PESTSMART

A systematic review of ground-based shooting for pest animal control

Andrew Bengsen

2016

Invasive Animals CRC

Australian Government
Department of Industry, Innovation and Science

Business
Cooperative Research Centres Programme

A systematic review of ground-based shooting for pest animal control

Andrew Bengsen

NSW Department of Primary Industries

Vertebrate Pest Research Unit

1447 Forest Rd
Orange NSW 2016

2016

An Invasive Animals CRC Project

Invasive Animals CRC

Australian Government
Department of Industry, Innovation and Science

Business
Cooperative Research Centres Programme

Published by: Invasive Animals Cooperative Research Centre.

Email: contact@invasiveanimals.com

Internet: http://www.invasiveanimals.com

ISBN: 978-0-9924083-8-1

Web ISBN: 978-0-9924083-9-8

The IA CRC gratefully acknowledges funding support from the Australian Government through its Cooperative Research Centres Program.

This document should be cited as: Bengsen, A J (2016). *A systematic review of ground-based shooting for pest animal control*. PestSmart Toolkit publication, Invasive Animals Cooperative Research Centre, Canberra, Australia.

Front cover photo: Peter West

Contents

List of Figures

List of Tables

Executive Summary

Ground-based shooting is commonly used to try and reduce the impacts or abundance of over-abundant animal populations in many parts of the world. It encompasses a wide range of activities carried out by many different types of people driven by a variety of interacting motivations. Given this contextual complexity, it is unsurprising that results of ground shooting operations for pest animal control range from counter-productive to highly effective.

This review systematically examines a sample of published papers that report on the efficacy of ground-based shooting operations in Australasia, North America, Europe and Japan. Although the sample was small and the literature surveyed included many flaws and inconsistencies, several key themes that contribute to effectiveness were identified. These included: 1) the use of tools or methods that enhance efficiency; 2) a manageable geographic area of operations; and 3) the use of highly skilled and committed shooters. Factors repeatedly shown to detract from efficacy included: 1) the inability of harvest-oriented shooters to sustain effort as target populations declined; 2) insufficient spatial or temporal coverage to counter immigration; and 3) the presence of refugia within treatment areas.

It is clear that ground shooting can make important contributions to the management of pest or over-abundant species, but shooting alone is often insufficient or prohibitively inefficient to achieve desired outcomes. Managers planning to use ground shooting as part of a population management strategy should: 1) carefully examine the options to determine what type of shooting operation is likely to be most useful; 2) establish and monitor meaningful objectives; 3) ensure that operations are sufficiently resourced to meet and maintain those objectives; and 4) integrate ground shooting with other control methods wherever possible. Operations that are poorly-planned, resourced, integrated and executed are unlikely to deliver useful outcomes. Ground-based shooting is rarely, if ever, a cheap and easy method for reducing pest impacts or abundance.

Review Panel

An initial draft of this report was reviewed by an external expert panel comprising:

Dr Tony Pople
Invasive Plants & Animals Research
Biosecurity Queensland, Department of Agriculture and Fisheries

Dr A. David M. Latham
Wildlife Ecology and Management Team
Landcare Research Manaaki Whenua

Dr David Peacock
Biosecurity South Australia
Department of Primary Industries and Regions South Australia

Abbreviations

AO	Area of operations
DPI	NSW Department of Primary Industries
OEH	NSW Office of Environment and Heritage
SSAA	Sporting Shooters Association of Australia inc.
TI	Thermal imaging

1. Introduction

Natural resource managers and landholders in many parts of the world use ground-based shooting programs to reduce the density of pest or over-abundant animal populations in order to protect environmental, agricultural or other valued assets. These programs span a spectrum of management intensity ranging from highly organised shooting operations using professional teams to achieve specific measurable objectives (e.g. Barron et al. 2011) to laissez faire programs in which recreational hunters are allowed to harvest over-abundant species at their leisure (e.g. Massei et al. 2015). In Australia, shooting has been a popular method for controlling a wide range of pest animals (Reddiex et al. 2006, West & Saunders 2007).

Despite the importance that resource managers often place in ground-shooting, in Australia and internationally, its efficacy as a control tool has rarely been tested (Rutberg 1997, Reddiex & Forsyth 2006, Bengsen & Sparkes 2016, Davis et al. 2016). Furthermore, there may be a publication bias towards favourable evaluations (Peterson & Nelson 2016). It is, therefore, often difficult for managers to accurately predict the likely value of ground-based shooting as a pest control tool for any given situation, and therefore to determine how it might best be integrated into, or left out of, strategic pest management programs. In many cases, the choice to use shooting as a control tool seems to be based on practical or political convenience, or simply because there seems to be no other option available except doing nothing (Rutberg 1997, West & Saunders 2007). Nonetheless, the use of ground-based shooting as a pest control tool appears to be increasing in many parts of Australia. This apparent increase coincides with an upsurge of organisation and lobbying by groups representing recreational hunters, and also with the availability of new tools that have the potential to increase the efficiency of professional shooters.

This report describes the outcomes of a systematic review of published literature that aimed to evaluate the potential value of ground-based shooting as a vertebrate pest control tool, particularly in the contemporary Australian context. First, the scene is set with a brief survey of the broad range of shooting types conducted in Australia and internationally. This is followed by an examination of select local and international case studies that describe the effectiveness of ground shooting programs in different situations. From this examination, several generalisations are drawn about when, where and how ground shooting is most likely to be effective. In particular the review aims to determine whether the effectiveness of ground shooting for pest control operations tend to vary according to:

1. The status of the shooters involved (government, professional or unpaid);
2. The primary motivation for organising the shooting activity;
3. The geographic scale of operations;
4. Whether shooting is integrated into a management strategy that also uses other control methods.

The conclusion includes a short series of recommendations for resource managers considering the use of ground shooting as a pest animal control tool.

1.1 Ground shooting for pest control in Australia

There are many different ways in which ground shooting can contribute to pest management objectives. These can be classified using a typology based on the type of shooters involved, the primary motivation for the operation and the tenure of the land on which the operation is conducted (Figure 1). Some pest management programs may combine different types of shooting operations as part of a broader strategy. Also, nil tenure pest management, in which management tactics are planned without reference to property boundaries (Fleming et al. 2014), can result in some overlap at the lowest level of organisation. Nonetheless, the basic typology provides a useful construct for evaluating the effectiveness of shooting operations as a pest control tool.

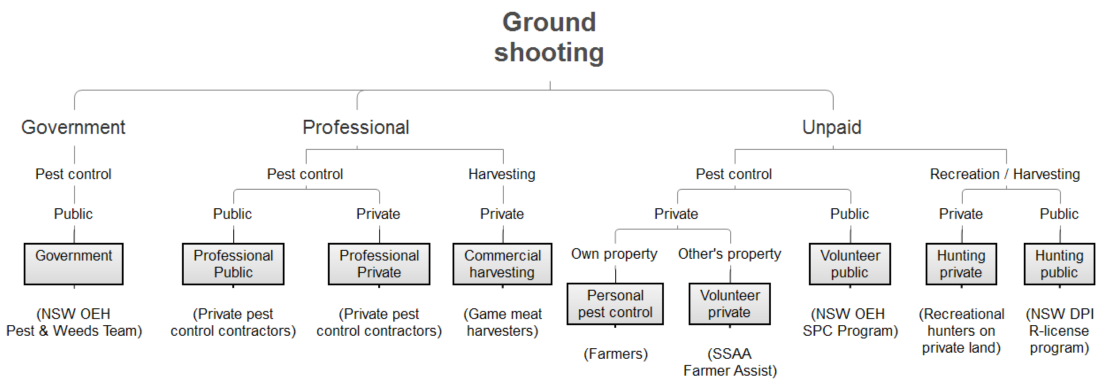


Figure 1: A hierarchical typology of different classes of ground shooting operations organised by the employment status of the shooter, the motivation for organizing the operation and the tenure of land on which operations are conducted. Examples of each type are shown in the lowest level.

Currently, ground shooting is used in programs aiming to control wild dogs (*Canis* spp.), foxes (*Vulpes vulpes*), cats (*Felis catus*), rabbits (*Oryctolagus cuniculus*), pigs (*Sus scrofa*), goats (*Capra hircus*), deer (Cervidae), macropods and native waterfowl (Grigg, 1995, Bomford & Sinclair 2002, Reddiex et al. 2006, West & Saunders 2007). It is not possible to estimate the relative importance of different types of shooting operations to the control of each of these species. However, ground shooting has traditionally been regarded as an important tool for managing deer and cats because few other options have been available for these species (West & Saunders 2007, Davis et al. 2016).

While recreational hunting is, by definition, not primarily intended to achieve pest control objectives, a recent survey estimated that between 200,000 and 350,000 hunters used public or private land to hunt introduced species in Australia (Finch et al. 2014). Contrary to North America and Europe (Enck et al. 2000, Massei et al. 2015), the number of hunters in Australia appears to have increased in recent decades (Franklin 1996, Bengsen et al. 2016), although numbers remain small when standardised by area (Table 1). There is much uncertainty around the role of recreational hunting as a pest control tool in Australia (Bengsen & Sparkes 2016).

Table 1: Estimated numbers of active recreational hunters in 13 countries, ordered by decreasing number of hunters per square kilometre.

Country	Year	Number of hunters ($\times 10^6$)	Per cent of total population	Hunters km^{-2}
Spain	2011[3]	1.07†	2.28	2.12
Italy	2012[3]	0.62†	1.03	2.05
France	2012[3]	1.16†	1.76	1.80
Portugal	2011[3]	0.14†	1.35	1.53
United States	2011[5]	13.70	4.40	1.39
Germany	2012[3]	0.36†	0.44	1.00
Sweden	2013[3]	0.27†	2.83	0.60
Japan	2000[6]	0.17	<0.00	0.44
Poland	2012[3]	0.11†	0.29	0.36
Russia	2013[3]	3.19†	2.22	0.19
New Zealand	1988[4]	0.05	1.52	0.19
Canada	1996[2]	1.51	5.10	0.15
Australia	2012[1]	0.20 to 0.35	0. 90 to 1.52	0.03 to 0.05

†Hunter numbers estimated from digitized plots

[1] Finch et al. (2014), [2] Gray et al. (2003), [3] Massei et al. (2015), [4] Nugent (1992), [5] U.S. Fish & Wildlife Service. (2011), [6] Kaji et al. (2010)

2. Methods

2.1 Literature search

Relevant literature items were identified and collated using a five step search. First, the author’s personal bibliography management database was searched for articles in which the words “shooting” or “hunting” appeared in the title, abstract or keywords. The online Web of Science Core Collection database was then searched on 4 November 2016 using the terms “shooting OR hunting” and “pest OR overabundant”, within topics. The search was limited to items published since 1980. The resulting list of items was refined using the categories of ecology, forestry, biology, zoology, environmental sciences and environmental studies. Time constraints on the project precluded a wider search. Because this project was mainly concerned with making inferences relevant to the Australian situation, studies that focused on the hunting of uncommon native species, such as cougars (*Puma concolor*) in North America, were excluded.

