CENTRE FOR INVASIVE SPECIES SOLUTIONS

COST-EFFECTIVE MANAGEMENT OF WILD DEER

FINAL REPORT FOR PROJECT P01-L-001

AUTHORS

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COST-EFFECTIVE MANAGEMENT OF WILD DEER

FINAL PROJECT REPORT FOR P01-L-001

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EXECUTIVE SUMMARY

Six species of feral deer have established wild populations in Australia spreading from coastal habitats to the highest alpine ecosystems. Their presence in all states and territories results in strong impacts on natural ecosystems, primary industries and poses high health and safety issues for the communities. If not addressed rapidly, these issues will likely increase in the next decade.

Best practice guidelines for managing feral deer, together with on-ground training and supporting technical expertise, were identified as key needs by participants at the 2016 National Wild Deer Management Workshop. In Australia, the main tools used for managing feral deer are aerial shooting, ground shooting, exclusion fencing, and trapping.

This report aims to provide animal-welfare outcomes and cost-effective assessments of these management tools using demonstration sites in Qld, NSW, Vic, Tas in collaboration with local land managers. This report synthesises the findings from eleven peer-reviewed scientific publications and three technical reports.

METHODS

We first systematically reviewed the literature to assess the trends, precision and bias of the methods used to estimate deer abundance and density. We refined aerial mark-recapture distance sampling and assessed the accuracy and cost-effectiveness of automated-detection from thermal footage captured by unmanned aircraft. We assessed the animal-welfare outcomes of professional vehicle-based ground shooting of rusa deer (NSW) and of aerial shooting of chital deer (Qld) and fallow deer (ACT and NSW).

We conducted a five-year experiment to assess the cost-effectiveness of contract and volunteer ground-based shooting of sambar deer in Alpine National Park, Victoria. We monitored the effect of control effort on in deer abundance and their impacts on endangered peatlands. We also conducted a monitoring of a fallow deer population in Tasmania in relation to recreational hunting activity. We assessed the cost-effectiveness of aerial shooting using pre-control surveys and shooting data from 12 operations aiming to reduce fallow deer and chital deer in NSW and Qld, respectively.

We consulted our network of practitioners in NSW, Vic and Tas to gather information on cost and technical requirements to build effective deer-exclusion fences. We finally estimated the costs generated by feral deer in Australia, including loss of primary production, management expenditures and vehicle collision.

RESULTS

From the 3,870 estimates of deer abundance and density published between 2004–18, only 32% had some measure of uncertainty. The most precise methods were vehicular spotlight counts and motion-sensitive cameras (using capture-recapture). Based on ante- and post-mortem data collection, we showed that eighty-five percent of deer shot at during ground-based shooting were killed. The frequency of non-fatal wounding (i.e. escaping wounded) was 3.5%. For aerial shooting, shots were fired at 69–76% of deer that were observed. Non-fatal wounding only occurred when wounded deer were able to escape into thick vegetation or when deer were shot only once before being left.

The five-year ground-shooting trial in Alpine National Park, we showed that ground-based shooting reduced sambar deer activity and abundance in and around peatlands. Shooting at night using spotlight or thermal vision-equipment was the most effective methods. We found that contract shooters removed up to four time more deer than volunteer shooters for the same time effort, but the latter were 10% cheaper per deer killed. Ground-based shooting reduced six (e.g. trampling, pugging) out of nine deer impacts on endangered peatlands. Recreational hunters in Tasmania were killing fallow deer seven time less efficiently than contract shooters killed sambar deer in Alpine National Park.

Aerial shooting proved to be able to reduce deer populations by up to 75% and 88% (for fallow and chital deer respectively). Our results showed an asymptotic kill rate with an expected maximum efficiency of 50 deer per hour. To remove 35% of the population (i.e. to prevent population growth), managers should plan for 11h per 1000 deer present with costs expected to range from $15,880 at five deer per km^2 to $136,590 at 40 deer per km^2.

Deer-exclusion fences should be a minimum of 1.9 m in height, and mesh netting of 17/190/15 and posts spaced at a maximum of 10 m or 5 m when using an apron to prevent animal digging under the fence. Electric outrigger can be used on either side of the fence to reduce the pressure from deer and other wildlife. The costs for fencing depend on the design used, the length of the fence and the topography and the difficulty to clear the fence line.

In 2021, we estimated the national cost of feral deer for the primary industry to reach $69 million. This included losses of production and costs of control operations. Vehicle collisions were estimated at $4.5 million (road and rail). With an additional $18 million for government led research and management programs, the annual cost of feral deer in Australia for 2021 exceed $91 million.

IMPLICATIONS

During the course of the project, we conducted a series of presentation during scientific conferences, we organised workshops and deer management courses and presented our work during field day hosted by our collaborators. In addition to open access scientific publications and reports, we summarised our findings into a Glovebox Guide freely accessible on CISS's website.

Based partly on our findings, there has been an expansion of the area subject to helicopter-based shooting of deer in NSW, ACT and Qld. Pre-shoot estimates of deer population size are fundamental to estimate the adequate effort and budget to achieve the objective of each program. Animal-welfare outcomes for helicopter-based deer shooting in Australia could be improved with a national-level standard operating procedure requiring helicopters to fly back over shot animals and repeatedly shoot animals in the head or thorax.

Ground-based shooting can be effective to control deer populations in areas with high density of roads. The effectiveness of ground-shooting increased for night operations using spotlight or thermal-vision equipment and when using professional shooters. Preliminary data from the fallow deer hunters in Tasmania suggest that recreational hunting has a much lower effectiveness than organised ground-shooting operations. Improving shooter training could result in better animal-welfare outcomes of ground-based shooting of deer.

Well-constructed fences are expensive but should last more than 15 years with minimal maintenance. Regular inspection for holes and breaks is needed if there are trees within falling distance of the fence, and as soon as possible after floods.

The distributions of deer populations in Australia are expanding, and densities are increasing. Consequently, the annual cost of the impact of deer is expected to increase to significantly more than $91 million over the next decade, unless major strategic management programs are deployed.

