were euthanised due to trap-related injuries (fractured metacarpus). No studies were found that reported on the effectiveness of cage trapping for foxes in Australia.

Several factors can influence trapping efficiency, including the trapper's experience, trap type, and the use of lures. Kay et al. (2000) found that fox density strongly affects trapping success, particularly in the aftermath of a drought. Trapping efficiency declines exponentially as fox density decreases, making it highly inefficient at very low densities. Several Australian studies have reported that the sex ratio of trapped foxes is generally close to 1:1 (Bubela et al. 1998; Marlow 1992; Meek 1998). However, Kay et al. (2000) found a biased sex ratio, with more males than females being trapped (1:0.67), in contrast to those shot, where the ratio was 1:0.96.

10.5 Den fumigation

Historically, substances such as chloropicrin and phosphine were used to fumigate fox dens. However, in Victoria, only carbon monoxide (Den-co-Fume®, Animal Control Technologies) is registered for use as a fumigant (Gentle 2006). Fumigation of breeding or natal dens with carbon monoxide gas is occasionally used to eliminate young cubs, although it can also kill adult foxes. Carbon monoxide is a colourless, odourless gas that causes oxygen depletion, leading to unconsciousness and rapid, painless death without noticeable discomfort (Hart et al. 1996). Den fumigation with CO reduced fox cub activity by 80% compared to dens that were closed but not fumigated (KTRI 1995). However, this method is not effective as a general, large-scale fox control strategy (Sharp 2012d).

Fumigating fox dens is a challenging and labour-intensive task, primarily due to the difficulty of locating the dens (Carter et al. 2012; Hart et al. 1996). Dens are typically used only during the whelping and cub-rearing period (usually from early spring to summer), limiting the window for effective fumigation to this timeframe (Saunders et al. 1995, 2010). A recent survey of ACUP users found that only 12% of respondents would consider fumigation if 1080 were no longer available, and just 1% regarded it as the primary tool for fox control (Quantum Market Research 2024).

Building a den requires considerable energy, which is why many dens are reused in successive breeding seasons. If dens are not subsequently destroyed, fumigation will allow them to be recolonised in the next breeding season. If machinery can access the dens, deep ripping may be employed to destroy them. Dens can also be collapsed using explosives, filled with soil, or blocked with rocks or wire mesh to prevent re-entry.

10.6 Cost-effectiveness

10.6.1 Ground baiting (1080 and PAPP) and CPEs

Gentle (2005), using the cost per bait consumed by foxes or per lethal bait presented, found that fresh meat baits (e.g. chicken wings, day-old chicks) were more cost-effective for short campaigns (up to four weeks) than manufactured baits (FOXOFF), due to their higher palatability, despite having a shorter longevity. He concluded that maximising cost-efficiency depends on using highly palatable baits, although practical considerations, such as bait storage, also play a role.

Newsome et al. (2014) investigated the relative cost-effectiveness of baiting and shooting for fox control. They estimated the density of foxes on an agricultural study property in south-east New South Wales using distance sampling and rates of bait uptake before and after a control programme. Using the estimated costs associated with the control programme, they calculated a kill-per-unit-effort value, which was then compared to the costs of baiting from (Gentle 2005). A total of 66 hours were spent shooting, removing 47 foxes at a total cost of $2,440.71, equating to a kill-per-unit-effort value of $51.84 per fox. According to Gentle (2005), higher kill rates than those obtained during the shooting programme could be achieved, with bait uptake rates of 50% after a 28-day campaign using FOXOFF, at a cost of $2,071.51.

There are no studies comparing the cost-effectiveness of FOXOFF and FOXECUTE. In terms of the relative cost of each bait type, FOXECUTE baits are approximately 55% more expensive than FOXOFF (FOXOFF $1.35/bait, FOXECUTE $2.43/bait). However, the cost of bait is a relatively minor component of the total budget for the on-ground delivery of a fox programme. For instance, a large-scale fox control project in eastern Victoria costs around $1 million annually to deliver, covering salaries, vehicles, and labour for all aspects of the project. The cost of FOXOFF for delivering nine rounds of baiting across 3,500 bait stations is approximately $50.5K, or about 5% of the total budget. Replacing FOXOFF with FOXECUTE would increase the cost to roughly $78K, or 8% of the overall project delivery budget, a 3% increase. Since PAPP baits are as effective as FOXOFF at reducing fox populations (65–80% reductions in abundance) and the relative cost difference is marginal, the main distinction lies in the non-target and animal welfare impacts (Section's 1 and 15).

CPEs are more target-specific, can be effective at managing fox populations (Marks et al. 2003; van Polanen Petel et al. 2004), and can reduce or eliminate caching of toxic bait. However, no studies have compared the relative cost-effectiveness of CPEs and baiting, either with FOXOFF or FOXECUTE. Using a landscape-scale fox control operation in south-west Victoria as an example, we estimated the relative costs of using 1080 and PAPP baits and replacing baits with CPEs.

Three locations are baited continuously, with baits checked and replaced fortnightly. The number of bait stations at each location is 45, 242, and 82. Using costs for labour, vehicles, and baits ($1.90 per FOXOFF, $2.95 per FOXECUTE), along with the cost of replacing the lure and 1080 capsule for a CPE ($5.50), we estimated the cost to deliver the programme using each tool (Table 7). Individual CPEs cost approximately $63.00 without the collar modification (which reduces the likelihood of Dingoes activating the CPE), and $120.00 with the collar modification.

Using an individually-based spatially explicit population model (Hradsky et al. 2019), the fox control operation for location 1 in Table 7 was modelled. The predicted reduction in the fox population was 73%, from a pre-control density of approximately 2 foxes per km² to about 0.54 foxes per km². Assuming the same rate of reduction for all three methods and 1092 bait nights and 714 CPE nights, the kill-per-unit-effort value would be $12.55 for FOXOFF, $13.67 for FOXECUTE, and $21.98 for CPE.

Table 7. Relative costs of implementing a fox control operation using FOXOFF, FOXECUTE and CPEs across three locations in southwest Victoria.

Locations	Size (km^2)	FOXOFF	FOXECUTE	% change from FOXOFF	CPE*	% change from FOXOFF
Location 1	47	$13,708.24	$14,930.89	8%	$15,692.74	13%
Location 2	330	$51,495.60	$58,070.74	11%	$62,167.80	17%
Location 3	89	$15,095.60	$17,323.54	13%	$18,711.80	19%

* Based on CPE checking and replacement every three weeks. Cost could be reduced further if checking and replacement was every four weeks.

10.6.2 Aerial baiting

Aerial baiting has been used successfully in Western Australia but is not currently permitted for fox control in Victoria. Nonetheless, it could also enhance cost-effectiveness in eastern Australia but faces several challenges. In higher rainfall areas, where bait decomposes quickly, maintaining lethal bait through frequent replacement or increased density may be necessary. Additionally, native animals in eastern Australia, that are generally less tolerant of 1080 toxin than those in the west, may face higher non-target risks (see Section 13.1.3). While studies have not found significant population-level impacts on non-target species, aerial baiting's surface presentation of baits could elevate this risk (Allen et al. 1989; Glen et al. 2007). Further, regulatory and logistical challenges due to fragmented landscapes and denser human populations in eastern Australia complicate aerial baiting implementation (McIlroy and Saunders 1998; Saunders and McLeod 2007). Although, aerial baiting has been delivered to manage livestock loss and targeting Dingoes and Wild Dogs in restricted locations in Victoria using dried meat baits containing 6 mg of 1080.

10.6.3 Ground-based shooting

Shooting has often been dismissed as an ineffective population control tool, primarily because it is generally too inefficient to achieve meaningful population reductions. Published examples of kills per unit effort (without reported costs) for foxes in eastern Australia range from 0.24 foxes per hour (Coman 1992) to 0.78 foxes per hour (Fleming 1997; Newsome et al. 2014). With sufficient repeated and organised effort, shooting was able to reduce fox populations in agricultural landscapes in New South Wales over four years. In this instance, the cost per fox shot ranged from $43.00–$132.00, and the kills per unit effort ranged from 0.14–0.88 foxes per hour, with the cost per kill decreasing as the number of foxes shot per hour increased (McLeod, pers. comm.). This suggests that, similarly to that for Feral Pigs, the efficiency of shooting declines as the density of the target species decreases (Choquenot et al. 1999). In Victoria, kill rates per unit effort have been reported as ranging between 0.2 and 0.6 foxes per hour, with the cost (total contract cost) per fox shot varying between $382.00 and $1,245.00 (Mike McStephen, Ruby Wicks, pers. comm.).

Spotlight shooting is limited to areas with good visibility and vehicle access, although recent advances in the use of thermal technologies has improved efficacy. Newsome et al. (2014) and Saunders and McLeod (2007) found that spotlight shooting for fox control was likely to be more costly and less effective than poison baiting, although no economic analyses comparing shooting and other methods have been conducted.

Recreational hunting of foxes for conservation purposes has also been promoted in Australia. However, only the number of foxes shot is presented as evidence of effectiveness; no study has yet linked the shooting of foxes to environmental recovery, nor has any study assessed its cost-effectiveness in the scientific literature (Mcleod et al. 2008; Saunders et al. 2010).

10.6.4 Trapping and den fumigation

We did not discover any data on the cost-effectiveness or relative costs of trapping or den fumigation, or any data on combining these methods with baiting or shooting for managing foxes.

Table 8 compares the reported cost-effectiveness, non-target impacts, and the advantages and disadvantages of the various lethal control methods used to manage foxes.

Table 8. Summary of cost-effectiveness, target specificity, and advantages and disadvantages of lethal fox control methods used in Victoria. Adapted from the State and National Codes of Practices and updated using outcomes from the literature review.

Control technique	Cost-effectiveness	Target specificity and non-target impacts	Advantages	Disadvantages
Ground baiting with 1080	Cost-effective	There is a risk of poisoning non-target animals. Strategic ground baiting, where baits are buried, reduces risk to non-target species. Uneaten baits can be collected and destroyed.	Currently the most cost-effective technique available.	1080 ingestion can also kill non-target animals including native species, cats, dogs and livestock. 1080 is toxic to humans; operators need to take precautions to safeguard against exposure.
Ground baiting with PAPP	Cost-effective	There is a risk of poisoning non-target animals. Strategic ground baiting, where baits are buried reduces risk to non-target species. Uneaten baits can be collected and destroyed. Some species are more susceptible to PAPP, e.g., quolls, southern brown bandicoot, varanids, while others are less susceptible compared to 1080, e.g., brush-tailed possums, some bird species	Currently the most humane technique available. Antidote available but needs to be administered within 20 minutes.	PAPP ingestion can also kill non-target animals including native species, cats, dogs and livestock. PAPP is toxic to humans; operators need to take precautions to safeguard against exposure.
Cand Pest Ejector (1080/PAPP)	Can be cost-effective in certain situations	Target specific, particularly when used with collar to restrict Dingo access	Unspent capsules can be collected and destroyed. Can be used with either 1080, or PAPP. Requires relatively little time to establish. Can be deployed for longer periods than baits.	Slightly more expensive than baiting. 1080 is toxic to humans; operators need to take precautions to safeguard against exposure. Requires a moderate level of technical ability and local knowledge.
Ground shooting	Generally, not cost-effective, can be if coordinated and repeated	Target specific. No non-target impacts.	Target specific Can be effective if well-coordinated	Labour intensive, only suitable for smaller-scale operations.

Den fumigation using carbon monoxide	Not cost-effective. Can be cost-effective in some situations.	Target specific. Need to take steps to ensure dens are not occupied by native species.	Useful for localised control, where baiting and shooting are not feasible	Not effective for broadscale control. CO is toxic to humans; operators need to take precautions.
Trapping (soft jaw foot hold traps)	Generally, not cost-effective. Can be cost-effective in some situations.	May catch non-target animals.	Important control technique in areas where baiting or aerial shooting is not possible.	Not practical for large-scale control.

11 Lethal methods for managing Dingoes and Wild Dogs

11.1 1080

Baiting with 1080 to manage Dingoes and Wild Dogs is widely used across Australia (Fleming et al. 2001; Philip 2021; Reddiex et al. 2006) and Victoria and is generally the most practical and effective means of reducing the impacts on animal agriculture over large areas (Fleming et al. 2001, 2014). Table 9 compares the reported percentage reduction in Dingo and Wild Dogs achieved using the various control methods used in Victoria.

Unlike the other three pest species, the aim is not to drive populations to very low levels, but to reduce the rate of attack on livestock. To help facilitate this, the management of Dingoes and Wild Dogs in Victoria is restricted to areas of eastern Victoria within a 3-km zone bordering private and public land with the objective of protecting livestock and livestock production. In Victoria, 42% of respondents in a survey of 1080- and PAPP-endorsed ACUP holders reported using 1080 baiting as the primary control tool to control Dingoes and Wild Dogs, and 91% (n=203) of those that used it in the last 5 years, had done so in conjunction with other control methods (Quantum Market Research 2024).

There are four types of 1080 baits registered for the control of Wild Dogs in Victoria. Three of them are shelf stable bait manufactured meat bait (DOGGONE®, ACTA 1080 Dried Meat Wild Dog Bait and De-K9 1080 Wild Dog bait). The fourth type is a fresh meat bait injected with aqueous 1080 solution and prepared and supplied by licenced manufacturers under an APVMA permit.

In Victoria, 1080 baits can be deployed either as ground laid, buried baits or deployed by air (fresh meat bait) in certain, restricted locations by Government land managers under a permit issued by Agriculture Victoria.

11.1.1 Ground-based baiting

The results of ground-based bating operations for the control of Dingo and Wild Dogs have been reported in several research papers to have variable effectiveness at reducing abundance. After a ground-based baiting campaign with small meat baits containing 20 mg of 1080 in central Australia, Best et al. (1974) achieved a 69% reduction in Dingo sign. Their programme was assessed by counting Dingo tracks around waterholes before and after baiting. A study by Bird (1994) in the arid zone of South Australia used a single placement of 430 baits to achieve a reduction of 10–13% of 300–400 Dingoes that were watering at a single bore. In two trails conducted in Kosciusko National Park, NSW with a single application of fresh meat bait, 22% of radio-collared Dingoes (n = 9) were killed (McIlroy et al. 1986). In contrast, a bating programme using replacement baiting (baits removed were replaced each day) resulted in a mean reduction in abundance of 76.1% (Fleming 1996). In a trial in eastern Victoria at two sites, a combination of camera traps and trapping to attach tracking collars provided an estimate of the known population of Wild Dogs at each site. Poison baiting using standard operating procedures (SOPs) at both sites for seven weeks with predator meat baits containing 4.5 mg of 1080 killed 70% and 11% of the known population at each site (Robley 2008).

The main factors that reduce the success of a poisoning campaign are the rapid loss of toxicity of the baits after their distribution, the rapid rate at which they are removed by other animals (particularly foxes and birds), and Dingo and Wild Dogs' apparent preference for natural prey (McIlroy et al. 1986). In a study in Western Australia, Kreplins et al. (2018) monitored 337 baits. Young Wild Dogs (<8 months old) removed only four. In warmer months, baits were largely consumed by varanids, and in cooler months, when baits were taken it was predominantly by corvids.

11.1.2 Aerial baiting

In Victoria, aerial baiting for the control of Wild Dogs was first undertaken in 1953 in Gippsland and continued intermittently until 1969 (Corbett 1974). More recently, aerial baiting for Wild Dog control was designated a controlled action under the EPBC Act. Following an application that included ground monitoring data and information on the presence of Spot-tailed Quolls (*Dasyurus maculatus*) in baiting areas, the Australian Government granted conditional approval in 2014 to conduct aerial baiting at six remote sites in Gippsland and Northeast Victoria. The sites were selected following community consultation because they were,

- inaccessible to conventional control methods
- are known pathways for canids
- have proximity to private land where impacts on livestock and livestock production have been reported.

This and a subsequent approval allowed baiting operations to continue until 31st December 2024. At the time of writing this report, no decisions were made on its future use. Aerial baiting in Victoria has been conducted biannually, in autumn and spring, across six areas. Each operation has been taking place over two days per season, with baits laid at an approximate rate of 10 baits per linear kilometre, while not exceeding one bait per 10 hectares.

Most studies on aerial baiting have reported wild canid population reductions exceeding 80% shortly after baiting (Burrows et al. 2003; Fleming et al. 1996; Thomson 1986; Thomson et al. 2000). In trials comparing the effectiveness of two baiting rates, Fleming and Ballard (2014) and Ballard et al. (2020) found that using 10 baits per km resulted in a 55.3% mortality rate among collared dogs (n = 38), while increasing the rate to 40 baits per km led to a 90.6% mortality rate (n = 32). In east Gippsland, Victoria, a study assessed the effectiveness of aerial baiting by deploying baits at 10 baits per linear kilometre, using 250 g meat baits injected with 6 mg/kg of 1080. The results showed a 27% decrease in abundance following the baiting, with numbers dropping from 48 to 36, and density declining from 0.026 to 0.019 dogs per km² (Robley et al. 2018). In comparison, Ramsey (2018) showed that properties within 0.5 km of an aerial baiting transect had an expected relative reduction in the incident of livestock attacks of 79% (95% CI, 0.31–0.94) in the following quarter. This reduced to a 10% (95% CI, 0.03–0.18) reduction for properties located 5 km from the nearest aerial baiting transect. Although, estimates could have been potentially affected by unmeasured effects of on-farm stock related management causing bias in the estimated effects.

The published studies on long-term efficacy of aerial baiting suggest that aerial baiting can achieve sustained reductions in wild canid populations or their impacts, when conducted over large areas (Burrows et al. 2003; Thomson et al. 2000) or when applied frequently to counter dispersal and recruitment (Fleming et al. 1996; Moseby and Hill 2011; Priddel and Wheeler 1997).

Intrinsic factors that are considered critical to the success of aerial baiting include the type of bait used (Allen et al. 1989), the longevity of the toxin within the baits (Allen et al. 1989; Fleming and Parker 1991; Twigg et al. 2000), and the patterns and densities of bait distribution in relation to the dispersion and density of the target population (Thomson 1986; Thomson and Marsack, 1992;Thomson et al. 2000). Key extrinsic factors likely include the availability of alternative food sources, the age and social structure of the target population, rainfall immediately following baiting, and the degree of bait uptake by non-target species (Allen et al. 1989; Fleming 1996; Thomson 1986; Thomson et al. 2000).

11.2 PAPP (DOGABAIT/CPEs)

PAPP was registered for use against Wild Dogs and foxes in Australia in 2016. It is currently available in branded products such as DOGABAIT® and FOXECUTE and in capsules used in CPEs.

We discovered no studies assessing the effectiveness of PAPP bait for controlling Dingoes and Wild Dogs in Australia, as measured by population reduction or a reduction in some relative index of abundance. While literature searches did not return papers directly addressing the efficacy of DOGGONE® baits, a few studies have explored PAPP use in CPEs. In a Queensland trial, Allen (2019) found that 10 out of 11 (91%) Wild Dogs died within 3 hours after PAPP was administered via CPEs. In comparison, (Kreplins et al. 2021) investigated the effectiveness of CPEs to reduce Dingo populations in the southern rangelands of WA and reported reductions in density ranging between 5% and 46% (Table 9).

Other studies have focused on the longevity of PAPP in baits. For example, Gentle et al. (2017) found that PAPP in buried Wild Dog baits declined more rapidly than in surface-laid baits under typical field conditions in northeastern Australia, although both types retained lethal doses for Dingoes, Wild Dogs, and domestic dogs for 6–16 weeks.

Despite the advantages of PAPP in terms of humaneness, it is still not widely used in Victoria. Its higher cost per bait likely contributes to its limited uptake by land managers. A recent survey of ACUP users in Victoria revealed that 32% of respondents would consider using PAPP if 1080 were unavailable, while only 9% had used it in the past five years (Quantum Market Research 2024). Southwell et al. (2013) surveyed both public and private land managers to gauge their perceptions of wild canid management and identify the social factors influencing the adoption of PAPP. They found that decisions to adopt PAPP were not solely based on its benefits compared to 1080. Factors such as beliefs about the role of wild canids in the ecosystem, neighbour participation, and the coordination of management efforts also played a significant role.

11.3 Trapping

In Victoria, trapping of Dingoes and Wild Dogs is a key component of an integrated management programme aimed at mitigating their impact on livestock. Trapping is also used in situations where poison baiting proves less efficient, such as in or around lambing paddocks where food is abundant, or where other methods, like shooting, cannot be used due to proximity to peri-urban or urban areas. Additionally, trapping serves as a follow-up measure after 1080 baiting programmes, though it is considered an inefficient approach for general population control (Sharp 2012e). In recent years, the humaneness of leghold traps has garnered increasing attention from animal welfare groups and anti-trapping advocates, driven by growing societal concerns about the welfare of trapped animals (Allen et al. 2022) (see Section 15). In Victoria, the use of trap alert systems (which send text messages altering operators of a trap closer) have decreased response times.

A recent survey of ACUP users in Victoria revealed that 23% use trapping as their primary control method, while 51% have employed it within the last five years. Public land managers were more likely to use trapping (67%) than commercial or hobby farmers (Quantum Market Research 2024).

Although leghold traps have been used to control Dingoes and Wild Dogs in Australia since the introduction of Sheep by European settlers (Fleming et al. 1988; Harden and Robertshaw 2014), there is limited published research on the efficacy of trapping (but see notable studies by Meek et al. 1995; Newsome et al. 1983, and Pacioni et al. 2021), and even less research as it relates to a reduction in the population.

Capture efficacy (CE) is typically defined as the number of target animals captured per 100 trap-nights. Fleming et al. (1988) analysed data from nine sites across Australia, seven of which used leghold traps to target Wild Dogs. They reported a CE of 2.45 for padded Lane's traps and 2.11 for Victor Soft® Catch traps. McIlroy et al. (1986) used modified Oneida leghold traps to capture Wild Dogs in southeastern Australia, achieving a CE of 1.56 (TN = 896) and a 56% reduction in the population. Newsome et al. (1983) reported a CE of 1.72 using Oneida traps (TN = 2692) (Table 9). Estimates of trapping efficacy can vary depending on factors such as the trapper's experience, target animal population density, non-target animal density, prior exposure of the target species to trapping, the sex and age distribution of the target population, and seasonal and site conditions (Fleming et al. 1988). In a study on trapping Dingoes and Wild Dogs in Victoria, Pacioni et al. (2021) found that the mean probability of trapping an individual dog was 8–10% with 15 traps or 15–20% with 30 traps over 28 days.

Confinement traps (cage traps) are not used to manage Dingoes or Wild Dogs in Victoria.

11.4 Shooting

We found no studies investigating the efficacy of shooting as a control tool for reducing the abundance of Dingo or Wild Dog populations. In Victoria, shooting is employed as a supplementary measure within an integrated strategy to mitigate their impact on livestock. Unlike ground-based shooting for foxes—which can be effective when conducted by professional shooters across multiple properties in a coordinated effort (McLeod et al. 2011)—the shooting of Dingoes and Wild Dogs is typically ad hoc. It is often carried out by individual farmers or in response to reported incidents, with government trappers targeting animals sighted on affected properties.

In a recent survey of ACUP users in Victoria, 26% of respondents identified shooting as their primary control method, while 76% reported using shooting within the past five years. Hobby farmers were more likely to employ shooting (44%) than public or commercial land managers (Quantum Market Research 2024).

A bounty system for Wild Dogs operated in Victoria between 2011 and October 2024, during which 5,413 Wild Dog body parts were submitted. However, it is widely acknowledged that bounty systems are ineffective for large-scale pest animal management (Hassal and Associates P/L 1998).

11.5 Cost-effectiveness

We found very limited information in the literature regarding the cost-effectiveness of Dingo and Wild Dog control in Victoria, or more broadly in Australia. While several studies report the effectiveness of various methods at reducing abundance, few address the associated costs (e.g. Thompson and Fleming 1991), and none compare the cost-effectiveness of combinations of different methods. A few studies have assessed the cost-benefits of reducing livestock losses (Lightfoot 2010; Wicks et al. 2014). Some studies report the costs of conducting operations but do not relate these costs to achieving specific management objectives, such as reducing the population by a certain amount or to a specified level or reducing stock loss or increasing productivity. Table 10 compares the efficacy, non-target impacts, and the advantages and disadvantages of methods used to manage Dingoes and Wild Dogs in Victoria.

Wicks et al. (2014) assessed the cost-benefit of Wild Dog control for beef and lamb enterprises in southwest Queensland. The estimated returns, in 2014 net present value terms, from each dollar invested in Wild Dog control in southwestern Queensland ranged from –$0.14 to $3.11, depending on the rate of livestock deaths in the absence of control. With 2% and 5% growth in attack rates, the returns from Wild Dog control were less than the cost of investment in controls. However, when attack rates were assumed to grow by 10% or more without control, the benefits of control outweighed the costs, with a benefit–cost ratio greater than one. When the growth in Wild Dog attack rates in the absence of control was assumed to be 10%, the expected benefits of control only just outweighed the estimated costs. For the control to generate net economic returns in this scenario, its effectiveness would need to exceed 99%. If the growth in Wild Dog attack rates was assumed to be 20%, the expected benefits of Wild Dog control were significantly higher than the costs.

Table 9. Comparisons of reported changes in Dingo and Wild Dog abundance using different lethal control methods in Australia.

Method	Percentage reduction	Region	Method used to measure change in abundance	Reference
1080 baiting (ground-based)	10–13	Arid region SA	Activity index at water points	Bird, 1994
	22–44	Yarrangobilly Village, NSW	Proportion of radio collared animals killed	McIlroy et al. 1986
	76	NSW	Pre- and post-baiting bait take indices	Fleming 1996
	50–70	Finke Gorge National Park, NT	Pre- and post-baiting track-based index	Twigg et al. 2000
	Significant reduction reported	Four locations in NT	Activity index at water points	Eldridge et al. 2000
	11–70	Eastern Vic	Camera trap index and radio collared individuals	Robley et al. 2008
	54 (9–100)	12 baiting programmes in QLD	Passive tracking index before and after bating	Allen 2015
	33–76	Southern NT	Track-based index before and after with paired treatment/non/treatment sites	Edwards et al. 2021
	-4 – +204	Two properties in the Murchison River region, WA	Change in density estimates pre- and post-baiting	Kennedy et al. 2021
Aerial baiting (1080)	55	Southern NSW (10 baits km^{-1})	Mortality rate collared individuals	Fleming and Ballard 2014
	27	Eastern Victoria (10 baits km^{-1})	Pre- and post-baiting density estimates	Robley et al. 2018
	91	Southern NSW (40 baits km-1	Mortality rate collared individuals	Ballard 2020
CPE (PAPP)	91	Strzelecki Desert of north-eastern South Australia	Number of observed mortalities of captured individuals	Allen 2019
	5–46	Southern rangelands WA	Change in density estimates pre- and post-baiting	Kreplins et al. 2021
Trapping (leghold traps)	56	Southeastern Australia		McIlroy et al. 1986

Method	Percentage reduction	Region	Method used to measure change in abundance	Reference
	2.11	Southeastern Australia	Capture efficiency (no. of target animals captured per 100 trap-nights)	Fleming et al. 1988
	1.72		Capture efficiency (no. of target animals captured per 100 trap-nights)	Newsome et al. 1983
Shooting	We found no studies reporting changes in abundance from shooting			

Table 10. Summary of efficacy, cost-effectiveness, target specificity, and advantages and disadvantages of lethal control methods for Dingoes and Wild Dogs used in Victoria. Adapted from the State and National Codes of Practices and updated using outcomes from the literature review.

Control technique	Cost-effectiveness	Target specificity and non-target impacts	Advantages	Disadvantages
Ground baiting with 1080	No literature assessing cost effectiveness. Probably cost-effective.	There is a risk of poisoning non-target animals. Strategic ground baiting, where baits are buried, reduces risk to non-target species. Uneaten baits can be collected and destroyed.	Currently the most cost-effective technique available. 1080.	Ingestion can also kill non-target animals including native species, cats, dogs and livestock. 1080 is toxic to humans; operators need to take precautions to safeguard against exposure.
Ground baiting with PAPP	No literature assessing cost effectiveness. Probably cost-effective.	There is a risk of poisoning non-target animals. Strategic ground baiting, where baits are buried, reduces risk to non-target species. Uneaten baits can be collected and destroyed. Some species are more susceptible to PAPP, e.g., quolls, southern brown bandicoot, varanids, while others are less susceptible compared to 1080, e.g., brush-tailed possums, some bird species	Currently the most humane poisoning technique available. Antidote is available but needs to be administered within 20 minutes.	PAPP ingestion can also kill non-target animals including native species, cats, dogs and livestock. PAPP is toxic to humans; operators need to take precautions to safeguard against exposure.
Canid pest ejector (1080/PAPP)	No literature assessing cost effectiveness. Probably cost-effective. Can be effective in certain situations.	Target specific.	Unspent capsules can be collected and destroyed. Can be used with either 1080, or PAPP. Requires relatively little time to establish. Can be deployed for longer periods than baits.	Slightly more expensive than baiting. 1080 is toxic to humans; operators need to take precautions to safeguard against exposure. Requires a moderate level of technical ability and local knowledge.
Aerial baiting (1080)	No literature assessing cost effectiveness. Probably cost-effective.	There is a risk of poisoning non-target animals.	Can be used cover lager areas	Ingestion can also kill non-target animals including native species, cats, dogs and livestock. 1080 is toxic to humans; operators need to take precautions to safeguard against exposure.

Control technique	Cost-effectiveness	Target specificity and non-target impacts	Advantages	Disadvantages
Ground shooting	No literature assessing cost effectiveness. Probably cost-effective Probably not cost-effective.	Target specific. No non-target impacts.	Is very target specific	Labour intensive, only suitable for smaller scale operations.
Trapping (padded foot-hold traps)	No literature assessing cost effectiveness. Probably cost-effective. Can be effective in certain situations.	May catch non-target animals. No non-target impacts.	Important control technique in areas where baiting or aerial shooting is not possible.	Not practical for large-scale control.

12 Non-lethal methods for managing European Rabbits, Feral Pigs, Red Foxes, and Dingoes and Wild Dogs

Concerns regarding the use of lethal control methods, including 1080, have spurred the development of non-lethal methods, including fertility control, fencing, repellents, diversionary feeding, and translocation (Massei et al. 2011). Several reviews have examined non-lethal alternatives for managing predators and their impacts on livestock in Australia (Boronyak and Jacobs 2023; Boronyak and Quartermain 2022; van Eeden et al. 2018a; van Eeden et al. 2018b; van Eeden et al. 2021). However, there has been limited research on non-lethal methods for managing rabbits and Feral Pigs.

Existing reviews primarily summarise surveys and interviews with land managers about alternative approaches and attitudes towards non-lethal controls, with minimal quantitative data on outcomes. For example, van Eeden et al. (2018a) reviewed 114 studies spanning over 40 years and found a lack of quantitative comparisons or experimental controls, limiting the ability to assess method effectiveness. Similar conclusions were drawn by Miller et al. (2016), Treveset al. 2016), and Eklund et al. (2017) in their reviews of predator control methods.

Out of the 114 studies reviewed by van Eeden et al. (2018a), only eight were conducted in Australia, focusing on Dingoes (seven studies) and foxes (one study). Four of these examined non-lethal methods: three on LGDs and one on deterrents. Khorozyan and Waltert (2019) analysed 117 cases from 23 countries, assessing 12 interventions for protecting human assets from predators. Their findings indicated that electric fences, guardian animals, calving control, and physical deterrents were the most effective. However, none of these studies were Australian.

Although studies such as Miller et al. (2016), Treves et al. (2016), Moreira-Arce et al. (2018) and Khorozyan and Waltert (2019) identified effective non-lethal methods (e.g. electric fences, guarding animals, protective collars, fladry tape), they highlighted significant methodological flaws, including the absence of treatment/non-treatment comparisons, replication, and randomisation.

The adoption of non-lethal methods by land managers remains complex, requiring evidence that they are as effective or superior to conventional lethal approaches. To highlight this point, the majority of all 1080 ACUP permit holders surveyed in Victoria (71%) disagreed that non-lethal control methods are a viable alternative to 1080 (Quantum Market Research 2024). In the same survey, respondents that had used 1080 in the past 5 years were asked to consider the effectiveness of pest control if 1080 were no longer available. Only 6% considered that rabbits could be effectively controlled, 12% for Feral Pigs, 3% for foxes and 3% for Dingoes and Wild Dogs.

Non-lethal methods often involve greater time and effort and may not always be practical. For example, loud sirens or bright lights can deter pests but may also disrupt livestock and livelihoods, making them unsuitable for widespread use. Additionally, some methods fail to align with traditional or cultural values. Remote farming operations face logistical challenges, such as the difficulty and expense of installing, maintaining, and replacing equipment. Furthermore, methods may not effectively target specific problem individuals, and certain repellents may work for one species but attract another. For example, using urine or recorded vocalisations to mimic territoriality might repel one sex while attracting the other, undermining their effectiveness.

Comprehensive reviews highlight the complexities of adopting a holistic, non-lethal approach to managing pest animals in agricultural contexts (Boronyak and Jacobs 2023; van Eeden et al. 2018a; Smith and Appleby 2018; Smith et al. 2021). These approaches typically fall into three broad categories:

1. **Livestock husbandry**: Examples include guardian animals and livestock collars.
2. **Enclosures**: Fencing remains a key non-lethal method.
3. **Predator deterrents**: Devices such as frightening systems can be adapted to local conditions, including livestock type, terrain, and wildlife presence.

Additional livestock management practices, such as rotational grazing, frequent movement of herds, closer supervision of vulnerable animals (e.g. lambing ewes), carcass disposal, and remotely activated warning systems, could complement these methods within an integrated pest management strategy. While these are beyond the scope of this review, they are recognised as valuable components (Boronyak and Jacobs 2023; Smith et al. 2021).

Although non-lethal tools are primarily developed to protect agricultural values, pest species like rabbits, feral pigs, and predators also impact biodiversity conservation. Non-lethal methods for biodiversity conservation rely mainly on fencing and potential fertility control. However, no viable fertility control options currently exist for these species, leaving fencing as the main non-lethal method for mitigating their impact on biodiversity. However, LGD's have been used to protect Eastern Barred Bandicoots on a small offshore island that is periodically connected to the mainland (Richard Hill, DEECA, pers comm.).

Table 11 compares the effectiveness, target specificity and advantages and disadvantages of 1080 with the various non-lethal control options available for the management of the four pest species in Victoria.