To uncover grey literature and try to reduce the impact of publication bias, Google Scholar was searched on 4 November 2016 for articles containing the following sets of keywords: “hunting shooting pest”, “hunting shooting overabundant” and “hunting ‘over abundant’ shooting”. Only the first 50 articles returned by each search were used. The Invasive Animals Cooperative Research Centre’s PestSmart Connect online database was searched on 13 November 2016 for documents containing the terms “shooting”, “hunting” or “case study” to identify additional literature directly relevant to Australia. Finally, 13 researchers, managers or representatives of shooting organisations across Australia were emailed or telephoned to ask if they could provide any leads on unpublished reports or evaluations

As the review progressed, several items in the reference list of papers that were identified during the initial formal search were followed up on. Due to the time constraints on this project, these items were limited to those that were likely to provide the strongest levels of inference or new insights that hadn’t been revealed in other items.

2.2 Evaluating effectiveness

In determining whether the shooting operations described in a study could be considered effective, we first asked whether any *a priori* quantifiable management objectives had been set and whether the operation achieved those objectives. We expected that management objectives would be framed in terms of reducing either the damage caused by pest animals or the growth or spread of pest populations. If no objectives were specified, we asked whether any reduction in damage or population growth was reported. We also asked whether studies reported stakeholder satisfaction as a positive outcome because this is also often an important, though rarely stated, management objective.

To compare the effectiveness of volunteers and professionals, the nine shooting type categories (Figure 1) were collapsed into five super-categories by removing the lowest level of organisation, land tenure. The super-categories were: government, professional pest control, commercial harvesting, unpaid pest control and unpaid harvesting. The small sample size precluded useful statistical comparisons of differences in effectiveness. Instead, for those studies that stated clear objectives relating to pest or wildlife populations, the results of the studies (objective achieved or not) were tabulated by shooting type. For those studies that did not provide clear objectives, the authors’ opinions of whether operations were effective of not were tabulated by shooting type.

2.3 Factors contributing to effectiveness

For each paper that was considered to have been at least partially effective, key points that authors believed contributed the program’s effectiveness were extracted so that commonalities or unique experiences could be uncovered. Examples of common factors that inhibited effectiveness or efficiency were also sought.

Finally, plots and cross-tabulations were used to check whether effectiveness varied with the following variables:

- taxonomic family of the target population (six levels);
- native or introduced status of the target population (two levels);

- geographic region (six levels);
- geographic extent of operations (1 : 83,500 km^2);
- landscape type (four levels); and
- whether other population control tools were used in a broader program (two levels).

The large number of potential variables relative to the number of literature items available precluded any formal analysis of these relationships.

2.4 Cost-effectiveness

For each paper in the sample, details relating to the actual or relative costs of shooting operations were tabulated. All dollar values were corrected for inflation in local currency before being converted to a current (November 2016) Australian dollar value.

2.5 Limitations

This review was conducted over a three week period with a tight deadline. This limited the size of the sample that could be examined effectively, and precluded a wider search of the literature using additional search terms. Consequently, the sample of papers reviewed here may exclude relevant studies that could have provided greater detail and a greater ability to identify patterns in results. The tight deadline also made it very difficult to source useful unpublished material which may have provided additional informnation unlikely to be reported in peer-reviewed literature. Nonetheless, the sample of papers examined here was selected and evaluated in a transparent and repeatable fashion, and the content represents a diverse range of situations.

3. Results

3.1 Search results

The literature search and filter procedure yielded 36 journal articles or other items describing unique studies published between 1988 and 2016 (Table 2). Three items described manipulative experiments, in which the effects of deliberately manipulating population control methods at different sites were assessed (Hanson et al. 2009, Forsyth et al. 2013, Simard et al. 2013). By their nature, these provided the strongest evidence of causal relationships between shooting operation inputs and population outputs (Platt 1964). A further eight items described comparative mensurative or cross-sectional studies, in which the likely effects different types or intensities of pre-existing population control were compared across a range of sites. The remaining items were all observational in nature, describing the effects of a single trial or management program. Appendix A includes a full list of items.

Table 2: Summary of literature search results.

Step	Search location	Date	Number of items returned	New items shortlisted	New items used
1	Endnote	4-Nov-16	133	40	24
2	ISI Web of Science	4-Nov-16	1,427	24	8
3	Google Scholar	4-Nov-16	50†	3	1
4	PestSmart Connect	13-Nov-16	344	4	2
5	Direct requests	throughout project	0	0	0
6	Reference list leads	throughout project	3	3	1

†Only the first 50 results were examined for each of three Google Scholar searches. There was substantial overlap in results among search results.

Most studies were from North America and Australasia (Figure 2). Government shooting was the most common shooting type in Australasian studies whereas North American, European and the single Asian study were dominated by studies using unpaid hunters (Figure 3). No studies reported on programs or trials of professional shooting operations on public land. Most shooting programs in the sample targeted ungulates (deer n = 16, pigs n =14, goats n = 2). The remainder targeted carnivores (foxes n = 3, cats n = 2) or macropods (n = 1). Some studies targeted more than one species. Twelve studies used shooting in a broader strategy with other tools, but most relied entirely on shooting to achieve or maintain reduced population densities or reduced damage (Figure 4).

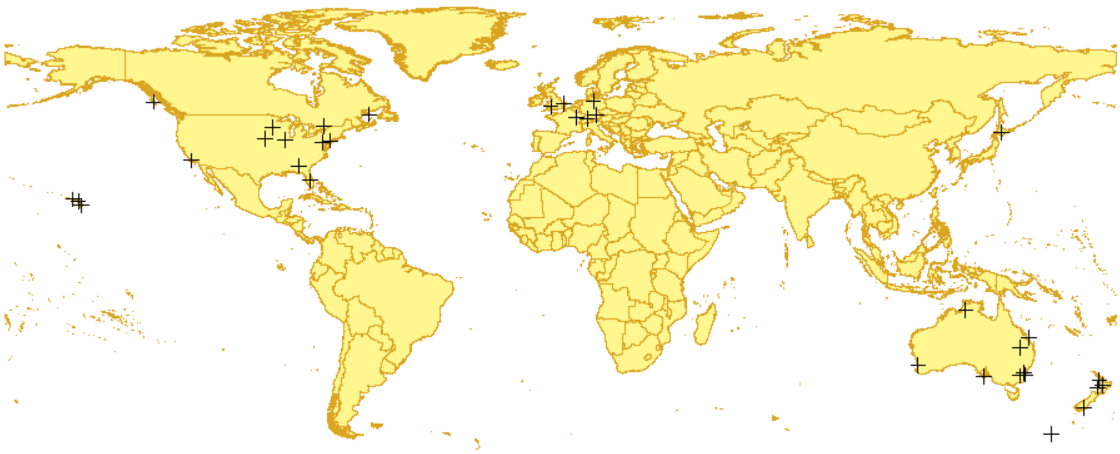


Figure 2: Locations of 36 studies describing ground-based shooting operations or trials.

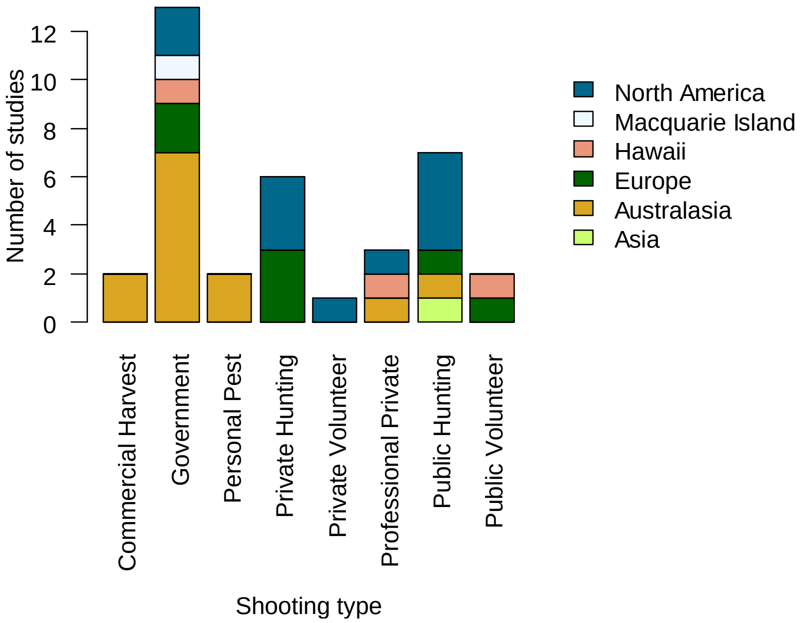


Figure 3: Distribution of 36 studies describing ground-based shooting operations or trials across eight different types of shooting operation and six geographic regions.

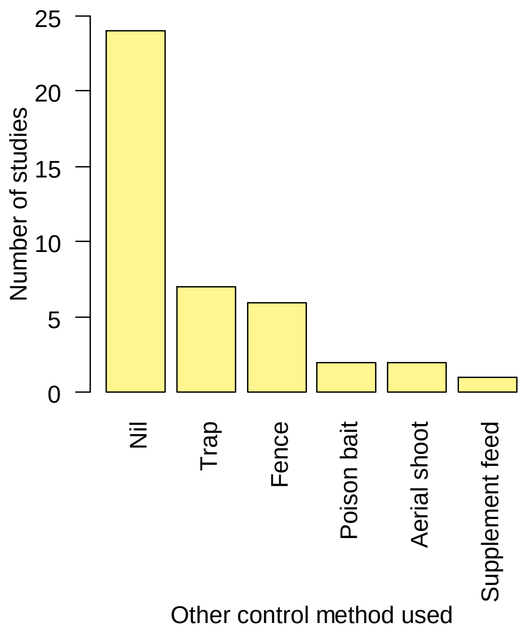


Figure 4: Number of studies that used other population control tools as part of a broader management program that included ground-based shooting. The sum of all values is greater than the sum of the programs examined because some programs used several alternate control tools.

3.2 Effectiveness

Most studies (64%) were quantitatively or qualitatively judged to have been effective, either by achieving *a priori* objectives relating to population or damage reduction, or by achieving a level of population or damage reduction that was considered useful by the authors.

Only 14 studies stated a clear, measurable objective against which success could be judged. Most of these studies involved government shooters. In nine of these cases, the stated objective was eradication of pests from insular systems. Most studies that had clear objectives were either successful or ongoing. Of the 22 studies that did not state a specific objective, most (16) used unpaid shooters, either recreational hunters or volunteers, for at least part of their operations. Twelve reported either a population reduction or an immediate increase in mortality and were considered to have been at least partially successful by the authors. Nine studies reported that target populations or damage did not decline as a result of management (one study did not address the effects of hunting at the population scale).

The proportion of shooting operations or programs that were judged to be effective appeared to be greater for:

- operations that targeted introduced species rather than overabundant natives;
- operations that used government or professional pest controllers rather than unpaid shooters or commercial harvesters;
- operations in which the primary purpose for organizing shooting events was pest control rather than harvesting; and
- programs in which shooting operations were used as part of a broader strategy with other control tools (Figure 5).