INTRODUCTION

CONTEXT

Feral deer are present in all Australian states and territories and are causing increasing agricultural and environmental impacts including: eating and fouling pasture, crops and other agricultural products; acting as vectors of diseases and pathogens; providing food for wild dog/dingo (*Canis familiaris*) and red fox (*Vulpes vulpes*) populations; altering native plant communities; acting as interspecific competition with native fauna; modifying habitats; and changing water quality and soil properties.

The six species of deer present in Australia [fallow deer (*Dama dama*), sambar deer (*Cervus unicolor*), rusa deer (*Cervus timorensis*), chital deer (*Axis axis*), red deer (*Cervus elaphus*), hog deer (*Axis porcinus*)] occupy a wide variety of habitats including temperate and tropical rangelands, coastal and montane forests, and peri-urban areas.

Since all six species have not yet attained their maximum potential distributions, it is highly likely that the impacts of feral deer will greatly increase in the next decade unless cost-effective deer management solutions are identified and adopted.

The primary methods used to manage the impacts of other wild ungulates [e.g. feral pigs (*Sus scrofa*) and feral goats (*Capra hircus*)] in Australia are aerial shooting, ground shooting, exclusion fencing, and trapping.

Land managers have been using these methods to manage feral deer, but there is uncertainty about the cost-effectiveness and animal-welfare outcomes of each method for each different species of deer and various habitats they live in. For example, aerial shooting could be the most cost-effective method to reduce deer abundance and impacts in open agricultural habitats, but could be socially unacceptable in peri-urban settings.

Best practice guidelines for managing feral deer, together with on-ground training and supporting technical expertise, were identified as key needs by participants at the 2016 National Wild Deer Management Workshop.

OBJECTIVES

This project had four key objectives:

1. In collaboration with project partners and third parties in NSW, Qld, Vic and Tas, establish demonstration sites with current or planned on-ground management, research and training.
2. Evaluate the costs and effectiveness of the main control tools (i.e. aerial shooting and ground shooting) at demonstration sites, supported by population modelling to assess longer-term effects of control tools on deer populations and their impacts.
3. Disseminate knowledge widely through: field days at demonstration sites; presentations at workshops, symposia and conferences; media releases; articles in peer-reviewed journals; and Glovebox Guides available in hard copy or from the PestSmart website.
4. Build technical and research capacity in feral deer management by upskilling research and technical staff involved in vertebrate pest management, and by training postgraduate students.

Note: throughout this report, we refer to our resulting publications in superscript (e.g. [M3] indicates Manuscript 3, and [R1] indicates Report 1).

METHODS

A National Workshop on Wild Deer Management (funded by the Invasive Animals Cooperative Research Centre) was convened in Adelaide on 17−18 November 2016. The aim of the workshop was to identify national priorities for research and innovation that would improve understanding and management of feral deer impacts in Australia. There were 29 participants, with all states and territories represented except the Northern Territory.

The workshop used breakout groups to identify and prioritise research and innovation (that would improve the management of feral deer impacts) within four themes. Consideration was given to the benefits, costs, feasibility and time frame of the research and innovation.

This project then addressed priorities identified by workshop participants which follow as subheadings.

METHODS TO MEASURE DEER ABUNDANCE AND DENSITY

We systematically reviewed journal articles published 2004–18[M3] to evaluate spatiotemporal trends in study objectives, methodologies, and deer abundance and density estimates, and determine how they varied with biophysical and anthropogenic attributes. We also reviewed the precision and bias of methods to estimate deer abundance.

We evaluated and refined aerial mark-recapture distance sampling methods for surveying deer in Australia.[M4]

In collaboration with the Centre's project P01-L-003, we evaluated the accuracy and cost-effectiveness of automated-detection methods in comparison to manual detection of thermal footage of deer captured by remotely piloted aircraft systems.[M12]

ANIMAL-WELFARE OUTCOMES OF DEER MANAGEMENT IN AUSTRALIA

HOW MANY TO SAMPLE? STATISTICAL GUIDELINES FOR MONITORING ANIMAL-WELFARE OUTCOMES[M1]

We first evaluated the effect of sample size on precision and statistical power in reporting the frequency of adverse animal-welfare outcomes. We next used these findings to assess the precision of published animal-welfare investigations for a range of contentious animal-use activities, including livestock transport, horse racing, and wildlife harvesting and capture. Finally, we evaluated the sample sizes required for comparing observed outcomes with specified standards by using hypothesis testing.

FOR GROUND-BASED SHOOTING[M7]

We assessed vehicle-based night shooting of peri-urban rusa deer by professional contractors in eastern Australia. Shooters targeted the heads of deer using .223 Remington® rifles and 55-grain bullets. Independent veterinarians conducted ante-mortem (i.e. from the shooting vehicle) and post-mortem (i.e. inspecting the carcass) observations. The ante-mortem data were used to estimate the proportion of deer seen that were shot at, killed, or wounded and escaped. We assessed the influence of variables predicted to affect shooting outcomes. The numbers and locations of bullet wounds were recorded post-mortem.

FOR HELICOPTER-BASED SHOOTING[M5]

Three deer-control operations were assessed. These operations targeted: (1) chital deer in Queensland, (2) fallow deer in Australian Capital Territory and (3) fallow deer in New South Wales. For each operation, an independent veterinarian conducted ante-mortem (i.e. from the helicopter as shooting occurred) and post-mortem (i.e. from the ground after shooting had ceased) observations.

The ante-mortem data were used to estimate the proportion of deer seen that were shot, chase time (CT), time to insensibility (TTI) and total time (TT = CT + TTI). The numbers and locations of bullet wounds were recorded post-mortem.

COST-EFFECTIVENESS OF GROUND SHOOTING TO CONTROL DEER

SYSTEMATIC REVIEW OF GROUND-BASED SHOOTING TO CONTROL OVERABUNDANT MAMMAL POPULATIONS[M2]

We systematically reviewed the literature to identify studies involving ground-shooting published between 1980 and 2017. From each study, we collated information about operational objectives, target taxa, geographic context, type of shooter used, effort, effectiveness, and use of additional control tools.