12.1 Livestock guardian animals

In general, LGAs are classed as a form of 'non-lethal' predator control, thereby facilitating the coexistence of livestock, carnivores, and land managers. Studies have demonstrated the ability of the LGAs to defend their herds without physical interaction if approached by a carnivore; preventing livestock depredation (Allen et al. 2016; van Bommel and Johnson 2023). Typically, Livestock Guardian Dogs (LGDs) deter predators through shepherding behaviour and boisterous vocalisations (Coppinger et al. 1988; Allen et al. 2016), but they occasionally kill predators and other wildlife unintentionally and can cause injuries, fear, distress, anxiety, and pain during a chase or lethal interaction (Allen et al. 2019).

Jenkins (2003) conducted telephone interviews with 85 producers in the ACT and NSW, reporting that 11% had used, or were using LGAs. A recent survey by (Quantum Market Research 2024) involving Victorian ACUP users found that 2% of respondents identified LGAs as their primary control method, while 11% reported using them within the past five years to manage fox populations. Additionally, 9% indicated they would increase their use of LGAs if 1080 baiting was no longer available. For those managing Dingoes and Wild Dogs, LGAs were not typically employed as a primary method. However, 10% reported using them in the past five years, and 12% stated they would increase their reliance on LGAs if 1080 were unavailable. These findings suggest that LGA usage has not changed substantially since 2003. However, van Bommel and Johnson (2023) noted that information sharing among farmers had contributed to a net increase in the use of livestock guardian dogs (LGDs) in Australia.

The DEECA recently commissioned a review examining the effectiveness of non-lethal management techniques for Dingoes and Wild Dogs in Victoria (Inspiring Excellence 2024). This review discussed three types of LGAs: LGDs, Alpacas (*Vicugna pacos*), Llamas (*Lama glama*), and Donkeys (*Equus asinus*). Broadly, it concluded that LGAs can be effective when incorporated into integrated management strategies that may also involve lethal methods. However, the review highlighted a general lack of rigorous evidence in Australia regarding the effectiveness of LGAs.

12.1.1 Livestock guardian dogs

Anecdotal evidence, case studies, interviews, and international experiences suggest that LGDs can effectively mitigate predation risks in both Australia and abroad (Jenkins 2003). However, in Australia, LGDs are rarely used without some form of lethal control, making it challenging to assess their standalone efficacy as an alternative to methods like 1080 baiting.

The researchers, van Bommel and Johnson (2012), based on a survey of 93 respondents, reported that 65.7% of land managers using LGDs observed a complete cessation of predation, while 30.2% noted a reduction. The study also found that when the livestock-to-dog ratio exceeded 100, predation could persist. Proper training, bonding with livestock, and appropriate numbers of LGDs per flock were identified as critical factors for success. The researchers also determined that LGDs were effective for both large- and small-scale holdings, provided they were well-trained and managed.

A follow-up survey conducted ten years later revealed that 50% of respondents were still using LGDs, with 48% of these users confirming their continued effectiveness. Of those who had discontinued use, 12% cited issues with the dogs themselves as the main reason, while 9.5% attributed their decision to conflicts with neighbours (van Bommel and Johnson 2023).

Numerous studies and reviews have emphasised that successful deployment of LGDs requires consistent training, ongoing care, the use of containment fencing, and proper bonding with livestock. The number of dogs required typically increases with flock size (van Bommel 2010; van Bommel and Johnson 2023; Rigg 2001). Therefore, LGDs are likely to be less suitable for enterprises with large herds and property sizes. For example, at ratio of 1:100, land holders in the northwest of Victoria would need 30 dogs to look after 3,000 head of Sheep. Some literature also discusses the potential impact of LGDs on wildlife, with reports of LGDs killing native animals such as Dingoes (Allen et al. 2019; Smith et al. 2020), thereby classifying them as potentially lethal control tools and raising animal welfare concerns.

12.1.2 Llamas and Alpacas

The DEECA review on non-lethal management for Dingoes and Wild Dogs highlighted the use of Alpacas and Llamas as LGAs, primarily for protecting Sheep and Goats from foxes (Inspiring Excellence 2024). However, anecdotal accounts from landholders suggest that Alpacas are less effective against Dingoes and Wild Dogs. For instance, one report described lambs being taken from a flock ‘protected’ by three Alpacas. As with all LGAs, proper management, including bonding with the flock, is crucial for success.

Alpacas, being only slightly larger than Sheep and Goats, can themselves fall victim to attacks by Dingoes and Wild Dogs. In 2021, the Victorian Wild Dog Management Programme documented 40 incidents involving a total of 86 Alpacas killed or injured by Dingoes or Wild Dogs. However, Alpacas are capable of killing smaller predators such as foxes when they pursue and corner them (Jenkins 2003).

Llamas, which are larger (weighing approximately 200 kg and standing 2 metres tall) and faster than Alpacas, are considered more effective for livestock protection. Franklin and Powell (1993) conducted a study in the United States involving telephone interviews with 145 Sheep producers using 204 guard Llamas. The average pasture size was 100–120 hectares, and most producers had used Llamas for three years. Predation losses, averaging 11% annually before Llama use, dropped to 7% after Llamas were introduced. Furthermore, 88% of producers expressed satisfaction with their Llamas, citing ease of maintenance and effective predator deterrence as key benefits. While no equivalent studies have been conducted in Australia, (Tyrell and Hunt 2006) reported decreased stock attacks in a two-year study involving 21 Llamas across 13 properties. However, the study did not specify predator species or quantify the reduction in attacks.

Most documented successes with Llamas and Alpacas occur in areas with low predation pressure or open terrain. Research on their efficacy in Australian conditions remains limited, and further studies are required.

12.1.3 Donkeys

Donkeys, introduced to Australia in 1866, thrived in arid areas unsuitable for horses and bullocks. However, following mechanisation, they were abandoned and subsequently considered vermin (Bough 2016). No feral or wild Donkey populations exist in Victoria.

Donkeys’ innate dislike of canines has been harnessed to guard livestock in various countries. In Switzerland, they are used in the Alps to protect Sheep and Goats from wolves (Rigg Unpublished). Similarly, in North America, Donkeys have been employed successfully to deter predators such as coyotes, foxes, and bobcats (Meade 2015; Smith et al. 2000; Tapscott 1997). Public outcry over coyote poisoning led to initiatives in the United States promoting non-lethal deterrents, including Donkeys (Fox 2013).

Donkeys are among the most cost-effective LGAs, requiring minimal maintenance, because they consume the same feed as the livestock they protect. They are hardy and long-lived, remaining with flocks for extended periods (Bough 2016). However, effectiveness has been reported to be highly variable, with failure linked to the type of predator, poor husbandry practices, and unrealistic expectations by landowners. Eleven conditions have been listed for successful use of Donkeys as LGAs (Walton and Feild 1989), including using them in small pastures (240 ha) with not more than 200 head of Sheep. However, research on their use as LGAs in Australia is limited. Most references are anecdotal or based on international studies in arid areas, e.g. Texas, USA, with little data available to evaluate their effectiveness in Australian conditions, particularly in wetter environments. While reports highlight both successes and failures, the reasons for these outcomes remain poorly understood.

12.2 Fences

Fencing is a non-lethal method used to manage foxes, Dingoes, Wild Dogs and to a lesser extent Feral Pigs and rabbits by creating a physical barrier to protect vulnerable assets. In Australia, exclusion fencing has been widely employed to safeguard plant and animal agriculture from pest species since the early days of European settlement (Hayward and Kerley 2009; Long and Robley 2004; McKillop et al. 1988). In contrast, fences designed to protect populations of high-value native species are a more recent innovation (Dickman 2012).

The design of exclusion fences varies depending on the target species. Designs for Feral Pigs have been described in various studies (Doupé et al. 2010; Hone and Atkinson 1983; Hone and Stone 1989; Katahiraet al. 1993). Similarly, Poole and Mckillop (2002), and Long and Robley (2004) provide information on fences for foxes, while Mckillop et al. (1988) detail designs for rabbits. Exclusion fencing for Dingoes and Wild Dogs has also been addressed by Long and Robley (2004). However, experimental assessments of fence effectiveness are limited (Moseby and Read 2006; Poole et al. 2002; Robley et al. 2006). For instance, Moseby and Read (2006) evaluated the cost-effectiveness and functionality of various wire netting and electric fence designs against foxes, feral cats, and rabbits in northern South Australia. Similarly, Robley et al. (2006) tested six fence designs to identify optimal features for preventing breaches by foxes and feral cats. However, no experimental studies specifically assess fence designs for excluding Dingoes and Wild Dogs (Coman and McCutchan 1994; Long and Robley 2004). Kreplins et al. (2022) investigated wild dog activity after a cell fence was completed and noted that activity decreased over nearly two years following extensive baiting, shooting and trapping within the fenced area.

Although conservation fences play a vital role in preventing extinctions in the short term, their coverage represents only a small fraction of the historical ranges of most species. Additionally, their high construction and maintenance costs, coupled with criticisms of these areas as being akin to captive breeding programmes, limit their broader application (Pickard 2007). In addition, lethal control is required to remove pest animals from within fenced conservation areas or when individuals are contained after fence construction. There are also animal welfare and humaneness issues associated with fences, which have been covered in Section 15.

12.2.1 European Rabbits

Barrier fencing to control rabbits in Australia dates to their introduction and establishment in the 19th century. By the 1880s, fencing was a widely relied-upon method, persisting as a primary tool until the 1950s. Despite its widespread use, early fencing efforts, such as the ‘dog fence’ and the Number 1 Rabbit-Proof Fence in Western Australia, demonstrated significant shortcomings. Stretching over 1,700 kilometres, these barriers ultimately failed to halt rabbit invasions, as did the barrier fence between Queensland and New South Wales.

As rabbit control methods evolved to include fumigation, warren ripping, and poisoning, the use of rabbit-proof netting fences declined significantly. The high costs of construction and labour required to maintain these fences have made them a less viable option. The costs for rabbit exclusion fencing in Australia are estimated at AUD $55,261 per kilometre (Long and Robley 2004). Consequently, most farmers no longer aim to completely eradicate rabbits on their properties, choosing instead to adopt integrated pest management strategies.

In a recent survey of ACUP holders, 2% reported fencing as their primary rabbit control method, while 18% had used fencing in the past five years. Among those who used 1080 for rabbit control, 14% indicated they would increase their use of fencing if 1080 were no longer available (Quantum Market Research 2024).

12.2.2 Feral Pigs

Exclusion fencing is generally not considered an optimal control method for Feral Pigs, except in the case of small, high-value areas (McIlroy 1993, cited in Choquenot et al. 1996). It is primarily used to protect agricultural crops, and livestock (Mitchell et al. 1977; Plant et al. 1977), and, more recently, tropical wetlands (Negus et al. 2019; Waltham and Schaffer 2021). For instance, Pavlov et al. (1981) demonstrated that electric fencing increased lamb survival by preventing Feral Pig access to paddocks. Similar outcomes were observed in Texas and Japan, where fencing significantly reduced crop damage (Matthew et al. 2008; Saito et al. 2011). In the Northern Territory, fencing excluded feral buffalo, horses, and Feral Pigs, leading to substantial environmental improvements in culturally significant billabongs (Ens et al. 2016).

Despite these successes, fencing is not universally effective. For example, (Geisser and Reyer 2004) found no reduction in crop damage with increased fencing in Switzerland, and in Queensland, fencing around wetlands showed no measurable biodiversity benefits (Doupé et al. 2010; Waltham and Schaffer 2019). Given the robust size of Feral Pigs, reaching up to 115 kg in size (Choquenot et al. 1996), fences must be durable, often incorporating woven-wire mesh and barbed wire or using electric components for cost-effectiveness. Feral Pig movement was effectively controlled using fences with 0.80–1.2-m-tall woven-wire mesh with a ground-level strand of barbed wire, facilitating eradication from several management units in Hawaii Volcanoes National Park (Hone and Stone 1989), and the Pinnacles National Monument in California (McCann and Garcelon 2008). Electric fences have also been effective in decreasing movements of Feral Pigs (Choquenot et al. 1997; Hone and Atkinson 1983; Matthew et al. 2008). Electric fences are easier to construct and are cost effective; however, sturdier and consequently more expensive and permanent designs are required for complete exclusion of Feral Pigs (Reidy et al. 2008).

In a recent ACUP survey, 7% of respondents identified fencing as their primary control method for Feral Pigs, with 23% employing it in the past five years. Among those using 1080, 4% indicated they would increase their reliance on fencing if 1080 became unavailable (Quantum Market Research 2024).

12.2.3 Red Foxes

Exclusion fencing is commonly employed in zoos, private wildlife parks, and areas of intensive agriculture affected by fox predation. In such scenarios, fencing, particularly designs incorporating a roof or overhang, has proven effective (Saunders et al. 1995). A recent survey of 1080 ACUP holders in Victoria reported that 1% of respondents used fencing as their primary method of fox control, while 7% had employed it in the past five years. Among those who used 1080 baits for fox management, 7% indicated they would increase their use of fencing if 1080 became unavailable (Quantum Market Research 2024).

In recent years, fenced areas, often referred to as 'mainland islands' or havens, have become a prominent approach to wildlife management. These areas typically involve the removal of introduced predators, such as foxes, feral cats, and rabbits, often using lethal control methods. This concept was pioneered at Warrawong Sanctuary in South Australia in 1975 (Wamsley 1995). Since then, the network of conservation fences has grown, with the Commonwealth Government's Threatened Species Strategy (Commonwealth of Australia 2021) promoting further expansion. As of 2018, Australia had 19 predator-proof fenced areas, covering a total of 350 km^2. Of those 19 fenced areas, 17 hold 49 populations of 27 taxa (25 species) (Legge et al. 2018). In Victoria, four fenced areas covering 12.8 km^2, protect seven species, all listed under the EPBC Act (1999), with three being at risk from fox and/or feral cat predation (Eastern Barred Bandicoot, Eastern Quoll [*Dasyurus viverrinus*], and Southern Brown Bandicoot) (Legge et al. 2018).

12.2.4 Dingoes and Wild Dogs

Fencing provides an effective non-lethal method for managing Dingoes and Wild Dogs, serving as a first line of defence to protect livestock. However, its effectiveness is contingent on proper construction, regular maintenance, and supplementary measures, such as removing animals that breach the fence or were enclosed within it during construction. Breaches are inevitable, underscoring the importance of integrated control strategies.

Several types of fencing are used, including cell fencing (enclosing individual paddocks), cluster fencing (enclosing multiple properties), and linear fencing (extending across single or multiple properties). Linear fences are often less effective, as they may shift the problem to neighbouring areas or be circumvented by animals walking around the ends.

In Victoria, the predominant approach is linear fencing, sometimes combined with cell fencing. These fences typically feature a single electric wire positioned 150 mm above the ground and extending 200 mm horizontally from a pre-existing fence. Anecdotal evidence suggests that this design has been successful in eastern Victoria, improving lambing percentages and mitigating livestock losses. However, fencing is rarely used in isolation; lethal control methods remain a standard component of Dingo and Wild Dog management by both public and private land managers. No cases in Victoria document integrated, non-lethal control strategies as a standalone approach for managing these predators.

A recent survey of ACUP users in Victoria revealed that 6% employed fencing as their primary management tool for Dingoes and Wild Dogs, with 31% having used fencing in the past five years. Among respondents who used 1080, 32% indicated they would increase fencing efforts if 1080 were no longer available (Quantum Market Research 2024).

12.3 Diversionary feeding

Diversionary feeding refers to the deliberate provisioning of food to change the behaviour of target species and reduce unwanted behaviour (Kubasiewicz et al. 2016) by exploiting the propensity of foraging individuals to utilise the most easily accessed resources (Pyke 1984). The approach is not currently known to be used in Australia (Bengsen et al. 2017). Crucially, diversionary feeding may increase the pest animals' reproductive output, carrying capacity and hence population size, ultimately leading to increases in damage (Calenge et al. 2004; Miloš et al. 2016). For this reason, diversionary feeding may be considered an activity which facilitates the spread of pest species, and is therefore illegal in many Australian jurisdictions (Bengsen et al. 2017).

It has been used to reduce the predation impact of single predator species, such as red kites (*Milvus milvus*) on lapwings (*Vanellus vanellus*) (Mason et al. 2021) and kestrels (*Falco tinnunculus*) on little terns (*Sternula albifrons*) (Smart and Amar 2018), foxes on black grouse (*Tetrao tetrix*) and Western capercaillie (*Tetrao urogallus*) (Finne et al. 2019), grizzly bears (*Ursus arctos*) on Moose (*Alces alces*) (Boertje et al.1995), and to reduce crop damage by Feral Pigs (Geisser and Reyer 2004). However, the success of diversionary feeding is often species and context specific (Kubasiewicz et al. 2016). Large-scale experimental evidence is limited yet vital in establishing how diversionary feeding can function as a widely applied conservation intervention. It is also needed to assess new species-specific contexts and locations, or for differing outputs, such as alleviating nest predation pressure.

12.4 Livestock collars

Livestock collars can either protect livestock, deter attacks or act as lethal control options (Burns et al.1996). A relatively new and untested method of livestock protection involves the use of plastic collars designed to prevent canids from gripping and killing Sheep. The King Collar, developed in South Africa, was created to protect livestock from jackals, which are similar to coyotes and Dingoes in appearance and behaviour. According to the manufacturer, the collar prevents jackals from biting the cheek and trachea. However, they do not prevent injuries from attack on other parts of the body, nor exhaustion and stress from being chased. In a 2-year study of Dingoes in pastoral country in Western Australia, (Thomson 1984) reported that Dingoes generally started their attacks by biting the hind end of the Sheep, wounding the rump or hind legs or often, in the case of rams, the scrotum. Of 191 Sheep attacked that were assessable, 155 were damaged at the hind end.

While the novelty of these collars may temporarily deter predators, their adaptability and learning abilities suggest that developing long-term, practical, and effective animal armour will be challenging. Further research and development are needed to assess their potential more thoroughly (Shivik 2004).

12.5 Repellents

The primary objective of repellents is to disrupt predator behaviour. Two categories of repellents are recognised: primary repellents, which provoke a fright or startle response, and secondary repellents, which utilise aversive stimuli to condition predators against specific behaviours, such as livestock predation (Shivik et al. 2003).

Extensive research on repellents has been conducted internationally, targeting predators such as Grey Wolves (*Canis lupus*), bears (*Ursus* spp.), Coyotes, Pumas (*Puma concolor*), and Lions (*Panthera leo*) (Breck et al. 2002; Darrow and Shivik 2009, 2009; Linhart 1984; Linhart et al. 1992; Miller 1983; Shivik et al. 2003; VerCauteren et al. 2003; Zarco-Gonzalez and Monroy-Vichis 2014). (Miller et al. 2016) reviewed 66 peer-reviewed studies on lethal and non-lethal techniques for reducing livestock predation. These studies, covering 16 large carnivore species across 27 countries and six continents (including two studies from Australia (van Bommel and Johnson 2012; Edgar et al. 2007)), found that deterrents—including aversive stimuli, behavioural conditioning, or repellents—showed high variability in effectiveness (0–100%) in reducing livestock losses. Effectiveness was defined as the percentage change in depredation rates when a method was applied, along with the duration of its efficacy. For example, they found that fladry tape was 100% effective but only for a few weeks, while shock collars reduced depredation by about 70% for over 17 months. However, sample sizes were often small, and most techniques were tested on single species without combinations.

In Australia, research on repellents is limited. (Edgar et al. 2007) evaluated a commercial ultrasonic device with four captive Dingoes and found no effect. (Appleby et al. 2017) tested modified domestic dog shock collars on K’gari (Fraser Island) Dingoes but encountered equipment failures, similar to other studies (Hawley et al. 2009; Shivik et al. 2003). Appleby et al. (2017) found that mechanised water jets elicited aversive behaviour in young Dingoes, while air horns did not, likely due to habituation to loud noises. (Smith, et al. 2000) tested shotgun sounds and an inflatable human effigy to deter captive Dingoes from food. While the shotgun sounds failed, the effigy reduced food access by 25%, suggesting its potential in human-wildlife conflict zones.

Taste aversion studies have also been conducted on Dingoes and foxes. (Tauchmann 1999) tested conditioned taste aversion (CTA) in Dingoes using food lures treated with lithium chloride or thiabendazole, observing reduced bait consumption at one site. Andrewartha et al. (2023) demonstrated that free-ranging foxes could be conditioned to avoid target food items using baits containing encapsulated levamisole, resulting in at least a 30% reduction in bait consumption for 68 days.

Repellents are generally short-lived in effectiveness. While canids initially avoid novel objects like effigies or sounds, rapid habituation is common (Ausband et al. 2013). Recent studies have investigated using natural chemical signals to deter canids. For example, (Jackson et al. 2012) effectively contained African Wild Dogs (*Lycaon pictus*) near protected areas using translocated scent stations, while (Ausband et al. 2013) used biofencing to manipulate Grey Wolf movements with initial success but later failure, potentially due to insufficient scent reinforcement or buffer distances. Shivik et al. (2011), however, found that conspecific urine attracted Coyotes, highlighting species-specific responses. In Australia, Robley et al. (2015) examined synthetic chemicals mimicking dominant male Dingo urine, finding some ability to manipulate captive Dingo behaviour. Other factors, such as sex, social status, and weather, also influenced outcomes.

The limited and temporary effectiveness of repellents aligns with other reviews (Bangs et al. 2006; Breitenmoser et al. 2005), suggesting they are best applied during high-risk periods, such as calving or lambing seasons (Schultz et al. 2005). For species with large or seasonally structured territories, strategies inducing avoidance of smaller areas or peripheral zones may be more realistic than attempting to exclude animals from entire territories (Hansen 2024).

Table 11. Summary of cost-effectiveness, target specificity advantages and disadvantages of 1080 and non-lethal control methods used in Victoria for each of the four pest species. Adapted from the State and National Codes of Practices and updated using outcomes from this literature review.

Species	Control technique	Cost-effectiveness	Target specificity	Advantages	Disadvantages
European Rabbit	Ground baiting with 1080 Oats or Carrots	Cost-effective	Potential risk of poisoning and secondary poisoning non-target animals	Effective for reducing rabbit populations prior to warren destruction.	1080 ingestion can also kill non-target animals including native species, cats, dogs and livestock. 1080 is toxic to humans; operators need to take precautions to safeguard against exposure.
	Exclusion fencing	Expensive – variable effectiveness	Can be in certain situations. Non-target species can be impacted	Effective for small, critical (economically or environmentally) sensitive areas.	Maintenance costs are high and expensive to build.
Feral Pig	Ground baiting with 1080	Cost-effective	Relatively large amounts of 1080 are required to kill pigs; therefore, there is a risk of poisoning non-target animals. Strategic ground baiting uses fewer baits than aerial baiting programmes. Uneaten baits can be collected and destroyed. Potential risk to non-target species if stomach contents, stomach, gastrointestinal tract, and/or any vomit is consumed • To minimise non-target impacts, remove livestock from paddocks, locking gates to paddocks, use a HogHopper™ and exclusion fencing • All canids can die if they consume vomit, eat a meat bait (where	Currently the most cost-effective technique available. Highly palatable even after prolonged storage and proven to effectively knockdown pigs Very little non-target interest • Stays attractive and palatable in hot and dry conditions	1080 ingestion can kill non-target animals including native species, cats, dogs and livestock.

Species	Control technique	Cost-effectiveness	Target specificity	Advantages	Disadvantages
			allowable for use) or feed on a poisoned carcase.		
	Exclusion fencing	Expensive, limited effectiveness	Can be in certain situations. Non-target species can be impacted.	Effective for small, economically or environmentally critical areas.	Maintenance costs are high.
	Diversionary feeding	Not cost effective	Target specific. No non-target impacts.	Relatively cheap to implement, may be useful for small-scale enterprises for short periods.	Not suitable for large-scale control. Only effective for short periods of time. May increase reproductive output, carrying capacity, and therefore, population size. May attract non-target (other pest) species
	Frightening devices	Not cost effective	Target specific. No non-target impacts.	Relatively cheap to implement, may be useful for small-scale enterprises for short periods.	Not suitable for large-scale control.
Red Fox	Ground baiting with 1080	Cost-effective	There is a risk of poisoning non-target animals. Strategic ground baiting, where baits are buried, reduces the risk to non-target species. Uneaten baits can be collected and destroyed.	Currently the most cost-effective technique available.	1080 ingestion can also kill non-target animals including native species, cats, dogs and livestock. 1080 is toxic to humans; operators need to take precautions to safeguard against exposure.
	Exclusion fencing	Expensive. Effective if foxes can be eradicated from within fence area.	Can be in certain situations. Non-target species can be impacted.	Fencing can be effective for large areas containing threatened species.	Maintenance costs are high. Limited to conservation reserves.
	LGAs (e.g. dogs, Alpacas, Llamas, Donkeys)	Can be expensive. No cost-effective data available. Can be effective when suitable LGA stock is used, and animals are managed appropriately.	LGDs may chase and harass native animals, pets and livestock and kill pest species.	Likely to be most effective for small holdings.	Require additional time and management to be effective, can have off-target impacts and cause problems with neighbours.

Species	Control technique	Cost-effectiveness	Target specificity	Advantages	Disadvantages
	Frightening devices	Not cost effective	No non-target impacts known	Most humane alternative to 1080	Only effective in the short term and in localised areas.
Dingo and Wild Dog	Ground baiting with 1080	Cost-effective	There is a risk of poisoning non-target animals. Strategic ground baiting, where baits are buried, reduces risk to non-target species. Uneaten baits can be collected and destroyed.	Currently the most cost-effective technique available. 1080.	Ingestion can also kill non-target animals including native species, cats, dogs and livestock. 1080 is toxic to humans; operators need to take precautions to safeguard against exposure.
	Exclusion fencing	Expensive. Can be effective when constructed and maintained appropriately.	Can be in certain situations. Non-target species can be impacted.	Fencing can be effective in some situations.	Maintenance costs are high. Not suitable to all landscapes.
	LGAs (e.g. dogs, Alpacas, Llamas, Donkeys)	Insufficient data. Can depend on the species of LGA.	LGDs may chase and harass native animals, pets and livestock and kill pest species.	Likely to be most effective for small holdings.	Require additional time and management to be effective, can have off-target impacts and cause problems with neighbours.
	Frightening devices	Not cost effective	No non-target impacts known	Most humane alternative to 1080	Only effective in the short term and in localised areas.

13 Non-target impacts of lethal methods for managing European Rabbits, Feral Pigs, Red Foxes, and Dingoes and Wild Dogs

All pest animal control operations should aim to minimise the impact on non-target animals. Within this general premise, there are two broad, but not separate components: (1) the humaneness and animal welfare considerations at the level of the individual animal; and (2) the impact of the control action on the population of non-target animals.

This section reviews the literature on the possible population-level impacts on non-target species from the use of 1080 and its alternatives. Where this information is not available, we include information on the theoretical impact of toxins and general field observations on the response of native animals. We review the humaneness and animal welfare of the control measures in Section15.

13.1 Impacts of toxic bait on non-target species (1080, PAPP, sodium nitrite, pindone)

Laboratory and theoretical studies show that a range of Australian native animals are susceptible to: 1080, and sodium nitrite poisoning at the doses required to kill a Feral Pig (Lapidge and Eason 2010; McIlroy 1986; O'Brien et al. 1986; Shapiro 2017; Twigg et al. 2005); the dose rates of 1080 and PAPP in baits for killing Dingo and Wild Dogs and foxes (Marks et al. 2023; McIlroy 1981, 1982, 1983; McIlroy and Archer 1982; McIlroy et al. 1985); and dosages in 1080 baits for killing European Rabbits (McIlroy and Gifford 1991, 1992).

The standard metric for determining if individuals of a species are at risk to poisoning is the amount of poison that, under controlled conditions, will be a lethal dose to 50% of a large number of test animals of a particular species (LD_{50}). The value is expressed in milligrams of the substance being tested per kilogram of animal body weight (mg/kg).

In reality, various factors, including bait acceptance and deployment strategy, will influence the number and variety of non-target populations that could be affected by poisoning. In addition, neophobia to novel items, the attractiveness and palatability of the bait, the probability that an individual will find and then consume the bait, the number of baits within the home range of non-target animals, the actual level of toxicity of the bait at the time of consumption, and the amount of bait that can be physically consumed all influence the ultimate risk to individual animals and by extension the population (Kortner et al. 2003; Marks 2001). Numerous approaches have been developed over time to reduce the likelihood of non-target animals consuming toxic baits, and to make them more attractive to target animals.

13.1.1 European Rabbits

In a simulated rabbit baiting trial using pellets, carrots and oats, six native species consumed pellet bait, one consumed oat bait and a different six species consumed oat bait in sufficient quantities to be at risk (Brunner 1983). Rabbit-poisoning campaigns appear to have no significant effect on populations of some of the more common birds and mammals (McIlroy and Gifford 1991). Pellet baits for rabbits, however, appear to have killed all adult residents in a marked population of the patchily distributed silky mouse (*Pseudomys apodemoides*) in one area in western Victoria. Fortunately, the effect was only temporary, with juvenile animals quickly recolonising the area (A. Cockburn, personal communication, in McIlroy 1982).

13.1.2 Feral Pigs

PIGOUT baits for the control of Feral Pigs, were developed to address the issue of non-target bait take associated with previous forms of delivering 1080 by making the baits less attractive to non-target species and more attractive to Feral Pigs (e.g. incorporating animal and vegetable matter into bait material to deter dietary specialists (O'Brien et al. 1986), dyeing bait material to prevent detection by visual foragers (Bryant et al. 1984), including the use of pig-specific attractants (Campbell and Long 2009), and incorporating the 1080 toxin into the centre of the bait matrix to eliminate the degree of toxin redistribution and reducing potential non-target poisoning (Smith et al. 2005). Despite substantial improvements in target specificity, PIGOUT is still consumed by various non-target species (Bengsen et al. 2010; Campbell et al. 2006; Cowled et al. 2006). A Feral Pig specific feeder has been shown to significantly reduce non-target bait-take during Feral Pig control programmes (Long et al. 2010). Both types of PIGOUT baits are dispensed using HogHoppers™, metal cubes with internal dividers that allow Feral Pigs to access bait through gravity-activated guillotine doors. These bait stations exploit the size, reach, and feeding behaviours of Feral Pigs, thereby minimising access by non-target species (Campbell et al. 2012). Tests of the HogHopper system have been conducted in the US, where it has been shown to be highly species specific (Campbell et al. 2013; Lapidge et al. 2012). Despite this improvement, risks to non-target animals can still occur when bait is spilled from the bait dispensers by feeding pigs, and is subsequently made accessible to birds (Snow et al. 2021, 2024).

Similar improvements to reduce non-target risk have also been made to HOGGONE baits during the course of its development. (Snow et al. 2021) reported the outcome of several years of development in Australia and Texas, where non-target species that succumbed to the dropped bait mostly included small granivorous birds, and to a lesser extent Raccoons (*Procyon lotor*) and Wild Turkeys (*Meleagris gallopavo*). This led to modification of the bait and the bait station, and subsequently resulted in a 19-fold decrease in the amount of bait left outside the bait station. However, non-target species mortalities were recorded in a subsequent set of trials (three Australian Ravens [*Corvus coronoides*] in Queensland, two Virginia Opossums [*Didelphis virginiana*] in Alabama, and 35 granivorous-passerine birds, mostly Dark-eyed Juncos [*Junco hyemalis*]) in Texas (Snow et al. 2021). However, the researchers reported that there were no detectable declines at a population level for any of these impacted species. In a further development, Kinsey et al. (2023) assessed three different types of bait presentation set in a bait hopper. They found that there was a 90+% reduction in bait spilled outside bait station when it was compacted in trays, as opposed to being manually crumbled into pieces. These results influenced the design of the paste hoppers and the presentation method of the paste. Paste was presented in trays, and the hopper was modified so trays could be locked into position during feeding. They reported a mean spill rate of 0.913 g of bait per wild pig. Conservative risk assessments for nine non-target species for which sodium nitrite toxicity data exist, indicate that there is relatively low risk of lethal exposure. In Australia, it is a regulatory requirement to use the HOGGONE paste bait hopper (Lavelle et al. 2018) with HOGGONE (ACTA 2024).

13.1.3 Dingoes and Wild Dogs, and Red Foxes

1080 baits

A range of native species are potentially at risk from toxins used to manage Dingoes and Wild Dog’s, and foxes (Glen and Dickman 2003b; Marks et al. 2023). Marsupial carnivores are the main species at potential risk to canid baits because of their feeding habits and sensitivity to 1080 and PAPP. For example, the estimated LD_{50} for a 2.8 kg Spotted-tailed Quoll is a little over 5 mg 1080, compared with 3 mg 1080 in fox baits and 6 mg 1080 in dog baits. Brush-tailed Phascogales (*Phascogale tapoatafa*) may also be at risk of poisoning because they are sensitive, and are voracious and opportunistic feeders (APVMA 2005; McIlroy 1981). While predatory and scavenging birds such as Wedge-tailed Eagles (*Aquila audax*), kites, ravens and owls are capable of consuming bait, they would generally need to consume large amounts of bait to receive a lethal dose (APVMA 2005; Eldridge, et al. 2000). McIlroy (1984) determined acute oral LD_{50} for several Australian bird species, including Wedge-tailed Eagles. Results indicate that their sensitivity to 1080 (95.6% purity) was very high, 9.49 mg/kg. Based on laboratory testing of one amphibian and five reptiles, McIlroy et al. (1985) concluded that it is unlikely that amphibians and reptiles face any direct poisoning risk from pest-poisoning campaigns involving 1080, given their high tolerance and the enormous amounts of poisoned bait that would have to be eaten. (McIlroy 1982) tested 14 species of rodents and found that individuals of most species of rodents would appear to face a considerable risk. However, he noted that the crucial factor governing the actual effect on populations was more than just the sensitivity to oral doses of aqueous 1080 solution, and that factors such as body size, capacity to consume the required amount of bait material and how many individuals found and ate the baits all contribute to the actual risk to individual species.

Also, considering the relatively high rate of population increase of many rodent species (range 0.98–4.48; (Hone et al. 2010), the level of annual population reduction needed is high Hone et al. (2010) reported a range of 59–94% annually). In addition, the density of bait per home range is likely to be quite low given rodent species tend to have home ranges of less than 10 ha and baits are generally deployed at rates of 3–4 km^{-2} for managing foxes, and 10 baits km^{-2} within restricted locations during aerial baiting operations for managing Dingoes and Wild Dogs in Victoria (Marks 2001).