Effectiveness did not vary greatly with taxonomic family of the target species, landscape type, average treatment area or geographic region (except for an apparently higher proportion of studies reporting on ineffective programs in Europe and a single report on an ineffective program in Asia)(Figure 6).

Seven key themes emerged from our systematic examination of the literature as contributing to the success of shooting operations. Numbers of studies citing these themes as influential are included in brackets:

1. The use of tools or methods that enhance efficiency (14)
2. A small area of operations (AO, 5)
3. The use of experienced and committed shooters (4)
4. A highly accessible AO (3)
5. Financial incentives for professional or commercial shooters (2)
6. A strong conservation or management ethic in unpaid shooters (2)
7. Favourable environmental or topographical features in the AO (2)

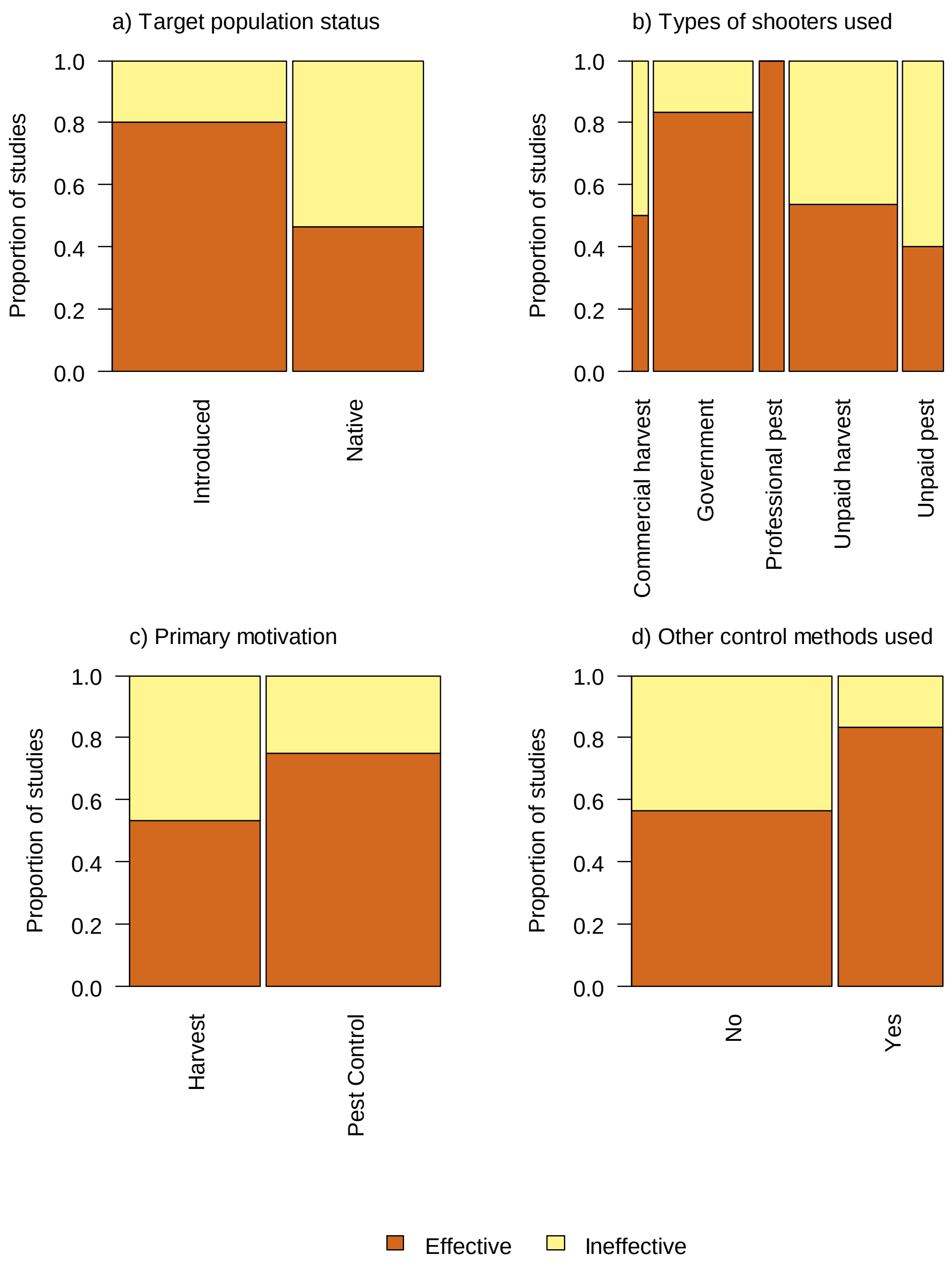


Figure 5: Distribution of shooting program effectiveness split by four different variables in 36 studies of pest or overabundant population management. Width of bars represents the relative number of studies and height of bars represents the proportion of studies deemed to be ineffective or effective.

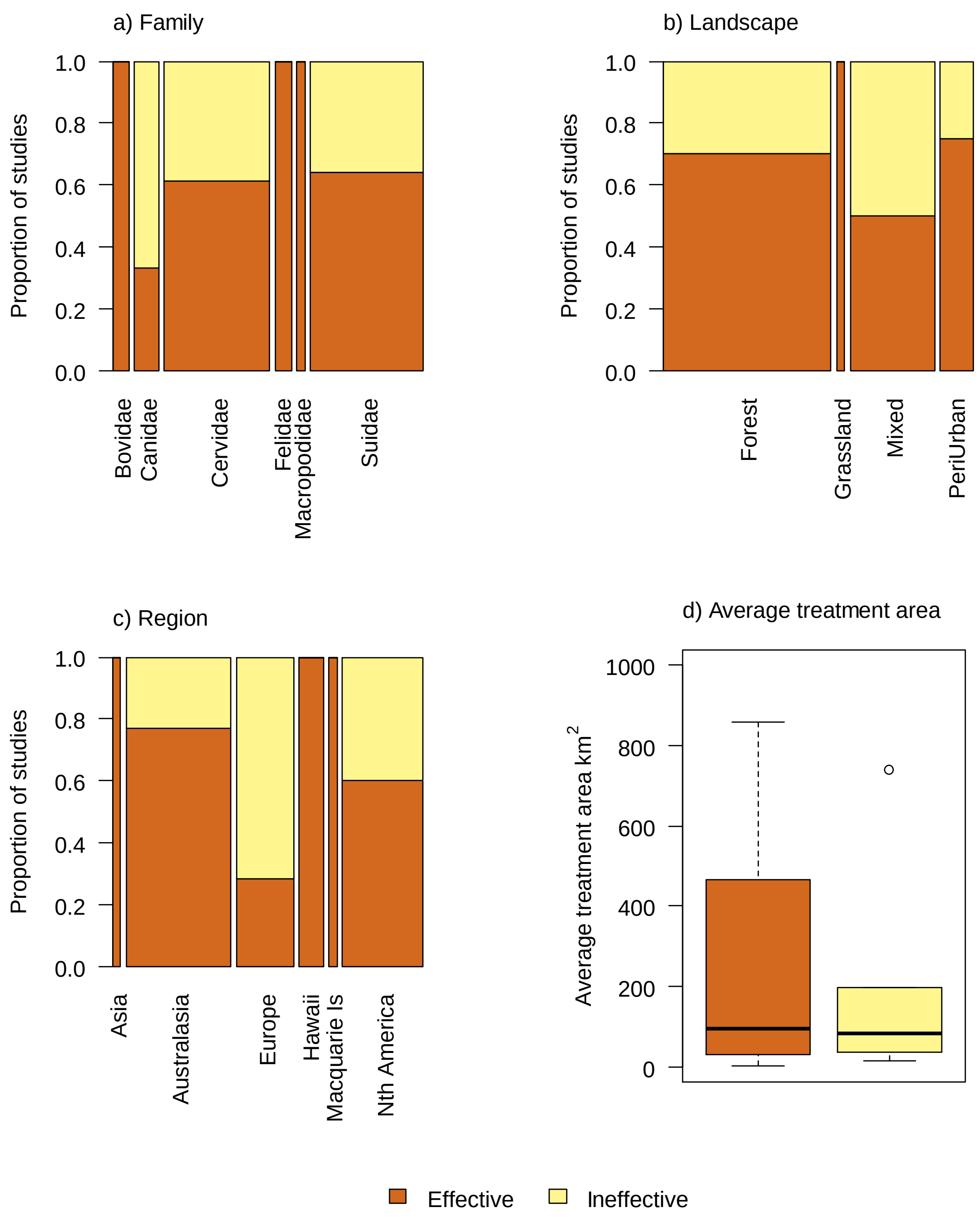
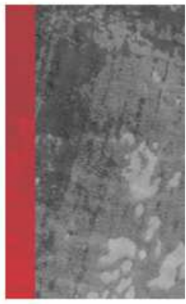


Figure 6: Distribution of shooting program effectiveness split by four different variables in 36 studies of pest or overabundant population management. Three outliers > 1,000 km^2 are excluded from panel d.



A further seven themes were consistently identified as detracting from the success of operations:

1. The functional response of shooters to declining pest populations (11)
2. Insufficient spatial or temporal coverage (7)
3. The presence of refugia (5)
4. Selective harvesting (4)
5. Low control intensity relative to the population's reproductive capacity (2)
6. Perceived unavailability of tools or methods that enhance efficiency (2)
7. Behavioural adaptation in target populations exposed to repeated persecution (2)

An additional three themes were identified in single studies: lack of support for harvest objectives by shooters, unfavourable vegetation structure in the AO and slow recovery of plants after predation by overabundant herbivores was reduced.

3.3 Cost-effectiveness

Eleven studies in our sample provided information on aspects of absolute or relative cost. This information was generally in the form of average cost per animal killed or estimation of the total cost of a particular program. One study was excluded because it was impossible to separate costs of shooting operations from other control tools used in the program.

Cost per animal killed ranged from $34 for shooting foxes by spotlight on a farm in eastern Australia (Newsome et al. 2014) to $428 in current terms for police officers shooting deer over bait or in drives in urban parklands in the US (Doerr et al. 2001)(median cost = $229 per animal, n = 6). The three studies that provided details on cost per animal over time all showed that costs increased as populations declined. Two studies that compared the relative cost of shooting operations to other control tools in Australia reported that shooting was more expensive and probably less effective than poison baiting for pigs or foxes (McIlroy & Saillard 1989, Newsome et al. 2014). The other study that compared costs reported that ground shooting was less expensive than aerial shooting in difficult conditions, even when ground shooting targeted very low population densities (Anonymous 2013).

Two New Zealand studies reported that expected costs of maintaining feral goat or pig densities at acceptable levels were $876 and $515 km^{-2} year^{-1}, respectively (Forsyth et al. 2003, Krull et al. 2016). However, it was not possible to compare these figures with expected costs of achieving similar results using other control methods such as poison baiting or aerial shooting. Two studies from the United States that reported on the net costs of managing recreational or volunteer shooters on peri-urban public land provided vastly different estimates (mean $864 km^{-2} year^{-1} for recreational hunters and $1,501 km^{-2} year^{-1} for volunteers)(Doerr et al. 2001, Williams et al. 2013). The cost of managing recreational hunters would have been about 2.5 times greater if it were not offset by licensing fees (Doerr et al. 2001).

