Animal Welfare Assessment of Kangaroo Culling: Australian Capital Territory, 2017

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EXECUTIVE SUMMARY

This report described an independent animal welfare assessment of the 2017 Australian Capital Territory kangaroo management program. The report is in two parts; Part 1: descriptive analysis and auditing of compliance with procedural documents (Jordan Hampton: *Ecotone Wildlife Veterinary Services*) and Part 2: data analysis of explanatory variables influencing animal welfare outcomes (Brendan Cowled: *Ausvet Pt Ltd*).

Part 1 of the report describes field observations performed by two independent veterinarians of 338 kangaroos that were shot at over six nights in May–June 2017. Important animal welfare parameters were quantified including the frequency of shots missing kangaroos, of animals escaping, and of inaccurate shots. Generally, animal welfare outcomes were comparable to other professional shooting programs. The guiding procedural document, the *National code of practice for the humane shooting of kangaroos and wallabies for non-commercial purposes* (the COP) was complied with in all aspects. A minority of kangaroos were missed (4%), killed but not rendered immediately insensible by initial shooting (4%), or non-fatally wounded (1%). These outcomes were considered to constitute 'adverse animal welfare events' and data analysis was performed to determine which variables best explained their occurrence.

Part 2 of the report describes data analysis performed to elucidate the role of several explanatory variables in influencing the occurrence of adverse animal welfare events. Variables examined included animal variables (age, sex), shooting variables (calibre, optics etc.), and operational variables (consecutive nights of shooting, minimum temperature etc.) Modelling revealed that shooter identity, inferred as shooter skill, was most likely to affect the probability of an adverse outcome. In addition, the sex of animals was a key factor for adverse outcomes, with male kangaroos less likely to be rendered immediately insensible than females. However, there were un-recorded variables (shooting distance etc.) that were responsible for influencing the likelihood of adverse animal welfare outcomes.

Three recommendations were made:

1. For continuing compliance with the COP, currently used shooting protocols should be maintained.
2. The managing agency should examine shooter selection and training as the identity of the shooter is the most important variable in determining welfare outcomes.
3. Shooters should exercise additional caution when targeting male kangaroos as they are more likely to experience adverse animal welfare outcomes.

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PART 1: OBSERVATIONS AND PROCEDURAL COMPLIANCE

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1.1. Introduction

Populations of kangaroos (*Macropus* spp.) reach high densities on conservation estate in many parts of Australia (Howland *et al.* 2014) and are often subjected to ongoing reduction, or 'culling' programs (Mawson *et al.* 2016). Peri-urban populations of eastern grey kangaroos (*M. giganteus*) in the Australian Capital Territory (ACT) have been subjected to ongoing reduction programs for this reason (ACT Government 2010). To date, reduction of kangaroo populations deemed overabundant has been largely achieved by non-commercial or "damage-mitigation" professional shooting (described in Hampton and Forsyth 2016). The eastern grey kangaroo in the ACT is declared a controlled native species under the Nature Conservation Act 2014. The use of ground-based night shooting (shooting) as a management tool for the reduction of kangaroo population densities in the ACT is described in the Eastern Grey Kangaroo: Controlled Native Species Management Plan (ACT Government 2017). The ACT Kangaroo Management Plan (ACT Government 2010) remains the source document for the background and justification of kangaroo management in the ACT, and is the sole ACT policy document for kangaroo management at Googong Foreshores, New South Wales (NSW).

Under the Controlled Native Species Management Plan and ACT Kangaroo Management Plan, all kangaroo shooting programs are required to be conducted in accordance with the *National code of practice for the humane shooting of kangaroos and wallabies for non-commercial purposes* (hereafter 'the COP'; Commonwealth of Australia 2008). The COP sets a minimum standard of humane conduct for persons undertaking the non-commercial culling of kangaroos.

The 2017 ACT kangaroo management program targeted kangaroos in several peri-urban sites in the ACT as well as one larger site in an adjacent area of NSW (Googong Foreshores). The program was conducted with the intent of strict adherence to the standards outlined in the COP. To facilitate compliance with the COP and to allow transparent demonstration of animal welfare outcomes, an independent animal welfare audit was conducted. Two veterinarians, independent of the shooting program (i.e. not a member of the shooting team or an employee of the managing agency) collected ante-mortem (before death) and post-mortem (after death) data from a representative sample of shot animals. The independence of the observers from the shooting team and the managing agency was considered important to provide an unbiased assessment of the program to stakeholders and the general public. The importance of independent observers for the transparent quantification of animal welfare parameters has been recognised for many contentious wildlife management programs (e.g. Hampton and Forsyth 2016).