COST-EFFECTIVENESS OF VOLUNTEER AND CONTRACT SHOOTERS IN ALPINE NATIONAL PARK[M6,M8,M10]

We conducted a five-year management-scale experiment to assess the cost-effectiveness of ground-based shooting and how it alters the impacts of sambar deer on endangered alpine sphagnum bogs and associated fens in south-eastern Australia.

Ground-based shooting operations were organised in two blocks. Within each block, four ~4200-ha management units were delimited, of which two were randomly assigned as treatment (organised ground-based shooting) and two as non-treatment (no organised ground-based shooting). In the treatment units, ground-based shooting was conducted using either volunteers or contractors. Each shooting team recorded their effort and the numbers of deer seen and shot, using a GPS to record their track log and the time and locations of deer shot. Key costs were recorded for both shooter types.

To estimate sambar deer activity, camera traps were continuously deployed for four years in two of the ~4200-ha units in Alpine National Park, Victoria, south-eastern Australia. One unit was subject to management operations using ground-based shooting to target deer and the other was not. Monthly activity of sambar deer was modelled using biotic (woody vegetation cover), abiotic (snow depth; aspect; slope; distances to water, road and peatland) and management (treatment versus non-treatment) covariates. Additional camera traps were deployed in both units to monitor sambar deer activity at wallows.

In all eight management units, we monitored changes in deer relative abundance using faecal pellet counts along transects in alpine peatlands before and after the shooting operations. We also monitored nine sambar deer impacts on alpine peatlands in and around wallows and natural pools: general assessment score, ground degradation, pugging intensity and water turbidity.

TASMANIAN GROUND-SHOOTING TRIAL

A ground-shooting trial was conducted for fallow deer in a private reserve managed by the Tasmanian Land Conservancy. Hunters have been using the reserve for recreational deer hunting for more than 60 years.

To assess the effect of recreational hunting on the deer population, each hunter was provided with a GPS so that their hunting effort was quantified in space and time. Annual and long-term changes in fallow deer abundance were monitored using a grid of 64 camera traps.

COST-EFFECTIVENESS OF AERIAL SHOOTING[M4]

We evaluated the costs and effectiveness of 12 aerial shooting operations aiming to reduce fallow deer (n = 8) or chital deer (n = 4) population densities at nine sites in eastern Australia. Sites were characterised by fragmented woodland, and all but one operation aimed to reduce grazing competition with livestock. We used pre-control population-density estimates and operational monitoring data to estimate the costs and outcomes of each operation. We combined data from all operations to estimate the relationship between shooting effort and population reduction, as well as costs associated with different levels of effort.

EXCLUSION FENCING TO MANAGE IMPACTS[R1]

The national and international literature on deer-fencing designs, costs and effectiveness (for farmed and feral deer) was reviewed for information relevant to the deer species and environments present in Australia. Concurrently, we consulted our network of government and private land managers to identify deer-exclusion fences in NSW, Vic and Tas that could also provide such information. We visited some of the fenced sites, but others could not be visited due to COVID-19 travel restrictions.

We report the key lessons for people interested in using exclusion fencing to reduce the impacts of feral deer in Australia, and key features of deer-exclusion fences that should be considered in the planning of a deer-exclusion fence. There are many guides on how to construct livestock and vertebrate pest–exclusion fences in Australian conditions, and those documents could also be consulted. In addition, some local fencing contractors would have experience in constructing deer-exclusion fences, and they can provide further advice about materials and construction relevant to local conditions (topography, soil and the mammal species present).

ANNUAL COSTS OF WILD DEER IN AUSTRALIA[R2]

A loss–expenditure approach was used to determine the costs generated by feral deer. Annual production losses (agricultural output losses) due to competition with feral deer were estimated for the horticultural, plantation timber and livestock industries (dairy, wool, sheepmeat and beef). Estimates of the annual expenditure on deer control (e.g. fencing and shooting) borne by landholders and the public sector, and on motor vehicle and train collisions with deer were also prepared. These costs were summed to obtain an overall annual economic impact assessment.

COLLABORATION AND ENGAGEMENT

COLLABORATIVE RESEARCH WAS KEY

The best outcomes for extensive research projects are strongly associated with efficient collaboration strategies. This project was therefore explicitly designed as a collaboration between state agencies and local land managers across eastern Australia (including Qld, NSW, ACT, Vic, SA and Tas) with the aim of creating a feedback loop for cost-effective management of feral deer.

For each of the three deer-management strategies previously identified (ground shooting, aerial shooting and exclusion fencing), we contacted land managers who had run, or were running or planning management operations for local deer populations.

We were thus able to gather empirical data from real-life management operations across eastern Australia—allowing us to assess the cost-effectiveness of the different methods used. The knowledge gained through these collaborations was then made available for all local land managers, state and federal agencies and researchers.

OUR TARGETED COMMUNICATION STRATEGY

The key to an effective communication strategy was to adapt the message and the media to the targeted audience. For deer management, and more specifically regarding cost-effectiveness of the management, there were three main target audiences: the scientific community, government agencies and end-user practitioners.

Each group was receptive to specific media, and all had different expectations for the communication content. We transferred the knowledge gained through this project by diversifying our communication activities, tailored to each audience group.

FOR THE SCIENTIFIC COMMUNITY: PUBLICATIONS AND CONFERENCES

We delivered a total of 11 peer-reviewed journal articles,[M1–11] We edited a special issue of the journal *Wildlife Research* named 'Ecology, impacts and management of wild deer in Australasia' (in preparation).

Through collaboration with other CISS projects (P01-L-002 and P01-L-003), we contributed to an additional 11 publications[M12–22].

We also presented our findings to land managers and researchers at scientific conferences. These events allowed for a more interactive discussion on the findings, and often led to new research questions and collaborations. During the life of the project, we presented our results at:

- annual conferences of the Australasian Wildlife Management Society. These conferences were generally attended by ~150 scientists and practitioners from all around Australia and New Zealand. The conferences were held virtually in 2020 and 2021 due to the COVID-19 pandemic.
- the 2021 Australasian Vertebrate Pest Conference. Initially planned as an in-person conference in Melbourne, it was changed to virtual due to the COVID-19 pandemic.