The results from field studies of Dingo-poisoning campaigns indicate that the campaigns have no significant effect on populations of small mammals and birds in mountain forest areas in southeastern Australia (McIlroy 1992; McIlroy et al. 1986), on populations of Northern Quolls (*Dasyurus hallucatus*), and probably other dasyurids and rodents in pastoral areas of Western Australia (King 1989), on Southern Bush Rats (*Rattus fuscipes assimilis*) and Brown Antechinus (*Antechinus stuartii*) in northeast NSW (Fenner et al. 2009), or on Spotted-tailed Quoll (Claridge et al. 2021; Claridge and Mills 2007; Kortner 2007; Kortner and Watson 2005). Allen et al. (2014) conducted a series of landscape-scale, multi-year, manipulative experiments at nine sites spanning five ecosystem types across the Australian continental rangelands to investigate the responses of sympatric prey populations to contemporary poison-baiting programmes intended to control Dingoes. Prey populations were almost always in similar or greater abundances in baited areas. Short-term prey responses to baiting were seldom apparent. Longer-term prey population trends fluctuated independently of baiting for every prey species at all sites.

Results from field studies on the impact of fox baiting (buried or surface laid) indicate that control operations have had no significant impact on populations of Spotted-tail Quolls (Körtner et al. 2003), Brush-tailed Phascogales (Marlow et al. 2015), or on the abundance of bandicoots, Brush-tailed Possums (*Trichosurus vulpecula*) and lyrebirds (*Menura* spp.) in southern NSW (Claridge et al. 2010). As noted previously, several studies have demonstrated increased measures of abundance of a range of native mammal and reptile species in response to the implementation of successful fox control using 1080 baits, suggesting a positive impact on those native species (e.g. Dexter and Murray 2009; Hunter and Lagisz 2018; Jessop et al. 2016; Robley et al. 2014; de Tores 2020). Given the benefits to many non-target species of removing feral predators by baiting (e.g. Kinnear et al. 1988; Kinnear et al. 2002; Morris et al. 2003), the net effect on their populations is more likely to be positive, despite the potential loss of some individuals.

In Victoria, it is a permit condition that baits used in ground-based operations for the control of Dingoes and Wild Dogs, and foxes, are burred to a depth of 8 - 10 cm to further manage the risk (Bloomfield 1999). The burial of baits has been found to reduce the uptake by non-target animals (Allen et al. 1989; Glen and Dickman 2003a). However, some non-target individuals have been observed to excavate buried baits (e.g. Fleming 1996; Belcher 1998; Dexter and Meek 1998; Glen and Dickman 2003b; Robley et al. 2009, Mason et al. 2025), and burial may also reduce the consumption of baits by target animals (Robley et al. 2009; Thomson and Kok 2002).

PAPP baits

There are two products containing PAPP for the management of foxes and Dingoes and Wild Dogs in Victoria, FOXECUTE (35 g fox bait containing 400 mg PAPP) and DOGABAIT PAPP Bait (60 g Wild Dog bait contains 1000 mg PAPP). PAPP is also available in capsules for use in CPEs.

We could find no published literature that quantitatively assessed the impact of field-based baiting operations on native species from FOXECUTE or DOGABAIT PAPP Bait. PAPP bait products are relatively new, and the bait products are more expensive, limiting the broadscale uptake of these products, particularly in Victoria. Consequently, no large-scale programmes have implemented the use of PAPP baits for enough time to robustly monitor population responses in native species.

As noted for other toxins, testing using direct dosing or using indirect methods (modelled non-lethal dose response curves) has shown that a number of native species are at potential risk from PAPP (Eason et al. 2014; Marks et al. 2023). The most sensitive Australian bird species assessed is the little Australian Raven (*Corvus coronoides*) with an LD_{50} of 130–133 mg/kg, making it moderately sensitive. The Common Crow (*Corvus brachyrhynchos*), the Silver Gull *(Larus novaehollandiae*) and the Australian Magpie (*Gymnorhina tibicen*) have a low sensitivity. The Lace Monitor (*Varanus varius.* LD_{50} 3 mg/kg) and Rosenberg's Goanna (*Varanus rosenbergi,* LD_{50} 12 mg/kg), are highly sensitive to acute toxicity (Eason et al. 2014). The southern brown bandicoot (LD_{50}s of 6.4 mg/kg) and Dingo (LD50 8.5 mg/kg) are highly sensitive (LD_{50} <10 mg/kg). The Spotted-tailed Quoll was the next most sensitive Australian native species tested, with an LD_{50} of 24.8 mg/kg. The toxicity to other native species tested ranged from 89–120 mg/kg for the Dama Wallaby (*Macropus eugenii*), Fat-tailed Dunnart (*Sminthopsis crassicaudata*) and Tasmanian Devil (*Sarcophilus harrisii*), and > 500 mg/kg for the Brushtail Possum (*Trichosurus vulpecula*), Brown Antechinus and Bush Rat (*Rattus fuscipes*).

13.1.4 Risk of secondary poisoning

Secondary poisoning can be a risk for non-target species during poison control operations. For example, some Feral Pigs will vomit after ingesting 1080 poison, with vomit likely to contain concentrations of 1080 that would be hazardous to many non-target species if ingested (O'Brien et al. 1986). Carcasses of Feral Pigs killed by 1080 poisoning also showed residues of 1080 poison in all tissues tested, although the concentrations were minimal except in the digestive tract. This suggests that secondary poisoning from carcasses is unlikely for most Australian species except for Dingoes and invasive carnivores (Gentle et al. 2005; Twigg et al. 2005). However, in a study on the use of deer carcasses by Dingoes, foxes and feral cats, Forsyth et al. (2014) found that Dingoes did not feed on carcasses for long periods and the amount of feeding activity was a less important predictor of the loss of edible biomass than season. Reasons for the low impacts included the spatially and temporally unpredictable distribution of carcasses in the landscape, the rapid rate of edible biomass decomposition in warm periods, low Dingo densities, and the availability of alternative food resources.

Similarly, measurements of sodium nitrite residue in carcasses of Feral Pigs killed by HOGGONE poisoning showed that only scavengers that consume the digestive tract would be at risk of secondary poisoning (Lapidge et al. 2012; Snow et al. 2018, 2019). The incidence of vomiting after consuming sodium nitrite prior to death is lower than for 1080, which should also reduce secondary poisoning risks (Lapidge and Eason 2010). There is no literature on the use of Feral Pig carcasses by Dingoes, and therefore, this is an area requiring further investigation.

Secondary poisoning from rabbits targeted with 1080 is also a possibility. McIlroy and Gifford (1992) assessed the potential hazards that poisoned rabbits present to different carrion-eating animals by comparing the amounts of 1080 that carrion-eaters could ingest from feeding on poisoned corpses with their measured sensitivity to the poison. Foxes, Dingoes, and feral cats faced a greater risk of secondary poisoning than other animals. The extent of secondary poisoning to some birds and small dasyurids, may depend on their feeding habits, particularly what and how much of the different tissues and organs of poisoned animals they eat, and whether they vomit or regurgitate partly digested food. Twigg et al. (2003) investigated the amount of residual 1080 in rabbits poisoned by 1080 oats. They concluded that, except for eutherian carnivores, which are highly sensitive to 1080, there is little potential risk of secondary poisoning to native wildlife with the correct use of 1080 baits in pest-control programmes.

Fisher et al. (2015) looked at the residual amounts of pindone in rabbit tissue and the risk to non-target species. They found that the highest concentrations of pindone residues were in the liver and fat tissue of poisoned rabbits, with consistently lower concentrations in muscle tissue. Rabbit carcasses collected after field-baiting operations had generally higher pindone residue concentrations than did laboratory rabbits. Concentrations of residual pindone in fat and liver of poisoned rabbits suggest that the risk of secondary poisoning (i.e. from the potential toxicity of the material and not the probability of it being eaten) to some non-target predators and scavengers is high. The lack of field-based assessments of the non-target impacts of pindone is a marked information gap that needs to be addressed.

13.2 Livestock guardian animals

In recent years in Australia and overseas, there has been an increase in the literature reporting on the impact of LGAs on pest predators, non-target species and in some cases the animals they are charged with protecting. LGDs have been reported killing a range of predator and prey species, including Cheetahs (*Acinonyx jubatus),* Coyotes, and Black-backed Jackals (*Canis mesomelas*), deer fawns (*Odocoileus hemionus*), and Marmots (*Marmotta* spp.) (Black and Green 1985; Hansen and Smith 1999; Potgieter et al. 2016; Whitehouse-Tedd et al. 2020). Furthermore, (Drufke 2000) documented lethal incidents involving guardian Llamas in the United States and Canada, noting that Llamas killed 9% of predators and injured 16% during flock protection.

LGAs could also chase or otherwise harass wildlife. Harassment of wildlife, including predators, by LGDs is evidently common (e.g. Coppinger et al. 1988; Hansen and Smith 1999; Gingold et al. 2009). Harassment is most likely to be directed at medium-to-large-sized animals that are easily detected, or predators that might be perceived as threatening to livestock. van Bommel and Johnson (2016) reported evidence of LGDs altering the behaviour of herbivores and foxes. Swamp Wallabies and Sambar Deer were excluded from areas occupied by LGDs; Grey Kangaroos (*Macropus giganteus*) showed strong spatial and temporal avoidance of LGD areas; and foxes showed moderately strong spatial and temporal avoidance of LGD areas.

13.3 Shooting

Shooting is generally regarded as target specific and does not generally directly impact on other species. However, there is a risk of injuring or killing non-target animals, including livestock, if shots are taken at movement, colour, shape, sound or, when spotlighting, eye reflection ('eye shine'). Standard operating procedures advise that operators only shoot at a target animal once it has been positively identified. Shots are never to be taken over the top of hills or ridges as other animals or people may be out of sight beyond the hill within the firearm danger zone. There can be negative animal welfare impacts on any dependent young, where practical shooting is generally undertaken at times of the year when dependent young are less likely to be impacted.

The primary risk to non-target species during Feral Pig shooting programmes is indirectly from lead poisoning from consuming contaminated carcasses (Hampton et al. 2018). Lead is a heavy metal that is toxic to all animals, even in small concentrations, and which can build up in the body through repeated exposures (Pain et al. 2019). Despite these dangers, shotgun pellets and rifle bullets are primarily made of lead, both of which leave tiny, easily consumed fragments dispersed in carcass tissue. High lead concentrations and many lead fragments have been documented in culled pig carcasses (Dobrowolska and Melosik 2008; Hampton et al. 2021), and these lead accumulations may be subsequently consumed by a range of scavenger species (O'Brien et al. 2007).

Scavenging birds are particularly at risk due to their ability to search large areas for carcasses, increasing their potential exposure (Hampton et al. 2018). Elevated lead has been documented in 10–13% of Wedge-tailed Eagle (*Aquila audax*) carcasses tested on the mainland and Tasmania, with high enough concentrations to cause negative individual impacts and possibly negative population impacts (Hampton et al. 2023; Pay et al. 2021). Other raptors, corvids, varanids and carnivorous mammals are also likely to be at risk. For example, O'Brien et al. (2007) documented that pig carcasses were scavenged by a range of avian species as well as bandicoots, possums, rodents, frogs, varanids and skinks in south-west Western Australia.

Aerial shooting of pigs is likely to increase the risk of lead poisoning in non-target species, because more bullets are typically used per pig than from ground shooting, and carcasses are rarely retrieved, increasing potential exposure (Hampton et al. 2018a). Hampton et al. (2021) estimated that the average ~20,000 Feral Pigs that are shot through aerial shooting programmes in New South Wales would contain ~67,000 toxic doses of lead for raptors.

The risk of lead-poisoning to non-target species can be mitigated by switching to lead-free bullets. There has been resistance to making this switch over animal welfare concerns (lead-free bullets are perceived as killing less efficiently) and increased costs. (Hampton et al. 2021) assessed the efficacy of lead-free bullets in comparison to standard lead bullets during a Feral Pig aerial shooting programme in New South Wales. The authors found that there was no difference in the number of shots needed per pig, and that the cost difference of lead-free bullets was $1.68 per pig.

13.4 Den and warren fumigations

We found no research papers that attempted to quantify the impact of den or warren fumigation on non-target species in Australia. The NSW and National Code of Practice and Standard Operating Procedures for fox den fumigation (NSW DPI 2022; Sharp 2012d) state that, when used correctly, fumigation of dens is target specific and will have no significant impact on non-target species. They also state that there is no significant risk of secondary poisoning if carcasses of gassed animals are consumed by non-target predatory or scavenger species.

The National Standard Operating Procedures for diffusion fumigation of rabbit warrens using phosphine gas (Sharp 2012f) states that fumigation must not be performed if a warren appears not to be empty or possibly occupied by a non-target species (e.g. wombats, Dingoes, lizards, snakes). They also state that there appears to be no significant risk of secondary poisoning if carcasses of gassed animals are consumed by non-target predatory or scavenger species.

13.5 Canid pest ejectors

Studies on non-target impacts of CPEs or those that have reported non-target triggering as incidental to the main aim, have been limited. Previous studies have documented corvids, feral cats and varanids pulling, triggering or dismantling ejector devices, but fatality has been recorded only for cats and canids in Australia (Connolly 1988; Gil-Fernández et al. 2021; Hunt 2010; Kreplins et al. 2021; van Polanen Petel et al. 2004; van Polanen Petel et al. 2001; Young et al. 2024; F. Gigliotti, unpubl. data, as cited in van Polanen Petel et al. 2004). These have mostly been undertaken using uncollared CPEs. Nicholson and Gigliotti (2005) designed but did not trial an alternative collar for CPEs that exploited differences in head morphology between foxes, and the Spotted-tailed Quoll and Tasmanian Devil, but not Dingoes or domestic dogs. The addition of a collar surrounding the lure head has been shown to limit access to the lure head to foxes while excluding Dingoes and Wild Dogs (Young et al. 2024).

Field research undertaken from 2005 to 2010 by DECCW Pest Management Unit (Hunt 2010) with 99,190 (891 non-lethal, 10,520 cyanide and 87,779 1080) uncollared ejector night presentations across seven monitoring periods identified consistent activation of ejectors by Wild Dogs and foxes with very few non-target activations. A combination of animal signs on sand plots at ejector sites, remote cameras, and carcass recovery were used to assess target and non-target activations of uncollared CPEs. Brush-tailed Possums were the primary non-target species interacting with ejectors during the field trials. Five Brush-tailed Possum carcasses (1.7% of visits to a cyanide ejector, n=10520 nights) were retrieved. Single lethal activations were recorded for one goanna (*Varanid* sp., 1,050 cyanide nights) and one Black Wallaby (*Wallabia bicolor)* (3,510 cyanide nights; 0.3% of recorded visits).

Hunt (2010) also undertook a small trial investigating the potential impact on Spotted-tailed Quolls. They reported on uncollared ejector deployments over 28 nights, where ejectors were spaced at 500 m intervals with two ejectors per site, each containing 0.2 ml (6 mg) of 1080, giving a possible total of 1008 ejector night presentations. Over the 28 nights, Spotted-tailed Quolls were identified from remote camera images as being present within < 1 m of an ejector on five occasions at different locations, with no activations recorded.

In a study assessing the required pulling force to trigger an ejector, Marks and Wilson (2005) found that an ejector trigger force of 26.46 N was needed for foxes of > 3 kg to set off an ejector. This pull force excluded 26 of 31 native species that were considered to have the potential to set off an ejector. At their heaviest recorded weight, Spotted-tailed Quolls were estimated to be able to exert a pull force capable of triggering a CPE. However, these trials were conducted on pull force only and did not assess species' ability to access collared CPEs. In addition, Marks and Wilson (2005) noted that several other factors would influence the risk of non-target species, such as the animal's ability to firmly grasp the lure head. Future work should specifically investigate the risk to Spotted-tailed Quolls in Victoria.

14 Cultural and social considerations of managing European Rabbits, Feral Pigs, Red Foxes and Dingoes and Wild Dogs

Although social and cultural considerations are connected to humaneness and animal welfare (with the latter being an expression of societies cultural values), they have been presented separately in this review for clarity. The humaneness and animal welfare implications of using 1080, along with lethal and non-lethal alternatives are reviewed in Section's 15 and 12.

Social and cultural factors are themselves also interconnected. The term 'social' encompasses a broad spectrum of human experiences at both individual and collective levels, affecting families, groups, communities, and society as a whole (Vanclay 2002). The way culture is defined is diverse and rarely agreed upon in the literature. Kroeber and Kluckhohn (1952, cited in Spencer-Oatey 2012), critically reviewed concepts and definitions of culture, and compiled a list of 164 different definitions. Broadly, culture has been defined as a way of life of a group of people – the behaviours, beliefs, values, and symbols that they accept, generally without thinking about them, and that are passed along by communication and imitation from one generation to the next, although this is far from the definitive definition.

We acknowledge that Indigenous Australians' views on introduced species are diverse, nuanced, and dynamic (Seebens 2024; Vaarzon-Morel and Edwards 2012), and that the relationship between Indigenous Australians and Dingoes is particularly significant. We discovered very little reference material in the published literature that discusses indigenous Australia's relationship with Dingoes. How the use of 1080 and its alternatives impact on cultural values is a specialised, complex and nuanced topic, and an in-depth analysis and review was beyond the scope of this report.

For the purposes of this review, we focused on the potential social impacts of lethal control for the management of the four pest species. Social impacts can refer to changes in various aspects of life, including lifestyle, community cohesion, the physical environment, economic structures, and overall physical, and psychological wellbeing. These impacts can be felt at the individual or local-community level, affecting neighbouring properties or a community of land managers.

The social impact of pest animal control has received little attention in Australia, with no studies or reports found specifically addressing the social impact of using 1080, or alternative lethal or non-lethal control options. The literature that exists focuses on the social impacts of the pest species and not the impacts of the tools.

In a reassessment of the use of 1080 in New Zealand (Environmental Risk Management Authority 2007), the benefits to society of using 1080 were identified as being a reduced concern about native ecosystem degradation, benefits to farming communities from reduced incidences of Bovine Tuberculosis, and enhanced enjoyment of recreational activities that rely on healthy forests and native biodiversity. The reassessment also identified several effects of using 1080 on society and communities. These were the loss of opportunity to hunt because of reduced deer and pig populations; anxiety resulting from disagreement between pest control agencies and the hunting community about the best way to manage pests; and concern for the welfare of target and non-target animals exposed to 1080. The assessment also identified several positive and negative effects on Māori society.

While no studies in Australia were found to assess the social impact of the use of 1080, it is reasonable to assume similar potential impacts. As noted above, Indigenous Australian's highly value Dingoes because they are part of dreamtime stories, and the impacts on traditional owner social values arising from the destruction of Dingoes can be significant. In a review and case study of the social impacts of invasive animals in Australia, Fitzgerald and Wilkinson (2009) allude to the social impact of using control tools indirectly by stating that the increasing diversity of rural land use and rural residents may also cause intracommunity conflicts. Based on interviews with a range of stakeholders, they found that the main challenges faced by the agriculture sector in managing pest species included 'interference' in farming by urban-based interests (such as animal welfarists and environmentalists — who are often opposed to the use of toxins), and adapting to the changing nature of the rural population, with increases in smallholdings and hobby farms (and with them, a greater diversity of values and attitudes towards farming and community — and attendant conflicts).

The social dimensions of using different pest management tools are complex, with wide-ranging impacts on individuals and communities. Future work should explore the social impacts of using lethal control options and how transitioning to non-lethal methods might mitigate the impacts while respecting cultural values and enhancing community wellbeing. The influence of social media and other communication platforms has on the social licence to use lethal and non-lethal control tools is also an area with little quantitative information.

15 Humaneness and animal welfare issues when managing European Rabbits, Feral Pigs, Red Foxes, and Dingoes and Wild Dogs

Animal welfare is a consideration of the social licence for activities or operations that involve the management or use of animals (Hampton et al. 2020) including lethal control of wild animals in biosecurity contexts (von Esson and Redmalm 2023)

A model for assessing welfare/humaneness was developed to be applicable to the range of lethal and non-lethal pest animal control techniques used in Australia (Sharp and Saunders 2011). In this context, the term 'animal welfare' covers a complex construct including objective and subjective aspects of the physical and mental well-being of animals, while the term 'humaneness' of a pest animal control method relates to minimising pain and reducing time to death wherever possible. The model uses scientific and technical information combined with expert opinion to assess the negative impacts that a control method has on an animal's welfare and, if a lethal method, how the animal is killed. The assessment of overall animal welfare impact is based on five domains:

1. Thirst/hunger/malnutrition
2. Environmental challenge
3. Injury/disease/functional impairment
4. Behavioural/interactive restriction
5. Anxiety/fear/pain/distress.

Under the Sharp and Saunders (2011) model, humaneness of a pest animal control method refers to the overall welfare impact that the method has on an individual animal rated from 1–8, with higher numbers representing increased welfare impacts prior to death. The model assessment process also considers the impacts of a control method on the suffering experienced by the affected animals rated from A–G. Combining these ratings is used to determine an overall humaneness score. The model was not designed to provide an absolute measure of humaneness but allows comparisons of relative humaneness among different control methods. There is no one pest control method that does not have some sort of impact on an animal. However, a relatively more humane method will have less impact than a relatively less humane method.

The application of the model process produces a 'humaneness matrix' which represents a relative humaneness score for vertebrate pest species (https://pestsmart.org.au/). We have summarised the outcome of the model process in Table 12 to show the relative difference in overall humaneness score of other control methods compared to 1080.

Table 12. Relative humaneness scores derived using the Sharp and Saunders (2011) model process to assess lethal control methods for European Rabbits, foxes, Feral Pigs, and Dingoes and Wild Dogs.

Higher numbers – increasing welfare impact, ascending letters – increased suffering. Red – relatively more welfare impact and suffering compared to 1080, Green – relatively less welfare impact and suffering compared to 1080. NA – method not applicable.

Species	1080	PAPP	Sodium Nitrite	Pindone	Warren ripping	Warren Fumigation	Biocontrol (RHDV-K5)	Shooting	Trapping	CPE
European Rabbit	1D-1E	NA	NA	1G	3F	Chloropicrin - 3F Phosphine - 3D	1E-1F	Head – 2A Chest – 1A	NA	NA
Feral Pig	1E-1F	NA	1D	NA	NA	NA	NA	Head (ground) – 2A Chest (ground) – 2D Chest (aerial) – 4B	4A	NA
Red Fox	1E-1F	1C-1D	NA	NA	NA	3A-3C	NA	Head – 2A Chest – 2D	Cage (with shooting) – 4B Leg-hold (with shooting) – 5B	1E-1F
Dingoes and Wild dogs	1E-1F	1C-1D	NA	NA	NA	NA	NA	Head – 2A Chest – 2D	Cage (with shooting) – 4A Leg-hold (with shooting) – 5B	1E-1F

15.1 Toxic baiting

Welfare impacts of toxicants used in pest animal control have received increasing research attention in the past two decades (e.g. Beausoleil et al. 2016). There has been a particular focus on the humaneness of 1080, in both social discourse and formal research efforts (e.g. Sherley 2007; Twigg and Parker 2010). This focus may be due to various factors including the relatively long history of operational use of 1080 in Australia and New Zealand, the range of vertebrate pest species it is used to control, and its well-documented risk in the unintentional poisoning of domestic dogs (e.g. Zeven et al. 2023).

Development and registration of PAPP and sodium nitrite formulations was motivated, in part at least, by a need for effective alternatives to 1080, with lower animal welfare impacts for targeted animals (e.g. Fleming et al. 2006; Cowled et al. 2008). Application of the Sharp and Saunders (2011) model allows an assessment of the relative humaneness for compounds that have different modes of toxic action.

15.1.1 1080

After ingestion by an animal, fluoroacetate (the toxic principle of 1080) undergoes metabolic conversion to fluorocitrate. There is a variable latent period (30 min to 3 hrs in mammals) between the time fluoroacetate is ingested and signs of poisoning first appear. This is assumed to be the time required for fluoroacetate to be absorbed, to penetrate cells, be metabolised to fluorocitrate in mitochondria and then begin to disrupt cellular processes. The latent period is likely to be associated with minimal pain or distress (e.g. Marks et al. 2000).

Fluorocitrate inhibits the tricarboxylic acid cycle (TCA) enzyme aconitase and mitochondrial citrate transport. The resulting block in the TCA cycle, and the inhibition of citrate transport mechanisms, ultimately result in the accumulation of citrate in the tissues and plasma, energy deprivation and death (Beausoleil et al. 2010). The earliest effects of 1080 poisoning appear to occur in cells or organs with high energy demands, e.g. cardiac muscle. Death is likely a multifactorial event and includes the occurrence of neurotoxic effects in highly sensitive species (e.g. canids). The neurotoxic effects of fluorocitrate may result from citrate as an inhibitor of the production of acetylcholine, the main neurotransmitter involved in the communication between muscles and their associated nerve junctions (Beausoleil et al. 2010).

As a generalised observation of signs of 1080 poisoning, herbivores experience cardiac failure, whereas carnivores experience central nervous system (CNS) disturbances and convulsions and die of respiratory failure. Some species, usually omnivores such as pigs, can be equally affected by both CNS and cardiac signs. After the onset of clinical signs when there is little or no CNS disturbance, it is likely that they could experience distress, confusion, anxiety and pain (Marks et al. 2000). In the later stages, when severe CNS dysfunction has developed, it is unknown if animals are perceiving pain. 1080 impairs neurological function (including some pain receptors), so it is difficult to interpret the behaviour of affected animals, or to assess their ability to experience discomfort and pain (Twigg and Parker 2010). Perception of pain by an animal requires that it is conscious, and it is difficult to assess if 1080-affected animals are conscious after collapse and during convulsive episodes (Sherley 2007). If animals are conscious during the convulsive episodes or if they become conscious afterwards, it is possible that they may experience pain and/or anxiety.

As the latent period of 1080 poisoning is variable between species and between individual animals, so too is the time to death. However, the humaneness score for 1080 is the same across species (Table 13). In an experimental study of foxes dosed with 1080 in meat baits, there was a mean time of 4.05 hours between dosage and onset of clinical signs, and a mean of 1.57 hours from the onset of clinical signs until death (Marks et al. 2000). McIlroy (1982) reported latent periods in rabbits of 1.1–10.1 hours and times to death of 3.0–44.3 hours. In pigs, first signs of poisoning appeared within 1.9–47.3 hours of dosing with 1080 and deaths occurred 2.8–80.0 hours afterwards (McIlroy 1983). A study involving oral dosing of Dingoes with 1080 recorded latent periods of 4.8–14.6 hours and time until death in the range of 5.3–10.8 hours (McIlroy 1981).

15.1.2 PAPP

With PAPP, insensibility only occurs just prior to death and the period from collapse to death can be variable. During the period from collapse to insensibility, when poisoned canids are incapacitated, they are potentially vulnerable to a range of welfare impacts such as predation, injury, environmental exposure, and distress resulting from not being able to perform normal behaviours. The longer this period of vulnerability, the more severe the welfare impact prior to death.

As described in the national SOPs for Wild Dogs (https://pestsmart.org.au/toolkit-resource/baiting-of-wild-dogs-with-papp/) and foxes (https://pestsmart.org.au/toolkit-resource/baiting-of-foxes-with-para-aminopropiophenone-papp/), there is a lag period before signs of toxicosis such as lethargy, ataxia (difficulty maintaining balance), salivation and increased heart rate are observed following the ingestion of PAPP. As methaemoglobin levels increase, cyanosis—blue colouration of the mucous membranes due to deoxygenated haemoglobin in blood vessels near the skin surface—becomes evident, particularly around the tongue and gums. Although, the duration of the lag phase, duration and severity of symptoms and time to death can be variable.

In a pen study of 10 foxes, the average lag period lasted for approximately 40 minutes, clinical signs were present for around an hour and average time to death was around 1.5 hours (Marks et al. 2004). In another captive trial, three of four foxes died within 3 hours after PAPP administration; the mean time to unconsciousness was 78 minutes and mean time to death was 121 minutes (Allen 2019). No behavioural signs of poisoning were observed in these foxes before death.

As reported by Allen (2019), ten of 11 Wild Dogs in controlled trials died within 3 hours after PAPP administration. The mean time to unconsciousness was 65 minutes and mean time to death was 84 minutes. Signs of distress and anxiety between the time of PAPP administration and unconsciousness were also observed in all 11 Wild Dogs, and some animals appeared to drop in and out of consciousness as symptoms progressed. All affected dogs were observed to vocalise (a laboured high-pitch howl) before running out of breath. Leg paddling occurred in five dogs and excessive salivation in some instances.

Documentation of 13 suspected clinical cases of non-target PAPP toxicity of domestic dogs in Victoria described acute collapse, vomiting and cyanotic or brown mucous membranes as the most common presenting signs. All dogs received antidotal treatment of intravenous methylene blue with a mean hospitalisation time of 1.6 days and a 77% survival to discharge (Llewellyn et al. 2025). The relative humaneness score for PAPP is lower than for 1080 (Table 13Table 12).

15.1.3 Sodium nitrite

Sodium nitrite was developed as a toxicant for Feral Pig control to exploit pigs' susceptibility to methaemoglobin-forming compounds (most likely related to their low levels of methaemoglobin reductase), and as a potentially more humane alternative to 1080 (Cowled et al. 2008). Pen trials with pigs showed that lethal ingestions of sodium nitrite caused rapid and lethal rises in methaemoglobin, with death occurring within 80 minutes of the onset of clinical signs. The progression of sodium nitrite toxicosis in pigs was initial lethargy, in-coordination and reduced consciousness, with limited vomiting in some animals, an increased respiratory rate with severe dyspnoea when close to death and limited terminal seizures before coma and death (Cowled et al. 2008).

The overall humaneness score for sodium nitrite in Feral Pigs is 1D which is relatively lower than for 1080 (Table 13) (https://pestsmart.org.au/wp-content/uploads/sites/3/2020/07/pig_baiting_sodium_nitrite.pdf).

15.1.4 Pindone

Pindone formulations have been registered for rabbit management in Australia since the 1980s. Pindone is one chemical in a wider group of anticoagulant compounds referred to as 'anticoagulants' and commonly used as rodenticides. Anticoagulants work to inhibit the metabolism of vitamin K in the liver of mammals and birds, reducing the production of factors essential for blood coagulation. Following a toxic dose of anticoagulants, the blood cannot clot normally, and this eventually leads to haemorrhaging. Death through anticoagulant poisoning is generally caused by extensive internal bleeding. Veterinarians can (usually) successfully treat animals showing signs of anticoagulant poisoning, through delivery of Vitamin K.

After pindone baits are eaten, there is a variable 'lag' period of up to 11 days when there may be no, or only mild welfare impacts. This delayed onset reflects the time required to deplete existing stores of vitamin K and blood-clotting factors. After the lag period, blood clotting becomes impaired and the normal daily damage to blood vessels can no longer be repaired. Rabbits show changes in behaviour and progress through increasing levels of functional impairment – while still conscious – until death occurs around 1–4 days later. Therefore, in rabbits that receive multiple small doses of pindone, the time to death is around 10–14 days after the initial dose. Affected rabbits will experience lethargy, laboured breathing, weakness and anorexia as well as pain and discomfort from local haemorrhages in multiple sites such as internal organs, muscles and joints. They die from multiple causes associated with anaemia or from hypovolemic shock due to severe blood loss (Fisher et al. 2015).

The overall humaneness score for pindone in rabbits is 1G and is relatively higher than for 1080 (Table 13) (https://pestsmart.org.au/wp-content/uploads/sites/3/2020/07/rabbit_baiting_pindone.pdf).

15.2 Den and warren fumigation

Fumigation involves the introduction of toxic gas into a warren or den to reach lethal concentrations, where it is inhaled by target animals (rabbit or foxes) to cause death. Typically, diffusion fumigation is used where a formulation (tablet or cartridge) is placed inside the warren, activated to produce the fumigant gas and then sealed within the warren. There is potential for non-target animals that are occupying warrens or dens at the time of fumigation to also be affected.

The 2024 1080 user survey (Quantum Market Research 2024) found that 11% of land managers who controlled rabbits used 'warren fumigation' as a primary control method, but the survey did not distinguish between use of chloropicrin and phosphine. Relative humaneness scores have been summarised for fumigants in Table 13.

15.2.1 Phosphine (rabbit warrens)

Exposure to high concentrations of phosphine in vertebrates leads to a profound fall in blood pressure followed by death. Lower concentrations cause pulmonary oedema, which may result in death but occurs over a longer duration. Signs in rabbits after collapse include gasping, convulsions and paddling (Gigliotti et al. 2009).

Time to onset of symptoms is variable because the spread of gas through a warren relies on diffusion. Time to death (from when tablets are placed in a warren) is on average 225 minutes. If the concentration of phosphine is high, there will be a relatively short duration of severe signs prior to death. At lower concentrations, the animal is likely to suffer for longer. For example, at concentrations of 400 ppm phosphine can kill rabbits in 30 minutes, whereas at 25 ppm death can take 4 hours (Gigliotti et al. 2009).

The time taken to reach high concentrations throughout the warren largely depends on the amount of moisture in the soil and air, or on the tablets. In low humidity, complete release of phosphine gas from the tablets may take hours or even days. Higher humidity will cause a rapid rate of diffusion and therefore result in higher concentrations of gas so that the rabbit will be exposed to a lethal dose in a shorter time and will have less chance to dig out of the warren.

As per the national SOP for rabbit warren fumigation (https://pestsmart.org.au/toolkit-resource/diffusion-fumigation-of-rabbit-warrens/) phosphine is currently the preferred toxin for diffusion fumigation until more humane methods are developed. Phosphine is relatively less humane compared to 1080 (Table 13).

15.2.2 Chloropicrin (rabbit warrens)

Chloropicrin causes intense irritation of the respiratory tract with death resulting from pulmonary oedema, bronchopneumonia or bronchiolitis obliterans (a condition referred to as 'popcorn lung').

Initial signs of toxicosis include rapid blinking, nose twitching, distress vocalisations and laboured breathing and signs prior to collapse include profuse lacrimal (eye and tear duct) and nasal discharge, congested breathing and uncoordinated paddling (Marks 2009). Signs before death are variable, with some rabbits remaining hunched and immobile for up to an hour before death (Gigliotti et al. 2009). Time to death is 70–95 minutes when power fumigation with chloropicrin is used (Gigliotti et al. 2009). However, there can be wide variation in time to death (from 5–135 minutes) for rabbits depending on the exposure concentration of chloropicrin, with higher concentrations associated with shorter times to death (Gleeson and Maguire 1957). Exposure to chloropicrin that is not acutely lethal may cause a protracted death over hours or days (Marks 2009).

As per the national SOP for rabbit warren fumigation (https://pestsmart.org.au/toolkit-resource/diffusion-fumigation-of-rabbit-warrens/), chloropicrin (trichloronitromethane) is considered to be inhumane (Table 13Table 12) and its use is not recommended. Whether chloropicrin is still applied as a rabbit fumigant in Victoria is not known, although any use is expected to be minor and limited.