1.2. Methods

Methodology for the 2017 independent animal welfare audit was identical to that used to assess the same management program in 2015 (Hampton 2016). The methodology used was initially derived from peer-reviewed studies of animal welfare outcomes in terrestrial wildlife shooting programs (Lewis *et al.* 1997; Hampton *et al.* 2015; Hampton and Forsyth 2016). Methods were also adapted from non-peer-reviewed reports that have studied kangaroo shooting (ACT Parks and Conservation Service 2013; McLeod and Sharp 2014) but were adapted to ensure that selection bias resulting from shooter selection of animals to be assessed was minimised (see Hampton *et al.* 2015). Resource-based measures were used to assess protocol compliance, and animal-based measures were used to assess animal welfare outcomes (Hampton *et al.* 2016). One independent observer was present for each assessed shooting event, with one observer present for four nights of shooting and the other observer present for three nights of shooting. Both observers were present for one night of shooting to ensure that methodology and interpretation of data was consistent.

1.2.1. Study area

Shooting events were observed over six nights in May−June 2017. Shooting events were observed at one site in the ACT (Callum Brae Nature Reserve) and one site in a neighbouring area of NSW (Googong Foreshores; **Table 1**).

1.2.2. Shooting configuration observations

The COP specifies that shooters should only take ‘head shots’; to aim to hit adult kangaroos in the brain, and that juvenile ‘young-at-foot’ animals should be shot so as to be hit in the brain or heart. The COP specifies that a rifle of minimum .204 Ruger® centrefire calibre should be used. The COP specifies that immediately after shooting of adult kangaroos, pouches of shot females should be checked for the presence of live pouch young, and if detected, they should be euthanased with blunt cranial trauma or decapitation. The independent observers recorded the specifications of all equipment used and documented procedures followed by the shooting teams.

The independent observers assessed shooting teams from three separate agencies; two agencies were private contractors and the third agency was the ACT Parks and Conservation Service. Each shooting team consisted of a shooter and a driver. In some instances, a shooter from a private agency operated with a driver from the ACT Parks and Conservation Service. In total, seven shooters were observed during the assessment (**Table 1**).

Customised four-wheel drive buggy vehicles (without windscreens) were driven slowly (5−10 km/h), with a shooter and driver sitting in the seats and an observer seated behind them. The vehicle was stopped when a stationary kangaroo was sighted and estimated to be within the maximum shooting distance specified by the COP (i.e. <200 metres). Shooting was not to be undertaken from a moving vehicle, nor targeting moving or non-standing animals. Following the COP, the shooter shot at the cranium (brain) as the sole target anatomical zone for adult kangaroos and the brain or thorax as target anatomical zones for sub-adults (young-at-foot). Two bolt-action rifle calibres were used: 1) .223 Remington®

rifles were used to fire 55 grain polymer-tip hollow-point ammunition, and 2) .204 Ruger® rifles were used to fire 40 grain polymer-tip hollow-point ammunition.

To allow visualisation of kangaroos for night-time shooting, two illumination approaches were used: 1) animals were shot at with the use of white-light spotlights (as per the COP), and 2) infra-red technology (thermal and night-vision) was used to permit shooting without spotlights (see Hampton and Forsyth 2016). Further specifications of the configuration of illumination equipment have not been published to protect the intellectual property and anonymity of the shooting teams. For both illumination approaches, rifles were fitted with telescopic scopes as per the COP. All rifles used noise suppressors to minimise disturbance to nearby housing. The observers recorded ante-mortem and post-mortem data for all shooting events during the assessment.

1.2.3. Ante-mortem observations

From each shooting event, the observer recorded the following data as per Hampton *et al.* (2015) and Hampton and Forsyth (2016): the number of shots fired at each animal, whether shots hit animals, the apparent time to insensibility for shot animals ('time to death'; TTD), whether shot animals died or escaped wounded, and whether killed animals were found. As soon as possible after shooting one or more kangaroos, the animals were approached to confirm death, check for the presence of pouch young and assess ballistic pathology (bullet wound injuries). Animals were searched for after shooting using infra-red technologies and limited white light illumination.

When adult female kangaroos were shot, any pouch young present were required to be euthanased immediately, as per the COP. Euthanasia procedures were performed with the intent of complying with the conditions specified by the COP. To assess this component of the operation, observation methodology was largely derived from a study of animal welfare outcomes in commercial kangaroo shooting (McLeod and Sharp 2014). The authors of this study argued that unfurred pouch young do not meet the scientific criteria for sentience, or the capacity to suffer, prior to the age of fur development and eye opening, due to limited brain development. For a discussion of neurological development and the onset of sentience in marsupials, see McLeod and Sharp (2014).