FOR PUBLIC AGENCIES: SMALL-GROUP MEETINGS AND PUBLICATIONS

For this audience, the key was to translate the scientific knowledge into practical and applied advice, and general guidelines. This created a strong base on which we could build communication adapted to individual or local requirements.

The best way to efficiently communicate was by devoting time to in-person courses with small audiences:

- deer masterclasses: a training opportunity for public agency staff involved in deer management, held over two days. The courses typically consist of technical presentations from experts on deer monitoring and control techniques, complemented by *in-situ* group projects. We organised six masterclasses:
    a. four in NSW (2019, 2021, 2022)
    b. two in Qld (2022)

    and

    c. participated virtually during a masterclass in SA (2021).
- NSW Vertebrate Pest Management Course: an annual one-week training course organised by NSW DPI. We presented our research to biosecurity officers from NSW Local Land Services and National Parks and Wildlife Service.

We also presented our findings during the following targeted meetings:

- Queensland Invasive Plants and Animals Committee (July 2019)
- NSW Game and Pest Management Advisory Board meeting (November 2020)
- Queensland local government natural resources management forum in Airlie Beach (May 2021)
- North Queensland Dry Tropics Regional Pest Management Group (June 2021)
- Australian Alps National Park ungulate management workshop (March 2022)
- Regional Deer Coordinators meeting, Victoria (April 2022)
- Hunter Regional Pest Animal Committee meeting (May 2022)
- NSW LLS statewide Advisory Group (July 2022).

We also produced two technical reports and a Glovebox Guide for public agency staff to use.

We ensured that the peer-reviewed journal articles were published in open-access journals so they can be accessed by public agency staff without payment.

FOR END USERS: FIELD DAYS, MEDIA AND PUBLICATIONS

Just as for the public agencies, the communication strategy for end users relied on direct presentations organised locally with a broader range of stakeholders. Field days were organised in collaboration with our local collaborators, usually as a one-day presentation. We organised field days in Queensland, NSW, Victoria and Tasmania. The audiences included landholders, recreational hunters and conservation-agency staff.

The two technical reports and Glovebox Guide will be available to all end users on the PestSmart website.

Dr Dave Forsyth was interviewed for two ABC television features on feral deer: *Landline* (by journalist Prue Adams) and *7.30 Report* (by journalist Ellen Coulter). Key findings from the project were discussed in both interviews. Dr Anthony Pople was interviewed for the CISS podcast 'Towards a feral free future' to present the key findings from the project (by journalist Prue Adams).

As noted above, we ensured that the peer-reviewed journal articles were published in open-access journals so they can be accessed by end users without payment.

RESULTS

METHODS TO MEASURE DEER ABUNDANCE AND DENSITY

Our systematic review[M3] of deer abundance and density estimates published in peer-reviewed journals during 2004–18 returned 3,870 estimates derived from field data collected between 1980 and 2017. Most estimates (58%) were for white-tailed deer (*Odocoileus virginianus*), red deer (*Cervus elaphus*), and roe deer (*Capreolus capreolus*). The six key methods used to estimate abundance and density were pedestrian sign (track or faecal) counts, pedestrian direct counts, vehicular direct counts, aerial direct counts, motion-sensitive cameras and harvest data.

There were regional differences in the use of these methods, but a general pattern was a temporal shift from using harvest data, pedestrian direct counts and aerial direct counts to using pedestrian sign counts and motion-sensitive cameras. Only 32% of estimates were accompanied by a measure of precision. The most precise estimates were from vehicular spotlight counts and from capture–recapture analysis of images from motion-sensitive cameras. For aerial direct counts, capture–recapture methods provided the most precise estimates. Bias was robustly assessed in only 16 studies. Most abundance estimates were negatively biased, but capture–recapture methods were the least biased.

Surveys conducted to evaluate the efficacy of aerial shooting showed that aerial mark-recapture distance sampling provided an effective and practical method for surveying deer populations during 12 operations in eastern Australia.[M4] In addition, when reviewing thermal footage captured by unmanned aerial vehicles, the automated-detection algorithm (machine learning) identified 67–100% of deer detected using manual review and was 84% cheaper.[M12]

ANIMAL-WELFARE OUTCOMES OF MANAGING DEER IN AUSTRALIA

FOR GROUND-BASED SHOOTING[M7]

Of the 269 deer seen in 21 nights of ground-based shooting in 2018 and 2019, 48% were shot at. Eighty-five percent of those shot at were killed by either one (87%), two (10%) or three (3%) shots. The frequency of non-fatal wounding (i.e. escaping wounded) was 3.5% for those shot at and hit, and the median TTI for the deer that were shot multiple times was 289s.

There was variation among shooters in their ability to hit a deer, and also to do so with a killing shot. The number of bullet wounds per deer ranged from 1 to 3 (mean = 1.1), with 83% of shots striking the brain and 17% striking the anterior skull, neck or jaw.

The poorer welfare outcomes for rusa deer than for eastern grey kangaroos (*Macropus giganteus*) were likely to be related to differences in terrain, shooting distance and species susceptibility (especially their flight behaviours).

FOR HELICOPTER-BASED SHOOTING[M5]

During the three operations, veterinarians performed 114–318 ante-mortem and 60–105 post-mortem observations for deer. Shots were fired at 69–76% of deer that were observed. Median CT ranged 73–145 s. Median TTI ranged 17–37 s and median total time ranged 109–162 s. The mean number of bullet wounds per deer ranged 1.43–2.57.

Animal-welfare outcomes were better in the two fallow deer operations than in the chital deer operation. In both fallow deer operations, most deer were shot multiple times and at least once in the head or thorax. In contrast, chital deer were shot fewer times and less often in the head or thorax, and non-fatal wounding was observed. Non-fatal wounding occurred when wounded deer were able to escape into thick vegetation or when deer were shot only once before being left.