15.2.3 Carbon monoxide (fox dens)

With den fumigation, the time to unconsciousness and death depends on factors such as CO concentration (influenced by size of den, porosity of the soil in the den, full or incomplete combustion of the cartridge) and animal age. Neonatal animals are relatively resistant to hypoxia and may therefore take longer to become unconscious and die than adult animals.

Hypoxia induced by CO has been considered to induce unconsciousness without pain or discomfort, but a range of animal studies have reported short periods of anxiety followed by vocalisation and agitation that could occur prior to loss of consciousness. Muscular convulsions and spasms may be also observed but these are thought to occur after the animal has become unconscious. During a study with rabbits, some animals showed signs of agitation and most exhibited lethargy, stupor, shallow breathing and uncoordinated movement prior to collapse (Gigliotti et al. 2009). If animals are exposed to sub-lethal levels there may be neurological (e.g. reduced vision, blindness) or cardiac effects depending on the degree of anoxia experienced. Therefore, it is essential to achieve lethal concentrations. To reduce suffering prior to death, it is recommended that fumigation should seek to ensure exposure to concentrations greater than 1% and to gradually increase concentrations to prevent the onset of convulsions.

The national SOP (https://pestsmart.org.au/toolkit-resource/fumigation-of-fox-dens-using-carbon-monoxide/) states that carbon monoxide fumigation appears to be a humane method (Table 13) of fox destruction provided that high enough concentrations of CO to bring about a rapid death can be introduced into the den; that cubs are sufficiently grown to be fully susceptible to the effects of CO; and, that animals are not exposed to high temperatures during combustion of the cartridges.

15.3 Rabbit warren ripping

Ripping causes a warren to collapse, and the rabbits are usually crushed or suffocate. The weight of the soil prevents effective movement of the rabbit's diaphragm resulting in asphyxia. Welfare outcomes of ripping are optimised when the number of rabbits in the warren is low and when powerful machinery is used to achieve complete disintegration of the warren, so that the rabbits are killed quickly.

Direct wounding of rabbits in the warren can occur from the ripping tines. If rabbits are found that are injured but not killed, these must be destroyed by a shot to the brain or by cervical dislocation. Failure to cause complete collapse in deep warren systems may result in some rabbits becoming trapped in partly destroyed tunnels and then suffocating or starving over a long period of time. Ripping also affects rabbits that are not inside the warren at the time by depriving them of shelter from extreme heat, cold and predators.

Under best practice conditions, the overall humaneness score of rabbit warren ripping is 3F (https://pestsmart.org.au/wp-content/uploads/sites/3/2020/07/rabbit_warren_destruction_ripping.pdf), considered relatively less humane than 1080, primary due to the risk of suffering from caused by incomplete disintegration of warrens and the impact on rabbits not inside at the time of ripping.

15.4 Biological control (for rabbits)

RHDV1 (the Czech strain released in 1996 and K5 strain released in 2017) is considered a more humane method than Myxoma Virus (released in 1950), because the extremely high virulence of RHDV1 results in a short course of disease. RHDV1 kills susceptible rabbits between 36 and 72 hours after infection, with typical clinical signs of fever and lethargy (Strive and Cox 2019). Ambient temperature influences the time to death from RHDV, with lower temperatures associated with shorter time to death (Cooke and Berman 2000).

There could be severe suffering for a short period (minutes) just prior to death for some rabbits (although it is not clear whether they are conscious at this time). In the peracute form of the disease, rabbits die suddenly without previous clinical sign within a few hours of the incubation period. In the acute form, animals perish after a short period of disease (1–3 days), with convulsions and signs of suffocation. Shortly before death opisthotonus (a condition in which the body is held in an abnormal posture with the body rigid, the head thrown backward and the back is severely arched), sudden crying, and uncoordinated movements or paddling of the limbs may occur (Mitro and Krauss 1993).

The overall humaneness score for RHDV1 in rabbits is 1F-G (https://pestsmart.org.au/wp-content/uploads/sites/3/2020/07/rabbit_bait_delivery_RHDV-1.pdf), which is comparable to 1080 (Table 13).

15.5 Livestock guardian animals

The use of LGAs to protect livestock from predation by Wild Dogs/Dingoes and foxes is not assessed using the Sharp and Saunders (2011) model because it is regarded as a non-lethal method. However, LGDs have been reported to injure or kill a range of predator species, and guardian Llamas have also been documented to kill or injure predators (Allen et al. 2019). Harassment of wildlife by LGDs appears common, particularly medium-to-large-sized animals that are perceived as threats to livestock.

To assess the animal welfare impacts of introducing predators like LGDs, (Allen et al. 2019) used the 'Five Domains' model, first developed by (Mellor and Reid 1994). This approach assigns lethal and non-lethal animal control tools an overall 'humaneness score' that enables their animal welfare impacts to be assessed, allowing them to be compared to other potential tools. (Allen et al. 2019) found that guardian dogs can cause considerable lethal and non-lethal animal welfare impacts to the individual animals they are intended to control. They also note that LDGs themselves can be harassed or killed by Dingoes (Allen et al. 2016).

15.6 Fencing

The most direct impact of fencing on animal welfare is entanglement and effective snaring of wildlife in fences (Smith et al. 2020) often resulting in death (Allen and Hampton 2020) of entangled animals. Likely causes of death for entangled animals include injury, hyper/hypothermia or thirst, which all represent potentially high animal welfare impacts. Reports of entanglement of non-target species are far more common than for the target species (which a fence is intended to exclude) and affect a wide variety of species across the world, most often migrating and wide-ranging species, reptiles and low-flying birds (Smith et al. 2020). Barbed wire has been identified as a particular feature associated with entanglement of Australian wildlife (van der Ree 1999). The extent and welfare impact of entanglement associated with exclusion fencing for pest animal management has not been well researched.

15.7 Shooting (for all species)

Shot placement is a critical determinant of the welfare outcomes of shooting as a pest animal control method. A bullet strike to the upper portion of the central nervous system (head) is the only certain method of delivering an instantaneous death, and while not instantaneous, rapid death through massive blood loss can be induced through severe disruption of vital organs and blood vessels in the thorax (Smith and Ryeng 2022).

Shot placement either at the head or chest is among the ‘best practice’ requirements under which shooting is considered a humane method for rabbits, foxes, Feral Pigs and Wild Dogs/Dingoes. Other best practice requirements include shooting be conducted by suitably licenced and skilled shooters using appropriate firearms and ammunition for the target animals, in situations where targets can be clearly identified and are within range of the firearm.

The highest potential for poor animal welfare as a direct result of shooting is through unintentional wounding of targeted animals, and when the lactating female animals are shot leaving dependent young without maternal care. Best practice shooting operations require that wounded animals be located and killed (shot) as quickly as practicable, and that if a shot animal is found to be lactating then efforts are made to find and kill any dependent young as quickly as practicable.

Detailed best practice requirements for shooting as a control method for a range of pest animal species are described in SOPs on the Pestsmart website https://pestsmart.org.au/. Assuming that best practice in accordance with these SOPs is followed, humaneness scores derived using the (Sharp and Saunders 2011) model process for ground shooting are summarised in Table 13. In general, head shot placement had slightly lower (more humane) scores than chest shot placement, and both are relatively more humane than 1080 poisoning.

Rabbit shooting programs in south-eastern Australia were assessed for animal welfare outcomes by estimating three critical parameters in shot rabbits: apparent time to death (ATTD); instantaneous death rate (IDR); and wounding rate (WR) (Hampton et al. 2015). The mean IDR was 0.60, ATTD was 12 s and WR was 0.12. A large proportion of rabbits (0.75) were shot in the cranium or thorax, as required by the national SOP (Sharp 2016). The probability of rabbits being wounded and missed increased with shooting distance, indicating that reducing shooting distances would likely improve animal welfare outcomes of shooting programs. There appears to have been no similar, field-based assessments of animal welfare impacts for shooting foxes, Feral Pigs or Wild Dogs/Dingoes in Australia.

There is generalised evidence that disturbance through hunting (with firearms) can affect wildlife movements (Doherty et al. 2021), and that hunting can alter wildlife behaviour, population structure, and distribution patterns (Knight and Cole 1995). The potential for pest animal shooting programs to have indirect animal welfare impacts through disturbance of non-target animals is not well studied in Australia. However national SOPs outline best practice to minimise unwanted animal welfare impacts through disturbance to livestock e.g. ‘*shooting should be used with caution around lambing paddocks as it may disturb the lambing flock and cause mismothering. Also avoid paddocks containing horses or deer. They are easily frightened by spotlights and gunshots and may injure themselves by running into fences and other obstacles*’.

15.8 Trapping

In Victoria, confinement traps are the only trap type used for Feral Pig control but are not typically used to control Dingoes and Wild Dogs. Confinement traps for fox or rabbit control are appropriate in situations where it is essential to release captured non-target animals unharmed e.g. urban settings. Leg-hold traps (or containment traps) are smooth jawed, spring-operated traps designed to capture an animal by the foot or leg. They are used for control of Wild Dogs/Dingoes, foxes and less commonly for rabbits. From an animal welfare perspective, the sale, setting, and use of traps in Victoria are regulated under the POCTA Act and Prevention of Cruelty to Animals Regulations 2019 (POCTA Regulations).

Regardless of trap type, some level of welfare impact is expected to result from trapping – wild animals experience at least some distress from restraint or confinement (Allen et al. 2022). In this context, an important determinant of welfare impacts is the time a live animal spends in the trap, during which it can potentially suffer from distress or shock, injury through attempting to escape, exposure, thirst, starvation and vulnerability to attack by other animals. Best practice measures to minimise these potential impacts include inspection of traps at least once daily and placement of traps to protect from extremes of the immediate environment. Trapped animals should be approached carefully and quietly to minimise panic, further stress and risk of injury.

Shooting at close range is the best practice method for killing a trapped Feral Pig, Fox or Wild Dog/Dingo, with shot placement aimed to destroy the major centres at the back of the brain near the spinal cord (head shot). For trapped rabbits or pigs under 5 kg, concussive force to the head is the most appropriate killing method.

The Pestsmart website https://pestsmart.org.au/ provides best practice trapping SOPs for each species and trap type. Assuming that best practice in accordance with these SOPs is followed, the model approach (Sharp and Saunders 2011) has been applied to assess the relative humaneness of trapping methods for a range of vertebrate species (e.g. Beausoleil et al. 2022), with relative humaneness scores summarised for containment and leghold traps (Table 13). Confinement traps (cage traps with shooting) are scored somewhat more humane than 1080 poisoning while leg-hold traps are scored less humane than 1080 poisoning.

15.8.1 Confinement traps

Confinement traps generally cause fewer injuries than leghold traps. The greatest potential for a trapped animal to be injured in a confinement trap is during any frantic attempts to escape. Elements of trap design, such as smaller wire mesh diameter and absence of protrusions can assist to reduce the potential for such injuries. An important feature of confinement traps is that non-target captures can usually be released unharmed.

15.8.2 Leghold traps

Leg-hold traps used in Victoria must have rubber-like padding on each jaw to cushion the initial impact and provide friction, which prevents the captured leg from sliding along or out of the jaws. Design features to reduce potential injury include offsetting of the trap jaws leaving a specified small gap between the metal parts when closed, and a spring and swivels in the anchor chain to reduce momentum and potential for twisting and entanglement. However, it is recognised that even best practice use of leg-hold traps can cause serious injuries to both target and non-target animals. These typically include swelling and lacerations to the foot from the pressure of the trap jaws, and dislocation of a limb if the animal struggles to escape. Welfare impacts of leghold traps have increasingly been addressed in published science literature worldwide (e.g. Lossa et al. 2007; de Ridder et al. 2024; Meek et al. 2020).

15.8.3 Trap alert systems

In Victoria, traps applied for fox, rabbit, Feral Pig or Wild Dog/Dingo management must be physically inspected at least once every 24 hours. Trap alert systems (e.g. Meek et al. 2020; Martin 2022) are a relatively recent technological development aimed at improving efficacy and welfare outcomes for trapped animals by reducing the time that animals spend caught in a trap. These systems utilise electronic sensors on the trap and communication networks to send real-time notifications to a trapper when a trap is sprung, allowing for prompt, targeted inspection and servicing of the trap. In late 2024, DEECA, through Vertebrate Species Management Officers (VSMOs), implemented a satellite-based trap monitoring system for leghold trapping activities in eastern Victoria regions. Pending a full operational analysis, initial results are promising for reliability of alerts and improved welfare outcomes in terms of reduced time in traps for captured animals.

15.8.4 Lethal trap devices for canid leg-hold trapping

As defined under the POCTA Regulations 2019, a lethal trap device (LTD) is 'a device attached to a trap that contains a lethal substance for the purposes of causing the rapid death of trapped target animals through ingestion of the substance'. LTDs in Australia can be applied on leghold traps used for fox and Wild Dog control, comprising a toxicant applied to cloth wraps around one jaw of the trap. Wild Dogs and foxes typically bite at the trap once they are captured, which can result in a lethal ingestion of the toxicant, reducing the time that the animal experiences the effects of being trapped.

Strychnine is a registered toxicant for use in LTD but is not used in Victoria. PAPP has recently been registered as 'PAPPutty™ (a formulation for application to cloth used as an LTD) and may be used in Victoria under Minister approval. It is considered a more humane toxicant than strychnine, and field assessment of PAPPutty has shown that over 85% of trapped Wild Dogs ingested a lethal exposure of PAPP (Meek et al. 2019). There appears to have not been any uses of PAPPutty in leghold trapping for foxes or Wild Dogs/Dingoes in Victoria. Formal assessment of the welfare impact of leg-hold trapping combined with PAPPutty has not yet been completed.

16 Environmental impacts of managing European Rabbits, Feral Pigs, Red Foxes and Dingoes and Wild Dogs

Social license to operate (SLO) relates to community acceptance (or not) of activities conducted as the legitimate business of an agency or organisation. Negative externalities can factor into the status and maintenance of social licence (Dumbrell et al. 2020). For pest animal management practices, these externalities potentially include animal welfare and impacts on natural environments.

Where pest animal management practices are shown (or even perceived) to cause pollution of water, soil or air, biodiversity loss or land degradation (Dumbrell et al. 2021), this may decrease community acceptance.

16.1 Toxic baiting

16.1.1 1080

Label instructions for 1080 products typically include specifications to prevent toxic bait from entering bodies of water. 1080 is highly water soluble (Atzert 1971) so if baits are exposed to water (for example through rainfall or being moved by an animal), any toxin that leaches from the baits into water will be rapidly diluted and dispersed (e.g. Suren 2006). Parfitt et al. (1994) found that 1080 was degraded in biologically active water in 2–6 days, and Eason et al. (1993) showed that 1080 concentrations placed in aquaria containing plants and invertebrates declined by approximately 70% in 1 day and to below detectable limits in 4 days.

1080 is biodegraded by a range of micro-organisms, including bacteria and fungi, that are naturally present in soil (Gentle and Cother 2014). The major microbial degradation pathway for 1080 in soil is to the hydroxyl metabolite, hydroxyacetic acid, and mineralisation to carbon dioxide as the major transformation product (Northcott et al. 2014). Temperature, rather than soil type or moisture content, appears to be the dominant factor affecting the rate of degradation, with the rate of degradation being more rapid at higher temperatures. A laboratory trial measured the transformation half-life of 1080 in three soil types, which increased with decreasing temperature, varying from 6–8 d at 20 °C, 10–21 d at 10 °C, and 22–43 d at 5 °C (Northcott et al. 2014).

A range of studies have shown that sub-lethal exposures of 1080 are readily metabolised and excreted by mammals, such that residual concentrations are cleared from living animals within a few days. Consequently, 1080 is not considered to be bioaccumulative through food webs. In possums that have been sub-lethally poisoned, 1080 has a half-life of 9 hours, suggesting no significant amount of 1080 would be expected in the tissues of live possums 4 days after exposure (Eason et al. 2012).

1080 has the potential for secondary exposure of scavengers feeding on the carcasses of poisoned animals, with the highest risk of a lethal secondary exposure for relatively sensitive species such as dogs and cats. When other species, such as insects or birds, come into contact with 1080 through scavenging poisoned carcasses, sub-lethal poisoning, further biodegradation, and limited trophic transfer are the likely outcomes because insects and birds are less sensitive to 1080 than dogs (Eason et al. 2012).

Degradation of residual 1080 concentrations in carcasses is facilitated by various processes including microbial defluorination of fluoroacetate, leaching of 1080 from the carcass into the soil, and/or tissue autolysis (Eason et al. 2012). The degradation rate of residual 1080 in carcasses is expected to be most rapid under relatively warm and wet environmental conditions, and slower under dry and/or cold conditions (Eason et al. 2012).

16.1.2 PAPP

An evaluation undertaken by the Australian Pesticides and Veterinary Medicine Authority (APVMA 2015) noted that PAPP is moderately soluble in water, while its hydrochloride salt (PAPP-HCl) is much more water soluble. The physicochemical properties of PAPP indicate it is likely to be mobile in soil; in soil-leaching studies, PAPP appeared to absorb to clay components of soil but was very mobile in sand and to a lesser extent in sandy loam. The physicochemical properties of PAPP indicate it is unlikely to bioaccumulate, while a modelling approach indicated it was slightly bioconcentrating. PAPP and PAPP-HCl are both hydrolytically stable at pH’s of 4, 7 and 9. From the limited information summarised by (Eason et al. 2014), PAPP-HCl is likely to be leached from bait exposed to rainfall and to be mobile (in solution) through soil. It is reported to be biodegradable by microorganisms and to have low toxicity to soil invertebrates, though further details are not provided.

A field assessment was made of the degradation of PAPP in bait types used for fox and Wild Dog control in Australia (Gentle et al. 2017). Baits were placed in three treatments (buried, surface or storage) and sampled at eight intervals over 25 weeks. Analysis of stored baits showed they were shelf-stable, retaining ~90% of the original loading of PAPP at 25 weeks. Buried baits degraded more quickly than surface laid baits over 25 weeks, with surface laid baits retaining effective lethal amounts of PAPP (for a Wild Dog) for approximately 16 weeks and buried baits for approximately 8 weeks. Consequently, although PAPP is considered biodegradable (APVMA 2015), in some bait formulations it can remain toxic relatively longer for several weeks.

The (APVMA 2015) evaluation noted data from necropsy of foxes killed by PAPP poisoning, where stomach contents and the gastrointestinal tract retained 'quite high' (concentrations not specified) residual concentrations of unmetabolised PAPP. The high residual concentrations in the stomach were presumed to reflect the localised remnants of the pill used to administer the PAPP dose. Of the scavenger species that might consume tissues from the carcasses of animals poisoned by PAPP, goannas are potentially at risk of a lethal secondary exposure if they consume gastrointestinal tissue containing relatively high residual concentrations of the poison.

While the rate of degradation of residual PAPP in the carcasses of poisoned animals is not known, it is expected to be relatively rapid (within days) based on the results of laboratory assessments of biodegradability. PAPP is not expected to persist in the environment or bioaccumulate (APVMA 2015).

16.1.3 Pindone

Pindone acid and pindone sodium are both used as bait concentrates for preparing oat or carrot baits for rabbit control. Baits prepared from pindone sodium may be expected to lose the toxicant more rapidly under wet conditions because the sodium salt is water-soluble, although the acid and salt forms of pindone are essentially equivalent in oral toxicity (National Registration Authority 2002).

Limited information is available about dispersal and degradation of pindone in natural environments (NRA 2000). Photodegradation (through exposure to sunlight) has been proposed as a likely pathway for the detoxification of uneaten pindone baits over time, but this remains to be demonstrated in formal research. From the limited information available about similar anticoagulant compounds (such as diphacinone and chlorophacinone), residual pindone leaching from bait into soil would be expected to remain localised and to degrade at a moderate rate (with a likely half-life in the order of a month) (National Registration Authority 2002).

In rabbits that have ingested pindone but not died of poisoning, residual concentrations in liver tissue will decrease over a period of days (if no further exposure to pindone occurs). Based on data from other mammal species, it is expected that rabbits sub-lethally exposed to pindone will metabolise and excrete residual concentrations within 10 days. In rabbits that have died of pindone poisoning, unmetabolised residual pindone will be present in most soft tissues, with highest concentrations likely in liver and fat tissue. The degradation rate of residual pindone in rabbit carcasses has not been evaluated (Fisher et al. 2015).

Predatory or scavenging wildlife that eat rabbits, have potential for multiple, consecutive secondary exposures to pindone following rabbit baiting programs, depending on the likelihood of them consuming sufficient prey to attain lethal concentrations of the toxin before it degrades. This is the scenario most likely to result in secondary non-target mortality, rather than a single instance of scavenging. The extent to which such mortality occurs is not well described. Pindone has lower toxicity than 1080 for dogs and cats, so overall presents a lower risk of secondary poisoning for domestic pets.

16.1.4 Sodium nitrite

Sodium nitrite is an inorganic salt that does not bioaccumulate and is very mobile in the environment (Gad 2024). An environmental assessment of sodium nitrite, as applied in the HOGGONE bait formulation for Feral Pig control, was carried out by the United States Department of Agriculture (USDA 2019). The assessment outlined expected environmental pathways and the fate for sodium nitrite; it does not adhere well to soil particles and remains as a particulate in the air pockets in soil because it is not volatile. In the air (both above the soil and within the soil) sodium nitrite gradually oxidizes to nitrate. In water, sodium nitrite immediately dissociates into sodium and nitrite ions which easily oxidise to nitrate, and nitrate is the more predominant compound of the two detected in groundwater.

Nitrate and nitrite are likely to remain in water until consumed by plants or other organisms. Biodegradation of nitrite in the environment occurs when bacteria oxidise nitrites to nitrates. Then, anaerobic bacteria present in soil and sediment reduce nitrates to nitrogen, which is then absorbed into the nitrogen cycle. Bioconcentration or bioaccumulation of nitrite is not expected for residues that could occur in aquatic systems. Nitrite is highly soluble, which is not typical for compounds that may accumulate in aquatic biota (USDA 2019).

Sublethal intake of sodium nitrite is rapidly eliminated in living animals. The blood half-life in various species is measured in only minutes (Gad 2024). For example, in rats orally dosed with 80 mg/kg of sodium nitrite, peak plasma concentrations were achieved at 30 mins after dosing and these decreased to below the limit of detection after 8 hours (Shapiro et al. 2018). The potential secondary poisoning risks of sodium nitrite for dogs, cats and chickens in captive trials were assessed as minimal (Shapiro et al. 2018).

16.2 Den and warren fumigation

Rabbit warren or fox den fumigation involves the identification of all entrances to a warren/den system so that these can be dug in and blocked immediately after the application of the fumigant. Best practice application of a fumigant product within warrens or dens confines the release of the formulation or combustion byproducts to the air within the den and the surrounding soil or substrate. These below-ground use patterns of fumigants preclude significant exposure of non-target terrestrial species that do not use burrows, and of aquatic species.

16.2.1 Phosphine (for rabbit warrens)

Phosphine gas is the active chemical produced by metal phosphide products (Phostoxin, Gastion or Magtoxin) available in Victoria for rabbit warren fumigation. These formulations are sold as pellets/tablets of aluminium, calcium or magnesium phosphide mixed with inert ingredients such as ammonium carbonate from which phosphine has evolved by a reaction with water (added at application to warrens). The potential flammability hazard of generated phosphine is minimised by these formulations releasing the gas slowly to allow safe dilution with the surrounding air (Ryan and De Lima 2013). Unreacted tablets or their residues left in warrens represent a localised, time-limited toxic environmental hazard if they cannot be recovered and disposed of appropriately – however, phosphine itself and the solid forms of zinc, magnesium, and aluminium phosphides are recognised as inherently degradable and not considered persistent in the environment.

Phosphine is normally undetectable in air, water, or soil. Phosphine in air reacts with HO radicals and is removed by this mechanism with a half time of 5–28 h. Phosphine in air is slowly absorbed by soil at a rate that is dependent on surface effects and the permeability of the soil matrix and is slower in wet conditions. Aluminium and magnesium phosphides are rapidly hydrolysed in neutral moist conditions. Phosphides ultimately become inorganic phosphate, water, and metallic compounds (World Health Organisation 1988).

16.2.2 Chloropicrin (for rabbit warrens)

Chloropicrin (product name Larvacide) is the common name for trichloronitromethane, a colourless liquid that has high volatility to produce toxic gases such as nitrogen oxides, phosgene, nitrosyl chloride, chlorine, and carbon monoxide. Its most common use, globally, is in agricultural and production settings as a soil fumigant to control microorganisms (European Food Safety Authority (EFSA) et al. 2020). Australia appears to be the only country that uses chloropicrin as a registered fumigant for rabbit control.

Chloropicrin is stable to hydrolysis in neutral aqueous solution and is only slightly soluble in water, so will not move rapidly in aquatic environments (Extoxnet 1996). It is expected to have high mobility in soil, and volatilisation from moist soil surfaces or from water is likely an important pathway for environmental dissipation. Biodegradation and exposure to light (photolysis) of chloropicrin in soil and water is likely to be a major degradation pathway (Extoxnet 1996; Raman 2014).

16.2.3 Carbon monoxide (for fox dens)

The registered fox den fumigation product DEN-CO-FUME is a cardboard tube with cardboard end caps, filled with approximately 240 g of materials that produce carbon monoxide (CO) when ignited. A 50 cm fuse is inserted in one end of the cartridge. Fumigation cartridges that produce CO typically contain the active ingredients, sodium nitrate and charcoal, and other inert ingredients. Sodium nitrate in gas cartridges supports the combustion of the charcoal, which emits carbon monoxide under combustion. After combustion of the gas cartridge, the byproducts are Na_2CO_3 (a solid), CO and nitrogen gas.

The fate of CO inside burrows/dens is inhalation by target animals, uptake by soil microorganisms, or entry into various environmental carbon cycles (e.g. via conversion to carbon dioxide or fixation by bacteria). Any nitrogen gas produced as a byproduct of combustion spreads into the surrounding air and does not produce a biological hazard. The secondary risk to nontarget animals that may eat animals asphyxiated with CO is nil because carbon monoxide adsorption and movement within the target animal presents no risk (Lemay and Hall 2017).

16.3 Rabbit warren ripping

Rabbit warrens typically disrupt soil structure and decrease vegetation to create localised areas of unstable and more readily erodible soil. Disturbance of Aboriginal cultural heritage sites and potential impacts on waterways are localised environmental considerations for planning warren ripping programs.

While warren ripping itself creates significant disturbances of natural surface morphology and deeper soil structure along with removal of vegetation, in the longer term it can help to restabilise areas associated with extensive warren systems (Eldridge and Myers 2001). Germinable seed banks on ripped warrens can be dominated by weedy exotic species so that ripped areas are likely to have reduced vegetation diversity and structure in the following medium-long term (Eldridge et al. 2014).

Rabbit warrens can provide an important refuge and foraging resource for a range of other species (native and introduced), so warren ripping removes these resources from a localised environment (Dean et al. 2023). Where introduced species such as foxes and feral cats' benefit from the presence of rabbit warrens, ripping may help to decrease their impacts.

16.4 Biological control (for rabbits)

The viral biocontrol agents Myxoma Virus (MYXV) and Rabbit Haemorrhagic Disease Virus (RHDV1), released in 1950 and 1996 respectively, resulted in significant and lasting landscape-scale suppression of rabbit populations in Australia (Strive and Cox 2019). Multiple environmental benefits resulted, for example, in arid Australia the long-term reduction of rabbit populations and associated decline of introduced predators such as feral cats and foxes allowed for the recovery of some native species. Drastic reduction of rabbit grazing pressure benefitted graziers and facilitated the regeneration of tree and shrub species preferred by rabbits (Strive and Cox 2019).

Following their initial introduction, both viruses became endemic in Australia's wild rabbit populations, causing smaller but regular outbreaks at varying intervals. Long-term trends have shown that approximately one decade after the release of RHDV1, rabbit numbers gradually began to increase again (Strive and Cox 2019). To 'boost' rabbit biocontrol, an additional variant of RHDV1 ('K5') was recently released nationwide to counteract the decreasing effectiveness of RHDV1 and MYXV.

Two years prior to the K5 release, an exotic RHDV strain (RHDV2) appeared in Australia. The vaccine used to protect pet and farmed rabbits against the officially released K5, was ineffective against RHDV2, resulting in numerous deaths of domestic rabbits. RHDV2 has been reported to also infect and kill the European Brown Hare (*Lepus europeaus*), although the extent and environmental impacts relating to Australian (introduced) hare populations are not known.

16.5 Livestock guardian animals

A major factor in avoiding negative environmental effects of using LGAs is their containment to the property on which the guarded livestock are also confined. LGDs that develop unwanted behaviours such as excessive roaming or aggression (e.g. van Bommel and Johnson 2023) have potential environmental effects if they attack or kill non-target wildlife (e.g. Allen et al. 2019) or livestock on neighbouring properties. Use of Donkeys as livestock guardians (Rigg 2022) in Australian contexts could have negative environmental impacts if the Donkeys are not suitably contained on livestock properties, and they establish feral populations in new areas.

16.6 Fencing

Establishment and monitoring of exclusion fencing requires ground vehicle and/or foot access. Vegetation clearing and earthworks/soil disturbance are typically required to establish fences and thereafter maintain access for monitoring and repair of fencing. Combined with vehicle traffic, vegetation removal and access maintenance may represent non-negligible environmental impacts, especially for extensive or large-scale fencing.

Exclusion fencing is designed to prevent or limit the movement of a 'target' pest animal species into a protected area, but similarly affects the movements of non-target medium-to-large-sized wildlife in the area. (Smith et al. 2020) describes potential negative effects of fences on wildlife that are prevented access to resources in a fenced area including water, food or mates and breeding habitat. Nonetheless, there may also be some beneficial environmental effects of fencing in terms of protecting biodiversity within fenced areas.

Entanglement of non-target wildlife in exclusion fences (e.g. Smith et al. 2020) is an animal welfare issue (see Section 15), and potentially an environmental issue if entanglement mortality is frequent and sustained enough to affect localised populations of non-target wildlife outside the fences. Considerations of fence design features can mitigate entanglement risk for non-target species present in an area (e.g. Dowling et al. 2024).

In a review study, it was concluded that the effects of fences on their ecological surroundings are diverse, and that the same fence can be both environmentally beneficial and detrimental depending on species, scale and type of effect considered. In the context of establishing agricultural exclusion fencing in Australia, a priori environmental assessments of the potential environmental impacts are not usually undertaken (Smith et al. 2020).

16.7 Shooting (for all species)

Lead ammunition used for shooting contaminates soil, waterways and the tissues of shot animals. Carcasses of animals shot in pest control programs are not typically recovered for disposal, and in most cases are 'left to lie' in place. This creates pathways for exposure of wildlife to lead, particularly for species that eat carrion. There is also a lead exposure pathway for people and domestic animals that consume meat (e.g. rabbits or Feral Pigs) harvested by shooting (Hampton et al. 2018b). The environmental and human health risks of lead ammunition are widely recognised internationally but have only recently been subject to formal research scrutiny in Australia. For example, lead exposure has been confirmed in Wedge-tailed Eagles (Lohr et al. 2020) and in dogs used for hunting deer in Australia (Hampton et al. 2023).

Shot carcasses left to decompose in places where the public may encounter them create temporary environmental 'amenity' impacts (odour, visually distressing, insect attracting). Large-scale, repeated or intensive shooting programs, particularly aerial shooting of larger ungulates, potentially create a 'resource pulse' of carcasses for wildlife that scavenge (e.g. Dingoes, Spencer and Newsome 2021). The effects of such increased carcass availability on diet, movements or populations of scavengers have not been formally investigated in Victorian contexts.

Shooting is likely to constitute a localised/temporary disturbance to wildlife through the noise of firearm discharge, movement of vehicles (ground or aerial) and people on foot (ground shooting). There is generalised evidence that hunting (with firearms) is a disturbance that can affect the movements of wildlife, with human activities such as recreation and hunting having stronger impacts on animal movement than disturbances of habitat modification such as logging and agriculture (Doherty et al. 2021).

16.8 Trapping

Establishment and monitoring of animal traps require ground vehicle and/or foot access. Trap placement outside of established roads, tracks or pathways may require vegetation clearing and soil disturbance to maintain access, which combined with traffic may represent non-negligible environmental impacts if done over a large area.

Under Victorian legislation, established pest animal species (as declared under the CaLP Act including foxes, rabbits, Feral Pigs or Wild Dogs) that are live trapped must subsequently be destroyed. Trapping of these species in confinement or leg-hold traps is typically associated with shooting as the most common means of destruction.

Capture of non-target animals (wildlife) in traps set for pest animal management may have environmental impacts if non-targets are significantly injured by being trapped. In these instances, veterinary attention or euthanasia is required (under the Victorian Prevention of Cruelty to Animals Regulations 2019), which therefore has the environmental impact of removing individual non-targets from the local population. While best practice trapping techniques aim to minimise the incidence of serious injury to any non-target animals captured, the incidence of non-target captures and outcomes in pest animal trapping programs are not well described in Victoria.

17 Operator health and safety when managing European Rabbits, Feral Pigs, Red Foxes and Dingoes and Wild Dogs

In Victoria, SOPs available to Government employees and their agents for the control of all four established pest species outline the occupational health and safety issues and requirements for managing risk for each control measure. There are also National Standard Operating Procedures (NATSOPs, https://pestsmart.org.au/) that have been endorsed by the Environment and Invasives Committee 2024. These additionally describe the control techniques, their application, and strategies to minimise any harmful impacts when managing established pest animals in Australia.

In the context of this review, the health and safety of operators is considered for lethal control methods that require formal training. These include the use of Schedule 7 poisons and firearms.

For non-lethal techniques, OH&S is not formally reviewed, but it should be recognised by land mangers that using those techniques encompasses risks associated with the operational tasks (e.g. installation of fencing, operation of machinery). Products that can be purchased from commercial outlets (e.g. pindone for rabbit baiting or sodium nitrite for Feral Pig control) come with product use descriptions or other information that informs the users of the appropriate health and safety guidelines or directions.

Table 13 summaries the OH&S considerations identified in the NATSOPs for each of the lethal techniques for the control of each of the four pest species. Further information can be found at https://agriculture.vic.gov.au/ and https://pestsmart.org.au/.

Table 13. Occupational, health and safety considerations when using poisonous substances or other lethal control tools for the management of the four pest species.