4. Discussion

The diversity of shooters, target species and environmental and social contexts in which ground-based shooting has been used makes it difficult to draw generalisations about when, where, how and why shooting can be a useful tool for controlling overabundant animal populations. Nonetheless, there are some patterns across studies that suggest underlying commonalities and contrasts. There are also useful lessons to be learned from individual studies or operations.

4.1 Why do managers use ground shooting?

In the sample of studies we examined, and in the broader range of studies encountered, there appeared to be two main reasons for choosing to use ground shooting for population control. The first was that managers felt that no other options were available or practical. Most of the studies in our sample relied entirely on ground-based shooting. Often, this was because methods such as aerial shooting or poison baiting were thought to be unavailable due to environmental constraints such as dense vegetation (e.g. Forsyth et al. 2003); risks to non-target species (Hanson et al. 2009); regulatory constraints such as restrictions on pesticide use (McLeod et al. 2011); financial constraints (Hanson et al. 2009); or social resistance to other control tools (McLeod et al. 2011). A survey of pest control activities conducted in New South Wales in 2004 indicated that most deer or feral cat control programs in the state used ground shooting because there were few other tools available (West & Saunders 2007). However, a contemporaneous study suggested that trapping was the most commonly used feral cat control tool for biodiversity protection programs in Australia (Reddiex et al. 2006).

The second main reason for using ground shooting was to complement other control methods as part of a broader, strategic population management program. For example, ground shooting teams using tracking dogs were essential for completing the eradication of goats and cats from islands after other control methods had greatly reduced population densities (Parkes et al. 2010, Robinson & Copson 2014). The perceived importance of ground shooting as a complementary management tool varied among studies. Several reports indicated that ground shooting alone was ineffective or prohibitively inefficient for sustained population management, but it could be valuable for removing survivors of other control operations or obtaining samples for disease surveillance (McIlroy & Saillard 1989, Caley & Ottley 1995, Newsome et al. 2014). Conversely, other reports indicated that ground shooting was more effective or efficient at reducing populations or damage than other available methods such as aerial shooting (Anonymous 2013), poison baiting and trapping (Domm & Messersmith 1990) or fencing and supplementary feeding (Geisser & Reyer 2004).

Another reason for choosing ground shooting as a population control tool appears to be convenience. This is not commonly reported, but may be widespread. In Australia, convenience is probably common in private pest control, where land managers are able to conduct shooting operations at their convenience, rather than relying on third parties to provide services or materials such as poison baits (Newsome et al. 2014). The convenience factor is also apparent in some uses of commercial or recreational harvesters, where managers believe they are receiving a low cost or free pest control service from a third party (e.g. Gentle & Pople 2013). Convenience may also be important where pre-existing programs provide a means to continue with a 'business as usual' approach. The heavy reliance on recreational hunting for controlling deer populations in North America, for example, has been deeply embedded into the culture of wildlife management and some commentators have argued that it stifles adaptation and improvement (e.g. Rutberg 1997, Peterson & Nelson

2016). The dominance of hunting in North America was evident in our sample of studies (Figure 3).

4.2 Problems with assessing effectiveness

There are several difficulties in assessing the effectiveness of shooting programs reported in the literature. Perhaps the greatest and least tractable of these is establishing a consistent benchmark for effectiveness. Few reports provided any clear management objectives that could be measured in terms of population density or damage reduction. Most of those that did were well-resourced and carefully-executed strategic management programs (e.g. Parkes et al. 2010) or manipulative experiments (e.g. Simard et al. 2013). Some reports in the sample judged the effectiveness of shooting operations by the effects that they had on resources such as crops or native vegetation (e.g. Martin & Baltzinger 2002, Hothorn & Müller 2010). While not as meaningful as assessing whether shooting operations reduced damage to a pre-defined acceptable level, these studies are still useful in demonstrating some benefit of control.

The majority of reports we examined based their evaluation of effectiveness on the ability of operations to reduce absolute or relative population density; a program was considered successful if it reduced population density by a detectable amount. It is important to understand how management inputs, such as shooting activities, relate to program outputs, such as population density reductions (Choquenot & Hone 2002), and in many cases, a reduction in density will lead to a reduction in impacts (Hone 2007). However, not all density reductions can be expected to produce useful results. For example, many pest or overabundant populations appear to have threshold densities above which their impacts are unacceptable. Two North American studies in our sample cited a density of < 10 deer km^{-2} as desirable to reduce the impacts of overabundant deer on zoonotic disease transmission, vehicle collisions and landscape damage (Frost et al. 1997, Williams et al. 2013). An Australian analogy is the need to reduce rabbit populations to < 100 rabbits km^{-2} to allow regeneration of vulnerable woody species in many areas (e.g. Mutze et al. 2008, Bird et al. 2012). One study in our sample reported > 75% reductions in deer density but was considered to have been ineffective because deer densities stabilized above 10 km^{-2} (Williams et al. 2013). Had the authors not been more careful than most in identifying a meaningful objective, this study would have been considered a success.

4.3 Which ground shooting operations were most effective?

Notwithstanding the above limitations, comparisons of studies that were deemed to be effective or ineffective by their authors reveal some contrasts that are worth investigating. The greatest contrast was between situations in which the target species was introduced and those where it was native. Less than 50% of programs targeting native species were considered to have been effective, whereas 80% of those targeting introduced species were effective (Figure 5a). This could seem counter-intuitive; introduced, invasive species are often perceived as being more robust or resilient to persecution than native species because they tend to have high reproductive potential and are often released from predators, parasites or diseases of their native range (Conway 1976, Begon et al. 1996). However, all but one program targeting native species occurred in North America, Europe or Asia, and most of these relied solely on shooting by recreational hunters or volunteers. The native/introduced contrast is therefore partially confounded by differences in the types of shooter used and whether other shooting operations were integrated into a broader management strategy that also used other population control tools. Both of these variables were also associated with differences in effectiveness (Figure 5b, 5d), and may have been more important determinants of program effectiveness than the native or introduced status of the target species *per se*.

4.4 What factors contributed to effectiveness?

The most useful foundation for understanding where, when and how shooting programs are most likely to be effective comes from the identification of common themes across our sample of studies. The factor most frequently-cited as contributing to the success of shooting operations was the use of methods or equipment that enhanced shooters' efficiency. Tools or methods that enhance efficiency allow shooters to kill more animals per unit of time than they would otherwise be able to, and hence to have a greater impact on population mortality. Furthermore, the number of animals killed by a predator (e.g. a shooter) per unit of effort generally declines if animals are removed from the population faster than they are replaced, a concept known as the functional response (Holling 1959). Harvest-oriented shooters, such as commercial harvesters or recreational hunters, will usually have a threshold on this curve of diminishing returns below which further effort is unrewarding (e.g. Gentle & Pople 2013, Williams et al. 2013). If shooters can increase their efficiency (i.e. their harvest rate), they will increase the slope of their functional response curve, thereby allowing them to continue harvesting animals at lower population densities than would otherwise have been possible (Figure 7). Efficiency can be improved by increasing the rate at which shooters encounter animals or by increasing the proportion of encounters that are converted to kills.

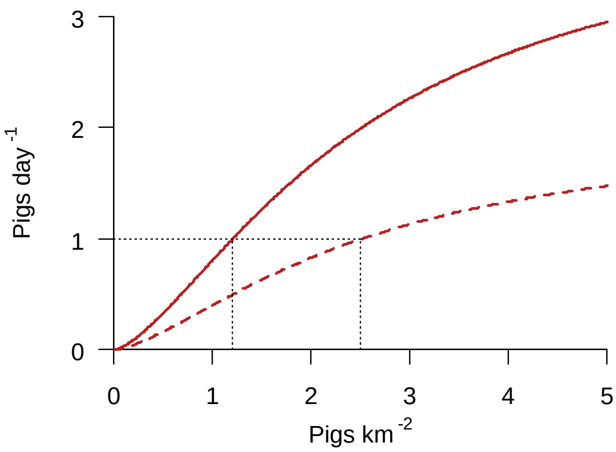


Figure 7: Hypothetical functional response curves for a recreational feral pig hunter with two different searching efficiencies. The solid curve represents the more efficient searching pattern, which allows the hunter to find and kill more pigs per hunting day. Dotted vertical lines show the minimum population density at which the hunter is able to kill one pig per day (1.2 pigs km^{-2} for the more efficient searching pattern and 2.5 pigs km^{-2} for the less efficient pattern)(adapted from Bengsen & Sparkes 2016).

One third of the studies in our sample used dogs to increase the success of shooters targeting cats (e.g. Robinson & Copson 2014), deer (e.g. Godwin et al. 2013), goats (Forsyth et al. 2003) or pigs (e.g. Parkes et al. 2010). Dogs that locate, track or pursue animals can enhance efficiency by increasing the rate at which shooters encounter animals. Dogs that bail or hold animals can further enhance efficiency by increasing the proportion of encountered animals that are killed. Bailing and holding (lugging) dogs are commonly used by unpaid and commercial hunters targeting pigs. However, the use of dogs in this way has been criticised by animal welfare or rights organisations and others on the grounds that it causes unnecessary suffering to both pigs and dogs (e.g. Shoebridge & Hopley 2014, RSPCA 2016), and the use of lugging dogs is illegal in Victoria. Using or condoning the use of bailing or lugging dogs in operations targeting feral pigs could therefore expose those operations to social risk. Dogs can also hinder control programs when escaping animals learn to avoid shooters (McIlroy & Saillard 1989).

The efficiency of ground shooting operations can also be influenced by the method used to find animals. Most of the shooting operations used in our sample of studies could be classified into one of five search types, although different studies used different labels for the same activity:

- Searching for animals on foot, with or without the assistance of dogs (stalking)
- Searching for animals from a vehicle, usually at night with a spotlight (spotlighting)
- Passive lying in wait, often over a feeding station (stand hunting)
- Lying in wait for animals driven by beaters, with or without dogs (drives)
- Opportunistic shooting.

No single search type was consistently reported as being more effective than any other. Their relative effectiveness probably varied depending on the situation, although no studies reported that opportunistic shooting improved efficiency. Two studies reported that drives were more efficient than stand hunting for deer or pigs (Frost et al. 1997, Keuling et al. 2010). However, other studies have found that harvest-oriented shooters using stands or stalking are often more selective than those using drives (e.g. Novak et al. 1991, Martınez et al. 2005), so differences in efficiency in some studies may be partly attributable to stand shooters passing up opportunities to kill animals. This also suggests that stand shooting may not be useful for ungulate management programs that use harvest-oriented shooters, unless systems are established to circumvent selectivity (e.g. Boulanger et al. 2012). Selective harvest-oriented shooters tend to target older male ungulates, whereas females and juveniles tend to make the greatest contribution to population growth (e.g. Toïgo et al. 2008).