COST-EFFECTIVENESS OF GROUND SHOOTING

SYSTEMATIC REVIEW OF GROUND-BASED SHOOTING TO CONTROL OVERABUNDANT MAMMAL POPULATIONS[M2]

Most studies reviewed had no *a priori* quantifiable objectives. However, 60% of the 64 case studies produced a detectable reduction in population density and/or damage. The most common type of operation used shooters who were unpaid or harvesting commercially to reduce herbivore density or damage.

Only 30% of the operations that used volunteer shooters or recreational hunters achieved their objectives. Target taxa, geographic area or integration of shooting with other population-control methods had no detectable effect on the effectiveness of shooting operations. Common factors that hindered the effectiveness of shooting operations included immigration of target species from adjacent areas (n = 13), decreasing effort from shooters as the target population declined (n = 7) and selective harvesting (n = 7).

COST-EFFECTIVENESS OF VOLUNTEER AND CONTRACT SHOOTERS IN ALPINE NATIONAL PARK[M6,M8,M10]

Sambar deer activity decreased when snow depth increased (between July and September), and was highest in easterly and northerly aspects with dense woody vegetation close to high-elevation peatlands and roads. During our study, sambar deer activity decreased in a treatment area subject to organised ground-based shooting but increased in a non-treatment area (i.e. no organised ground-based shooting). Sambar deer exhibited a crepuscular diel cycle, with greatest activity around sunset.

Empirical data collected during a five-year management program showed that, given the same access opportunities and similar equipment, contract ground-based shooters killed four times more sambar deer per hour than volunteer shooters in and around alpine peatlands in south-eastern Australia. This higher catch-per-unit-effort (CPUE) compensated for most, but not all, of the greater cost-per-unit-effort of contract shooters. Hence, contract shooters were, on average, 10.1% more expensive per deer killed than were volunteer shooters.

The CPUE and, hence, cost-effectiveness of volunteer shooters was strongly influenced by shooting method: it was highest when shooting at night from a vehicle with a spotlight or when stalking with thermal vision equipment. During the day, the use of gundogs to indicate deer significantly increased the CPUE of volunteer shooters. Both contract and volunteer shooters had a higher CPUE during the first half of the night and just before sunrise.

Contractors and especially volunteer shooters relied on roads and tracks to move within the treatment units to shoot sambar deer close to alpine peatlands. Although contract shooters covered more area than volunteer shooters, there were still large parts of the treatment units that had had little or no shooting effort over the five years.

Sambar deer relative abundance (faecal pellet counts) declined in the treatment units relative to the non-treatment units. Increasing culling intensity resulted in larger reductions in ground degradation (trampled vegetation and bare ground), pugging intensity and weed infestation. Finer-scale measures of culling effort typically revealed in stronger positive changes in deer impacts.

TASMANIA GROUND-SHOOTING TRIAL

Fallow deer activity on camera traps was mostly crepuscular (most detections occurred around sunrise and sunset). During the year, fallow deer activity showed two peaks: one in April associated with the rut season, and one in December–January when most births occur. The least activity was recorded in June–July when temperatures are the lowest.

Between February and July 2022, hunters participated in 75 hunts for a total of 803 hours (mean = 10.9 hours per hunt). A total of 35 deer were shot, resulting in a CPUE of 0.06 deer killed per hour, or

17.7 hours per deer killed. For comparison, shooters in the Alpine National Park Deer Control Program took 8.0 hours (volunteers) and 2.4 hours (contractors) to kill a sambar deer.

COST-EFFECTIVENESS OF AERIAL SHOOTING[M4]

Population reductions for aerial-shooting operations ranged 5–75% for fallow deer, and 48–88% for chital deer. The greatest population reductions occurred when effort-per-unit-area was greatest, and the largest reductions in deer density occurred when shooting was conducted in consecutive years. The functional response of hourly kills to deer density showed an asymptotic kill rate with a maximum expected efficiency of approximately 50 deer killed per hour. There was no support for the existence of a prey refuge; that is, a threshold population density below which no deer could be shot.

Helicopter charter was the primary cost of helicopter-based shooting programs, followed by labour; firearm and ammunition costs were relatively minor. For shooting operations aiming to suppress the growth of fallow deer populations (i.e. removal of 35% of the population) over an area of 135 km^2, the predicted cost of shooting operations using a Jet Ranger helicopter ranges from $15,880 at five deer per km^2 to $136,590 at 40 deer per km^2.

EXCLUSION FENCING TO MANAGE IMPACTS[R1]

Evidence-based fencing standards for deer have been developed as a result of the long history of farming deer in Australia and New Zealand. To exclude deer, fences should be a minimum of 1.9 m in height, and mesh netting of 17/190/15 and posts spaced at a maximum of 10 m are recommended. These specifications also prevent macropods, feral pigs and wild dogs from jumping over or pushing through fencing. To prevent animals from pushing or digging under fencing and creating holes for deer to move through, a 30-cm netting apron is also desirable. If an apron is used, the pole spacing needs to be shorter (typically 5-m intervals).

An electric outrigger wire outside the fence (20–60 cm above the ground, depending on the mix of species to be excluded) can reduce the pressure on the fence and apron from deer, feral pigs, macropods and wild dogs.

The costs of constructing deer fencing will primarily depend on the fence materials selected, the design, the fence length and the topography (steeper country is more expensive to fence than flat country). If the fence line needs to be cleared, then this will add considerable cost.

ANNUAL COSTS OF FERAL DEER IN AUSTRALIA[R2]

Annual farm-gate-level production losses were estimated at $55.8 million in 2021. Beef and sheep industry losses accounted for more than half of these agricultural sector production losses. The estimate for annual feral deer–control costs at the farm level was $13.2 million. Therefore, the combined cost of deer control and production loss due to feral deer for the included agricultural industries was estimated at $69 million for 2021.

Motor vehicle and train impacts involving deer were estimated to cost $3.3 million and $1.2 million per year, respectively. Although there were far more deer-related motor vehicle incidents than train incidents (estimated at 300 and 30 per year, respectively), the cost for a train call-out was far higher than that for a car call-out, so the total cost for train call-outs was of a much higher order. The greatest number of train–deer impacts occurred in the Illawarra region of NSW, whereas vehicle–deer impacts mainly occurred across NSW and Victoria.