Method	Occupational Health and Safety considerations
1080 (FOXOFF, DOGGONE, De-fox, De-K9 fresh and dried meat bait, capsules for use in candid pest ejectors, carrot and oat baits for rabbit control, PIGOUT/PIGOUT Econobait for the control of Feral Pigs)	1080 is a Schedule 7 poison (Dangerous Poisons) and is a restricted chemical product under Commonwealth legislation. The manufacture, sale and use of products containing 1080 is regulated. 1080 is highly toxic to humans and should be handled with care. Store prepared bait and 1080 concentrate in a labelled container in a locked cabinet away from children, animals and food. Do not handle 1080 where there is a risk of contaminating drinking water or foodstuff/feed intended for human or animal consumption. All 1080 use must comply with the Directions for the Use of 1080 and Papp Pest Animal Bait Products in Victoria and the product label. Users must hold an ACUP with a 1080 endorsement or be directly supervised by an appropriately authorised person. Operators using 1080 must strictly follow the directions on the approved label when preparing for use, using, storing, transporting or disposing of the pesticide. Bait containers should not be used for any other purpose and should be disposed of in accordance with the safe operating procedures. Additionally, Based on the concentration of 1080 residues recorded in pig tissues after poisoning, the risk to humans from harvesting and consuming pig tissue from poisoned carcasses is considered low, as long as the digestive tract is not consumed (Gentle et al. 2005; Snow et al. 2018). For further information, refer to the Material Safety Data Sheet (MSDS), available from the supplier.
PAPP (FOXECUTE, DOGABAIT)	PAPP is a Schedule 7 poison (Dangerous Poisons) and is a restricted chemical product under Commonwealth legislation. The manufacture, sale and use of products containing PAPP is regulated. PAPP baits can be harmful to humans if swallowed. Ingesting multiple baits may cause methaemoglobinaemia leading to anoxia, although the

Method	Occupational Health and Safety considerations
	lethal dose of PAPP (or levels of methaemoglobin) causing fatality for humans has not been positively established. PAPP use must comply with the Directions for the Use of 1080 and Papp Pest Animal Bait Products in Victoria and the product label. Users must hold an ACUP with a PAPP endorsement, or be directly supervised by an appropriately authorised person. Operators using PAPP baits must strictly follow the directions on the approved label when using, storing, transporting or disposing of the baits. Store bait in the original labelled container in a locked cabinet or room away from children, animals and food. Do not handle bait where there is a risk of contaminating drinking water or foodstuff/feed intended for human or animal consumption. Appropriate personal protective equipment, including trousers and long-sleeved shirts or overalls and chemical resistant gloves should be worn when handling PAPP baits.
Phosphine gas (diffusion fumigation with aluminium phosphide)	Aluminium Phosphide is a Schedule 7 poison, and an ACUP is required to purchase and use it. Schedule 7 poisons can only be used by the holder of an ACUP or under the direct supervision of an ACUP holder. Operators must strictly follow the directions on the approved label when using and storing aluminium phosphide tablets. They must not be used for any other purpose than the destruction of rabbits in active warrens. Fumigation must always be carried out by two trained persons and must not be carried out in wet conditions when it is likely that the tablets will become wet before insertion in the burrows. Phosphine is highly toxic to humans and can kill if the tablets are swallowed or the liberated gas is inhaled. Avoid contacting the skin with aluminium phosphide or breathing phosphine gas. For further information, refer to the MSDS, available from the supplier.
Shooting (ground-based and aerial shooting)	***Ground-based shooting*** All participants in a ground-based shooting programme must stand well behind the shooter when an animal is being shot. The line of fire must be chosen to prevent accidents or injury from stray bullets or ricochets. Shooting from a vehicle is potentially dangerous. An agreed safety procedure between the shooter and others in the vehicle must be in place to ensure that people do not enter the field of fire or disturb the taking of a shot. Firearm users must strictly observe all relevant safety guidelines relating to firearm ownership, possession and use. Firearms must be securely stored in a compartment that meets state legal requirements. Ammunition must be stored in a locked container separate from firearms. Adequate hearing protection should be worn by the shooter and others in the immediate vicinity of the shooter. Repeated exposure to firearm noise can cause irreversible hearing damage. Safety glasses are recommended to protect eyes from gases, metal fragments and other particles. Feral Pigs – Care must be taken when handling pig carcasses because they may carry diseases such as leptospirosis, Q fever, brucellosis, sparganosis, melioidosis and tuberculosis that can affect humans and other animals. Carcasses can be heavy (>100 kg), so care must be taken when lifting/dragging.

Method	Occupational Health and Safety considerations
	Dingoes and Wild Dogs – Care must be taken when handling carcasses as they may carry diseases such as hydatidosis and sarcoptic mange that can affect humans and other animals. An animal with obvious mange should only be handled while wearing gloves. ***Aerial shooting*** Shooting from a helicopter can be hazardous, particularly in rugged areas. The combination of low-level flight, proximity to obstacles (trees, rocks, wires), and the use of firearms makes this activity high-risk. The risks are mitigated through: • adhering to an approved aerial shooting safety management plan or similar jurisdictional documents • appropriate training and experience of all personnel (helicopter crew and shooter) • approval from landholders to undertake shooting on their property, reminders to landholders of when the shooting will occur, and notifying neighbours • mapping of the shooting zone, buffers, and no-shoot zones • clear communication among flight crew • daily reviews of operations • risk assessments and operational reviews. Aerial shooting operations must comply with the CASA requirements and jurisdictional work, health and safety legislation. When not in use, firearms and ammunition must be securely stored in a manner that meets jurisdictional requirements. Firearms are not loaded until the helicopter is in the air and approval is given by the pilot. Approved helmets and hearing protection should be worn by the shooter and others in the helicopter. Safety glasses, or visors attached to the helmets, may be used to protect the eyes from gases and metal fragments.
Carbon monoxide (CO diffusion fumigation with cartridges or pressure fumigation) Alternatively, and preferably, the Den-Co-Fume® Fumigator can be used.	Exposure to carbon monoxide results in a deficiency of oxygen reaching the body, causing tissue damage to a range of organs including the brain and heart. A review of the scientific and medical literature showed that exposure of humans to CO concentrations of more than 1% caused loss of sensibility before any unpleasant effects or convulsions occurred (Stewart 1976). Exposure to concentrations of 0.5% or less caused some unpleasant effects, but only after 29 min (at 0.41%) or 120 min (at 0.12%). Appropriate controls for the emission, use, handling and storage of carbon monoxide gas will reduce the risk of hazardous exposures and illness in the workplace. Do not touch burning cartridges; they can cause severe burns. Once ignited the cartridge will burn vigorously for several minutes, creating a risk of fire in surrounding vegetation. This can be minimised by ensuring that the cartridges are inserted and lighted in-situ. The ingredients in the cartridge are harmless until ignited. Precautions must be taken to prevent unintentional ignition during storage, transport and use. For further information, refer to the MSDS, available from the supplier.

18 Summary

The toxin 1080 is widely used and relied upon by land managers in Victoria to effectively manage the economic, environmental, social and cultural impact of European Rabbits, Feral Pigs, foxes and Dingoes and Wild Dogs. However, there is ongoing community discourse on the non-target impacts and humaneness of 1080, and therefore a need to consider the use of other methods and their relative impacts.

1080 is a cost-effective tool for controlling populations of rabbits, Feral Pigs, foxes, and Dingoes and Wild Dogs. It has been demonstrated to reduce populations of all four pests, improving the status of threatened plant and animal species, reducing the economic burden on agriculture, and arresting social and cultural impacts. Best practice management protocols minimise potential off target impacts.

However, despite being in use for more than 70 years in Australia, there remains uncertainty around the cost-effectiveness of some applications, and issues regarding humanness and social acceptance persist.

Other lethal and non-lethal tools for controlling each of the four pest species are available, and to some degree address these issues. These methods can be alternatives but are often used as part of an integrated control program. The majority of 1080 users in Victoria who have used it to control rabbits (98%), foxes (89%), Feral Pigs (96%) or wild dogs (91%) report they have used other methods in the last 5 years.

Whether these other methods are as cost-effective as 1080 products can depend on the pest species and the context of the control operations. For rabbits, integrated control using combinations of poisoning with pindone, warren ripping and fumigation timed to coincide with outbreaks of RHDV can achieve long-lasting knockdown effects. However, pindone has potential non-target impacts, requires repeat applications to be effective, making it less cost-effective than 1080, and is relatively less humane than 1080. Successful rabbit control can be achieved without the use of pindone or 1080 under the right circumstances. While there are some data on the relative cost-effectiveness of other methods, more information is needed on integrating RHDV-K5 with non-toxic control methods.

For Feral Pigs, localised reduction in density to levels that reduce or cease agricultural and environmental damage is possible using combinations of trapping, aerial shooting and poisoning with sodium nitrite. However, this relies on a better understanding of the environmental and ecological conditions to apply these tools in Victoria, and the relative cost-effectiveness of various combinations of these tools. In situations where poisoning is the appropriate tool, sodium nitrite is emerging as a viable alternative to 1080, although it is a more expensive option at present, but is considered more humane than 1080. There is also concern that in the event of an emergency animal disease outbreak, e.g., African Swine Fever, supply of sodium nitrite may be limited, as there is only currently one manufacturer in Victoria.

For foxes, 1080 is currently the most cost-effective tool for managing their populations and mitigating their impacts on biodiversity. PAPP is a more humane alternative and seems to have a comparable knockdown rate – although little quantitative data are available to make broad generalisations and therefore, further investigation is needed. PAPP also has potentially broader non-target impacts, which may limit its use to specific times or seasons or places. Other methods are ineffective at landscape-scale control. However, coordinated localised use of shooting, or fencing with LGAs is a viable option in smaller-scale agricultural settings. This too requires a better understanding of the use of LGAs and the associated impacts they might have on native and pest species.

For Dingoes and Wild Dogs, the use of 1080 is part of an integrated management strategy. Alternative methods are applied in a coordinated cross tenure and integrated management approach, with 1080 used as a pro-active tool in ground- and (until recently) aerial bating operations. Large-scale fencing (connecting neighbouring properties) that is well maintained in combination with trapping, and on-farm management practices are part of the overall control strategy to reducing livestock attacks. However, there needs to be a significant and lasting contribution from Government to support the community. LGAs have been shown to be effective under specific circumstances but to date, have been used in combination with fencing and some form of lethal control. The use of LGAs, as for foxes, requires further assessment to improve our understanding of their relative impacts and benefits.

Adequate monitoring is critical to understanding the effectiveness of all control methods. Outside 'research projects', the required data to properly assess if the investment in pest control is achieving the necessary level of population reduction, are generally lacking. While there are some data from Victoria, these data are not consistently recorded or recorded in a format that is readily accessible. For example, in their review on pest animal control in Australia, Reddiex et al. (2006) found that monitoring of the pests occurred in 50–56% of control actions in which foxes and Dingo and Wild Dogs were targeted, but only 22–26% of control actions in which rabbits and Feral Pigs were targeted. Efficacy and ethics require that management be evidence-based, and evidence of the benefit is needed to justify ongoing control actions. Detailed cost-effectiveness data were not available or collected in a form that could be readily accessed for all the control options across the four pest species. This information is crucial in making informed decisions on the economic effectiveness of 1080 compared to lethal and non-lethal alternatives. Based on the literature that was available, alternatives and combinations of other methods are likely to be more costly and generally less effective than 1080.

A critical piece of information needed to cost-effectively manage pest animal damage is our understanding of the relationship between the pest's density and the level of damage caused, and if we can effectively and acceptably reduce and maintain pests to levels below a threshold density that allows for mitigation or reversal of the impact. If we cannot reach or exceed and maintain this level, we risk wasting scarce public and private resources and potentially creating unintended consequences (e.g. increases in pest species via compensatory breeding (Lazenby et al. 2014), and changes in vegetation from over-browsing by herbivores (Dexter et al. 2013). Presently there is a considerable lack of understanding of density and damage thresholds for each of the four pest species considered in this review. Some knowledge does exist for fox predation of rabbits, and rabbit and Feral Pig damage to native vegetation and crops, but it is far from general knowledge and generally does not include comparisons with alternative control methods. Outside of this fundamentally important concept, lies a raft of associated dependencies that add significantly to our ability (or not) to effectively manage these pest species.

The question of efficacy is related to issues of humaneness, animal welfare and societies' acceptance of lethal pest control. Ineffective control actions result in pointless suffering, with little or no welfare or conservation benefit for native animals, or reductions in impacts on agricultural enterprise. This also acts to further erode public acceptance of different control tools. To be effective, all control actions must reduce the population of harmful species enough to achieve a net benefit. They must also be cost-effective, and the level of pain of suffering needs to be acceptable to the broader community.

None of the other lethal or non-lethal options to the use of 1080 are without issues pertaining to humaneness, animal welfare, environmental or social and cultural impacts. Sharp and Saunders (2011) developed a model approach to assess the relative humaneness and welfare of pest animal control options, which allows land managers to make an informed decision about the relative humaneness of each method. While this provides a practical approach enabling land managers to assess the relative impacts of specific control measure, it does not address the fundamental question about the ethics of subjecting pest animals to some degree of pain and suffering to achieve a reduction in, or elimination of, the social, economic, cultural, and environmental impact of the pest animal. Depending on the target pest species and circumstances where their management is required, there may be limited choices of legal and appropriate control methods.

Resolving this ethical and moral dilemma is outside the scope of this review; however, it is an important consideration and drives a considerable amount of the debate surrounding the use of lethal and non-lethal control and the impact on non-target animals (De Ridder and Knight 2024; PETA 2024; RSPCA 2019). The impact of using 1080 and other methods on social and cultural values is understudied and requires further investigation.

19 Knowledge gaps

During the review, we identified knowledge gaps in our understanding of the effectiveness of lethal and non-lethal control tools, as well as the impact of social and cultural values on the use of pest control tools. Assessing humanness remains an area of diverse views. Below is a list of knowledge gaps identified during the review that, if filled, could improve our understanding of the effectiveness of pest management in Victoria. These are presented in order of the review topics. A subject matter expert elicitation process would enable ordering these into priority areas.

All species and combinations of control methods

- There is a general lack of detailed formation on the cost-effectiveness of methods, or combination of methods for all species, particularly in Victoria. While some information exists, it is either not in the right format or is not in easily assessable formats. Appendix A1 presents a list of data that could be captured operationally to assess the cost-effectiveness of different control tools for each of the four pest species.

European Rabbits

- It is unclear if RDHV-K5 can be effective except under very specific circumstances given the prevalence of RHDV2.
- Under what conditions can RHDV-K5 be effectively combined with warren ripping, fumigation and poisoning with either pindone or 1080.
- The impact of warren fumigation on non-target species in Australia.

Feral Pigs

- It is possible that Feral Pig carcasses pose a secondary non-target risk to Dingoes. There is no information currently available in the literature on the use of Feral Pig carcasses poisoned with 1080 by Dingoes.

Red Foxes

- An evaluation of factors influencing the likelihood of non-target species, particularly Spotted-tailed Quolls, interactions with CPEs.
- The effectiveness of PAPP-based ground baits for foxes.
- There is no quantitative information on the risk to Dingoes from various bait substrates use in fox control.

Dingoes and Wild Dogs

- The effectiveness of PAPP-based ground baits for Dingoes and Wild Dogs.
- PAPP has had limited large-scale deployment, leaving field assessments of non-target and broader ecological impacts underexplored.

LGAs

- Donkeys have been suggested as potential LGAs with some advantages over Alpacas and Llamas. However, there are no data on the cost-effectiveness of these compared to other LGAs, and under what conditions they could be effective in Victoria.

Non-lethal methods

- Livestock collars aim to protect against predation by limiting predators' ability to grip and kill. While initially effective due to predator unfamiliarity, long-term efficacy is uncertain given predator adaptability. Further research is necessary to evaluate the practicality and durability of such measures in diverse environments.

Social and cultural issues

- Specific studies on the social and cultural effects of transitioning from 1080 to alternative methods are lacking. This could include studies on the impact of social media on social licence to implement lethal and non-lethal control options.

- Future research should explore how the use of different control tools can mitigate impacts while respecting cultural values and enhancing community wellbeing.

References

Abrantes, J., Van Der Loo, W., Le Pendu, J., and Esteves, P.J. (2012). Rabbit haemorrhagic disease (RHD) and rabbit haemorrhagic disease virus (RHDV): a review. *Veterinary Research* **43**(1):12.

ACTA. (2024). HOGGONE® mesn feral pig bait. https://animalcontrol.com.au/products/hoggone.(accessed 25/1/2025).

Adams, P.J., Fontaine, J.B., Huston, R.M., and Fleming, P.A. (2019). Quantifying efficacy of feral pig (*Sus scrofa*) population management. *Wildlife Research* **46**(7):587. doi: 10.1071/WR18100.

Agriculture Victoria. (2024). Directions for the use of 1080 and PAPP pest animal bait products in Victoria. Victorian Government, Melbourne.

Allen, B.L., Allen, L.R., Ballard, G., Drouilly, M., Fleming, P.J.S., Hampton, J.O., Hayward, M.W., Kerley, G.I.H., Meek, P.D., Minnie, L., O'Riain, M. Justin, P., Daniel M., and Somers, M.J. (2019). Animal welfare considerations for using large carnivores and guardian dogs as vertebrate biocontrol tools against other animals. *Biological Conservation* **232**:258–70. doi: 10.1016/j.biocon.2019.02.019.

Allen, B.L., Allen, L.R., Engeman, R.M., and Leung, L.K-P. (2014). Sympatric prey responses to lethal top-predator control: predator manipulation experiments. *Frontiers in Zoology* **11**, 1–30.

Allen, B.L. (2019). Efficacy and strategic use of PAPP-based ejectors for the control of dingoes and foxes. Pp. 97–99 in *Proceedings of the 1st Queensland Pest Animal and Weed Symposium. Brisbane, Weed Society of Queensland Pty Ltd*.

Allen, B.L., Ballard, G., Fleming, P.J.S., Meek, P.D., and Smith, D. (2022). Improving animal welfare outcomes for live-trapped terrestrial mammals in Australia. Pp. 97–119 in *Mammal Trapping–Wildlife Management, Animal Welfare & International Standards*. Canada: Alpha Wildlife Publications.

Allen, L.R., Stewart-Moore, N., Byrne, D., and Allen, B.L. (2016). Guardian dogs protect sheep by guarding sheep, not by establishing territories and excluding predators. *Animal Production Science* **57**(6):1118–27.

Allen, L.R., Fleming, P.J.S., Thompson, J.A., and Strong, K. (1989). Effect of presentation on the attractiveness and palatability to wild dogs and other wildlife of two unpoisoned wild-dog bait types. *Australian Wildlife Research* **16**:593–98.

AMTC (2024). The AMTC Australian Mammal Species List. Version 4.2 https://australianmammals.org.au/publications/amtc-species-list. (Accessed 22/04/2025)

Andrewartha, T., Evans, M., Blencowe, A., Brewer, K., Gordon, I.J., and Manning, A.D. (2023). Landscapes of nausea: Successful conditioned taste aversion in a wild red fox population. *Conservation Science and Practice* **5(8), e12984**. doi:DOI: 10.1111/csp2.12984.

Appleby, R, Smith, B., Mackie, J., Bernede, L., and Jones, D. (2017). Preliminary observations of dingo responses to assumed aversive stimuli. *Pacific Conservation Biology* **23**:295–301.

Appleby, R., Smith, B., Bernede, L., and Jones, D. (2017). Utilising aversive conditioning to manage the behaviour of k'gari (Fraser Island) dingoes (*Canis dingo*). *Pacific Conservation Biology* **23**(4):335. doi: 10.1071/PC17017.

APVMA (2005). *The reconsideration of registrations of products containing sodium fluoroacetate (1080) and their associated labels. Environmental Assessment*. Australian Pesticides and Veterinary Medicines Authority, Kingston, ACT.

APVMA. (2015). *Public release summary on the evaluation of the new active 4-aminopropiophenone (also known as para-aminopropiophenone (PAPP)) in the products FoxeCute fox bait & PAPP wild dog bait: APVMA product numbers 65095 and 65094*. Australian Pesticides and Veterinary Medicines Authority, Kingston, ACT.

Atzert, S.P. (1971). *A review of sodium monofluoroacetate (Compound 1080), its properties, toxicology and use in predator and rodent control. Special Scientific Report - Wildlife No. 146*. U.S. Fish and Wildlife Service.

Ausband, D.E., Mitchell, M.S., Bassing, S.B., and White, C. (2013). No trespassing: using a biofence to manipulate wolf movements. *Wildlife Research* **40**(3):207. doi: 10.1071/WR12176.

Ballard, G., Fleming, P.J.S., Meek, P.D., and Doak, S. (2020). Aerial baiting and wild dog mortality in south-eastern Australia. *Wildlife Research* **47**(2):99–105. doi: 10.1071/WR18188.

Bangs, E, Jimenez, M., Niemeyer, C., Fontaine, J., Collinge, M., Krsichke, R., Handegard, L., Shivik, J., Sime, A., Nadeau, C., Mack, S., Smith, C., Douglas, W., Asher, V., and Stone, S. (2006). Non-lethal and lethal tools to manage wolf-livestock conflict in the northwestern united states. *Proceedings of the Vertebrate Pest Conference* 22. doi: 10.5070/V422110170.

Barlow, N.D., and Kean, J.M. (1998). Simple models for the impact of rabbit calicivirus disease (RCD) on Australasian rabbits. *Ecological Modelling* **109**(3):225–41. doi: 10.1016/S0304-3800(98)00009-X.

Baur, J., and English, A. (2011). *Conservation through hunting: an environmental paradigm changes in NSW*. Game Council NSW.

Belcher, C.A. (1998). Susceptibility of the tiger quoll, *Dasyurus maculatus*, and the eastern quoll, *D. viverrinus*, to 1080-poisoned baits in control programmes for vertebrate pests in eastern Australia. *Wildlife Research* **25**:33–40.

Bengsen, A.J. (2014). Effects of coordinated poison-baiting programs on survival and abundance in two red fox populations. *Wildlife Research* **41**(3):194–202. doi: 10.1071/WR13202.

Bengsen, A.J., Forsyth, D.M., Harris, S., Latham, D.M., McLeod, S.R., and Pople, A. (2020). A systematic review of ground-based shooting to control overabundant mammal populations. *Wildlife Research* **47**(3):197–207. doi: 10.1071/WR19129.

Bengsen, A.J., Leung, L.K.P., Lapidge, S.J., and Gordon, I.J. (2010). Developing target-specific baiting methods for feral pigs in an omnivore-rich community. *Proceedings of the Vertebrate Pest Conference* **24**. doi: 10.5070/V424110703.

Bengsen, A.J., Leung, L.K-P., Lapidge, S.J., and Gordon, I.J. (2011a). Target-specificity of feral pig baits under different conditions in a tropical rainforest. *Wildlife Research* **38**(5):370–79. doi: 10.1071/WR11023.

Bengsen, A.J., Leung, L.K-P., Lapidge, S.J., and Gordon, I.J. (2011b). Using a general index approach to analyse camera-trap abundance indices. *The Journal of Wildlife Management* **75**(5):1222–27. doi: 10.1002/jwmg.132.

Bengsen, A.J., and Sparkes, J. (2016). Can recreational hunting contribute to pest mammal control on public land in Australia? *Mammal Review* **46**(4):297–310. doi: 10.1111/mam.12070.

Bengsen, A.J., West, P., and Krull, C.R. (2017). Feral pigs in Australia and New Zealand: range, trend, management, and impacts of an invasive species. Pp. 325–38 in *Ecology, Conservation and Management of Wild Pigs and Peccaries*. Cambridge University Press.

Berman, D., Brennan, M., and Elsworth, P. (2011). How can warren destruction by ripping control European wild rabbits (*Oryctolagus cuniculus*) on large properties in the Australian arid zone? *Wildlife Research* **38**(1):77. doi: 10.1071/WR09178.

Berry, O., Algar, D., Angus, J., Hamilton, N., Hilmer, S., and Sutherland, D. (2012). Genetic tagging reveals a significant impact of poison baiting on an invasive species. *The Journal of Wildlife Management* **76**(4):729–39. doi: 10.1002/jwmg.295.

Bicknell, K. (1993). Cost-benefit and cost-effectiveness analyses in pest management. *New Zealand Journal of Zoology* **20**(4):307–12. doi: 10.1080/03014223.1993.10420349.

Bird, P, Mutze, G., Peacock, D., and Jennings, S. (2012). Damage caused by low-density exotic herbivore populations: the impact of introduced European rabbits on marsupial herbivores and *Allocasuarina* and *Bursaria* seedling survival in Australian coastal shrubland. *Biological Invasions* **14**(3):743–55. doi: 10.1007/s10530-011-0114-8.

Black, H.L., and Green, J.S. (1985). Navajo use of mixed-breed dogs for management of predators. *Journal of Range Management* **38**(1):11. doi: 10.2307/3899323.

Blinksell, G. (1985). Electric fencing to control wild dogs in New South Wales, Australia. in *Gallagher 2nd World Wildlife Power Fencing Seminar Proceedings*. Dubbo, N.S.W.

Bloomfield, T.E. (1999). *Foxes: integrated fox control.* Landcare Notes Series No PA0012. State of Victoria, Department of Natural Resources and Environment.

Boertje, R.D., Kelleyhouse, D.G., and Hayes, R.D. (1995). Methods of reducing natural predation on moose in Alaska and Yukon: an evaluation. Pp. 505–13 in *Ecology and Conservation of Wolves in a Changing World*, edited by L. N. Carbyn, S. H. Fritts, and D. R. Seip. Canadian Circumpolar Institute, University of Alberta, Canada.

Bomford, M., and Quentin, H. (2002). Non-indigenous vertebrates in Australia. Pp. 25–44 in *Biological Invasions: economic and environmental costs of alien plant, animal, and microbe species*. Boca Raton: CRC Press.

van Bommel, L. (2010). *Guardian Dogs: Best practice manual for the use of livestock guardian dogs*. Invasive Animals Cooperative Research Centre, Canberra, ACT.

van Bommel, L., and Johnson, C.N. (2012). Good dog! using livestock guardian dogs to protect livestock from predators in Australia's extensive grazing systems. *Wildlife Research* **39**(3):220–29. doi: http://dx.doi.org/10.1071/WR11135.

van Bommel, L, and Johnson, C.N. (2016). Livestock guardian dogs as surrogate top predators? how Maremma sheepdogs affect a wildlife community. *Ecology and Evolution* **6**(18):6702–11. doi: 10.1002/ece3.2412.

van Bommel, L., and Johnson, C.N. (2023). Still a good dog! long-term use and effectiveness of livestock guardian dogs to protect livestock from predators in Australia's extensive grazing systems. *Wildlife Research* **51**(1). doi: 10.1071/WR23008.

Boronyak L, and Quartermain, E. (2022). *Predator Smart Farming: Modernising Australia's approach to livestock protection*. Humane Society International Australia.

Boronyak, L., and Jacobs, B. (2023). Pathways to coexistence with dingoes across Australian farming landscapes. *Frontiers in Conservation Science* **4**:1126140. doi: 10.3389/fcosc.2023.1126140.

Bough, J. (2016). Our stubborn prejudice about donkeys is shifting as they protect Australia's sheep from wild dogs. *Australian Zoologist* **38**:17–25.

Breck, S.W., Williamson, R., Niemyer, C., and Shivik, J.A. (2002). *Non-lethal radio activated guard for deterring wolf depredation in Idaho: Summary and call for research*. Staff Publications. Paper 467. USDA National Wildlife Research Centre.

Breitenmoser, U., Angst, C., Landry, J-M., Breitenmoser-Würsten, C., Linnell, J.D.C., and Weber, J-M. (2005). *Non-lethal techniques for reducing depredation*. Pp. 49–71 in *People and Wildlife*, edited by R. Woodroffe, S. Thirgood, and A. Rabinowitz. Cambridge: Cambridge University Press.

Brunner, H. (1983). Bait acceptance by non-target mammal species in simulated rabbit poisoning trials. *Australian Wildlife Research* **10**:129–38.

Bryant, H., Hone, J., and Nicholls, P. (1984). The acceptance of dyed grain by feral pigs and birds i. birds. *Wildlife Research* **11**(3):509. doi: 10.1071/WR9840509.

Bubela, T., Bartell, R., and Müller, W. (1998). Factors affecting the trappability of Red Foxes in Kosciusko National Park. *Wildlife Research* **25**(2):199–208.

Burbidge, Andrew A., and McKenzie, N.L. (1989). Patterns in the modern decline of Western Australia's vertebrate fauna: causes and conservation implications. *Biological Conservation* **50**(1–4):143–98.

Burley, J.R.W. (1986). Advances in the integrated control of the European Rabbit in South Australia. in *12th Vertebrate Pest Conference*. Davis, California: University of California Press.

Burns, R.J., Zemlicka, D.E., and Savarie, P.J. (1996). Effectiveness of large livestock protection collars against depredating coyotes. *Wildlife Society Bulletin* **24**(1):123–27.

Burrows, N.D., Algar, D., Robinson, A.D., Sinagra, J., Ward, B., and Liddelow, G. (2003). Controlling introduced predators in the Gibson desert of Western Australia. *Journal of Arid Environments*.

Busana, F., Gigliotti, F., and Marks, C.A. (1998). Modified m-44 cyanide ejector for the baiting of Red Foxes (*vulpes vulpes*). *Wildlife Research* **25**(2):209–15.

Calenge, C., Mailard, D., Vassant, J., and Brandt, S. (2002). Summer and hunting season home ranges of wild boar (*Sus scrofa*) in two habitats in France. *Game & Wildlife Science* **19**(4):281–301.

Calenge, C., Maillard, D., Fournier, P., and Fouque, C. (2004). Efficiency of spreading maize in the garrigues to reduce wild boar (*Sus scrofa*) damage to mediterranean vineyards. *European Journal of Wildlife Research* **50**(3):112–20. doi: 10.1007/s10344-004-0047-y.

Caley, P. (1994). Factors affecting the success rate of traps for catching feral pigs in a tropical habitat. *Wildlife Research* **21**(3):287. doi: 10.1071/WR9940287.

Caley, P., and Ottley, B. (1995). The effectiveness of hunting dogs for removing feral pigs (sus scrofa). *Wildlife Research* **22**:147–54.

Campbell, T., Foster, J., Bodenchuk, M., Eisemann, J., Staples, L., and Lapidge, S. (2013). Effectiveness and target-specificity of a novel design of food dispenser to deliver a toxin to feral swine in the United States. *International Journal of Pest Management* **59**(3):197–204. doi: 10.1080/09670874.2013.815830.

Campbell, T.A., Bodenchuk, M.J., Eisemann, J.D., Lapidge, S.J., Staples, L., and Morrow. (2012). Preliminary assessment of the HogHopper[tm] for excluding non-target wildlife. in *Proceedings of the Vertebrate Pest Conference*. Vol. 25.

Campbell, T.A., Lapidge, S.J., and Long, D.B. (2006). Using baits to deliver pharmaceuticals to feral swine in southern Texas. *Wildlife Society Bulletin* **34**(4):1184–89. doi: 10.2193/0091-7648(2006)34[1184:UBTDPT]2.0.CO;2.

Campbell, T.A., and Long, D.B. (2009). Strawberry-flavoured baits for pharmaceutical delivery to feral swine. *The Journal of Wildlife Management* **73**(4):615–19. doi: 10.2193/2008-326.

Campbell, T.A., Long, D.B., and Leland, B.R. (2010). Feral swine behaviour relative to aerial gunning in southern Texas. *The Journal of Wildlife Management* **74**(2):337–41. doi: 10.2193/2009-131.

Carter, A., Luck, G.W., and McDonald, S.P. (2012). Ecology of the Red Fox (*vulpes vulpes*) in an agricultural landscape. 2. home range and movements. *Australian Mammalogy* **34**(2):175–87.

Castle, G., Kennedy, M.S., and Allen, B.L. (2023). Stuck in the mud: persistent failure of 'the science' to provide reliable information on the ecological roles of Australian dingoes. *Biological Conservation* **285**:110234. doi: 10.1016/j.biocon.2023.110234.

Caughley, G. (1980). *Analysis of vertebrate populations.* John Wiley and Sons: London.

Choquenot, D., Kilgour, R.J., and Lukins, B.S. (1993). An evaluation of feral pig trapping. *Wildlife Research* **20**(1):15. doi: 10.1071/WR9930015.

Choquenot, D., and Lukins, B. (1996). Effect of pasture availability on bait uptake by feral pigs in Australia's semi-arid rangelands. *Wildlife Research* **23**(4):421–28. doi: 10.1071/wr9960421.

Choquenot, D., McIlroy, J., and Korn, T. (1996). *Managing vertebrate pests: feral pigs*. Canberra, Australia: Bureau of Resource Sciences, Australian Government Publishing Service.

Choquenot, D., and Ruscoe, W. (1999). Assessing the effect of poisoning programs on the density of non-target fauna: design and interpretation. *New Zealand Journal of Ecology* **23**(2): 139-147.

Choquenot, D., Hone, J., and Saunders, G. (1999). Using aspects of predator-prey theory to evaluate helicopter shooting for feral pig control. *Wildlife Research* **26**(3):251–61. doi: 10.1071/WR98006.

Choquenot, D, Lukins, B., and Curran, G. (1997). Assessing lamb predation by feral pigs in Australia's semi-arid rangelands. *Journal of Applied Ecology* **14**: 45–54.

Claridge, A.W., Ballard, G., Körtner, G., Fleming, P.J.S., Forge, T., and Hine, A. (2021). Lethal control of eutherian predators via aerial baiting does not negatively affect female spotted-tailed quolls (*Dasyurus maculatus maculatus*) and their pouch young. *Wildlife Research* **48**(3):273–88.

Claridge, A.W., Cunningham, R.B., Catling, P.C., and Reid, A.M. (2010). Trends in the activity levels of forest-dwelling vertebrate fauna against a background of intensive baiting for foxes. *Forest Ecology and Management* **260**(5):822–32. doi: 10.1016/j.foreco.2010.05.041.

Claridge, A.W., and Mills, D.J. (2007). Aerial baiting for wild dogs has no observable impact on spotted-tailed quolls (*Dasyurus maculatus*) in a rain shadow woodland. *Wildlife Research* **34**:116–24.

Coman, B.J. (1992). Simulated rabies eradication: the lessons from two exercises in Victoria. Pp. 91–95 in *Wildlife Rabies Contingency Planning in Australia: Bureau of Rural Resources Proceedings*. Bureau of Rural Resources, Canberra.

Coman, B.J., and McCutchan, J. (1994). Predator Exclusion Fencing for Wildlife Management in Australia. A report to the Australian Nature Conservation Agency. Canberra.

Coman, J. (1988). The age structure of a sample of Red Foxes (*Vulpes vulpes*) taken by hunters in Victoria. *Australian Wildlife Research* **15**:223–29.

Commonwealth of Australia. (2021). The Australian Governments threatened species strategy 2021-2031.