Spotlighting is widely used to target foxes and rabbits in Australia (e.g. Coman 1988) and it can reduce pest populations if applied with sufficient intensity (McLeod et al. 2011). Spotlighting has also been reported to be more efficient than stand shootng or drives for shooting deer in North America (Frost et al. 1997), and has been identified as the preferred primary ground shooting method for controlling deer in several Australian management plans or strategies (e.g. Masters 2009, Williams 2009). However, it has been repeatedly dismissed as an ineffective population control tool in its own right because it is generally too inefficient to be able to achieve meaningful population reductions: published examples of kills per unit effort for foxes in eastern Australia range from 0.24 foxes hr^{-1} (Coman 1992) to 0.78 foxes hr^{-1} (Fleming 1997, Newsome et al. 2014). Furthermore, spotlighting is limited to areas with good visibility and vehicle access.

Searching and killing efficiency can also be enhanced by using specialist equipment such as high performance thermal imaging (TI) scopes and sound suppressors (referred to as silencers under NSW firearms regulations). A wide range of TI equipment is now becoming available for general consumption, including rifle-mounted scopes. Many of these devices can improve a shooter's ability locate target animals. When combined with sound suppressors and appropriate ammunition to reduce sonic disturbance, whole groups of animals can be shot at once (G. Eccles, NSW OEH, 2016 NSW Vertebrate Pest Symposium, Orange, 26 October 2016). The use of TI scopes and suppressors can also reduce the risk of disturbing the public, thereby allowing nocturnal shooting operations to be conducted at locations where they have previously been unavailable. Despite a recent expansion of the conditions under which shooters can apply to acquire a suppressor in NSW, firearms regulations in Australian states place heavy restrictions on their possession and use, and they remain largely limited to professional and government operations.

The next most frequently cited aid to effectiveness, after improving efficiency, was the use of small AO's in which operations could be concentrated and population recovery through immigration from areas outside the AO could be minimised. This is exemplified by the eradication of feral cats from a small (1 km^2) island on the Great Barrier Reef (Domm & Messersmith 1990). Most operations, however, had to deal with larger AO's and more permeable borders. Four feral pig eradication programs used fencing to divide large areas into smaller management units that could be more easily and decisively handled (Hone & Stone 1989, Parkes et al. 2010, Barron et al. 2011, Burt et al. 2011). A feral goat eradication program on Kangaroo Island used unfenced management units based on natural barriers and road access to manage shooting and monitoring effort. These management units were important for sustaining the focus and activity of volunteer shooters as populations and harvest rates declined (N. Markopoulos, Kangaroo Island Natural Resources Management Board, pers. comm. 14 November 2016). Similarly, an evaluation of a long-running feral goat management program in New Zealand described the introduction of management units as a crucial action because it allowed managers to direct recreational hunters to locations where their activities could be most useful, in a timely manner (Forsyth et al. 2003). While manageable AO's can be important, failure to conduct operations over a sufficient spatial and temporal extent to minimise population recovery through immigration was identified as detracting from some studies in our sample (McLeod et al. 2011, Engeman et al. 2014, Newsome et al. 2014).

Apart from size, other geographic traits that were thought to be important included accessibility to shooters, particularly for harvest-oriented shooters, and features that provided high search and kill efficiencies such as flat terrain and sparse low-level vegetation. Three main aspects of accessibility were apparent: the remoteness of sites from commercial harvesting processors (e.g. Gentle & Pople 2013); remoteness of sites from populations of recreational hunters (e.g. Nugent 1988, Martin & Baltzinger 2002); and the ability of shooters to access all areas within an AO (e.g. Nugent 1988, Domm & Messersmith 1990, Foster et al. 1997).

Commercial harvesting of feral pigs in Australia relies on independent harvesters returning pig carcasses to a processing unit, known as a chiller, nightly. Harvesters' travel and opportunity costs increase as the distance between harvesting site and chiller increases, and there will generally be a threshold distance beyond which harvesting becomes uneconomical and a rational harvester will cease operations. The value of this threshold distance will vary, depending on conditions such as prices paid at the chiller, the number of pigs harvested per trip, travel costs and a harvester's minimum acceptable profit (Choquenot et al. 1995). The spatial concentration of chillers in southern Queensland and northern New South Wales led Gentle and Pople (2013) to conclude that commercial harvesting alone could not be relied on to suppress feral pig populations because there were too many large areas where pigs would not be targeted. These areas could provide a source of immigrants to compensate for harvest mortality in other areas.

A similar process appears to be common with recreational hunters. Studies in our sample showed that few hunters travelled more than 100 km to hunt deer at a site on New Zealand's South Island (Nugent 1988), and that hunting was able to protect plantation timber regeneration from deer in areas that were readily accessed by road, but not in areas that were only accessible to hunters by air or sea (Martin & Baltzinger 2002). Studies beyond our sample have also reported similar effects of remoteness on and the spatial distribution of hunting pressure, population mortality (e.g. Stoner et al. 2013) and on hunters' preferences (e.g. Bottan et al. 2003).

Accessibility also plays out at a smaller scale. Many studies have shown that harvest-oriented shooters have tended to concentrate their activity within areas that are most easily accessed and that hunting mortality diminishes with increasing distance from roads and flat ground (e.g. Brøseth & Pedersen 2000, Lebel et al. 2012). In our sample, Nugent (1988) found that hunters had little impact on deer in forests at distances farther than 1.5 km from access points. Simard et al. (2013) also reported that most deer killed by hunters were close to roads, and that large tracts of unfragmented forest probably protected large proportions of target populations from hunters. Some programs conducted in challenging terrain used helicopters to ferry hunters and equipment to remote locations to overcome these problems (e.g. Parkes et al. 2010, Burt et al. 2011). Foster et al. (1997) found that deer were most effectively harvested in areas with small, isolated forest patches that were easily accessible to hunters, and that suburban areas probably provided refuge. Other studies also reported that urban and suburban areas provided refugia that limited the ability of hunting and shooting operations to target all individuals in a population (Hygnstrom et al. 2011, Williams et al. 2013). Animals that are protected by refugia from harvesting or culling will reduce the level of population control that can be achieved in the first instance and can provide an important source of breeding stock for population recovery.

Most studies in our sample identified physical, demographic or environmental traits that were important contributors to the effectiveness of shooting operations. However, social and economic issues were also prominent. Two studies provided clear examples showing that shooting programs benefited from having experienced and committed shooters who were familiar with the target population and the area and method of operations:

- A core group of frequent recreational hunters, comprising 3.5% of the hunter population, was responsible for more than 50% of all deer kills at a site in New Zealand (Nugent 1988),
- Professional hunters targeting feral pigs in New Zealand were more efficient after their first foray into a new management area (Krull et al. 2016).

Other studies indicated that shooter experience and commitment was an important contributor to a program's effectiveness (Parkes et al. 2010, Barron et al. 2011) or that the lack of these traits probably reduced effectiveness (Burt et al. 2011). Moreover, prolonged involvement of individual harvest-oriented shooters in a program can help build a conservation or management ethic. This can enhance their efficacy by reducing their reluctance to take actions that are perceived as detrimental to the maintenance of future harvest opportunities, such as reducing populations to low densities or taking age and sex classes that make the greatest contribution to population growth (Hygnstrom et al. 2011, Williams et al. 2013). A reluctance of hunters to take females was thought to be a major barrier to effectiveness in some programs targeting deer (Martin & Baltzinger 2002, Kaji et al. 2010) and pigs (Toïgo et al. 2008). This type of selective harvesting to protect breeding stock has also been reported in Australia (Hall & Gill 2005) and is consistent with codes of conduct promulgated by some Australian hunting organisations (e.g. Australian Deer Association 2014).

Ground shooting can be a particularly labour-intensive and expensive form of pest animal control, so it is not surprising that many studies in our sample examined the costs associated with shooting operations. Cost and revenue estimates of various components of operations can be used to evaluate alternate control methods or strategies, prioritise investment and generate hypotheses about ways to improve effectiveness (e.g. Nugent & Choquenot 2004, Cooke et al. 2010). The two studies in our sample that combined cost estimates with population models to estimate the investment required to contain pest populations or damage to acceptable levels both reported substantial ongoing costs for sustained management (Forsyth et al. 2003, Krull et al. 2016). Several North American studies reported on programs that tried to avoid or reduce the costs of retaining staff or professional controllers for ongoing operations by using volunteer shooters or hunters. Some of these reported similar costs per animal to government shooting but lower costs per animal than other control tools such as trapping (Doerr et al. 2001, Hygnstrom et al. 2011). Conversely, an Australian study found that spotlight shooting to control foxes was likely to be more costly and less effective than poison baiting (Newsome et al. 2014). Other studies showed that there can still be substantial costs associated with managing volunteers or hunters (Williams et al. 2013), even when costs are partially offset by charging licence fees to hunters (Doerr et al. 2001, Hygnstrom et al. 2011). The cumulative cost of these expenses could potentially outweigh the cost of professional control if differences in efficiency between professional and unpaid shooters mean that greater input is needed from unpaid shooters than would be needed from professionals in the long term. Careful construction of contracts and milestones for professional shooters can provide efficiency incentives that can help to minimise the duration of shooting operations (Parkes et al. 2010).

Commercial harvesting provides another option that can be available to reduce the cost of shooting operations in some situations. As previously noted, the ability of commercial harvesting to knockdown and suppress populations over sufficiently large AO's is limited by economic constraints (Gentle & Pople 2013). Furthermore, feral pig harvesters rarely took a large enough proportion of the population to cause a decline in population growth (Gentle & Pople 2013), presumably because the harvesting rate at which operations became unprofitable was greater than the rate needed to reduce populations to densities at which growth was suppressed. However, it could be possible to reduce these constraints by increasing the price paid for carcasses (Ramsay 1994). Modeling studies indicate that subsidised harvesting should be more cost-effective than government culling in some situations (e.g. Nugent & Choquenot 2004). This was demonstrated in a study of commercial kangaroo harvesting in a small, insular system. Kangaroo population density was reduced to desired levels by paying subsidies to a commercial harvester to continue harvesting when it would otherwise have been unprofitable. This greatly reduced the operational cost of the program and the cost per animal, relative to what would otherwise have been expected (Mawson et al. 2016). Commercial harvesting can also help to overcome community resistance to control operations that would otherwise use a 'shoot to waste' policy (Mawson et al. 2016), as can the donation of carcasses to organisations that can use them for public benefit (Frost et al. 1997).

4.5 Limitations of ground shooting

The preceding discussion has shown that there are many situations when ground shooting can be a useful, and sometimes crucial, method for controlling overabundant or pest animal populations. However, the effectiveness of shooting operations is clearly constrained by a wide range of biophysical, social and economic factors. Perhaps the greatest overall constraint is the low efficiency of ground shooting compared to other control methods, such as poison baiting and aerial shooting, that can produce a large population reduction in a short time under favourable conditions (e.g. Saunders 1993, Thompson & Fleming 1994). The low efficiency of ground shooting has at least two important consequences:

1) Slow, drip-feed mortality from shooting operations is often offset by increased reproduction or immigration. This is particularly important for species that can increase their reproductive output to high levels in response to inefficient harvest mortality, such as feral pigs and some deer species (e.g. Hanson et al. 2009, Kaji et al. 2010, Servanty et al. 2011).