In 2021, federal, state and local governments spent ~$18 million on deer management and research.

The total national cost of feral deer in Australia in 2021 was therefore ~$91 million.

DISCUSSION

Our four-year project provided land managers with the tools and expertise required to cost-effectively manage feral deer in a range of settings. The project provided national leadership through the coordination of existing and planned deer management programs in Qld, NSW, Vic and Tas. We also provided the first national estimate of the annual costs of feral deer in Australia.

METHODS TO MEASURE DEER ABUNDANCE AND DENSITY

The usefulness of deer abundance and density estimates would be substantially improved by: (1) reporting key methodological details, (2) robustly assessing bias, (3) reporting the precision of estimates, (4) using methods that increase and estimate detection probability, and (5) staying up to date with new methods.

Aerial mark–recapture distance sampling provided an effective and practical method for surveying deer populations. Additionally, the use of machine learning should substantially reduce the time and cost burdens of manual analysis of thermal footage from unmanned aerial vehicles.

ANIMAL-WELFARE OUTCOMES OF DEER MANAGEMENT IN AUSTRALIA

Improving shooter training could result in better animal-welfare outcomes of ground-based shooting of deer. Assessment of shooter performance should be a routine part of ground-based shooting programs.

The best animal-welfare outcomes were achieved when helicopter-based shooting operations followed a fly-back procedure and mandated that multiple shots were fired into each animal. Animal-welfare outcomes for helicopter-based deer shooting in Australia could be improved with a national-level standard operating procedure requiring helicopters to fly back over shot animals and repeatedly shoot animals in the head or thorax.

COST-EFFECTIVENESS OF GROUND SHOOTING

Managers contemplating using ground-based shooting to reduce the impacts or density of wildlife populations should: (1) carefully consider whether this is a suitable management tool to achieve the desired outcomes, (2) establish clear objectives that aim to meet defined outcomes and allow for continuous improvement, and (3) ensure that operations are sufficiently resourced to achieve and maintain those objectives.

The effectiveness of ground-based shooters is increased by operating at night using vehicles, spotlights and thermal vision equipment. Ground-based shooting is therefore likely to be most effective when conducted at night with thermal vision equipment, and in areas with a high density of roads and tracks. Contract shooters kill sambar deer at a faster rate, but are 10% more expensive per deer killed, than volunteer shooters.

Control operations targeting sambar deer at high elevations in south-eastern Australia should be conducted during October–June. Outside this period, sambar deer appear to use lower elevation habitats. Knowing how culling varies spatially is important for understanding ecosystem responses to management of feral deer.

Preliminary data from the fallow deer hunters in Tasmania suggest that recreational hunting has a much lower effectiveness than organised ground-shooting operations of sambar deer in Victoria using volunteer or contract shooters.

COST-EFFECTIVENESS OF AERIAL SHOOTING

Aerial-shooting operations should include a pre-control survey to estimate population size so that managers can: (1) establish measurable objectives, (2) estimate and plan for the likely level of effort and cost required to meet objectives, and (3) estimate the realised population reduction.

EXCLUSION FENCING TO MANAGE IMPACTS

The key design considerations when constructing a deer-exclusion fence are: whether the fence needs to keep all deer out; and how easy it will be to inspect, maintain and repair the fence. Well-constructed fences are expensive, but should last more than 15 years with minimal maintenance. Regular inspection for holes and breaks is needed if there are trees within falling distance of the fence, and as soon as possible after floods.

The cost of constructing a deer-exclusion fence depends upon the design of the fence, the topography, and the difficulty of clearing the fence line (including any need to remove trees).

An indicative total cost for using heavy machinery to clear and level a fence line on an agricultural property; and constructing a fence that will exclude deer, macropods, feral pigs and wild dogs (i.e. including an apron) is $16,000 per kilometre. Constructing fences in remote, forested or alpine areas costs much more than this.

ANNUAL COSTS OF WILD DEER IN AUSTRALIA

The distributions of deer populations in Australia are expanding, and densities are increasing. Consequently, the annual cost of the impact of deer is expected to increase to significantly more than $91 million over the next decade, unless major strategic management programs are deployed.

BENEFITS FOR AND CHANGES TO ON-GROUND MANAGEMENT

Based partly on our findings, there has been an expansion of the area subject to helicopter-based shooting of deer in NSW, ACT and Qld.

We provided advice to Tasmania Parks and Wildlife Service which is planning helicopter-based shooting of fallow deer in 2023.

Robust monitoring has increased in deer management programs conducted by NSW Local Land Services.

Our findings were incorporated into the draft Queensland Feral Deer Management Strategy 2022–2027, and a review of the draft National Feral Deer Action Plan.

RECOMMENDATIONS

Based on the experience gained during this project, we identified potential directions for future research aiming to improve deer management in Australia.

MONITORING

- Continue to promote the use of robust monitoring for all deer management programs so that their cost-effectiveness can be accurately assessed.
- Publish Glovebox Guides for emerging technologies applicable to multiple vertebrate pest species (not just deer) such as DNA, thermal-vision equipment or drones.
- Robustly estimate the impacts of deer on primary industries, ecosystems and human communities, and the effects of management interventions on those impacts.

CONTROL

- Evaluate the costs and effectiveness of coordinated helicopter-based and ground-based shooting for reducing deer populations to very low densities.
- Conduct a cost-benefit analysis of large-scale, cross-tenure deer management programs.

GROUND-BASED SHOOTING

- Evaluate the costs and effectiveness of ground-based shooting in other landscapes and for other deer species. We have assessed the costs and effectiveness of volunteer and contract shooters for sambar deer in and around high-elevation peatlands in Victoria, and the effectiveness of recreational shooters for fallow deer on private property in Tasmania. Assessing the cost-effectiveness of ground shooting in landscapes dominated more by forestry and agriculture is needed.
- Conduct a cost-benefit analysis of commercial harvesting of deer.
- Publish Glovebox Guides for emerging technologies applicable to multiple vertebrate pest species (not just deer) such as thermal-vision equipment or drones.