Comte, S., Thomas, E., Bengsen, A.J., Bennett, A., Davis, N.E., Brown, D., and Forsyth, D.M. (2022). Cost-effectiveness of volunteer and contract ground-based shooting of sambar deer in Australia. *Wildlife Research* **50**(9):642–56. doi: 10.1071/WR22030.

Conejero, C., López-Olvera, J.R., González-Crespo, C., Ráez-Bravo, A., Castillo-Contreras, R., Tampach, S., Velarde, R., and Mentaberre, G. (2022). Assessing mammal trapping standards in wild boar drop-net capture. *Scientific Reports* **12**(1):15090. doi: 10.1038/s41598-022-17407-5.

Connolly, G. (1988). M-44 sodium cyanide ejectors in the animal damage control program, 1976-1986. in *Proceedings 13th Vertebrate Pest Conference*. University of California, Davis, California.

Connolly, G., and Simmons, G.D. (1984). Performance of sodium cyanide ejectors. Pp. 114–21 in *Proceedings 11th Vertebrate Pest Conference*. University of California, Davis, California.

Cooke, B.D. (1981). Rabbit control and the conservation of native mallee vegetation on roadsides in South Australia. *Wildlife Research* **8**(3):627. doi: 10.1071/WR9810627.

Cooke, B.D., and Fenner, F. (2002). Rabbit haemorrhagic disease and the biological control of wild rabbits, *Oryctolagus cuniculus*, in Australia and New Zealand. *Wildlife Research* **29**(6):689–706.

Cooke, B., Chudleigh, P., Simpson, S., and Saunders, G. (2013). The economic benefits of the biological control of rabbits in Australia, 1950–2011. *Australian Economic History Review* **53**(1):91–107. doi: 10.1111/aehr.12000.

Cooke, B.D. (2012). *Planning landscape-scale rabbit control*. *pestSmart Toolkit publication*. Invasive Animals Cooperative Research Centre, Canberra, Australia.

Cooke, B., Jones, R., and Gong, W. (2010). An economic decision model of wild rabbit *Oryctolagus cuniculus* control to conserve Australian native vegetation. *Wildlife Research* **37**(7):558. doi: 10.1071/WR09154.

Cooper, D., Larsen, E., and Shields, J. (2007). 1080 and wildlife: scientific and ethical issues raised by its use on Australian mammals. Pp. 229–32 in *Pest or Guest: The Zoology of Overabundance*, edited by D. Lunney, P. Eby, P. Hutchings, and S. Burgin. P.O. Box 20, Mosman NSW 2088, Australia: Royal Zoological Society of New South Wales.

Coppinger, R., Coppinger, L., Langeloh, G., Getiler, L., and Lorenz, J. (1988). A decade of use of livestock guarding dogs. Pp. 209–14 in *Proceedings of the 13th Vertebrate Pest Conference*, edited by A. C. Crabb and R. E. Marsh. University of California Press: Berkeley, CA, USA.

Corbett, L. (1974). 'Contributions to the biology of dingoes (*Carnivora: Canidae*) in Victoria.' MSc, Monash University, Clayton, Victoria.

Corbett, L.K. (1995). *The dingo in Australia and Asia*. University of New South Wales, Sydney, NSW: UNSW Press.

Cowled, B.D., Elsworth, P., and Lapidge, S.J. (2008). Additional toxins for feral pig (*Sus scrofa*) control: identifying and testing Achilles' heels. *Wildlife Research* **35**:651–62.

Cowled, B.D., Gifford, E., Smith, M., Staples, L., and Lapidge, S.J. (2006). Efficacy of manufactured PIGOUT® baits for localised control of feral pigs in the semi-arid Queensland rangelands. *Wildlife Research* **33**(5):427–37. doi: 10.1071/WR05083.

Cowled, B.D., Lapidge, S. J., Hampton, J.O., and Spencer, P.B.S. (2006). Measuring the demographic and genetic effects of pest control in a highly persecuted feral pig population. *Journal of Wildlife Management* **70**(6):1690–97. doi: 10.2193/0022-541X(2006)70[1690:MTDAGE]2.0.CO;2.

Cowled, B.D., Lapidge, S.J, Smith, M., and Staples, L. (2006). Attractiveness of a novel omnivore bait, PIGOUT ®, to feral pigs (*Sus scrofa*) and assessment of risks of bait uptake by non-target species. *Wildlife Research* **33**:651–60. doi: 10.1071/WR06054 1035-3712/06/080651.

Cox, T.E., Paine, D., O'Dwyer-Hall, E., Matthews, R., Blumson, T., Florance, B., Fielder, K., Tarran, M., Korcz, M., Wiebkin, A., Hamnett, P.W., Bradshaw, C.J.A., and Page, B. (2023). Thermal aerial culling for the control of vertebrate pest populations. *Scientific Reports* 13(1):1–12.

Cox, T.E., Ramsey, D.S.L., Sawyers, E., Campbell, S., Matthews, J., and 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):15229. doi: 10.1038/s41598-019-51847-w.

Darrow, P.A., and Shivik, J.A. (2009). Bold, shy, and persistent: variable coyote response to light and sound stimuli. *Applied Animal Behaviour Science* **116**:82–87. doi: 10.1016/j. applanim.2008.06.013.

Davis, A.J., Leland, B., Bodenchuk, M., VerCauteren, K.C., and Pepin, K.M. (2018). Costs and effectiveness of damage management of an overabundant species (*Sus scrofa*) using aerial gunning. *Wildlife Research* **45**(8):696. doi: 10.1071/WR17170.

De Ridder, N., and Knight, A. (2024). The animal welfare consequences and moral implications of lethal and non-lethal fox control methods. *Animals* **14**(11):1672. doi: 10.3390/ani14111672.

Dean, A.T., Brandle, R., Barmuta, L.A., Jones, M.E., and Jansen, J. (2023). Rabbit warrens: an important resource for invasive alien species in semi-arid Australia. *Wildlife Research* **51**(1). doi: 10.1071/WR22154.

DELWP. (2023). Flora and fauna guarantee act 1988 – potentially threatening processes list. Victorian Government.

Denham, A.J., and Auld, T.D. (2004). Survival and recruitment of seedlings and suckers of trees and shrubs of the Australian arid zone following habitat management and the outbreak of rabbit calicivirus disease (RCD). *Austral Ecology* **29**(5):585–99. doi: 10.1111/j.1442-9993.2004.01393.x.

Dennis, S.M. (1965). More light on lamb losses: third and final report of a survey of lamb mortalities in W.A. *Journal of the Department of Agriculture, Western Australia* 12:686–89.

Dexter, N. (1996). The effect of an intensive shooting exercise from a helicopter on the behaviour of surviving feral pigs. *Wildlife Research* **23**(4):435. doi: 10.1071/WR9960435.

Dexter, N., and Murray, A. (2009). The impact of fox control on the relative abundance of forest mammals in east Gippsland, Victoria. *Wildlife Research* **36**:252–61.

Dexter, N., Hudson, M., James, S., MacGregor, C., and Lindenmayer, D.B. (2013). Unintended consequences of invasive predator control in an Australian forest: overabundant wallabies and vegetation change. *PLoS ONE* **8**(8):e69087. doi: 10.1371/journal.pone.0069087.

Dexter, N., and Meek, P. (1998). An analysis of bait-take and non-target impacts during a fox-control exercise. *Wildlife Research* **25**(2):147. doi: 10.1071/WR97020.

Dickman, C.R. (2012). Fences or ferals? benefits and costs of conservation fencing in Australia. Pp. 43–63 in *Fencing for Conservation: Restriction of Evolutionary Potential or a Riposte to Threatening Processes?* Edited by M. J. Somers and M. W. Hayward. Springer Science & Business Media.

Dobrowolska, A., and Melosik, M. (2008). Bullet-derived lead in tissues of the wild boar (*Sus scrofa*) and red deer (*Cervus elaphus*). *European Journal of Wildlife Research* **54**(2):231–35. doi: 10.1007/s10344-007-0134-y.

Doherty, T.S., Hays, G.C., and Driscoll, D.A. (2021). Human disturbance causes widespread disruption of animal movement. *Nature Ecology and Evolution* **5**(4):513–19. doi: 10.1038/s41559-020-01380-1.

Doupé, R.G., Mitchell, J., Knott, M.J., Davis, A.M., and Lymbery, A.J. (2010). Efficacy of exclusion fencing to protect ephemeral floodplain lagoon habitats from feral pigs (*Sus scrofa*). *Wetlands Ecology and Management* **18**(1):69–78. doi: 10.1007/s11273-009-9149-3.

Dowling, J.M., Bower, D.S., Boscarino-Gaetano, R., and Nordberg, E.J. (2024). The influence of fence design on the movement patterns of eastern long-necked turtles. *The Journal of Wildlife Management* **88**(8):e22654. doi: 10.1002/jwmg.22654.

Drufke, N.K. (2000). ‘The use of llamas to protect goats, cattle, and poultry from canid predators. Master of Science, Iowa State University.

Dumbrell, N.P., Adamson, D., and Wheeler, S.A. (2020). Is social licence a response to government and market failures? evidence from the literature. *Resources Policy* **69**:101827.

Dumbrell, N.P., Adamson, D., Zuo, A., and Wheeler, S.A. (2021). How do natural resource dependent firms gain and lose a social licence? *Global Environmental Change* **70**:102355. doi: 10.1016/j.gloenvcha.2021.102355.

Eason, C.T., Miller, A., MacMorran, D.B., and Murphy, E.C. (2014). Toxicology and ecotoxicology of para-aminopropiophenone (PAPP) – a new predator control tool for stoats and feral cats in New Zealand. *New Zealand Journal of Ecology* **38**(2).

Eason, C.T., Gooneratne, R., Wright, G.R., Pierce, R., and Frampton, C.M. (1993). The fate of sodium monofluoroacetate (1080) in water, mammals, and invertebrates. Pp. 297–301 in. Rotorua: New Zealand Plant Protection Society.

Eason, C.T., Ross, J., and Miller, A. (2012). Secondary poisoning risks from 1080-poisoned carcasses and risk of trophic transfer—a review. *New Zealand Journal of Zoology* **40**:217–25. doi: 10.1080/03014223.2012.740488.

Edgar, J.P., Appleby, R.G., and Jones, D.N. (2007). Efficacy of an ultrasonic device as a deterrent to dingoes (*Canis lupus*): a preliminary investigation. *Journal of Ethology* **25**(2):209–2013.

van Eeden, L.M., Crowther, M.S., Dickman, C.R., Macdonald, D.W., Ripple, W.J., Ritchie, E.G., and Newsome, T.M. (2018). Managing conflict between large carnivores and livestock. *Conservation Biology* **32**(1):26–34. doi: 10.1111/cobi.12959.

van Eeden, L.M., Eklund, A., Miller, J.R.B., López-Bao, J.V., Chapron, G., Cejtin, M.R., Crowther, M.S., Dickman, C.R., Frank, J., Krofel, M., Macdonald, D.W., McManus, J., Meyer, T.K., Middleton, A.D., Newsome, T.M., Ripple, W.J., Ritchie, E.G., Schmitz, O.J., Stoner, K.J., Tourani, M., and Treves, A. (2018). Carnivore conservation needs evidence-based livestock protection. *PLOS Biology* **16**(9):e2005577. doi: 10.1371/journal.pbio.2005577.

Eklund, A., López-Bao, J.V., Tourani, M., Chapron, G., and Frank, J. (2017). Limited evidence on the effectiveness of interventions to reduce livestock predation by large carnivores. *Scientific Reports* **7**(1):2097. doi: 10.1038/s41598-017-02323-w.

Eldridge, D.J., and Myers, C.A. (2001). The impact of warrens of the European rabbit (*Oryctolagus cuniculus* l.) on soil and ecological processes in a semi-arid Australian woodland. *Journal of Arid Environments* **47**(3):325–37. doi: 10.1006/jare.2000.0685.

Eldridge, D.J., Costantinides, C., and Vine, A. (2014). A ripping yarn: the effect of rabbit warren ripping on plants and soil. Pp. 253–54 in *Proceedings of the Australia Rangelands Society Biennial Conference*. Australian Rangelands Society, Australia.

Eldridge, S.R., Berman, D.M., and Walsh, B. (2000). Field evaluation of four 1080 baits for dingo control. *Wildlife Research* **27**(5):495–500.

Ens, E.J., Daniels, C., Nelson, E., Roy, J., and Dixon, P. (2016). Creating multi-functional landscapes: using exclusion fences to frame feral ungulate management preferences in remote aboriginal-owned northern Australia. *Biological Conservation*.

Environmental Risk Management Authority. (2007). The reassessment of 1080. Department of Conservation, New Zealand. https://www.doc.govt.nz/about-us/statutory-and-advisory-bodies/nz-conservation-authority/submissions/1080-reassessment/

von Esson, E., and Redmalm, D. (2023). Social licence to cull: examining scepticism toward lethal wildlife removal in cities. *People and Nature* **5**(4):1353–63.

European Food Safety Authority (EFSA), et al. (2020). Peer review of the pesticide risk assessment of the active substance chloropicrin. *EFSA Journal* **18**(3). doi: 10.2903/j.efsa.2020.6028.

Extoxnet. (1996). National Pesticide Information Centre (NPIC) -chloropicrin profile. https://www.npic.orst.edu/factsheets/sfgen.html.

Fairbridge, D., and Marks, C.A. (2005). *Evaluation of the 2002-03 Victorian fox bounty trial*. Vertebrate Pest Research Unit, Department of Primary Industries, Victoria.

Fenner, S., Körtner, G., and Vernes, K. (2009). Aerial baiting with 1080 to control wild dogs does not affect the populations of two common small mammal species. *Wildlife Research* **36**(6):528. doi: 10.1071/WR08134.

Ferris, B. (2010). The 2008 - 2009 aerial feral pig and feral goat shooting program: a case study in northern New South Wales, Australia. *Proceedings of the Vertebrate Pest Conference* 24. doi: 10.5070/V424110611.

Finne, M.H., Kristiansen, P., Rolstad, J., and Wegge, P. (2019). Diversionary feeding of red fox in spring increased productivity of forest grouse in southeast Norway. *Wildlife Biology* **2019**(1): 1-12. doi: 10.2981/wlb.00492.

Fisher, P., Brown, S., and Arrow, J. (2015). Pindone residues in rabbit tissues: implications for secondary hazard and risk to non-target wildlife. *Wildlife Research* **42**(4):362. doi: 10.1071/WR15019.

Fitzgerald, G., and Wilkinson, R. (2009). *Assessing the social impacts of invasive animals in Australia*. *A report produced for the Invasive Animals Cooperative Research Centre*. Invasive Animals Cooperative Research Centre, Canberra.

Fleming, P., Dundas, S., Lau, Y., and Pluske, J. (2016). Predation by red foxes (*Vulpes vulpes*) at an outdoor piggery. *Animals* **6**(10):60. doi: 10.3390/ani6100060.

Fleming, P.J.S. (1997). Uptake of baits by red foxes (vulpes vulpes): implications for rabies contingency planning in Australia. *Wildlife Research* **24**(3):335. doi: 10.1071/WR95016.

Fleming, P.J.S., Allen, B.L., Allen, L.R., Ballard, G.A., Bengsen, A., Gentle, M., McLeod, L., Meek, P., and Saunders, G. (2014). Management of wild canids in Australia: free-ranging dogs and red foxes. Pp. 107–52 in *Carnivores of Australia*.

Fleming, P.J.S., Allen, L.R., Berghout, M.J., Meek, P.D., Pavlov, P.M., Stevens, P., Strong, K., Thompson, J.A., and Thomson, P.C. (1998). The performance of wild-canid traps in Australia: efficiency, selectivity and trap-related injuries. *Wildlife Research* **25**(3):327–38. doi: http://dx.doi.org/10.1071/WR95066.

Fleming, P.J.S., Choquenot, D., and Mason, R.J. (2000). Aerial baiting of feral pigs (*Sus scrofa*) for the control of exotic disease in the semi-arid rangelands of New South Wales. *Wildlife Research* **27**(5):531–37.

Fleming, P.J.S., Corbett, L., Harden, R., Thomson, P., and Bomford, M. (2001). *Managing the impacts of dingoes and other wild dogs*. Canberra: Bureau of Rural Sciences.

Fleming, P.J.S. (1996). Ground-placed baits for the control of wild dogs: evaluation of a replacement-baiting strategy in north-eastern New South Wales. *Wildlife Research* **23**:729–40.

Fleming, P.J.S., and Ballard, G. (2014). *An investigation of aerial baiting rates for strategic control of wild dogs: final report to biosecurity NSW, local land services and the Australian pesticides and veterinary medicines authority.* New South Wales Department of Primary Industries.

Fleming, P.J.S., and Ballard, G. (2019). Yes, killing is sometimes essential for conservation. *Australian Zoologist* **40**:5–12.

Fleming, P.J.S., Meek, P.D., and Allen, L.R. (1988). The performance of wild-canid traps in Australia: efficiency, selectivity and trap-related injuries. *Wildlife Research* **25**:327–38.

Fleming, P.J.S., and Parker, R.W. (1991). Temporal decline of 1080 within meat baits used for control of wild dogs in New South Wales. *Wildlife Research* **18**(6):729. doi: 10.1071/WR9910729.

Fleming, P.J.S., Thompson, J.A, and Nicol, H.I. (1996). Indices for measuring the efficacy of aerial baiting for wild dog control in north-eastern New South Wales. *Wildlife Research* **23**(6):665–74.

Fox, C. (2013). Coyotes, compassion conservation and coexistence. Pp. 119–24 in *Ignoring nature no more: the case for compassionate conservation.*, edited by M. Bekoff. London: University of Chicago Press.

Francis, L., Robley, A., and Hradsky, B. (2020). Evaluating fox management strategies using a spatially explicit population. Technical Report Series No. 304. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Franklin, W.L., and Powell, K.J. (1993). *Guard llamas.* Iowa State University, Ames.

Gad, S. C. (2024). Sodium Nitrite. Pp. 613–18 in *Encyclopedia of Toxicology (Fourth Edition)*, edited by P. Wexler. Oxford: Academic Press.

Gangwal, A., Ansari, A., Ahmad, I., Azad, A.K., Kumarasamy, V., Subramaniyan, V., and Wong, L.S. (2024). Generative artificial intelligence in drug discovery: basic framework, recent advances, challenges, and opportunities. *Frontiers in Pharmacology* **15**. doi: 10.3389/fphar.2024.1331062.

Garabedian, J. E., and Kilgo, J.C. (2024). Rapid recovery of invasive wild pig (*Sus scrofa*) populations following density reduction. *Biological Invasions* **26**(4):1075–89. doi: 10.1007/s10530-023-03230-0.

Gaskamp, J.A., Gee, K.L., Campbell, T.A., Silvy, N.J., and Webb, S.L. (2021). Effectiveness and efficiency of corral traps, drop nets and suspended traps for capturing wild pigs (*Sus scrofa*). *Animals* **11**(6):1565. doi: 10.3390/ani11061565.

Geisser, H., and Reyer, H.U. (2004). Efficacy of hunting, feeding and fencing to reduce crop damage by wild boars. *Journal of Wildlife Management* **68**(4):939–46.

Gentle, M. (2005). 'Factors affecting the efficiency of fox (*vulpes vulpes*) baiting practices on the central tablelands of New South Wales'. PhD Thesis, University of Sydney.

Gentle, M. (2006). *Red fox pest status review*. Queensland: Land Protection Department of Natural Resources and Water.

Gentle, M., Elsworth, P., and Parker, B. (2005). Sodium fluoroacetate residue in feral pig (*Sus scrofa*) carcasses - is it a significant secondary poisoning hazard? Pp. 143–47 in, *Proceedings of the 13th Australasian Vertebrate Pest Conference*.

Gentle, M., Wilson, C., and Cuskelly, J. (2022). Feral pig management in Australia: implications for disease control. *Australian Veterinary Journal* **100**(10):492–95. doi: 10.1111/avj.13198.

Gentle, M., and Cother, E. (2014). Biodegradation of 1080: testing soils in south-eastern Australia for sodium fluoroacetate-degrading micro-organisms. *Ecological Management & Restoration* **15**(1):52–57.

Gentle, M., and Pople, A. (2013). Effectiveness of commercial harvesting in controlling feral-pig populations. *Wildlife Research* **40**(6):459–69. doi: 10.1071/WR13100.

Gentle, M., Speed, J., Allen, B.L., Harris, S., Haapakoski, H., and Bell, K. (2017). The longevity of para-aminopropiophenone (PAPP) wild dog baits and the implications for effective and safe baiting campaigns. *Environmental Science and Pollution Research* **24**:12338–46.

Gigliotti, F., Marks, C.A., and Busana, F. (2009). Performance and humaneness of chloropicrin, phosphine and carbon monoxide as rabbit-warren fumigants. *Wildlife Research* **36**:333–41.

Gil-Fernández, M., Harcourt, R., Towerton, A., Newsome, T., Milner, H.A., Sriram, S., Gray, N., Escobar-Lasso, S., González-Cardoso, V.H., and Carthey, A. (2021). The canid pest ejector challenge: controlling urban foxes while keeping domestic dogs safe. *Wildlife Research* **48**(4):314–22. doi: 10.1071/WR20078.

Gingold, G., Yom-Tov, Y., Kronfeld-Schor, N., and Geffen, E. (2009). Effect of guard dogs on the behaviour and reproduction of gazelles in cattle enclosures on the Golan heights. *Animal Conservation* **12**(2):155–62. doi: 10.1111/j.1469-1795.2009.00235.x.

Glen, A.S., and Dickman, C.R. (2003a). Effects of bait-station design on the uptake of baits by non-target animals during control programmes for foxes and wild dogs. *Wildlife Research* **30**(2):147. doi: 10.1071/WR01060.

Glen, A.S., and Dickman, C.R. (2003b). Monitoring bait removal in vertebrate pest control: a comparison using track identification and remote photography. *Wildlife Research* **30**(1):29. doi: 10.1071/WR01059.

Glen, A.S., Dickman, C.R., Soulé, M.E., and Mackey, B.G. (2007). Evaluating the role of the dingo as a trophic regulator in Australian ecosystems. *Austral Ecology* **32**(5):492–501. doi: 10.1111/j.1442-9993.2007.01721.x.

Glen, A.S., Gentle, M.N., and Dickman, C.R. (2007). Non-target impacts of poison baiting for predator control in Australia. *Mammal Review* **37**(3):191–205. doi: 10.1111/j.1365-2907.2007.00108.x.

Green, W., and Rohan, M. (2012). Opposition to aerial 1080 poisoning for control of invasive mammals in New Zealand: risk perceptions and agency responses. *Journal of the Royal Society of New Zealand* **42**(3):185–213. doi: 10.1080/03036758.2011.556130.

Greentree, C., Saunders, G., McLeod, L., and Hone, J. (2000). Lamb predation and fox control in south-eastern Australia. *Journal of Applied Ecology* 37(6):935–43.

Grunwald, H.A., Gantz, V.M., Poplawski, G., Xu, X.S., Bier, E., and Cooper, K.L. (2019). Super-mendelian inheritance mediated by crispr case in the female mouse germline. *Nature* **566**:105–9.

Haber, C. (1996). Biological; conservation, and ethical implications of exploiting and controlling wolves. *Conservation Biology* 10(4).

Hafi, A., Arthur, T., Medina, M., Warnakula, C., Addai, D., and Stenekes, N. (2023). *Cost of established pest animals and weeds to Australian agricultural producers*. Australian Bureau of Agricultural Resource Economics and Sciences (ABARES), Canberra.

Hallett, C. (2002). *Wild dog exclusion fencing audit for the northeast region of Victoria.* Department of Natural Resources and Environment, unpublished report.

Hamnett, P.W., Saltré, F., Page, B., Tarran, M., Korcz, M., Fielder, K., Andrews, L., and Bradshaw, C.J.A. (2023). Stochastic population models to identify optimal and cost-effective harvest strategies for feral pig eradication. doi: 10.1101/2023.03.08.531659.

Hampton, J.O., Cobb, M.L., Toop, S.D., Flesch, J.S., and Hyndman, T.H. (2023). Elevated lead exposure in Australian hunting dogs during a deer hunting season. *Environmental Pollution* **323**:121317. doi: 10.1016/j.envpol.2023.121317.

Hampton, J.O., Eccles, G., Hunt, R., Bengsen, A.J., Perry, A.L., Parker, S., Miller, C.J., Joslyn, S.K., Stokke, S., Arnemo, J.M., and Hart, Q. (2021). A comparison of fragmenting lead-based and lead-free bullets for aerial shooting of wild pigs. *PLoS ONE* **16**(3):1–15.

Hampton, J.O., and Forsyth, D.M. (2016). An assessment of animal welfare for the culling of peri-urban kangaroos. *Wildlife Research* **43**(3):261. doi: 10.1071/WR16023.

Hampton, J.O., Jones, B., and McGreevy, P.D. (2020). Social license and animal welfare: developments from the past decade in Australia. *Animals* **10**(12):2237. doi: 10.3390/ani10122237.

Hampton, J.O., Laidlaw, M., Buenz, E., and Arnemo, J.M. (2018). Heads in the sand: public health and ecological risks of lead-based bullets for wildlife shooting in Australia. *Wildlife Research* **45**(4):287–306. doi: 10.1071/WR17180.

Hampton, J.O., Lohr, M.T., Specht, A.J., Nzabanita, D., Hufschmid, J., Berger, L., McGinnis, K., Melville, J., Bennett, E., and Pay, J.M. (2023). Lead exposure of mainland Australia's top avian predator. *Environmental Pollution* **332**:122004. doi: 10.1016/j.envpol.2023.122004.

Hansen, I., and Smith, M.E. (1999). Livestock-guarding dogs in Norway part II: different working regimes. *Journal of Range Management* **52**(4):312. doi: 10.2307/4003539.

Hansen W.K., Jordan, N.R., Claase, M.J., Suraci J.P., McNutt, J.W., Dhruv, A., and Wilmers, C.C. (2024). Experimental modification of African wild dog movement and behaviour using translocated conspecific scent. *Biological Conservation* **294**. Available at: https://doi.org/10.1016/j.biocon.2024.110645

Harden, R.H., and Robertshaw, J.D. (2014). Ecology of the dingo in northeastern New South Wales. v. human predation on the dingo. *Australian Zoologist* **24**(1):65–72. doi: 10.7882/AZ.1987.005.

Harding, E.K., Doak, D.F., and Albertson, J.D. (2001). Evaluating the effectiveness of predator control: the non-native red fox as a case study. *Conservation Biology* **15**(4):1114–22. doi: 10.1046/j.1523-1739.2001.0150041114.x.

Harriott, L., Allen, B.L., and Gentle, M. (2021). The effect of device density on encounters by a mobile urban carnivore: implications for managing peri-urban wild dogs. *Applied Animal Behaviour Science* **243**:105454. doi: 10.1016/j.applanim.2021.105454.

Hart, S., Marks, C.A., and Staples, L. (1996). Den-co-fume®-humane control of foxes (*Vulpes vulpes*) in natal dens. Pp. 58–61 in *Humaneness and Vertebrate Pest Control Report Series Number 2.*, Edited by P. M. Fisher and C. A. Marks. Department of Natural Resources and Environment, Victoria, Australia.

Hassal and Associates P/L (1998). *Economic evaluation of the role of bounties*. Bureau of Resource Sciences, Australian Government Publishing Service. Available at: https://pestsmart.org.au/wp-content/uploads/sites/3/2020/06/Economic-evaluation-of-the-role-of-bounties.pdf [accessed 16 December 2024]

Hawley, J.E., Gehring, Thomas M., Shultz, R.N., Rossler, S.T., and Wydeven, A.P. (2009). Assessment of shock collars as nonlethal management for wolves in Wisconsin. *The Journal of Wildlife Management* **73**(4):518–25. doi: 10.2193/2007-066.

Hayward, M.W., and Marlow, N. (2014). Will dingoes really conserve wildlife and can our methods tell? *Journal of Applied Ecology* **51**(4):835–38. doi: 10.1111/1365-2664.12250.

Hayward, M.W., and Kerley, G.I.H. (2009). Fencing for conservation: restriction of evolutionary potential or a riposte to threatening processes? *Biological Conservation* **142**:1–13.

Hebeisen, C., Fattebert, J., Baubet, E., and Fischer, C. (2008). Estimating wild boar (sus scrofa) abundance and density using capture–resights in canton of Geneva, Switzerland. *European Journal of Wildlife Research* **54**(3):391–401. doi: 10.1007/s10344-007-0156-5.

Henzell, R.P., Cunningham, R.B., and Neave, H.M. (2002). Factors affecting the survival of Australian wild rabbits exposed to rabbit haemorrhagic disease. *Wildlife Research* **29**(6):523–42. doi: 10.1111/j.1749-4877.2009.00155.x.

Hone, J. (1983). A short-term evaluation of feral pig eradication at Willandra in western New South Wales. *Wildlife Research* **10**(2):269. doi: 10.1071/WR9830269.

Hone, J. (1987). 'Theoretical and practical aspects of feral pig control'. PhD Thesis, Australian National University, Canberra.

Hone J (1994). *Analysis of Vertebrate Pest Control*. (Cambridge University Press) doi:10.1017/CBO9780511525797

Hone, J. (1990). Predator prey theory and feral pig control, with emphasis on evaluation of shooting from a helicopter. *Wildlife Research* **17**(2):123. doi: 10.1071/WR9900123.

Hone, J. (1999). On rate of increase (r): patterns of variation in Australian mammals and the implications for wildlife management. *Journal of Applied Ecology* **36**:709–18.

Hone, J. (1999). Fox control and rock-wallaby population dynamics - assumptions and hypotheses. *Wildlife Research* **26**:671–73.

Hone, J. (2012). *Applied population and community ecology: the case of feral pigs in Australia*. John Wiley & Sons.

Hone, J., and Atkinson, B. (1983). Evaluation of fencing to control feral pig movement. *Wildlife Research* **10**(3):499–505.

Hone, J., Bryant, H., Nicholls, P., Atkinson, W., and Kleba, R. (1985). The acceptance of dyed grain by feral pigs and birds. 3. comparison of intakes of dyed and undyed grain by feral pigs and birds in pig-proof paddocks. *Wildlife Research* **12**(3):447–54. doi: 10.1071/wr9850447.

Hone, J., Duncan, R.P., and Forsyth, D.M. (2010). Estimates of maximum annual population growth rates (*rm*) of mammals and their application in wildlife management. *Journal of Applied Ecology* **47**(3):507–14. doi: 10.1111/j.1365-2664.2010.01812.x.

Hone, J., and Stone, C.P. (1989). A comparison and evaluation of feral pig management in two national parks. *Wildlife Society Bulletin* **17**(4):419–25.

Hradsky, B.A., Kelly, L.T., Robley, A., and Wintle, B.A. (2019). FoxNet: an individual-based model framework to support management of an invasive predator, the red fox. *Journal of Applied Ecology* **56**(6):1460–70.

Hunt, R. (2010). *1080 ejector training manual.* Department of Environment, Climate Change and Water, Parks & Wildlife Group, Pest Management Unit, New South Wales.

Hunter, D.O., Lagisz, M, L.V., Nakagawa, S., and Letnic M. (2018). Not all predators are equal: a continent-scale analysis of the effects of predator control on Australian mammals. *Mammal Review* **48**: 108–122. doi:10.1111/mam.12115.

IACRC. (2014). RHD-boost. import and evaluate new rabbit haemorrhagic disease virus (RHDV) variants to strengthen rabbit biocontrol. Canberra.

Inspiring Excellence. (2024). *Desk-top research into effectiveness of non-lethal management of wild-living dogs*. Department of Energy, Environment and Climate Action, Melbourne.

Jackson, C.R., McNutt, J.W., and Apps, P.J. (2012). Managing the ranging behaviour of African wild dogs (*Lycaon pictus*) using translocated scent marks. *Wildlife Research* **39**:31–34.

Jackson, S.M., Fleming, P.J.S., Eldridge, M.D.B., Archer, M., Ingleby, S., Johnson, R.N., and Helgen, K.M. (2021). Taxonomy of the dingo: it's an ancient dog. *Australian Zoologist* **41**(3):347–57. doi: 10.7882/AZ.2020.049.

Jenkins, D.J. (2003). Guard animals for livestock protection: Existing and potential use in Australia. Vertebrate Pest Research Unit, NSW Agriculture, Orange NSW. Available at: https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/178908/guard-animals.pdf [accessed 6 August 2024].

Jessop T.S., Gillespie, G.R., and Letnic, M. (2016). Examining Multi-Scale Effects of the Invasive Fox on a Large Varanid (*Varanus varius* White, 1790) Mesopredator. In (Ed M Cota.) Interdisciplinary World Conference on Monitor Lizards'. pp. 221–236.

Katahira, L.K., Finnegan, P., and Stone, C.P. (1993). Eradicating feral pigs in montane mesic habitat at Hawaii volcanoes national park. *Wildlife Society Bulletin* **21**(3):269–74.

Kay, B., Gifford, E., Perry, R., and van de Ven, R. (2000). Trapping efficiency for foxes (*Vulpes vulpes*) in central New South Wales: age and sex biases and the effects of reduced fox abundance. *Wildlife Research* **27**(5):547–52.

Keem, J.L., Hradsky, B.A., Benshemesh, J., Le Pla, M., Watkins, A., Weeks, A.R., Van Rooyen, A., Black, J, and Southwell, D. (2023). Evaluating predator control using two non-invasive population metrics: a camera trap activity index and density estimation from scat genotyping. *Wildlife Research* **51**(1). doi: 10.1071/WR23033.

Kennedy, S., and Ferns, L. (2015). *Predation vulnerability ratings (PVR) for Victoria's mainland vertebrate fauna. version 1*. Unpublished report, Department of Environment, Land, Water and Planning, Knowledge and Decision Systems Branch.

Keuling, O., and Massei, G. (2021). Does hunting affect the behaviour of wild pigs? *Human–Wildlife Interactions* **15**(1). doi: https://doi.org/10.26077/3a83-9155.

Khorozyan, I., and Waltert, M. (2019). A framework of most effective practices in protecting human assets from predators. *Human Dimensions of Wildlife* **24**(4):380–94. doi: 10.1080/10871209.2019.1619883.

King, D.R. (1989). An assessment of the hazard posed to northern quolls (*Dasyurus hallucatus*) by aerial baiting with 1080 to control dingoes. *Australian Wildlife Research* **16**:569–74.

Kinnear, J.E., Onus, M.L., and Bromilow, R.N. (1988). Fox control and rock-wallaby population-dynamics. *Wildlife Research* **15**(4):435–50.

Kinsey, J.C., Foster, J.A., Snow, N.P., Wishart, J.D., Staples, L.D., Bush, J.K., and VerCauteren, C. (2023). Assessment of spilled toxic bait by wild pigs and potential risk to non-target species. *Pest Management Science* **79**(11):4589–98. doi: 10.1002/ps.7658.