2) Diminishing returns on increased shooting effort dictate that it will often be very expensive, or practically impossible, to achieve desired levels of population or damage reduction using shooting alone (e.g. Krull et al. 2016). This is especially relevant when harvest-oriented or unpaid shooters are used because they are likely to abandon operations when the harvest rate declines to unrewarding levels, which will often be greater than the harvest levels required to meet management objectives (e.g. Gentle & Pople 2013, Williams et al. 2013).

The limiting effects of low efficiency are likely to be strongest in widespread, well-established pest populations that occur at densities close to environmental carrying capacity. These populations can be expected to have a greater capacity to compensate for increased mortality from shooting operations by increasing reproductive output, survival or immigration (Bengsen & Sparkes 2016).

Ground-based shooting operations are likely to be most beneficial when they target spatially-restricted populations that occur at densities well below carrying capacity, in environments that offer little refuge. Examples include populations that have been recently established, that are restricted to insular systems, or that have been reduced by other control methods or environmental conditions. Reliance solely on harvest-oriented shooters is potentially risky in these situations because the harvest rates required to contain the target population within a "predator pit" (sensu Walker & Noy-Meir 1982) may be lower than those at which continued effort is unrewarding. Furthermore, obtaining sufficient volunteer shooters or recreational hunters to maintain useful hunting pressure has often been challenging in North America and Europe (e.g. Simard et al. 2013, Massei et al. 2015), where hunter populations occur at much greater densities than in Australia (Bengsen et al. 2016).

5. Conclusions and recommendations

Ground-based shooting has been used in activities aiming to reduce pest animal densities and impacts in Australia since the earliest years of European settlement. The use of ground shooting is likely to increase in coming years as technological advances and a growing population of recreational hunters broaden the scope of situations in which it can be used. However, there are major limitations on the ability of ground shooting operations to contribute to pest management objectives, and poor application of ground shooting methods can potentially cause more harm than good. Shooting programs and operations examined in this review tended to fall along a continuum between:

1) Well planned and resourced programs with clear objectives that were designed to maximize efficiency and generate reliable information that could be used to improve future iterations, and
2) Ad hoc programs that relied on convenient resources and assessed their efficacy in terms of whether they achieved a noticeable reduction in pest activity or an increase in participant satisfaction.

Managers considering the use of ground shooting to help control pests should strive to place their operations towards the first end of this continuum by:

- Carefully considering whether ground shooting is actually the best method available for their purposes, and what types of shooting will be most useful;
- Establishing clear, meaningful and measurable objectives to allow for performance assessment, operational learning and continuous improvement;
- Ensuring that operations have adequate financial and human resources (numbers and talent) for the duration of the program to develop and execute operations that maximize efficiency, minimize risks, and are able to suppress populations to densities necessary to achieve desired outcomes;
- Integrating shooting operations with other control methods where appropriate.

Ground shooting can often appear to offer a simple solution to pest management problems, but the studies reviewed here show that that is rarely the case. In some cases, a quick response to an emerging problem is required. However, proper investment of time and effort before commencing operations will often reduce the risk of management programs developing into ineffectual, expensive and cumbersome sustainable harvesting programs.

Acknowledgements

This review was funded by the New South Wales Natural Resources Commission. Comments from David Latham, Tony Pople and David Peacock improved an earlier draft.

References

Anonymous. (2013). Case study: feral goat eradication on Kangaroo Island. In I. A. C. R. Centre (ed). Invasive Animals Cooperative Research Centre PestSmart Toolkit Publication.

Australian Deer Association (2014). Code of Conduct | Australian Deer Association. http://www.austdeer.com.au/about-ada/code-of-conduct/

Barron, M. C., Anderson, D. P., Parkes, J. P., & Ohukani'ohi'a Gon III, S. (2011). Evaluation of feral pig control in Hawaiian protected areas using Bayesian catch-effort models. New Zealand Journal of Ecology 35: 182-188.

Begon, M., Harper, J., & Townsend, C. (1996). Ecology: Individuals, Populations and commnities. (Blackwell Science, Oxford).

Bengsen, A. J., & Sparkes, J. (2016). Can recreational hunting contribute to pest mammal control on public land in Australia? Mammal Review 46: 297-310.

Bengsen, A. J., Sparkes, J., & McLeod, S. R. (2016). Can recreational hunting control pests on public lands? In P. Murray & G. Baxter (eds) Conservation Through Sustainable Use of Wildlife. University of Queensland, Brisbane.

Bird, P., Mutze, G., Peacock, D., & 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: 743-755.

Bomford, M., & Sinclair, R. (2002). Australian research on bird pests: impact, management and future directions. Emu 102: 29-45.

Bottan, B., Hunt, L., & Haider, W. (2003). A choice modelling approach to moose management: a case study of Thunder Bay moose hunters. Alces 39: 27-40.

Boulanger, J. R., Goff, G. R., & Curtis, P. D. (2012). Use of “earn-a-buck” hunting to manage local deer overabundance. Northeastern Naturalist 19: 159-172.

Brøseth, H., & Pedersen, H. C. (2000). Hunting effort and game vulnerability studies on a small scale: a new technique combining radio-telemetry, GPS and GIS. Journal of Applied Ecology 37: 182-190.

Burt, M. D., Miller, C., & Souza, D. (2011). The use of volunteer hunting as a control method for feral pig populations on O'ahu, Hawai'i. In C. R. Veitch, M. N. Clout & D. R. Towns (eds) Island Invasives: Eradication and Management, 402-406. (IUCN, Gland).

Caley, P., & Ottley, B. (1995). The effectiveness of hunting dogs for removing feral pigs (Sus scrofa). Wildlife Research 22: 147-154.

Choquenot, D., & Hone, J. Using bioeconomic models to maximize benefits from vertebrate pest control: lamb predation by feral pigs. In Proceedings of the Human conflicts with wildlife: economic considerations, Proceedings of the Third NWRC Special Symposium (Ed. by L. Clark), pp. 65-79.

Choquenot, D., O'Brien, P., & Hone, J. (1995). Commercial use of pests: Can it contribute to conservation objectives? In G. C. Grigg, P. T. Hale & D. Lunney (eds) Conservation Through Sustainable Use of Wildlife, 251-258. (Centre for Conservation Biology, the University of Queensland, Brisbane).

Coman, B. (1988). The Age Structure of a Sample of Red Foxes (Vulpes vulpes L) Taken by Hunters in Victoria. Wildlife Research 15: 223-229.

Coman, B. (1992). Simulated rabies eradication: the lessons from two exercises in Victoria. In P. O'Brien & G. Berry (eds) Wildlife Rabies Contingency Planning in Australia: Bureau of Rural Resources Proceedings No. 11, 91-95. (Bureau of Rural Resources, Canberra).

Conway, G. (1976). Man versus pests. In R. M. May (ed) Theoretical Ecology, 257-281. (Blackwell Scientific Publications, Oxford).

Cooke, B., Jones, R., & Gong, W. (2010). An economic decision model of wild rabbit Oryctolagus cuniculus control to conserve Australian native vegetation. Wildlife Research 37: 558-565.

Davis, N. E., Bennett, A., Forsyth, D. M., Bowman, D. M. J. S., Lefroy, E. C., Wood, S. W., Woolnough, A. P., West, P., Hampton, J. O., & Johnson, C. N. (2016). A systematic review of the impacts and management of introduced deer (family Cervidae) in Australia. Wildlife Research 43: 515-532.

Doerr, M. L., McAninch, J. B., & Wiggers, E. P. (2001). Comparison of 4 methods to reduce white-tailed deer abundance in an urban community. Wildlife Society Bulletin 29: 1105-1113.

Domm, S., & Messersmith, J. (1990). Feral cat eradication on a Barrier Reef island, Australia. Atoll Research Bulletin 338: 1-4.

Enck, J. W., Decker, D. J., & Brown, T. L. (2000). Status of hunter recruitment and retention in the United States. Wildlife Society Bulletin 28: 817-824.

Engeman, R., Hershberger, T., Orzell, S., Felix, R., Killian, G., Woolard, J., Cornman, J., Romano, D., Huddleston, C., Zimmerman, P., Barre, C., Tillman, E., & Avery, M. (2014). Impacts from control operations on a recreationally hunted feral swine population at a large military installation in Florida. Environmental Science and Pollution Research: 1-9.

Finch, N., Murray, P., Hoy, J., & Baxter, G. (2014). Expenditure and motivation of Australian recreational hunters. Wildlife Research 41: 76-83.

Fleming, P. J. S. (1997). Uptake of baits by red foxes (Vulpes vulpes): implications for rabies contingency planning in Australia. Wildlife Research 24: 335-346.

Fleming, P. J. S., Allen, B. L., Allen, L. R., Ballard, G. A., Bengsen, A. J., Gentle, M. N., McLeod, L. J., Meek, P. D., & Saunders, G. R. (2014). Management of wild canids in Australia: free-ranging dogs and red foxes. In A. S. Glen & C. R. Dickman (eds) Carnivores of Australia: Past, Present and Future, 105-149. (CSIRO Publishing, Collingwood).

Forsyth, D. M., Hone, J., Parkes, J. P., Reid, G. H., & Stronge, D. (2003). Feral goat control in Egmont National Park, New Zealand, and the implications for eradication. Wildlife Research 30: 437-450.

Forsyth, D. M., Ramsey, D. S., Veltman, C. J., Allen, R. B., Allen, W. J., Barker, R. J., Jacobson, C. L., Nicol, S. J., Richardson, S. J., & Todd, C. R. (2013). When deer must die: large uncertainty surrounds changes in deer abundance achieved by helicopter- and ground-based hunting in New Zealand forests. Wildlife Research 40: 447-458.

Foster, J. R., Roseberry, J. L., & Woolf, A. (1997). Factors influencing efficiency of white-tailed deer harvest in Illinois. Journal of Wildlife Management 61: 1091-1097.

Franklin, A. (1996). Australian hunting and angling sports and the changing nature of human-animal relations in Australia. Journal of Sociology 32: 39-56.

Frost, H. C., Storm, G. L., Batcheller, M. J., & Lovallo, M. J. (1997). White-tailed deer management at Gettysburg National Military Park and Eisenhower National Historic Site. Wildlife Society Bulletin 25: 462-469.

Geisser, H., & Reyer, H.-U. (2004). Efficacy of hunting, feeding, and fencing to reduce crop damage by wild boars. Journal of Wildlife Management 68: 939-946.

Gentle, M., & Pople, A. (2013). Effectiveness of commercial harvesting in controlling feral-pig populations. Wildlife Research 40: 459-469.

Godwin, C., Schaefer, J. A., Patterson, B. R., & Pond, B. A. (2013). Contribution of dogs to white-tailed deer hunting success. The Journal of Wildlife Management 77: 290-296.