AERIAL SHOOTING

- Evaluate the costs and effectiveness of helicopter-based shooting for other deer species and in other landscapes. We have assessed the costs and effectiveness of this method for fallow deer and chital deer in predominantly agricultural landscapes. It would be desirable to assess it for rusa deer and sambar deer in forested landscapes.
- Evaluate the costs and effectiveness of thermal-assisted helicopter-based shooting of deer, and contrast them with ‘traditional’ helicopter-based shooting.

ALTERNATIVE CONTROL METHODS

- Investigate the cost-effectiveness of trap designs for different deer species and in different landscapes.
- Evaluate the effectiveness of non-lethal methods for mitigating deer impacts (e.g. virtual fences, sound deterrents, habitat alteration).
- Conduct a cost-benefit analysis of exclusion fencing in agricultural and conservation settings.

CONTRIBUTION TO KNOWLEDGE

METHODS TO MEASURE DEER ABUNDANCE AND DENSITY

Our global systematic review revealed the substantial effort expended estimating deer abundance and density, particularly in Europe and North America.

There is, however, opportunity to substantially improve the usefulness of estimates by: (1) reporting key methodological details, (2) assessing the bias of current and emerging methods, (3) reporting the precision of estimates, (4) using methods that increase and estimate detection probability, and (5) staying up to date with new methods.

ANIMAL-WELFARE OUTCOMES OF DEER MANAGEMENT IN AUSTRALIA

The animal-welfare outcomes of professional ground-based shooting we observed were comparable to those reported from other professional ground-based shooting programs for ungulates, but were poorer than those reported for professional ground-based shooting of peri-urban kangaroos. Improving shooter training is one way to improve the animal-welfare outcomes of vehicle-based shooting of peri-urban deer.

Helicopter-based shooting of deer led to variable animal-welfare outcomes, likely reflecting key procedural differences. The best animal-welfare outcomes were achieved when helicopter-based shooting operations followed a fly-back procedure and undertook repeat shooting in the thorax or head.

COST-EFFECTIVENESS OF GROUND SHOOTING

Ground-based shooting can be an effective management tool for overabundant wildlife populations, but many shooting operations did not achieve a notable decrease in animal abundance or subsequent impacts. The source of failure was most often not removing a sufficient proportion of the population to cause a population decline.

If there is a limited time frame for deer control, then contract shooters can be expected to remove more deer than volunteer shooters, but at a greater cost (10%). The timing of the shooting and the supporting equipment that can be used greatly affects shooter effectiveness and hence cost. Ground-based shooting of deer is likely to be most effective when conducted at night and with thermal vision equipment, in areas with high density of roads.

Our project provides the first experimental evidence that ground-based shooting of feral deer reduces their impacts on a range of ecosystem attributes. Knowing how culling varies spatially is important for understanding these ecosystems responses to management of feral deer.

COST-EFFECTIVENESS OF AERIAL SHOOTING

Helicopter-based shooting can rapidly reduce deer populations over large geographic areas, but the magnitude of the reduction depends on the effort (hours of shooting) per deer per km^2. A pre-control survey of deer density is therefore valuable to predict the effort and cost required to achieve the desired outcome, and to evaluate the outcome achieved.

As a rule of thumb: if the aim is to suppress population growth, aerial-shooting operations for fallow deer in fragmented woodlands should aim to commit at least 11 hours of shooting effort per 1,000 deer present.

EXCLUSION FENCING TO MANAGE IMPACTS

The key design and construction issues for deer-exclusion fences relate to whether they will be in agricultural or conservation settings.

In agricultural settings, it is usually desirable for the fence to also exclude macropods, feral pigs and wild dogs (if they are present); and fences are typically constructed along boundaries or around high-value paddocks. Existing sheep/cattle fences can be modified to exclude deer, and new fence lines are usually cleared and levelled with heavy machinery.

In conservation settings, fences typically enclose smaller areas and are in more remote locations. It is often not desirable or practical to clear and level the fence lines with heavy machinery. These deer-exclusion fences can be designed to facilitate the movement of native mammals by having a gap at the bottom of the fence, although this increases the risk of small deer getting through.

ANNUAL COSTS OF FERAL DEER IN AUSTRALIA

It is estimated that feral deer imposed a total cost of ~$91 million in Australia in 2021.

Agricultural losses in the grazing industries make up the largest share of this cost (~$69 million), public control expenditure is estimated at ~$18 million, motor vehicle impacts involving deer at ~$3.3 million, and train impacts involving deer at ~$1.2 million per year.

There is considerable uncertainty in the assumptions upon which these estimates are based, so the total cost estimate ranged $45-$206 million.

APPENDIX: PROJECT PUBLICATIONS

PEER-REVIEWED SCIENTIFIC ARTICLES

M1: Hampton, JO, MacKenzie, DI and Forsyth, DM (2019) ‘How many to sample? Statistical guidelines for monitoring animal welfare outcomes’, *PLoS ONE,* 14:e0211417, doi:10.1371/journal.pone.0211417.

M2: Bengsen, AJ, Forsyth, DM, Harris, S, Latham, ADM, McLeod, SR and Pople, A (2020) ‘A systematic review of ground-based shooting to control overabundant mammal populations’, *Wildlife Research,* 47:197–207, doi:10.1071/WR19129.

M3: Forsyth, DM, Comte, S, Davis, NE, Bengsen, AJ, Côté, SD, Hewitt, DG, Morellet, N and Mysterud, A (2022) ‘Methodology matters when estimating deer abundance: A global systematic review and recommendations for improvements’, *The Journal of Wildlife Management,* 86:e22207, doi:10.1002/jwmg.22207.

M4: Bengsen, AJ, Forsyth, DM, Pople, A, Brennan, M, Amos, M, Leeson, M, Cox, TE, Gray, B, Orgill, O, Hampton, JO, Crittle, T and Haebich, K (in press) ‘Effectiveness and costs of helicopter-based shooting of deer’, *Wildlife Research*, doi:10.1071/WR21156.