Kortner, G. (2007). 1080 aerial baiting for the control of wild dogs and its impact on spotted-tailed quoll (D*asyurus maculatus*) populations in eastern Australia. *Wildlife Research* **34**(1):48–53.

Kortner, G., Gresser, S., and Harden, B. (2003). Does fox baiting threaten the spotted-tailed quoll, D*asyurus maculatus*? *Wildlife Research* **30**(2):111. doi: 10.1071/WR02107.

Kortner, G., and Watson, P. (2005). The immediate impact of 1080 aerial baiting to control wild dogs on a spotted-tailed quoll population. *Wildlife Research* **32**:673–80.

Krebs, C.J. (1999). *Ecological methodology*. Menlo Park, Calif. Benjamin/Cummings.

Kreplins, T., Kennedy, M., Adams, P., Bateman, B., Dundas, S., and Fleming, P. (2018). Fate of dried meat baits aimed at wild dog (*Canis familiaris*) control. *Wildlife Research* **45**(6):528–38.

Kreplins, T., Kennedy, M., Fleming, T., Dawson, S., Miller, J., Barwick, J., MacLeay, C., Omogbene, M., Renwick, J., Cowan, M. (2022). *Assessment of the Biodiversity, Economic and Productivity Gains from Exclusion Fencing, Western Australia: Final Report for Project P01-L-006*. Report for the Centre for Invasive Species Solutions. Available at: https://invasives.com.au/wp-content/uploads/2023/06/L006-Final-release.pdf [accessed 23 August 2024].

Kreplins, T.L., Miller, J., and Kennedy, M.S. (2021). Are canid pest ejectors an effective control tool for wild dogs in an arid rangeland environment? *Wildlife Research* **49**(3):227–36. doi: 10.1071/WR21043.

Krull, C.R., Stanley, M.C., Burns, B.R., Choquenot, D., and Etherington, T.R. (2016). Reducing wildlife damage with cost-effective management programmes. *PLOS ONE* **11**(1):e0146765. doi: 10.1371/journal.pone.0146765.

KTRI. (1995). *Evaluation of carbon monoxide cartridges for the fumigation of fox natal dens*. Frankston, Victoria: Keith Turnball Research Institute. Department of Natural Resources and Environment.

Kubasiewicz, L.M., Bunnefeld, N., Tulloch, A.I.T., Quine, C.P., and Park, K.J. (2016). Diversionary feeding: an effective management strategy for conservation conflict? *Biodiversity and Conservation* **25**(1):1–22. doi: 10.1007/s10531-015-1026-1.

Lange, R.T., and Graham, C.R. (1983). Rabbits and the failure of regeneration in Australian arid zone acacia. *Australian Journal of Ecology* **8**(4):377–81. doi: 10.1111/j.1442-9993.1983.tb01334.x.

Lapidge, S., and Eason, C.T. (2010). *Pharmacokinetics and methaemoglobin reductase activity as determinants of species susceptibility and non-target risks from sodium nitrite manufactured feral pig baits*. Canberra, ACT: Invasive Animals Cooperative Research Centre.

Lapidge, S.J. (2004). The impact of sheep predators in Australia and new control methods under development. Pp. 159–63 in *Proceedings of the 14th Australian Sheep Veterinary Society Conference*. Canberra, Australia.

Lapidge, S., Wishart, J., Staples, L., Fagerstone, K., Campbell, T., and Eisemann, J. (2012). Development of a feral swine toxic bait (HOGGONE®) and bait hopper (HOGHOPPER™) in Australia and the USA.

Lavelle, M.J., Snow, N.P., Halseth, J.M., Kinsey, J.C., Foster, J.A., and VerCauteren, K.C. (2018). Development and evaluation of a bait station for selectively dispensing bait to invasive wild pigs. *Wildlife Society Bulletin* **42**(1):102–10. doi: 10.1002/wsb.856.

Lazarus, M. (1956). The toxicity and relative acceptability of some poisons to the wild rabbit, *Oryctolagus cuniculus* (l.). *C.S.I.R.O. Wildlife Research* **1**:96-100.

Lazenby, B.T., Mooney, N.J., and Dickman, C.R. (2014). Effects of low-level culling of feral cats in open populations: a case study from the forests of southern Tasmania. *Wildlife Research* **41**(5):407. doi: 10.1071/WR14030.

Le Pla, M.N., Birnbaum, E.K., Rees, M.W., Hradsky, B.A., Weeks, A.R., Van Rooyen, A., and Pascoe, J.H. (2022). Genetic sampling and an activity index indicate contrasting outcomes of lethal control for an invasive predator. *Austral Ecology* **47**(5):1062–76. doi: 10.1111/aec.13182.

Legge, S., Woinarski, J.C.Z., Burbidge, A.A., Palmer, R., Ringma, J., Radford, James Q., Mitchell, N., Bode, M., Wintle, B., Baseler, M., Bentley, J., Copley, P., Dexter, N., Dickman, C.R., Gillespie, G.R., Hill, B., Johnson, C.N., Latch, P., Letnic, M., Manning, A., McCreless, E.E., Menkhorst, P., Morris, K., Moseby, K., Page, M., Pannell, D., and Tuft, K.. (2018). Havens for threatened Australian mammals: the contributions of fenced areas and offshore islands to the protection of mammal species susceptible to introduced predators. *Wildlife Research* **45**:627–44.

Lemay, A., and Hall, T. (2017). The use of carbon monoxide in wildlife damage management. *Human Health and Ecological Risk Assessment for the Use of Wildlife Damage Management Methods by USDA-APHIS-Wildlife Services* 1–41.

Letnic, M., Baker, L., and Nesbitt, B. (2013). Ecologically functional landscapes and the role of dingoes as trophic regulators in south-eastern Australia and other habitats. *Ecological Management & Restoration* **14**(2):101–5. doi: 10.1111/emr.12035.

Lieury, N., Ruette, S., Devillard, S., Albaret, M., Drouyer, F., Baudoux, B., and Millon, A. (2015). Compensatory immigration challenges predator control: an experimental evidence-based approach improves management: compensatory immigration in carnivore management. *The Journal of Wildlife Management* **79**(3):425–34. doi: 10.1002/jwmg.850.

Lightfoot, C. (2010). *Social benefit cost analysis: wild dog management in Victoria.* Department of Primary Industries, Victorian Government, Melbourne.

Linhart, S.B. (1984). *Strobe light and siren devices for protecting fenced-pasture and range sheep from Coyote predation*. In Proceedings of the 11th Vertebrate Pest Conference. pp. 154–156. (University of Nebraska-Lincoln) Available at: https://digitalcommons.unl.edu/vpc11/20.

Linhart, S.B., Sterner, R.T., Dasch, G.J., Roberts, J.D., and Packham, C.J. (1992). Electronic frightening devices for reducing coyote predation on domestic sheep: efficacy under range conditions and operational use. Pp. 386–92 in *Proceedings 15th Vertebrate Pest Conference*. University of California Press: Berkeley, CA, USA.

Lohr, M.T., Hampton, J.O., Cherriman, S., Busetti, F., and Lohr, C. (2020). Completing a worldwide picture: preliminary evidence of lead exposure in a scavenging bird from mainland Australia. *Science of The Total Environment* **715**:135913. doi: 10.1016/j.scitotenv.2019.135913.

Long, D.B., Campbell, T.A., and Massei, G. (2010). Evaluation of feral swine-specific feeder systems. *Rangelands* **32**(2):8–13. doi: 10.2111/1551-501X-32.2.8.

Long, J.L., Mawson, P., Hubach, P., and Kok, N. (1988). Fox attacks on cashmere goats. *Journal of the Department of Agriculture, Western Australia* **29**(3):104106.

Long K, and Robley A (2004). Cost effective feral animal exclusion fencing for areas of high conservation value in Australia. Victoria Department of Sustainability and Environment, Melbourne.

Mahar, J.E., Read, A.J., Gu, X., Urakova, N., Mourant, R., Piper, M., Haboury, S., Holmes, E.C., Strive, T., and Hall, R.N. (2018). Detection and circulation of a novel rabbit haemorrhagic disease virus in Australia. *Emerging Infectious Diseases* **24**:22+.

Mann, T.L.J. (1968). A comparison of lamb survival in fox proof and unprotected enclosures. *Proceedings of the Australian Society of Animal Production* **7**:250–54.

Marks, C.A. (2001). Bait-delivered cabergoline for reproductive control of the red fox-non-target risk in south-eastern Australia. *Reproductive Fertility Development* **13**:499-510.

Marks, C.A., Gigliotti, F., and Busana, F. (2002). Estimated 1080 dose rate for the m-44 ejector for the control of red foxes (*Vulpes vulpes*). *Wildlife Research* **29**:291–94.

Marks, C.A., Gigliotti, F., Busana, F., Johnston, M., and Lindeman, M. (2004). Fox control using a para-aminopropiophenone formulation with the m-44 ejector. *Animal Welfare* **13**(4):401–7.

Marks, C.A., Allen, L., and Lindeberg, H. (2023). Non-lethal dose-response models replace lethal bioassays for predicting the hazard of para-aminopropiophenone to Australian wildlife. *Animals* **13**. doi:https://doi.org/10.3390/ani13030472.

Marks, C.A., and Bloomfield, T.E. (2006). Home-range size and selection of natal den and diurnal shelter sites by urban red foxes (*Vulpes vulpes*) in Melbourne. *Wildlife Research* **33**(4):339. doi: 10.1071/WR04058.

Marks, C.A., Busana, F., and Gigliotti, F. (1999). Assessment of the m-44 ejector for the delivery of 1080 for red fox (*Vulpes vulpes*) control. *Wildlife Research* **26**(1):101. doi: 10.1071/WR98014.

Marks, C.A., Gigliotti, F., and Busana, F. (2003). Field performance of the m-44 ejector for red fox (vulpes vulpes) control. *Wildlife Research* **30**(6):601–9.

Marks, C.A., Trought, K., Brown, S., Arrow, J., and Hopkins, B. (2023). Sensitivity of high conservation value birds to para-aminopropiophenone (PAPP) determined by sub-lethal dose–response assay. *Animals* **13**:433.

Marks, C.A., and Wilson, R. (2005). Predicting mammalian target-specificity of the m-44 ejector in south-eastern Australia. *Wildlife Research* **32**(2):151. doi: 10.1071/WR03102.

Marlow, N.J., Thomas, N.D., Williams, A.A.E., Macmahon, B., Lawson, J., Hitchen, Y., Angus, J., and Berry, O. (2015). Lethal 1080 baiting continues to reduce European red fox (*Vulpes vulpes*) abundance after more than 25 years of continuous use in south-west Western Australia. *Ecological Management & Restoration* **16**(2):131–41.

Marlow, N.J. (1992). 'The ecology of the introduced red fox (*Vulpes vulpes*) in arid Australia'. Ph.D., University of New South Wales.

Marlow, N J, Williams, A., Thomas, N., Maxwell, M., Wilson, I., Wittred, B., Brazell, R., and Withnell, B. (2015). Assessing the impact of 1080 pro-baits on wild brush- tailed phascogales (*Phascogale tapoatafa*) during an operational fox baiting campaign. *Conservation Science Western Australia* **9**(3).

Martin, J.T., and Eveleigh, J.N. (1979). Observations on the effectiveness of warren destruction as a method of rabbit control in a semi-arid environment. *Australian Rangeland Journal* **1**(3):238.

Mason, L.R., Green, R.E., Hirons, G., Skinner, J.M., Andrew M.J., Peault, S.C., Upcott, E.V., Wells, E., Wilding, D.J., and Smart, J. (2021). Experimental diversionary feeding of red kites *Milvus milvus* reduces chick predation and enhances breeding productivity of northern lapwings *Vanellus vanellus*. *Journal for Nature Conservation* **64**:126051. doi: 10.1016/j.jnc.2021.126051.

Mason, R.T., Rendall, A.R., Sinclair, R.D., Ritchie, E.G (2025). Assessing target and non-target species interactions with buried non-toxic meat baits across fire mosaics. *Wildlife Research* **52**. doi:10.1071/WR24117.

Massei, G., Roy, S., and Bunting, R. (2011). Too many hogs? a review of methods to mitigate impact by wild boar and feral hogs. *Human-Wildlife Interactions* **5**(1):79–99.

McCann, B.E., and Garcelon, D.K. (2008). Eradication of feral pigs from pinnacles national monument. *Journal of Wildlife Management* **72**(6):1287–95.

McFarlane, D. (1964). The effect of predators on perinatal lamb losses in the Monaro, Oberon and Canberra districts. *Wool Technology and Sheep Breeding* **11**(1).

McIlroy, J.C. (1981). The sensitivity of Australian animals to 1080 poison ii. marsupial and eutherian carnivores. *Australian Wildlife Research* **8**:385–99.

McIlroy, J.C. (1982). The sensitivity of Australian animals to 1080 poison iv. native and introduced rodents. *Wildlife Research* **9**(3):505. doi: 10.1071/WR9820505.

McIlroy, J.C. (1983). The sensitivity of Australian animals to 1080 poison v. the sensitivity of feral pigs, *Sus scrofa*, to 1080 and its implications for poisoning campaigns. *Australian Wildlife Research* **10**:139–48.

McIlroy, J.C. (1984). The sensitivity of Australian animals to 1080 poison VII. Native and introduced birds. *Australian Wildlife Research* **11**: 373-85.

McIlroy, J.C. (1986). The sensitivity of Australian animals to 1080 poison .9. comparisons between the major groups of animals, and the potential danger nontarget species face from 1080 poisoning campaigns. *Wildlife Research* **13**(1):39–48. doi: 10.1071/wr9860039.

McIlroy, J.C. (1992). The effect on Australia animals of 1080-poisoning campaigns. Pp. 356–59 in *Proceedings of the 15th Vertebrate Pest Conference*. University of California Davis USA.

McIlroy, J.C. (1995). New techniques for an old problem – recent advances in feral pig control in Australia. *Journal of Mountain Ecology* **3**:241–44.

McIlroy, J.C., and Archer, M. (1982). The sensitivity of Australian carnivorous mammals to 1080 poison. Pp. 267–71 in *Carnivorous marsupials*. Mosman, NSW: Royal Zoological Society of New South Wales.

McIlroy, J.C., Cooper, R.J., Gifford, E.J, Green, B.F., and Newgrain, K.W. (1986). The effect on wild dogs, *Canis f familiaris*, of 1080 poisoning campaigns in Kosciusko national park, NSW. *Wildlife Research* **13**(4):535. doi: 10.1071/WR9860535.

McIlroy, J.C., and Gifford, E.J. (1991). Effect on non-target animal populations of a rabbit trail-baiting campaign with 1080 poison. *Wildlife Research* 18:315–25.

McIlroy, J.C., and Gifford, E.J. (1992). Secondary poisoning hazards associated with 1080-treated carrot-baiting campaigns against rabbits (*Oryctolagus cuniculus*). *Wildlife Research* **19**:629–41.

McIlroy, J.C., and Gifford, E.J. (1997). The 'judas' pig technique: a method that could enhance control programmes against feral pigs, *Sus scrofa*. *Wildlife Research* **24**(4):483–91.

McIlroy, J.C., Gifford, E.J., and Forrester, R.I. (1993). Seasonal patterns in bait consumption by feral pigs (sus scrofa) in the hill country of south-eastern Australia. *Wildlife Research* **20**(5):637–51. doi: 10.1071/wr9930637.

McIlroy, J.C., King, D.R., and Oliver, A.J. (1985). The sensitivity of Australian animals to 1080 poison viii. amphibians and reptiles. *Wildlife Research* 12(1):113. doi: 10.1071/WR9850113.

Mcilroy, J.C., and Saillard, R.J. (1989). The effect of hunting with dogs on the numbers and movements of feral pigs, sus-scrofa, and the subsequent success of poisoning exercises in Namadgi National Park, ACT. *Wildlife Research* **16**(3):353. doi: 10.1071/WR9890353.

McIlroy, J.C., and Saunders, G.R. (1998). What is the future of fox management in Australia. Pp. 429–34 in. Agriculture Western Australia, Bunbury, Australia.

McIlroy, J.C., Saunders, G.R., and Pech, R.P. (1994). Immunocontraception of foxes in Australia — progress and problems. in *Proceedings of the 7th Annual Conference, Australasian Wildlife Management Society*. Alice Springs.

McKillop, I. G., Pepper, H.W., and Wilson, C.J. (1988). Improved specifications for rabbit fencing for tree protection. *Forestry* **61**:359–68.

McLeod, L., and Saunders, G. (2013). *Pesticides used in the management of vertebrate pests in Australia: a review*. New South Wales Department of Primary Industries.

Mcleod. L.J., Saunders. G.R., and Kabat. T.J. (2008). Do control interventions effectively reduce the impact of European Red Foxes on conservation values and agricultural production in Australia? CEE review 06-003 (SR24). Collaboration for Environmental Evidence. Available at: www.environmentalevidence.org/SR24.html.

McLeod, L.J., Saunders, G.R., McLeod, S.R., Dawson, M., and Van De Ven, R. (2010). The potential for participatory landscape management to reduce the impact of the red fox (*Vulpes vulpes*) on lamb production. *Wildlife Research* **37**(8):695. doi: 10.1071/WR10082.

McLeod, L.J., Saunders, G.R., and Miners, A. (2011). Can shooting be an effective management tool for foxes? preliminary insights from a management programme: *Ecological Management & Restoration* **12**(3):224–26. doi: 10.1111/j.1442-8903.2011.00613.x.

McLeod, L., Saunders, G., McLeod, S., and Walter, M. (2007). *Effective implementation of regional fox control programs. final report to the bureau of rural sciences, department of agriculture, fisheries and forestry.* Vertebrate Pest Research Unit, NSW Department of Primary Industries.

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

McPhee, S.R., and Butler, K.L. (2010). Long-term impact of coordinated warren ripping programmes on rabbit populations. *Wildlife Research* **37**(1):68. doi: 10.1071/WR09103.

Meade, T. (2015). Protect your flock with guard donkeys: Kick up herd protection on your hobby farm with a guard donkey. Available at: http://www.hobbyfarms. com/livestock-and-pets/guard-donkeys.aspx [accessed 25 October 2024].

Meek, P.D., Brown, S.C., Wishart, J., Milne, H., Aylett, P., Humphrys, S., Ballard, G., and Fleming, P. (2019). Efficacy of lethal-trap devices to improve the welfare of trapped wild dogs. *Wildlife Research* **46**(1):89–95. doi: 10.1071/WR18129.

Meek, P.D. (1998). The biology of the European red fox and free roaming dog on Bherwerre Peninsula, Jervis Bay. M.Sc., University of Canberra, ACT.

Meek, P.D., Jenkins, D.J., Morris, B., Ardler, A.J., and Hawksby, R.J. (1995). Use of two humane leg-hold traps for catching pest species. *Wildlife Research* **22**(6):733. doi: 10.1071/WR9950733.

Meek, P.D., Ballard, G., Milne, H., Croft, S., Lawson, G., and Fleming, P.J.S. (2020). Satellite and telecommunication alert system for foothold trapping. *Wildlife Research* **48**, 97–104.

Meldrum, G.K., Bignell, J.T., and Rowley, Ian. (1957). The use of sodium monofluoroacetate (compound 1080) for the control of the rabbit in Tasmania. *Australian Veterinary Journal* **33**(8):186–96. doi: 10.1111/j.1751-0813.1957.tb05738.x.

Mellor, D.J., and Reid, C.S.W. (1994). Concepts of animal well-being and predicting the impact of procedures on experimental animals. Pp. 3–18 in *Improving the Well-being of Animals in the Research Environment*, edited by R. M. Baker, G. Jenkin, and D. J. Mellor. Glen Osmond South Australia: ANZCAART.

Millar, A., Gentle, M., and Leung, L.K-P. (2015). Non-target species interaction with sodium fluoroacetate (1080) meat bait for controlling feral pigs (*Sus scrofa*). *Pacific Conservation Biology* **21**(2):158. doi: 10.1071/PC14915.

Miller, G.D. (1983). *Responses of captive grizzly and polar bears to potential repellents*. International Conference of Bear Restoration and Management. pp. 275-279. doi:10.2307/3872549.

Miller, J., Stoner, K., Cejtin, M., Meyer, T., Middleton, A., and Schmitz, O. (2016). Effectiveness of contemporary techniques for reducing livestock depredations by large carnivores: human-carnivore coexistence. *Wildlife Society Bulletin* **40**. doi: 10.1002/wsb.720.

Miloš, J., Michaela, H., Tomáš, K., and Jaroslav, Č. (2016). Creeping into a wild boar stomach to find traces of supplementary feeding. *Wildlife Research* **43**(7):590–98. doi: 10.1071/WR16065.

Mitchell, J. (1998). The effectiveness of aerial baiting for control of feral pigs (*Sus scrofa*) in north Queensland. *Wildlife Research* **25**:297–303.

Mitchell, T.D., Kearins, R.D., Marchant, R.S., and Plant, J.W. (1977). Electric fences to control feral pigs. *Agricultural Gazette of New South Wales* **88**:10–13.

MLA. (2024). Industry-projections 2024 - September update. Meat and Livestock Australia. https://www.mla.com.au/globalassets/mla-corporate/prices--markets/documents/trends--analysis/sheep-projections/september-2024-update_mla-australian-sheep-industry-projections_0209242.pdf.

Moreira-Arce, D., Ugarte, C.S., Zorondo-Rodríguez, F., and Simonetti, J.A. (2018). Management tools to reduce carnivore-livestock conflicts: current gap and future challenges. *Rangeland Ecology & Management* **71**(3):389–94. doi: 10.1016/j.rama.2018.02.005.

Mori, E. (2017). Porcupines in the landscape of fear: effect of hunting with dogs on the behaviour of a non-target species. *Mammal Research* **62**(3):251–58. doi: 10.1007/s13364-017-0313-5.

Moseby, K.E., and Hill, B.M. (2011). The use of poison baits to control feral cats and red foxes in arid south Australia I. aerial baiting trials. *Wildlife Research* **38**(4):338–49.

Moseby, K.E., and Read, J.L. (2006). The efficacy of feral cat, fox and rabbit exclusion fence designs for threatened species protection. *Biological Conservation* **127**(4):429–37. doi: https://doi.org/10.1016/j.biocon.2005.09.002.

Mutze, G., Bird, P., Jennings, S., Peacock, D., de Preu, N., Kovaliski, J., Cooke, B., and Capucci, L. (2014). Recovery of south Australian rabbit populations from the impact of rabbit haemorrhagic disease. *Wildlife Research* **41**(7):552–59.

Mutze, G., Cooke, B., and Alexander, P. (1998). The initial impact of rabbit haemorrhagic disease on European rabbit populations in south Australia. *Journal of Wildlife Diseases* **34**(2):221–27.

Mutze, G.J. (1991). Long-term effects of warren ripping for rabbit control in semi-arid south Australia. *The Rangeland Journal* **13**(2):96–106.

Mutze, G., Bird, P., Cooke, B., and Henzell, R. (2008). Geographic and seasonal variation in the impact of rabbit haemorrhagic disease on European rabbits, *Oryctolagus cuniculus*, and rabbit damage in Australia. Pp. 279–93 in *Lagomorph Biology*, edited by P. C. Alves, N. Ferrand, and K. Hackländer. Berlin, Heidelberg: Springer Berlin Heidelberg.

Mutze, G., Preu, N.D., Mooney, T., Koerner, D., McKenzie, D., Sinclair, R., Kovaliskli, J., and Peacock, D.E. (2018). Substantial numerical decline in south Australian rabbit populations following the detection of rabbit haemorrhagic disease virus 2. *Veterinary Record* **182**:574–574.

Mutze, G., Kovaliski, J., Butler, K., Capucci, L., and McPhee, S. (2010). The effect of rabbit population control programmes on the impact of rabbit haemorrhagic disease in south-eastern Australia. *Journal of Applied Ecology* **47**(5):1137–46. doi: 10.1111/j.1365-2664.2010.01844.x.

Myers, K., and Parker, B.S. (1975). A study of the biology of the wild rabbit in climatically different regions in eastern Australia. vi. Changes in numbers and distribution related to climate and land systems in semiarid north-western New South Wales. *Australian Wildlife Research* **2**:11–52.

Myers, K., and Parker, B.S. (1975). Effect of severe drought on rabbit numbers and distribution in a refuge area in semiarid north-western New South Wales. *Wildlife Research* **2**(2):103. doi: 10.1071/WR9750103.

Myers, K., and Poole, W.E. (1962). A study of the biology of the wild rabbit, *Oryctolagus cuniculus* (l.), in confined populations. III. reproduction. *Australian Journal of Zoology* **10**(2):225–67.

Mykytowcyz, R. (1960). Social behaviour of an experimental colony of wild rabbits, *Oryctolagus cuniculus* (l.), III. second breeding season. *C.S.I.R.O. Wildlife Research* **5**(1):1–20.

National Registration Authority. (2002). *The NRA review of pindone*. NRA Review Series. Canberra, Australia: National Registration Authority for Agricultural and Veterinary Chemicals.

Neave, M.J., Hall, R.N., Huang, N., McColl, K.A., Kerr, P., Hoehn, M., Taylor, J., and Strive, T. (2018). Robust innate immunity of young rabbits mediates resistance to rabbit haemorrhagic disease caused by *Lagovirus europaeus* GI.1 but not GI.2. *Viruses* **10**(9). doi: 10.3390/v10090512.

Negus, P.M., Marshall, J.C., Clifford, S.E., Blessing, J.J., and Steward, A.L. (2019). No sitting on the fence: protecting wetlands from feral pig damage by exclusion fences requires effective fence maintenance. *Wetlands Ecology & Management* **27**(4):581–85. doi: 10.1007/s11273-019-09670-7.

Newsome, A.E., Corbett, L.K., Catling P.C., and Burt, R.J. (1983). The feeding ecology of the dingo i. stomach contents from trapping in south-eastern Australia, and the non-target wildlife also caught in dingo traps. *Australian Wildlife Research* **10:**477–86.

Newsome, T., Crowther, M., and Dickman, C. (2014). Rapid recolonisation by the European red fox: how effective are uncoordinated and isolated control programs? *European Journal of Wildlife Research* **60**(5):749–57.

Nicholson, E., and Gigliotti, F. (2005). Increasing the target-specificity of the m-44 ejector by exploiting differences in head morphology between foxes and large *Dasyurids*. *Wildlife Research* **32**:733–36.

Norbury, G., and McGlinchy, A. (1996). The impact of rabbit control on predator sightings in the semi-arid high country of the South Island, New Zealand. *Wildlife Research* **23**:93–97.

Northcott, G., Jensen, D., Ying, L., and Fisher, P. (2014). Degradation rate of sodium fluoroacetate in three New Zealand soils. *Environmental Toxicology and Chemistry* **33**(5):1048–58. doi: 10.1002/etc.2536.

NSW DPI (2022). NSWFOX-SOP4 Fumigation of fox dens using carbon monoxide. Department of Primary Industries, NSW. Available at: https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/1396772/NSWFOX-SOP4-Fumigation-of-fox-dens-using-carbon-monoxide.PDF [accessed 8 October 2024].

O'Brien, P.H., Kleba, R., Beck, J.A., and Baker, P.J. (1986). Vomiting by feral pigs after 1080 intoxication: nontarget hazard and influence of anti-emetics. *Wildlife Society Bulletin* **14**:425–32.

O'Brien, R. C., Forbes, S.L., Meyer, J., and Dadour, I.R. (2007). A preliminary investigation into the scavenging activity on pig carcasses in Western Australia. *Forensic Science, Medicine, and Pathology* **3**(3):194–99. doi: 10.1007/s12024-007-0016-3.

Oliver, A.J., Wheeler, S.H, and Gooding, C.D. (1982). Field evaluation of 1080 and pindone oat bait, and the possible decline in effectiveness of poison baiting for the control of the rabbit, *Oryctolagus cuniculus*. *Wildlife Research* **9**(1):125. doi: 10.1071/WR9820125.

Orr, B., Malik, R., Norris, J., and Westman, Mark. (2019). The welfare of pig-hunting dogs in Australia. *Animals* **9**(10):853. doi: 10.3390/ani9100853.

Pachauri, R., Martínez-Guijosa, J., Ferreras-Colino, E., Ferreres, J., and Relimpio, D. (2024). Optimizing the baiting strategy for oral vaccine delivery to wild boar. *European Journal of Wildlife Research* **70**(1):18. doi: 10.1007/s10344-024-01771-w.

Pacioni, C., Ramsey, D.S.L., Woodford, L., and Robley, A. (2021). *Estimating the efficiency of reactive wild dog control to attacks on livestock. unpublished client report for the department of jobs, precincts and region.* Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Page, J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., and et al. (2020). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. doi:10.1136/bmj.n71 **|** BMJ 2021;372:n71.

Page, R.J.C. (1994). Laboratory and field assessment of a carbon monoxide producing fumigant cartridge for the use in the control of rabbits (*Oryctolagus cuniculus*). Pp. 175–79 in *Proceedings of the 16th*

Vertebrate Pest Conference. (Eds. W.S. Halverson and A.C. Crabb). University of California, Davis, California.

Pain, D.J., Mateo, R., and Green, R.E. (2019). Effects of lead from ammunition on birds and other wildlife: a review and update. *Ambio* **48**(9):935–53. doi: 10.1007/s13280-019-01159-0.

Parer, I., and Milkovits, G. (1994). Recolonisation by rabbits (*Oryctolagus* cuniculus) after warren ripping or warren fumigation. *The Rangeland Journal* **16**(1):51–63.

Parkes J.P., Ramsey, D.S.L., Macdonald, N., Walker, K., McKnight, S., Cohen, B.S., and Morrison, S.A. (2010). Rapid eradication of feral pigs (*Sus scrofa*) from Santa Cruz Island, California. *Biological Conservation* **143**, 634–641. doi:10.1016/j.biocon.2009.11.02810.1016/j.biocon.2009.11.028.

Parfitt, R.L., Eason, C.T., Morgan, A.J., Wright, G.R., Burke, C.M., and Seawright, A.A. (1994). The fate of sodium monofluoroacetate (1080) in soil and water. Pp. 59–66 in *Proceedings of the Science Workshop on 1080, 12-14 December 1993, Christchurch, New Zealand*, *Miscellaneous series / Royal Society of New Zealand*. Wellington: Royal Society of New Zealand.

Patel, K.K., Austin, C., Warner, K., Pickett, M., Khabiri, A., Mahzounieh, M., Hemmatzadeh, F., and Taggart, P.L. (2023). The impact of integrating rabbit haemorrhagic disease virus (K5) release with pindone baiting on wild rabbit populations. *Ecology and Evolution* DOI: 10.1002/ece3.10991

Pavlov, P.M., Hone, J., Kilgour, R.J., and Pedersen, H. (1981). Predation by feral pigs on merino lambs at Nyngan, New South Wales. *Australian Journal of Experimental Agriculture* **21**(113):570–74. doi: 10.1071/EA9810570.

Pay, J.M., Katzner, T.E., Hawkins, C.E., Koch, A.J., Wiersma, J.M., Brown, W.E., Mooney, N.J., and Cameron, E.Z. (2021). High frequency of lead exposure in the population of an endangered Australian top predator, the Tasmanian wedge-tailed eagle (*Aquila audax fleayi*). *Environmental Toxicology and Chemistry* **40**(1):219–30. doi: 10.1002/etc.4914.

pestSMART. (2024a). National code of practice for the humane control of feral pigs. *pestSMART, Centre for Invasive Species Solutions*. Retrieved 30 October 2024 (https://pestsmart.org.au/toolkit-resource/code-of-practice-feral-pigs/).

pestSMART. (2024b). Poisoning of feral pigs with sodium nitrite | HOGGONE®. *pestSMART, Centre for Invasive Species Solutions*. Retrieved 30 October 2024 (https://pestsmart.org.au/toolkit-resource/poisoning-of-feral-pigs-with-sodium-nitrite-hoggone/).

PETA (2024). 1080, the killer poison: What you need to know. People for the Ethical Treatment of Animals. Available at: https://www.peta.org.au/living/1080-killer-poison-need-know/ [accessed 25 October 2024].

Philip, J. (2021). A historical review of Australian aerial vertebrate pest control, targeting dingoes and wild dogs 1946 – 2019. *Australian Zoologist* **41**(3):580–92. doi: 10.7882/AZ.2020.011.

Pickard, J. (2007). Predator-proof fences for biodiversity conservation: some lessons from dingo fences. Pp. 197–207 in *Animals of Arid Australia: Out on their Own*, edited by C. R. Dickman, D. Lunney, and S. Bergin. Sydney: Royal Zoological Society of New South Wales.

Piesse, R.L. (1985). Assessing & implementing practical fencing to control kangaroos, pigs, wild dogs, wombats and other wild animals based on thirty years of experience. Pp. 1–24 in *Gallagher 2nd World Wildlife Power Fencing Seminar Proceedings*. Dubbo, N.S.W.

Pig Brig Trap Systems. (2024). Pig brig trap system. *Pig Brig Trap Systems*. Retrieved 30 October 2024 (https://pigbrig.com/products/pig-brig-trap-system).

Plant, J.W., Rees, D., Marchant, R.S., and Mitchell, T.D. (1977). Feral pigs, predators of lambs. *Agricultural Gazette of New South Wales* **88**:11–13.

van Polanen Petel, A.M., Kirkwood, R., Gigliotti, F., and Marks, C. (2004). Adaptation and assessment of m-44 ejectors in a fox-control program on Phillip Island, Victoria. *Wildlife Research* **31**(2):143. doi: 10.1071/WR02057.

Poole, D.W., and M, I.G. (2002). Effectiveness of two types of electric fence for excluding the red fox (*vulpes vulpes*). *Mammal Review* **32**(1):51–57.

Potgieter, G.C., Kerley, G.I.H., and Marker, L.L. (2016). More bark than bite? the role of livestock guarding dogs in predator control on Namibian farmlands. *Oryx* **50**(3):514–22. doi: 10.1017/S0030605315000113.

Priddel, D., and Wheeler, R. (1997). Efficacy of fox control in reducing the mortality of released captive-reared Malleefowl, *Leipoa ocellata*. *Wildlife Research* **24**(4):469–82. doi: 10.1071/wr96094.

Pyke, G.H. (1984). Optimal foraging theory: a critical review. *Annual Review of Ecology and Systematics* **15**(1):523–75. doi: 10.1146/annurev.es.15.110184.002515.

Quantum Market Research. (2024). Agriculture Victoria - 1080 use survey. Quantum Market Research prepared for the Department of Energy Environment and Climate Action, Melbourne.