Gray, P. A., Duwors, E., Villeneuve, M., Boyd, S., & Legg, D. (2003). The socioeconomic significance of nature-based recreation in Canada. Environmental Monitoring and Assessment 86: 129-147.

Grigg, G. (1995). Kangaroo harvesting for conservation of rangelands, kangaroos... and graziers. In G. C. Grigg, P. T. Hale & D. Lunney (eds) Conservation Through Sustainable Use of Wildlife, 161-165. (Centre for Conservation Biology, the University of Queensland, Brisbane).

Hall, G. P., & Gill, K. P. (2005). Management of wild deer in Australia. Journal of Wildlife Management 69: 837-844.

Hanson, L. B., Mitchell, M. S., Grand, J. B., Jolley, D. B., Sparklin, B. D., & Ditchkoff, S. S. (2009). Effect of experimental manipulation on survival and recruitment of feral pigs. Wildlife Research 36: 185-191.

Holling, C. S. (1959). The components of predation as revealed by a study of small-mammal predation of the European pine sawfly. The Canadian Entomologist 91: 293-320.

Hone, J. (2007). Wildlife Damage Control. (CSIRO Publishing, Collingwood).

Hone, J., & Stone, C. P. (1989). A comparison and evaluation of feral pig management in two National Parks. Wildlife Society Bulletin 17: 419-425.

Hothorn, T., & Müller, J. (2010). Large-scale reduction of ungulate browsing by managed sport hunting. Forest Ecology and Management 260: 1416-1423.

Hygnstrom, S. E., Garabrandt, G. W., & Vercauteren, K. C. (2011). Fifteen years of urban deer management: The Fontenelle Forest experience. Wildlife Society Bulletin 35: 126-136.

Kaji, K., Saitoh, T., Uno, H., Matsuda, H., & Yamamura, K. (2010). Adaptive management of sika deer populations in Hokkaido, Japan: theory and practice. Population Ecology 52: 373-387.

Keuling, O., Lauterbach, K., Stier, N., & Roth, M. (2010). Hunter feedback of individually marked wild boar Sus scrofa L.: dispersal and efficiency of hunting in northeastern Germany. European Journal of Wildlife Research 56: 159-167.

Krull, C. R., Stanley, M. C., Burns, B. R., Choquenot, D., & Etherington, T. R. (2016). Reducing wildlife damage with cost-effective management programmes. PLoS One 11.

Lebel, F., Dussault, C., Massé, A., & Côté, S. D. (2012). Influence of habitat features and hunter behavior on white-tailed deer harvest. Journal of Wildlife Management 76: 1431-1440.

Martin, J.-L., & Baltzinger, C. (2002). Interaction among deer browsing, hunting, and tree regeneration. Canadian Journal of Forest Research 32: 1254-1264.

Martınez, M., Rodrıguez-Vigal, C., Jones, O. R., Coulson, T., & San Miguel, A. (2005). Different hunting strategies select for different weights in red deer. Biology letters 1: 353-356.

Massei, G., Kindberg, J., Licoppe, A., Gačić, D., Šprem, N., Kamler, J., Baubet, E., Hohmann, U., Monaco, A., & Ozoliņš, J. (2015). Wild boar populations up, numbers of hunters down? A review of trends and implications for Europe. Pest Management Science 71: 492-500.

Masters, P. Management of fallow deer on Kangaroo Island. In Proceedings of the National Feral Deer Management Workshop (Ed. by S. R. McLeod), pp. 70-75. Invasive Animals Cooperative Research Centre, Canberra.

Mawson, P. R., Hampton, J. O., & Dooley, B. (2016). Subsidized commercial harvesting for cost-effective wildlife management in urban areas: A case study with kangaroo sharpshooting. Wildlife Society Bulletin 40: 251-260.

McIlroy, J. C., & 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. Australian Wildlife Research 16: 353-363.

McLeod, L. J., Saunders, G., & Miners, A. (2011). Can shooting be an effective management tool for foxes? Preliminary insights from a management program. Ecological Management & Restoration 12: 224-226.

Mutze, G., Bird, P., Cooke, B., & Henzell, R. (2008). Geographic and Seasonal Variation in the Impact of Rabbit Haemorrhagic Disease on European Rabbits, Oryctolagus cuniculus, and Rabbit Damage in Australia. In P. Alves, N. Ferrand & K. Hackländer (eds) Lagomorph Biology, 279-293. (Springer, Berlin).

Newsome, T., Crowther, M., & Dickman, C. (2014). Rapid recolonisation by the European red fox: how effective are uncoordinated and isolated control programs? European Journal of Wildlife Research: 1-9.

Novak, J. M., Scribner, K. T., Dupont, W. D., & Smith, M. H. (1991). Catch-effort estimation of white-tailed deer population size. Journal of Wildlife Management 55: 31-38.

Nugent, G. (1988). Successful control of fallow deer by recreational hunters in the Blue Mountains, Otago. New Zealand Journal of Forestry Science 18: 239-252.

Nugent, G. (1992). Big-game, small-game, and gamebird hunting in New Zealand: hunting effort, harvest, and expenditure in 1988. New Zealand journal of zoology 19: 75-90.

Nugent, G., & Choquenot, D. (2004). Comparing cost-effectiveness of commercial harvesting, state-funded culling, and recreational deer hunting in New Zealand. Wildlife Society Bulletin 32: 481-492.

Parkes, J. P., Ramsey, D. S. L., Macdonald, N., Walker, K., McKnight, S., Cohen, B. S., & Morrison, S. A. (2010). Rapid eradication of feral pigs (Sus scrofa) from Santa Cruz Island, California. Biological Conservation 143: 634-641.

Peterson, M. N., & Nelson, M. P. (2016). Why the North American model of wildlife conservation is problematic for modern wildlife management. Human Dimensions of Wildlife online early: 1-12.

Platt, J. R. (1964). Strong inference. Science 146: 347-353.

Ramsay, B. J. (1994). Commercial Use of Wild Animals in Australia. (Bureau of Resource Sciences, Canberra).

Reddiex, B., & Forsyth, D. (2006). Control of pest mammals for biodiversity protection in Australia. II. Reliability of knowledge. Wildlife Research 33: 711-717.

Reddiex, B., Forsyth, D. M., McDonald-Madden, E., Einoder, L. D., Griffioen, P. A., Chick, R. R., & Robley, A. J. (2006). Control of pest mammals for biodiversity protection in Australia. I. Patterns of control and monitoring. Wildlife Research 33: 691-709.

Robinson, S. A., & Copson, G. R. (2014). Eradication of cats (Felis catus) from subantarctic Macquarie Island. Ecological Management & Restoration 15: 34-40.

RSPCA (2016). What happens when dogs are used to hunt feral pigs? Royal Society for the Prevention of Cruelty to Animals. http://kb.rspca.org.au/What-happens-when-dogs-are-used-to-hunt-feral-pigs_543.html

Rutberg, A. T. (1997). The science of deer management: an animal welfare perspective. In W. J. McShea, H. B. Underwood & J. H. Rappole (eds) The Science of Overabundance: Deer Ecology and Population Management, 37-54. (Smithsonian Institution Press, Washington).

Saunders, G. (1993). Observations on the effectiveness of shooting feral pigs from helicopters in western New South Wales. Wildlife Research 20: 771-776.

Servanty, S., Gaillard, J. M., Ronchi, F., Focardi, S., Baubet, E., & Gimenez, O. (2011). Influence of harvesting pressure on demographic tactics: implications for wildlife management. Journal of Applied Ecology 48: 835-843.

Shoebridge, D., & Hopley, C. (2014). Amateur hunting: It's a blood-sport not a conservation measure. Nature New South Wales 2014: 28-29.

Simard, M. A., Dussault, C., Huot, J., & Côté, S. D. (2013). Is hunting an effective tool to control overabundant deer? A test using an experimental approach. Journal of Wildlife Management 77: 254-269.

Stoner, D. C., Wolfe, M. L., Rieth, W. R., Bunnell, K. D., Durham, S. L., & Stoner, L. L. (2013). De facto refugia, ecological traps and the biogeography of anthropogenic cougar mortality in Utah. Diversity and Distributions 19: 1114-1124.

Thompson, J., & Fleming, P. (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: 27-39.

Toïgo, C., Servanty, S., Gaillard, J.-M., Brandt, S., & Baubet, E. (2008). Disentangling natural from hunting mortality in an intensively hunted wild boar population. The Journal of Wildlife Management 72: 1532-1539.

U.S. Fish & Wildlife Service. (2011). National Survey of Fishing, Hunting, and Wildlife-Associated Recreation. Available at: http://www.census.gov/prod/2012pubs/fhw11-nat.pdf

Walker, B. H., & Noy-Meir, I. (1982). Aspects of the stability and resilience of savanna ecosystems. In B. Huntly & B. Walker (eds) Ecology of Tropical Savannas, 556-590. (Springer, Berlin).

West, P., & Saunders, G. (2007). Pest animal survey 2004-2006: A review of the distribution, impacts and control of invasive animals throughout NSW and the ACT. (NSW Department of Primary Industries, Orange).

Williams, M. Wild deer in South Australia: position paper for National Deer Workshop. In Proceedings of the National Feral Deer Management Workshop (Ed. by S. R. McLeod), pp. 66-69. Invasive Animals Cooperative Research Centre, Canberra.