M5: Hampton, JO, Bengsen, AJ, Pople, A, Brennan, M, Leeson, M and Forsyth, DM (2022) ‘Animal welfare outcomes of helicopter-based shooting of deer in Australia’, *Wildlife Research,* 49:264–273, doi:10.1071/WR21069.

M6: Comte, S, Thomas, E, Bengsen, AJ, Bennett, A, Davis, NE, Freney, S, Jackson, SM, White, M, Forsyth, DM and Brown, D (2022) ‘Seasonal and daily activity of non-native sambar deer in and around high-elevation peatlands, south-eastern Australia’, *Wildlife Research*, 49:659-672, doi:10.1071/WR21147.

M7: Hampton, JO, MacKenzie, DI and Forsyth, DM (in press) ‘Animal welfare outcomes of professional vehicle-based shooting of peri-urban rusa deer in Australia’, *Wildlife Research*, doi:10.1071/WR21131.

M8: Comte, S, Thomas, E, Bengsen, AJ, Bennett, A, Davis, NE, Brown, D and Forsyth, DM (in press) ‘Cost-effectiveness of volunteer and contract ground-based shooting of sambar deer in Australia’, *Wildlife Research*, doi:10.1071/WR22030.

M9: Pople, AR, Amos, M and Brennan, M (submitted) ‘Population dynamics of chital deer (*Axis axis*) in north Queensland: effects of drought and culling’.

M10: Comte, S, Thomas, E, Bengsen, AJ, Bennett, A, Davis, NE, Brown, D and Forsyth, DM (submitted) ‘A Before-After Control-Impact experiment reveals that culling reduces the impacts of invasive deer on endangered peatlands’.

M11: Boterill-James, T, Cunningham, CX, Johnson, CN, Brook, BW, Duncan, RP and Forsyth, DM (submitted) ‘Pattern-oriented modelling provides validated forecasts of an invading deer species under alternate management strategies’.

M12: Sudholz, A, Denman, S, Pople, T, Brennan, M, Amos, M, & Hamilton, G (2022) ‘A comparison of manual and automated detection of rusa deer (*Rusa timorensis*) from RPAS-derived thermal imagery’, *Wildlife Research,* 49:46–53, doi:10.1071/WR20169.

M13: Amos M, Pople A, Brennan M, Sheil D, Kimber M and Cathcart A (2022) ‘Home ranges of rusa deer (*Cervus timorensis*) in a subtropical peri-urban environment in South East Queensland’, *Australian Mammalogy*, doi:10.1071/AM21052.

M14: Huaman, JL, Pacioni, C, Forsyth, DM, Pople, A, Hampton, JO, Carvalho, TG and Helbig, KJ (2022) ‘Detection and characterisation of an endogenous Betaretrovirus in Australian wild deer’, *Viruses,* 14:252, doi:10.3390/v14020252.

M15: Huaman-Torres, JL, Pacioni, C, Sarker, S, Doyle, M, Forsyth, DM, Pople, AR, Hampton, JO, Helbig, K and Carvalho, TG (2021) ‘Molecular epidemiology and characterization of Picobirnavirus in wild deer and cattle from Australia: Evidence of genogroup I and II in the upper respiratory tract’, *Viruses,* 13:1492, doi:10.3390/v13081492.

M16: Huaman-Torres, JL, Pacioni, C, Forsyth, DM, Pople, A.R, Hampton, JO, Helbig, K and Carvalho, TG (2021) ‘Evaluation of haemoparasite and *Sarcocystis* infections in Australian wild deer’, *International Journal for Parasitology: Parasites and Wildlife,* 15:262–269, doi:10.1016/j.ijppaw.2021.06.006.

M17: Huaman-Torres, JL, Pacioni, C, Sarker, S, Doyle, M, Forsyth, DM, Pople, AR, Helbig, K and Carvalho, TG (2021) ‘Novel picornavirus detected in wild deer: identification, characterisation, and prevalence in Australia’, *Viruses,* 13:2412, doi:10.3390/v13122412.

M18: Huaman, J.L, Pacioni, C, Doyle, M, Forsyth, DM, Helbig, KJ and Carvalho, TG (submitted) ‘Wild deer contribute to the sylvatic cycle of *Neospora caninum* in Australia’.

M19: Huaman, JL, Helbig, KJ, Carvalho, TG, Doyle, M, Hampton, JO, Forsyth, DM, Pople, A and Pacioni, C (in press) ‘A review of viral and parasitic infections in wild deer in Australia with relevance to livestock and human health’, *Wildlife Research*.

M20: Li-Williams, S, Comte, S, Stuart, KC, Forsyth, DM, Dawson, M, Sherwin, WB and Rollins, LA (submitted) ‘Population genetic analyses reveal spatial structure in invading rusa deer’.

M21: Hill, E, Murphy, N, Li-Williams, S, Davies, C, Forsyth, DM, Comte, S, Rollins, LA, Hogan, F, Wedrowicz, F, Sherwin, WB, Crittle, T, Thomas, E, Woodford, L and Pacioni, C (in press) ‘Hybridisation rates, population structure, and dispersal of sambar deer (*Cervus unicolor*) and rusa deer (*Cervus timorensis*) in south-eastern Australia’, *Wildlife Research*.

M22: Comte, S, Bengsen, AJ, Cunningham, CX, Dawson, M, Pople, AR and Forsyth, DM (in preparation) ‘Professional vehicle-based shooting can control rusa deer population and community complaints in peri-urban landscapes’.

REPORTS AND GUIDELINES

R1: Forsyth, D M (2023) Using exclusion fencing to manage feral deer impacts in Australia. Produced by the NSW Department of Primary Industries, Orange, for the Centre for Invasive Species Solutions

R2: McLeod, R. (2023). Annual Costs of Feral Deer in Australia. Report prepared by eSYS Development Pty Ltd for the Centre for Invasive Species Solutions.

G1: Forsyth, DM, Comte, S, Bengsen, AJ, Hampton, JO and Pople, AR (in preparation) ‘Glovebox Guide for Managing Wild Deer. Version 1.0. PestSmart Toolkit publication’, will be provided to CISS for publication on the PestSmart website.

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