Raman, P. (2014). Chloropicrin. Pp. 903–6 in *Encyclopedia of Toxicology (3rd ed)*. Academic Press.

Ramsey, D., and Cally, J. (2024). *The abundance of dingoes Canis familiaris (dingo) in Victoria: results from a statewide survey.* Arthur Rylah Institute for Environmental Research Technical Report Series No. 382. Department of Energy, Environment and Climate Action, Heidelberg, Victoria.

Ramsey, D.S.L. (2021). *Efficacy of aerial control of invasive animals: results from the bushfire biodiversity response and recovery program*. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.: Unpublished Client Report for the Environment and Community Programs Branch, DELWP.

Ramsey, D.S.L., Campbell, K.J., Lavoie, C., Macdonald, N., and Morrison, S.A. (2022). Quantifying the probability of detection of wild ungulates with the judas technique. *Conservation Biology* **36**(4):e13898. doi: 10.1111/cobi.13898.

Ramsey, D.S.L., Cox, T., Strive, T., Forsyth, D.M., Stuart, I., Hall, R., Elsworth, P., and Campbell, S. (2020). Emerging RHDV2 suppresses the impact of endemic and novel strains of RHDV on wild rabbit populations. *Journal of Applied Ecology* **57**(3):630–41. doi: 10.1111/1365-2664.13548.

Ramsey, D.S.L. (2018). *The effect of management programs on wild dog attack rates on livestock in Victoria*. Unpublished Client Report for the Department of Economic Development, Jobs, Transport and Resources. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Ramsey, D.S.L., McPhee, S.R., Forsyth, D.M., Stuart, I.G., Scroggie, M.P., Lindeman, M., and Matthews, J. (2014). Recolonisation of rabbit warrens following coordinated ripping programs in Victoria, south-eastern Australia. *Wildlife Research* **41**(1):46–55.

Ramsey D.S.L., Patel, K.K., Campbell, S., Hall, R.N., Taggart P.L., and Strive, T. (2023). Sustained Impact of RHDV2 on Wild Rabbit Populations across Australia Eight Years after Its Initial Detection. *Viruses* **15**. doi:10.3390/v15051159.

Ramsey D.S.L., Caley, P.A., and Robley, A. (2015). Estimating population density from presence–absence data using a spatially explicit model. *The Journal of Wildlife Management* **79**, 491–499. doi:10.1002/jwmg.851.

Reddiex, B., Forsyth, D.M., McDonald-Madden, E., Einoder, L.D., Griffioen, P.A., Chick, R.R., and Robley, A. (2006). Control of pest mammals for biodiversity protection in Australia. i. patterns of control and monitoring. *Wildlife Research* **33**(8):691. doi: 10.1071/WR05102.

Reidy, M.M., Campbell, T.A., and Hewitt, D.G. (2008). Evaluation of electric fencing to inhibit feral pig movements. *The Journal of Wildlife Management* **72**(4):1012–18. doi: 10.2193/2007-158.

Reidy, M.M., Campbell, T.A., Hewitt, D.G. (2008). Evaluation of Electric Fencing to Inhibit Feral Pig Movements. *The Journal of Wildlife Management* **72**, 1012–1018. doi:DOI: 10.2193/2007-158.

Rigg R (2001). Livestock guarding dogs: their current use world wide. Paper No 1 [online]. IUCN/SSC Canid Specialist Group Occasional. Available at: http://www.canids.org/occasionalpapers/.

Rigg R (2022). Are Donkeys good livestock guardians? CDP News. Available at: https://cdpnews.net/wp-content/uploads/2023/11/cdpnews24_rigg_2022.pdf [accessed 21 October 2024].

Robinson, M.H., and Wheeler, H. (1983). A radiotracking study of four poisoning techniques for control of the European rabbit, *Oryctolagus cuniculus* (l.). *Australian Wildlife Research* **10**:513–20.

Robley, A., Purdey, D., Johnston, M., Lindeman, M., and Busana, F. (2006). *Experimental trials to determine effective feral cat and fox exclusion fence designs*. Melbourne: Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment, Melbourne.

Robley, A., Ramsey, D.S.L., and Woodford, L. (2018). *Estimating population changes in wild dogs, feral cats and foxes in relation to an aerial baiting operation in eastern Victoria*. *Technical Report*. 292. Arthur Rylah Institute for Environment Research, Department of Environment, Land, Water and Planning.

Robley, A. (2008). *Assessing the effectiveness of ground-based baiting for the control of wild dogs*. Heidelberg, Victoria: Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment.

Robley, Alan, Cook, Iain, Moloney, Paul, and Woodford, L. (2015). *Dingo semiochemicals: towards a non-lethal control tool for the management of dingoes and wild dogs in Australia*. Heidelberg, Victoria: Arthur Rylah Institute for Environmental Research.

Robley, A., Gormley, A.M., Forsyth, D.M., and Triggs, B. (2014). Long-term and large-scale control of the introduced red fox increases native mammal occupancy in Australian forests. *Biological Conservation* **180**:262–69.

Robley, A., Woodford, L., Lee, P., Kingston, V., Peters, W., Klippell, D., and Gormley, A. (2009). *Assessing the effectiveness of ground-based baiting for the control of wild dogs*. *Technical Report Series*. 193. Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment.

Ross, J., Page, R.J.C., Nadian, A.K., and Langton, S.D. (1998). The development of a carbon monoxide producing cartridge for rabbit control. *Wildlife Research* **25**(3):305. doi: 10.1071/WR97012.

Ross, J., and Eason, C. (2022). A 2022 review of sodium fluoroacetate for conservation and protecting endangered species in New Zealand. Pp. 1–8 in *Proceedings, 30th Vertebrate Pest Conference*. University of California Press.

Ross, J. (1986). Comparison of fumigant gasses used for rabbit control in Great Britain. Pp. 153–57 in *Proceedings 12th Vertebrate Pest Conference*. University of California, Davis, California.

Rowley, I. (1960). The effect of concentration on the ingestion of ‘1080’ poisoned baits by the rabbit. *CSIRO Wildlife Research* **5**(2):126–33.

Rowley, I. (1968). Studies on the resurgence of rabbit populations after poisoning. *CSIRO Wildlife Research* **13**(1):59–69.

Rowley, I. (1970). Lamb predation in Australia: incidence, predisposing conditions, and the identification of wounds. *CSIRO Wildlife Research* **15**(1):79–123.

RSPCA (2019). RSPCA Knowledgebase, What is the RSPCA’s view on using 1080 for pest animal control? Available at: https://kb.rspca.org.au/ knowledge-base/what-is-the-rspcasview-on-using-1080-for-pest-animalcontrol/. [accessed 25 October 2024].

Ryan, Robert F., and De Lima, C.P.F. (2013). Phosphine - an overview of a unique 80-year fumigant. *General and Applied Entomology* **42**:31–42.

Saito, M., Momose, H., and Mihira, T. (2011). Both environmental factors and countermeasures affect wild boar damage to rice paddies in Boso Peninsula, Japan. *Crop Protection* **30**(8):1048–54. doi: 10.1016/j.cropro.2011.02.017.

Saunders, G. (1993). Observations on the effectiveness of shooting feral pigs from helicopters. *Wildlife Research* **20**(6):771. doi: 10.1071/WR9930771.

Saunders, G., and Bryant, H. (1988). The evaluation of a feral pig eradication program during a simulated exotic disease outbreak. *Wildlife Research* **15**(1):73–81. doi: 10.1071/wr9880073.

Saunders, G., Gentle, M.N., and Dickman, C.R. (2010). The impacts and management of foxes *Vulpes vulpes* in Australia. *Mammal Review* **40**(3):181–211.

Saunders, G., Kay, B., and Nicol, H. (1993). Factors affecting bait uptake and trapping success for feral pigs (*Sus scrofa*) in Kosciusko National Park. *Wildlife Research* **20**(5):653–65. doi: 10.1071/wr9930653.

Saunders, G., Kinnear, J, Braysher, M, and Coman, B. (1995). *Managing Vertebrate Pests: foxes.* Canberra: Australian Government Publishing Service.

Saunders, G., McIlroy, J., Berghout, M., Kay, B., Gifford, E., Perry, R., and Van De, V. (2002). The effects of induced sterility on the territorial behaviour and survival of foxes. *Journal of Applied Ecology* **39**(1):56–66.

Saunders, G., and McLeod, L. (2007). *Improving fox management strategies in Australia.* Bureau of Resource Sciences, Australian Government Publishing Service.

Savarie, P.J., Pan, H.P., Hayes, D.J., Roberts, J.D., Dasch, G.J., Felton, R., and Schafer, E.W. (1983). Comparative acute oral toxicity o fpara-aminopropiophenone (PAPP) in mammals and birds. *Bulletin of Environmental Contamination and Toxicology* **30**(1):122–26. doi: 10.1007/BF01610109.

Schultz, R.N., Jonas, K.W., Skuldt, L.H., and Wydeven, A.P. (2005). Experimental use of dog-training shock collars to deter depredation by Gray Wolf *Wildlife Society Bulletin* **33**:142–48.

Seebens, H. (2024). Biological invasions on indigenous peoples' lands. *Nature Sustainability*.

Shapiro, L., Eason, C.T., Hix, Steve, Ogilvie, S.C., and MacMorran, D. (2010). Para-aminopropiophenone (PAPP) research, development, registration, and application for humane predator control in New Zealand. Pp. 115–18 in. University of California Davis USA: Proceedings of the 24th Vertebrate Pest Conference.

Shapiro, L. (2017). Primary poisoning risk for encapsulated sodium nitrite, a new tool for pest control. *New Zealand Journal of Zoology* **44**:108–21.

Shapiro, L., Blackie, H., Arthur, D., Ross, J., and Eason, C. (2018). Secondary poisoning risk for encapsulated sodium nitrite, a new tool for possum control. *New Zealand Journal of Ecology* **42**(1):1–9. doi: 10.20417/nzjecol.42.6.

Shapiro, L., Eason, C., Bunt, C., Hix, S., Aylett, P., and MacMorran, D. (2016). Efficacy of encapsulated sodium nitrite as a new tool for feral pig management. *Journal of Pest Science* **89**(2):489–95. doi: 10.1007/s10340-015-0706-7.

Sharp, T. (2012a). NATSOP-PIG005 National Standard Operating Procedure: Poisoning of feral pigs with 1080. pestSMART, Centre for Invasive Species Solutions. Available at: https://pestsmart.org.au/toolkit-resource/poisoning-of-feral-pigs-with-sodium-fluroacetate-1080/ [accessed 14 October 2024].

Sharp, T. (2012b). NATSOP-PIG001 National Standard Operating Procedure: Trapping of feral pigs. pestSMART, Centre for Invasive Species Solutions. Available at: https://pestsmart.org.au/toolkit-resource/trapping-of-feral-pigs/ [accessed 14 October 2024].

Sharp, T. (2012c). NATSOP-PIG003 National Standard Operating Procedure: Ground shooting of feral pigs. pestSMART, Centre for Invasive Species Solutions. Available at: https://pestsmart.org.au/toolkit-resource/groundshooting-of-feral-pigs/ [accessed 14 October 2024].

Sharp, T. (2012d). NATSOP-FOX004 national standard operating procedure: fumigation of fox dens using carbon monoxide. *pestSmart*. Retrieved 6 August 2024 (https://pestsmart.org.au/wp-content/uploads/sites/3/2024/04/NATSOP-FOX004.pdf) [accessed 14 October 2024].

Sharp, T. (2012e). NATSOP-DOG001 National Standard Operating Procedure: Trapping of wild dogs using padded-jaw traps. Available at: https://pestsmart.org.au/toolkit-resource/trapping-of-wild-dogs-using-padded-jaw-traps [accessed 14 October 2024].

Sharp, T. (2012f). Natsop-Rab004 National Standard Operating Procedure: Diffusion Fumigation of rabbit warrens. pestSMART, Centre for Invasive Species Solutions. Available at: https://pestsmart.org.au/toolkit-resource/diffusionfumigation-of-rabbit-warrens/ [accessed 17 October 2024].

Sharp, T., and Saunders, G. (2011). *A model for assessing the relative humaneness of pest animal control methods (second edition)*. Canberra, ACT: Australian Government Department of Agriculture, Fisheries and Forestry.

Sherley, M. (2007). Is sodium fluoroacetate (1080) a humane poison? *Animal Welfare* **16**(4):449–58. doi: 10.1017/S096272860002738X.

Shivik, J.A. (2004). Non-lethal Alternatives for Predation Management. *Sheep and Goat Research Journal* **19**, 64–71.

Shivik, J.A., Treves, A., and Callahan, P. (2003). Nonlethal techniques for managing predation: primary and secondary repellents. *Conservation Biology* **17**(6):1531–37. doi: 10.1111/j.1523-1739.2003.00062.x.

Shivik, J.A., Wilson, R., R., and Gilbert-Norton, L. (2011). Will an artificial scent boundary prevent coyote intrusion? *Wildlife Society Bulletin* **35**(4):494–97. doi: 10.1002/wsb.68.

Smart, J., and Amar, A. (2018). Diversionary feeding as a means of reducing raptor predation at seabird breeding colonies. *Journal for Nature Conservation* **46**:48–55. doi: 10.1016/j.jnc.2018.09.003.

Smith, B.R., Yarnell, R.W., Uzal, A., and Whitehouse-Tedd, K. (2020). The ecological effects of livestock guarding dogs (LGDs) on target and non-target wildlife. *Journal of Vertebrate Biology* **69**(3). doi: 10.25225/jvb.20103.

Smith, B.P., and Appleby, R.G. (2018). Promoting human–dingo co-existence in Australia: moving towards more innovative methods of protecting livestock rather than killing dingoes (*Canis dingo*). *Wildlife Research* **45**(1):1. doi: 10.1071/WR16161.

Smith, B.P., Appleby, R.G., and Jordan, N.R. (2021). Co-existing with dingoes: challenges and solutions to implementing non-lethal management. *Australian Zoologist* **41**(3):491–510. doi: 10.7882/AZ.2020.024.

Smith, D., King, R., and Allen, B.L. (2020). Impacts of exclusion fencing on target and non-target fauna: a global review. *Biological Reviews* **95**(6):1590–1606. doi: 10.1111/brv.12631.

Smith, M.E., Linnell, J. D. C., Odden, J., and Swenson, J.E. (2000). Review of methods to reduce livestock depredation. i. guardian animals. *Acta Agriculturae Scandinavica* **50**:279–90.

Smith, M.E., Linnell, J D C, Odden, J., and Swenson, J.E. (2000). Review of methods to reduce livestock depredation ii. aversive conditioning, deterrents and repellents. *Acta Agriculturae Scandinavica* **50**:304–15.

Smith, M., Lapidge, S., Cowled, B., and Staples, L. (2005). The design and development of PIGOUT® - a target-specific feral pig bait. *13th Australasian Vertebrate Pest Conference Proceedings* 129–35.

Snow, Nathan P., Foster, Justin A., VanNatta, Eric H., Horak, Katherine E., Humphrys, Simon T., Staples, Linton D., Hewitt, David G., and VerCauteren, Kurt C. (2018). Potential secondary poisoning risks to non-targets from a sodium nitrite toxic bait for invasive wild pigs. *Pest Management Science* **74**(1):181–88. doi: 10.1002/ps.4692.

Snow, N.P., Glow, M.P., Foster, J.A., and VerCauteren, K.C. (2024). Seasonal efficacy and risks from a sodium nitrite toxic bait for wild pigs. *Pest Management Science* **80**(7):3227–37. doi: 10.1002/ps.8025.

Snow, N.P., Glow, M.P., Lavelle, M.J., Fischer, J.W., Cook, S.M., Lutman, M.W., Foster, J.A., and VerCauteren, K.C. (2022). Dry and unwary are best conditions for baiting wild pigs (*Sus scrofa*). *Applied Animal Behaviour Science* **257**.

Snow, N.P., Horak, K.E., Humphrys, S.T., Staples, L.D., Hewitt, D.G., and VerCauteren, K.C. (2019). Low secondary risks for captive coyotes from a sodium nitrite toxic bait for invasive wild pigs. *Wildlife Society Bulletin* **43**:484–90.

Snow, N.P., Wishart, J.D., Foster, J.A., Staples, L.D., and VerCauteren, K.C. (2021). Efficacy and risks from a modified sodium nitrite toxic bait for wild pigs. *Pest Management Science* **77**(4):1616–25. doi: 10.1002/ps.6180.

Sodeikat, G., and Pohlmeyer, K. (2003). Escape movements of family groups of wild boar sus scrofa influenced by drive hunts in lower Saxony, Germany. *Wildlife Biology* **9**(1):43–49. doi: 10.2981/wlb.2003.063.

Southwell, D., Boero, V., Mewett, O., McCowen, S., and Hennecke, B. (2013). Understanding the drivers and barriers to participation in wild canid management in Australia: implications for the adoption of a new toxin, para-aminopropiophenone. *International Journal of Pest Management* **59**(1):35–46.

Spencer, E., and Newsome, T. (2021). Dingoes dining with death. *Australian Zoologist* **41**(3):433–51. doi: 10.7882/AZ.2021.008.

Spencer-Oatey, H. (2012). What is Culture? A compilation of quotations. GlobalPAD Core Concepts. Available at: http://go.warwick.ac.uk/globalpadintercultural [accessed 17 February 2025].

Strive, T., Wright, J.D., and Robinson, A.J. (2009). Identification and partial characterisation of a new *Lagovirus* in Australian wild rabbits. *Virology* **384**(1):97–105. doi: 10.1016/j.virol.2008.11.004.

Strive, T., and Cox, T.E. (2019). Lethal biological control of rabbits – the most powerful tools for landscape-scale mitigation of rabbit impacts in Australia. *Australian Zoologist* **40**(118–128).

Strive, T., Elsworth, P., Liu, J., Wright, J.D., Kovaliski, J., and Capucci, L. (2013). The non-pathogenic Australian rabbit calicivirus rcv-a1 provides temporal and partial cross protection to lethal rabbit haemorrhagic disease virus infection which is not dependent on antibody titres. *Veterinary Research* **44**(1):1–11. doi: 10.1186/1297-9716-44-51.

Suren, A.M. (2006). Quantifying contamination of streams by 1080 baits, and their fate in water. *New Zealand Journal of Marine and Freshwater Research* **40**(1):159–67. doi: 10.1080/00288330.2006.9517410.

Tapscott, B. (1997). Guidelines for using donkeys as guard animals with sheep. Available at: http://www.omafra.gov.on.ca/english/livestock/sheep/facts/donkey2.htm [accessed 25 October 2024].

Tauchmann, A. (1999). *Aversive conditioning trial on dingoes using lithium chloride and thiabendazole. Unpublished Report*. The University of Queensland, Gattan, QLD.

Thompson, J.A., and Fleming, P.J.S. (1991). The cost of aerial baiting for wild dog management in north-eastern New South Wales. *The Rangeland Journal* **13**(1):47. doi: 10.1071/RJ9910047.

Thompson, J.A., and Fleming, P.J.S. (1994). Evaluation of the efficacy of 1080 poisoning of red foxes using visitation to non-toxic baits as an index of fox abundance. *Wildlife Research* **21**(1):27. doi: 10.1071/WR9940027.

Thomson, P.C. (1984). Dingoes in sheep and pastoral areas. *Journal of Agriculture Western Australia* **25**:27–31.

Thomson, P.C. (1986). The effectiveness of aerial baiting for the control of dingoes in north-western Australia. *Wildlife Research* **13**(2):165. doi: 10.1071/WR9860165.

Thomson, P.C., and Kok, N.E. (2002). The fate of dried meat baits laid for fox control: the effects of bait presentation on take by foxes and non-target species, and on caching by foxes. *Wildlife Research* **29**(4):371. doi: 10.1071/WR01098.

Thomson, P.C., Marlow, N.J., Rose, K., and Kok, N.E. (2000). The effectiveness of a large-scale baiting campaign and an evaluation of a buffer zone strategy for fox control. *Wildlife Research* **27**(5):465. doi: 10.1071/WR99036.

de Tores, P. (2020). 'Native fauna response to large scale fox control in the northern jarrah forest of south-west western Australia: operation foxglove'. PhD Thesis, UNSW Sydney.

Treves, A., Krofel, M., and McManus, J. (2016). Predator control should not be a shot in the dark. *Frontiers in Ecology and the Environment* **14**(7):380–88.

Twigg, Laurie E., Eldridge, Steve R., Edwards, Glenn P., Shakeshaft, Bernie J., dePreu, Nicki D., and Adams, Neville. (2000). The longevity and efficacy of 1080 meat baits used for dingo control in central Australia. *Wildlife Research* **27**(5):473. doi: 10.1071/WR99044.

Twigg, L.E., Lowe, T.J., Kirkpatrick, W.E., and Martin, G.R. (2003). Tissue residue levels in rabbits and rats poisoned with 1080 one-shot bait and the location of poisoned rabbit carcasses. *Wildlife Research* **30**(6):621. doi: 10.1071/WR02098.

Twigg, L.E., Lowe, T., and Martin, G. (2005). Sodium fluoroacetate residues and carcass degradation of free-ranging feral pigs poisoned with 1080. *Wildlife Research* **32**(6):573–80. doi: 10.1071/WR05026.

Twigg, L.E., Lowe, T., and Martin, G. (2007). Bait consumption by, and 1080-based control of, feral pigs in the mediterranean climatic region of south-western Australia. *Wildlife Research* **34**(2):125–39. doi: 10.1071/WR06084.

Twigg, L.E., Gray, G.S., Massam, M.C., Lowe, T.J., Kirkpatrick, W., Bendotti, G., and Chester, D.R. (2001). Evaluation of bait stations for control of urban rabbits. *Wildlife Research* **28**(3.):299–310.

Tyrell, G., and Hunt, R. (2006). Llamas as livestock guards. Department of Environment and Climate Change NSW.

USDA (2019). Final Environmental Assessment - A Small Scale Field Evaluation of HOGGONE® 2 Sodium Nitrite Toxicant Bait for Feral Swine. United States Department of Agriculture Animal and Plant Health Inspection Service Wildlife Services. Available at: https://www.aphis.usda.gov/sites/default/files/al-2019-sodium-nitrite-feral-swine-final-ea.pdf [accessed 29 July 2024].

Vaarzon-Morel, P., and Edwards, G. (2012). Incorporating aboriginal people's perceptions of introduced animals in resource management: insights from the feral camel project. *Ecological Management & Restoration* **13**(1):65–71. doi: 10.1111/j.1442-8903.2011.00619.x.

Van Polanen Petel, A. M., Marks, C.A., and Morgan, D.G. (2001). Bait palatability influences the caching behaviour of the red fox (vulpes vulpes). *Wildlife Research* **28**(4):395. doi: 10.1071/WR00046.

Vanclay, F. (2002). Conceptualising social impacts. *Environmental Impact Assessment Review* **22**:183–211.

VerCauteren, K.C., Levelle, M.J., Moyles, S. (2003). Coyote activated frightening devices for reducing sheep predation on open range. USDA National Wildlife Research Centre, Staff Publication No. 285.

Wallach, A.D., Ritchie, E.G., Read, J., and O'Neill, A.J. (2009). More than mere numbers: the impact of lethal control on the social stability of a top-order predator. *PLoS ONE* **4**(9). doi: 10.1371/journal.pone.0006861.

Waltham, N.J., and Schaffer, J. (2021). Will fencing floodplain and riverine wetlands from feral pig damage conserve fish community values? *Ecology and Evolution* **11**(20):13780–92. doi: 10.1002/ece3.8054.

Waltham, N.J, and Schaffer, J. (2019). Feral pig exclusion fencing provides limited fish conservation value on tropical floodplains. *bioRxiv* 625053.

Walton, M.T., and Feild, C. A. (1989). Use of donkeys to guard sheep and goats in Texas. Pp. 87–94 in *Fourth Eastern Wildlife Damage Control Conference*. University of Nebraska-Lincoln.

Wamsley, J. (1995). At earth sanctuaries, the only good cat is a flat cat. *Issues* **32**:7–10.

West, P. (2018). *Guide to introduced pest animals of Australia*. CSIRO Publishing.

Weeks, A.R., Kriesner, P., Bartonicek, N., Van Rooyen, A., Cairns, K.M., Ahrens, C.W, (2025). Genetic structure and common ancestry expose the dingo-dog hybrid myth. *Evolution Letters* **9**, 1–12. doi:10.1093/evlett/qrae057.

Wheeler, S.H. (1984). How rabbit poisoning methods work. *Journal of the Department of Agriculture, Western Australia* **25**, 15–16.

Whisson, D.A., and Ashman, K.R. (2020). When an iconic native animal is overabundant: the koala in southern Australia. *Conservation Science and Practice* **2**(5). doi: 10.1111/csp2.188.

Whitehouse-Tedd, K., Wilkes, R., Stannard, C., Wettlaufer, D., and Cilliers, D. (2020). Reported livestock guarding dog-wildlife interactions: implications for conservation and animal welfare. *Biological Conservation* **241**:108249. doi: 10.1016/j.biocon.2019.108249.

Wicks, S., Mazur, K., Please, P., and Ecker, Saan. (2014). *An integrated assessment of the impact of wild dogs in Australia*. *Research report*. 14.4. Australian Bureau of Agricultural and Resource Economics and Sciences.

Wilcox, J.T., Aschehoug, E.T., Scott, C.A., and van Vuren, D.H. (2004). A test of the judas technique as a method for eradicating feral pigs. *Transactions of the Western Section of the Wildlife Society* **40**:120–26.

Williams, B.L., Holtfreter, R.W., Ditchkoff, S.S., and Grand, J.B. (2011a). Efficiency of time-lapse intervals and simple baits for camera surveys of wild pigs. *The Journal of Wildlife Management* **75**(3):655–59. doi: 10.1002/jwmg.75.

Williams, B.L., Holtfreter, R.W., Ditchkoff, S.S., and Grand, J.B. (2011b). Trap style influences wild pig behaviour and trapping success. *The Journal of Wildlife Management* **75**(2):432–36. doi: 10.1002/jwmg.64.

Williams, C.K., and Moore, R.J. (1995). Effectiveness and cost-efficiency of control of the wild rabbit, *Oryctolagus cuniculus* (l.), by combinations of poisoning, ripping, fumigation and maintenance fumigation. *Wildlife Research* **22**(3):253. doi: 10.1071/WR9950253.

Williams, K., Parer, I., Coman, B., Burley, J., and Braysher, M. (1995). *Managing vertebrate pests: rabbits*. Australian Government Publishing Service Canberra.

Wilson, C., and Gentle, M.N. (2022). *Feral pig population control techniques: a review and discussion of efficacy and efficiency for application in Queensland*. State of Queensland.

Wishart, J. (2013). An investigation into the ecology and management of feral pigs (*Sus scrofa*) in the Macquarie Marshes, New South Wales.

Wood, DH. (1985). Effectiveness and economics of destruction of rabbit warrens in sandy soils by ripping. *The Rangeland Journal* **7**(2):122–29.

Woodford, L., Ramsey, D., and Robley, A. (2023). *Assessing feral pig and deer abundance in indigenous protected areas adjoining Budj Bim National Park*. Technical Report Series.

World Health Organisation. (1988). *Phosphine and selected metal phosphides.* World Health Organisation.

Young, L.K., Skinner, K., Tyne, J.F., and Edwards, G. (2024). Increasing the target specificity of the canid-pest ejector for red fox (*Vulpes vulpes*) control by using a collar to exclude larger canids. *Wildlife Research* **51**(6):1–12. doi: 10.1071/WR23147.

Zarco-Gonzalez, M., and Monroy-Vichis, O. (2014). Effectiveness of low-cost deterrents in decreasing livestock predation by felids: a case in central Mexico. *Animal Conservation* **17**:371–78.

Appendices

Appendix 1. Information required to parameterise cost-effectiveness models of pest control

An operation can be a single control event or encompass several events, e.g. total number of days over which baiting or trapping occurs before baits are replaced/removed or a trap pulled up is an event, several baiting/trapping events make up an operation, a single flight shooting is an event, several flights, either per day or over multiple days is an operation, ripping or fumigating warrens per day in an event, multiple consecutive days is an operation.

Table A1. Data required from lethal rabbit control operations to parameterise cost-effectiveness models.

Parameter	Description
Operational data	
Date and location	Location should be x y coordinates of event location
Area (ha) of control	Needs to be the effective area treated per event.
No. of units of control used and duration per operations	Kg of carrots, oats or pindone laid/km and number of transects No. of rabbits inoculated with RHDV-K5 per day No. of warrens fumigated, and no. of phosphine/chloropicrin tablets used/warren No. of traps used, and no. of trap nights to catch rabbit for inoculation
Time spent on control effort	Number of hours per person spent on operation. For example: • hours per person to lay (free feed and poison) baits • hours per person preparing baits • hours per person fumigating • hours per person ripping warrens • hours per person spent trapping rabbits to inoculate with RHDV-K5. Excludes administration costs.
Labour cost for each method	Cost ($) per hour per person spent on the operational implementation of control
Cost and amount of materials	Cost of free feed and poison baits per operation Cost of fumigant per control event Cost of machine per hour to rip warrens/create furrows (if hired) Cost of RHDV-K5 per event

Parameter	Description
Distance travelled	Km flown or driven to and from and at control site Km flown or driven during control event
Cost of travel	$ per litre of fuel or total fuel cost per event cost of flying a control event ($/hr) Helicopter standby rate per operations
Pest animal data	
Pest abundance/density	A measure of the pre- and post-density of the pest or a measure of the relative abundance, or a count of individuals, e.g. mean of three consecutive nights of spotlight counts before and after control event/operation; and count of open entrances per warren or pellet counts before and after operation.
The number of individuals killed per event	NA for rabbits – see above
Number of warrens/dens ripped or fumigated per event	A count of warrens treated per event.

Table A2. Data required from lethal Feral Pig control operations to parameterise cost-effectiveness models.

Parameter	Description
Operational data	
Date and location	Location should be x y coordinates of event location
Area (ha) of control	Needs to be the effective area treated per event.
No. of units of control used and duration per operation	Kg of free feed laid per event Kg of PIGOUT laid per event Kg. of HOGONE paste used per event No. (and type) of traps set per event and no. nights operated per trap per event No. of traps/bait boxes used per event, and no. of trap nights per trap per event No. transects flown for aerial shooting per operation
Time spent on control effort	Number of hours per person spent on operation. For example: • number of hours free feeding and poison baiting per event • hours spent flying per aerial shooting event • hours spent ground shooting per event • hours establishing and operating traps/bait boxes. Includes preparation and cleanup time. Excludes administration costs.
Cost of labour for each method	Cost ($) per hour per person spent on the operational implementation of control
Cost of materials	Cost of all materials use in the control operations $/kg of baits used per event $/bullet used (including misses) Cost ($) and type of a single trap Cost ($) and type of a single bait box
Distance travelled	Km flown per transect of aerial shooting per event Km driven/walked ground shooting Km driven to and from control site Km driven between trap sites
Cost of travel	$ per litre of fuel or total fuel cost per event Cost of flying a control event ($/hr) Helicopter standby rate per operations

Parameter	Description
	Cost of travel for constructing bait stations ($/km) Cost of laying / replacing baits ($/km)
Pest animal data	
Pest abundance/density	A measure of the pre and post density, relative abundance, or a count of individuals.
The number of individuals killed per event	The number of pigs shot per transect. Number missed transect. No carcasses counted after poisoning, and time (hrs/spent) searching No of pigs trapped per event

Table A3. Data required from lethal fox control operations to parameterise cost-effectiveness models.

Parameter	Description
Operational data	
Date and location	Location should be x y coordinates of event location
Area (ha) of control	Needs to be the effective area treated per event.
No. of units of control used and duration per operations	No. of free feed bait laid per event, number of nights before replacement or pickup No. of poison laid per event, number of nights before replacement or pickup No. (and type) of traps set per event and no. nights operated per trap per event No. of CPEs set per event and no. nights operated per event No. of dens fumigated, and no. of Den-Co-Fume cartridges used/den
Time spent on control effort	Number of hours per person spent on operation. For example: number of hours free feeding and poison baiting per event (include bait replacement runs) • hours spent ground shooting per event • hours establishing and operating traps • hours establishing and operating CPEs • hours spent fumigating per event. Includes preparation and cleanup time. Excludes administration costs.
Cost of labour for each method	Cost ($) per hour per person spent on the operational implementation of control
Cost of materials	Cost of all materials use in the control operations $/bait used per event, $/bullet used (including misses) Cost ($) and type of a single trap Cost ($) and type of a single CPE Cost ($) and type of a single fumigation cartridge
Distance travelled	Km driven / walked ground shooting Km driven to and from control site Km driven per bait run/transect Km driven between trap/CPE sites
Cost of travel	$ per litre of fuel or total fuel cost per event

Parameter	Description
	Cost of travel for constructing bait stations ($/km) Cost of laying/replacing baits ($/km) Cost of travel for constructing/retrieving CPEs ($/km) Km driven/walked ground shooting
Pest animal data	
Pest abundance/density	A measure of the pre and post density, relative abundance, or a count of individuals.
The number of individuals killed per event	The number of foxes shot per transect and number missed transect. No of fox dens fumigated per event No. CPEs set-off per event No. of individuals trapped per trap per event No. baits taken per event

Table A4. Data required from lethal Dingo and Wild Dog control operations to parameterise cost-effectiveness models.

Operational data	**Parameter**
Date and location	Location should be x y coordinates of event location
Area (ha) of control	Needs to be the effective area treated per event.
No. of units of control used and duration per operations	No. of poison baits laid per event, number of nights before replacement or pickup No. (and type) of traps set per event and no. nights operated per trap per event
Time spent on control effort	Number of hours per person spent on operation. For example: • number of hours poison baiting per event (include bait replacement runs) • hours spent ground shooting per event • hours establishing and operating traps. Includes preparation and cleanup time. Excludes administration costs.
Cost of labour for each method	Cost ($) per hour per person spent on the operational implementation of control
Cost of materials	Cost of all materials use in the control operations $/bait used per event, $/bullet used (including misses) Cost ($) and type of a single trap
Distance travelled	Km driven/walked ground shooting Km driven to and from control site Km driven per bait run/transect
Cost of travel	$ per litre of fuel or total fuel cost per event Cost of travel for constructing bait stations ($/km) Cost of travel for constructing traps ($/km) Cost of Km driven/walked ground shooting
Pest animal data	
Pest abundance/density	A measure of the pre and post density, relative abundance, or a count of individuals.
The number of individuals killed per event	The number of individuals shot per transect and number missed transect. No. of individuals trapped per trap per event No. baits taken per event

DON'T DELET PAGE BREAK

www.deeca.vic.gov.au

www.ari.vic.gov.au