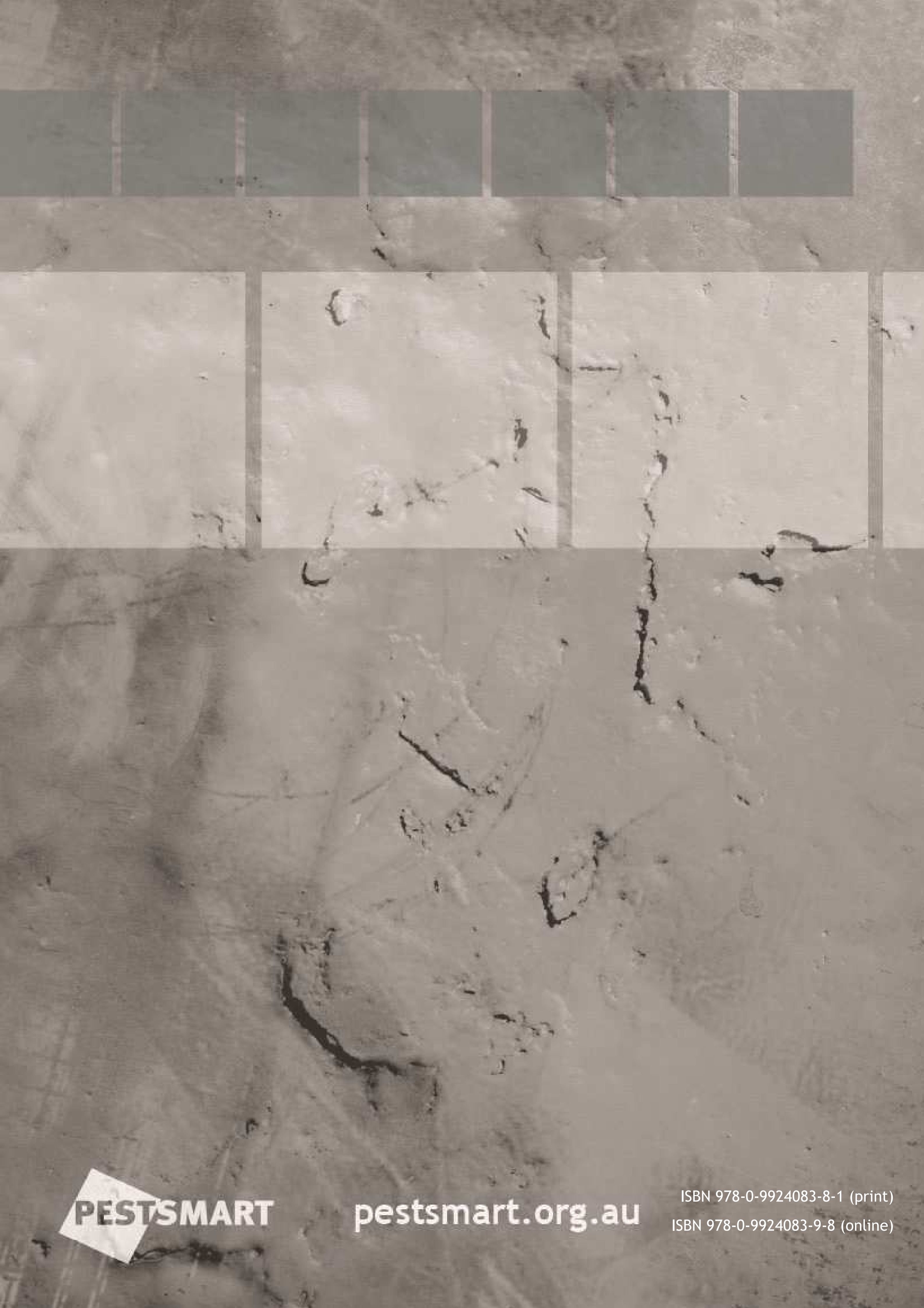
Williams, S. C., Denicola, A. J., Almendinger, T., & Maddock, J. (2013). Evaluation of organized hunting as a management technique for overabundant white-tailed deer in suburban landscapes. Wildlife Society Bulletin 37: 137-145.

Appendix A: Sample items

Publication	Type of shooting	Species
Anonymous (2013) Case study: feral deer eradication on Kangaroo Island. PestSmart Toolkit Publication	Government	*Dama dama*
Anonymous (2013) Case study: feral goat eradication on Kangaroo Island. PestSmart Toolkit Publication	Government	*Capra hircus*
Baker, P. J., & Harris, S. (2006) Does culling reduce fox (Vulpes vulpes) density in commercial forests in Wales, UK? European Journal of Wildlife Research	Public Volunteer, Personal Pest	*Vulpes vulpes*
Barron, M. C.; Anderson, D. P.; Parkes, J. P.; Ohukani'ohi'a Gon, S. M. O (2011) Evaluation of feral pig control in Hawaiian protected areas using Bayesian catch-effort models. New Zealand Journal of Ecology	Professional Private	*Sus scrofa*
Burt, M. D., Miller, C., & Souza, D. (2011) The use of volunteer hunting as a control method for feral pig populations on O'ahu, Hawai'i. Island Invasives: Eradication and Management	Public Volunteer	*Sus scrofa*
Caley, P., & Ottley, B. (1995) The effectiveness of hunting dogs for removing feral pigs (Sus scrofa). Wildlife Research	Personal Pest	*Sus scrofa*
Doerr, ML; McAninch, JB; Wiggers, EP (2001) Comparison of 4 methods to reduce white-tailed deer abundance in an urban community. Wildlife Society Bulletin	Government, Public Hunting	*Odocoileus virginianus*
Domm, S., & Messersmith, J. (1990) Feral cat eradication on a Barrier Reef island, Australia. Atoll Research Bulletin	Government	*Felis catus*
Engeman, R., Hershberger, T., Orzell, S., Felix, R., Killian, G., Woolard, J., Cornman, J., Romano, D., Huddleston, C., Zimmerman, P., Barre, C., Tillman, E., & Avery, M. (2014) Impacts from control operations on a recreationally hunted feral swine population at a large military installation in Florida. Environmental Science and Pollution Research	Public Hunting	*Sus scrofa*
Forsyth, DM; Hone, J; Parkes, JP; Reid, GH; Stronge, D (2003) Feral goat control in Egmont National Park, New Zealand, and the implications for eradication. Wildlife Research	Government, Public Hunting	*Capra hircus*
Forsyth, DM; Ramsey, DSL; Veltman, CJ; Allen, RB; Allen, WJ; Barker, RJ; Jacobson, CL; Nicol, SJ; Richardson, SJ; Todd, CR (2013) When deer must die: large uncertainty surrounds changes in deer abundance achieved by helicopter- and ground-based hunting in New Zealand forests. Wildlife Research	Government	*Cervus elaphus, Cervus nippon*
Foster, J. R., Roseberry, J. L., & Woolf, A. (1997) Factors influencing efficiency of white-tailed deer harvest in Illinois. Journal of Wildlife Management	Public Hunting	*Odocoileus virginianus*
Frost, H. C., Storm, G. L., Batcheller, M. J., & Lovallo, M. J. (1997) White-tailed deer management at Gettysburg National Military Park and Eisenhower National Historic Site. Wildlife Society Bulletin	Government, Public Hunting	*Odocoileus virginianus*

Publication	Type of shooting	Species
Geisser, H., & Reyer, H.-U. (2004) Efficacy of hunting, feeding, and fencing to reduce crop damage by wild boars. Journal of Wildlife Management	Private Hunting	*Sus scrofa*
Gentle, M., & Pople, A. (2013) Effectiveness of commercial harvesting in controlling feral-pig populations. Wildlife Research	Commercial Harvest	*Sus scrofa*
Godwin, C; Schaefer, JA; Patterson, BR; Pond, BA (2013) Contribution of dogs to white-tailed deer hunting success. Journal of Wildlife Management	Public Hunting	*Odocoileus virginianus*
Hanson, L. B., Mitchell, M. S., Grand, J. B., Jolley, D. B., Sparklin, B. D., & Ditchkoff, S. S. (2009) Effect of experimental manipulation on survival and recruitment of feral pigs. Wildlife Research	Public Hunting	*Sus scrofa*
Hone, J., & Stone, C. P. (1989) A comparison and evaluation of feral pig management in two National Parks. Wildlife Society Bulletin	Government, Public Hunting	*Sus scrofa*
Hothorn, T., & Müller, J. (2010) Large-scale reduction of ungulate browsing by managed sport hunting. Forest Ecology and Management	Private Hunting	*Capra hircus*
Hygnstrom, SE; Garabrandt, GW; Vercauteren, KC (2011) Fifteen Years of Urban Deer Management: The Fontenelle Forest Experience. Wildlife Society Bulletin	Private Hunting	*Odocoileus virginianus*
Kaji, K; Saitoh, T; Uno, H; Matsuda, H; Yamamura, K (2010) Adaptive management of sika deer populations in Hokkaido, Japan: theory and practice. Population Ecology	Public Hunting	*Cervus nippon*
Keuling, O., Lauterbach, K., Stier, N., & Roth, M. (2010) Hunter feedback of individually marked wild boar Sus scrofa L.: dispersal and efficiency of hunting in northeastern Germany. European Journal of Wildlife Research	Private Hunting	*Sus scrofa*
Krull, C. R., Stanley, M. C., Burns, B. R., Choquenot, D., & Etherington, T. R. (2016) Reducing wildlife damage with cost-effective management programmes. PLoS One	Professional Pest	*Sus scrofa*
Martin, J.-L., & Baltzinger, C. (2002) Interaction among deer browsing, hunting, and tree regeneration. Canadian Journal of Forest Research	Private Hunting	*Odocoileus hemionus*
Mawson, PR; Hampton, JO; Dooley, B (2016) Subsidized Commercial Harvesting for Cost-effective Wildlife Management in Urban Areas: A Case Study with Kangaroo Sharpshooting. Wildlife Society Bulletin	Commercial Harvest	*Macropus fuliginosus*
McIlroy, J. C., & 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. Australian Wildlife Research	Government	*Sus scrofa*
McLeod, L. J., Saunders, G., & Miners, A. (2011) Can shooting be an effective management tool for foxes? Preliminary insights from a management program. Ecological Management & Restoration	Professional Private	*Vulpes vulpes*
Newsome, TM; Crowther, MS; Dickman, CR (2014) Rapid recolonisation by the European red fox: how effective are uncoordinated and isolated control programs? European Journal of Wildlife Research	Personal Pest	*Vulpes vulpes*
Nugent, G (1988) Successful control of fallow deer by recreational hunters in the Blue Mountains, Otago. New Zealand Journal of Forestry Science	Public Hunting	*Dama dama*

Publication	Type of shooting	Species
Parkes, J. P., Ramsey, D. S. L., Macdonald, N., Walker, K., McKnight, S., Cohen, B. S., & Morrison, S. A. (2010) Rapid eradication of feral pigs (Sus scrofa) from Santa Cruz Island, California Biological Conservation	Professional Private	*Sus scrofa*
Robinson, S. A., & Copson, G. R. (na) Eradication of cats (Felis catus) from subantarctic Macquarie Island. Ecological Management & Restoration	Government	*Felis catus*
Servanty, S., Gaillard, J. M., Ronchi, F., Focardi, S., Baubet, E., & Gimenez, O. (2011) Influence of harvesting pressure on demographic tactics: implications for wildlife management. Journal of Applied Ecology	Government, Public Hunting	*Sus scrofa*
Simard, MA; Dussault, C; Huot, J; Cote, SD (2013) Is hunting an effective tool to control overabundant deer? A test using an experimental approach. Journal of Wildlife Management	Private Hunting	*Odocoileus virginianus*
Toïgo, C., Servanty, S., Gaillard, J.-M., Brandt, S., & Baubet, E. (2008) Disentangling natural from hunting mortality in an intensively hunted wild boar population. Journal of Wildlife Management	Public Hunting	*Sus scrofa*
Wäber, K., Spencer, J., & Dolman, P. M. (2013) Achieving landscape-scale deer management for biodiversity conservation: The need to consider sources and sinks. Journal of Wildlife Management	Government, Public Hunting, Private Hunting	*Capreolus capreolus, Muntjac reevesi*
Williams, SC; DeNicola, AJ; Almendinger, T; Maddock, J (2013) Evaluation of organized hunting as a management technique for overabundant white-tailed deer in suburban landscapes. Wildlife Society Bulletin	Public Volunteer	*Odocoileus virginianus*



PESTSMART

pestsmart.org.au

ISBN 978-0-9924083-8-1 (print)
ISBN 978-0-9924083-9-8 (online)