The protocol used by all staff involved furred and unfurred pouch young being euthanased via blunt trauma, while very small unfurred pouch young were euthanased using the 'thumb and forefinger' decapitation method described by McLeod and Sharp (2014). Some staff used a solid wooden board underneath the pouch young while delivering blunt trauma while others did not. For each pouch young euthanased, the observer recorded the following data as per McLeod and Sharp (2014) and Hampton and Forsyth (2016): the number of pouch young present, the age class of pouch young (furred or unfurred), and the euthanasia method applied (bunt trauma and/or decapitation).

Table 1. Logistical data for the collection of animal welfare data from the non-commercial shooting of eastern grey kangaroos (*Macropus giganteus*) in peri-urban conservation estate in the ACT and NSW, May–June 2017. Observers, shooters and agencies are designated by numbers rather than by name.

Night of observations	Observer	Shooter agency	Driver agency	Shooters observed	Field site	Animals shot at (*n*)
1	1	1	1	1, 2, 3	Callum Brae Nature Reserve	51
2	1	2	2	4	Googong Foreshores	70
3	1	1	1	1, 3	Callum Brae Nature Reserve	27
4	1, 2	2	2	5	Googong Foreshores	69
5	2	3	1	6	Googong Foreshores	72
6	2	3	1	7	Googong Foreshores	49
Total						**338**

1.2.4. Post-mortem observations

Adult kangaroos were subjected to post-mortem examination as soon as the vehicle containing the shooter/driver and observer approached their body. The observer recorded the age of each animal (adult or sub-adult), the sex of the animal, and the location and number of bullet wound tracts. Locations of bullet wounds were recorded following the methodology of Hampton *et al.* (2015). The pouches of adult female kangaroos were inspected.

1.3. Results

Observations were made for a total of 338 kangaroos that were shot at over six nights, between the 29th of May and the 24th of June 2017. Only one shooting team was assessed on each night of observations. The number of kangaroo shooting events observed on each night of the assessment are shown in **Table 1**, as are the field site, observer and shooting team for that night.

Table 2. Summary of ante-mortem data (as per Hampton and Forsyth 2016) collected from the non-commercial shooting of eastern grey kangaroos (*Macropus giganteus*) in peri-urban conservation estate in the ACT and NSW, May–June 2017.

Category	**Sample size (*n*)**
Number of animals targeted	338
Number of animals shot	324
Number of animals recovered	322
Number of animals rendered immediately insensible	309
Number of animals escaping unwounded	14
Number of animals not rendered immediately insensible and killed by blunt trauma	6
Number of animals missed and then shot	4
Number of animals not rendered immediately insensible and shot multiple times	3
Number of animals escaping wounded	2
Number of animals assumed to be killed but not recovered during observations	0

1.3.1. Shooting configuration

The firearms and ammunition used by the shooters are described in 2.2 (above), and complied with the COP. On all shooting nights observed, the firearm used was confirmed to be zeroed prior to use (and often during night) as per the COP.

1.3.2. Ante-mortem data

Over six nights, a total of 338 kangaroos were targeted (shot at). The shooting outcomes are shown in **Table 2**, as per Hampton *et al.* (2015) and Hampton and Forsyth (2016). All kangaroos were stationary and standing prior to shooting. A total of 348 shots were fired, with 21 shots observed to miss animals entirely, hence 94% of shots struck kangaroos (*n*=327). On four occasions where an initial shot missed, the targeted kangaroo was killed with a subsequent shot. All other kangaroos that were missed were observed to escape uninjured (*n*=14).
Three animals were shot a second time, after initial shooting did not render them immediately insensible (wounding). Another six kangaroos were not rendered insensible from the first shot, but were recumbent and immobile, were killed via blunt trauma rather than repeat shooting (as per the COP). Two kangaroos were shot at and appeared to be hit (wounding) but subsequent shots failed to kill them. These two animals were presumed to

have been non-fatally injured (**Table 2**). Median time to death (TTD; the duration from initial shooting to insensibility; Hampton *et al.* 2015) for animals that were killed but not rendered immediately insensible (*n*=9) was 60 seconds (range 5−300 seconds).

All other shot animals (*n*=309) were rendered immediately insensible from the first shot, based on observation. Instantaneous death rate (IDR; the proportion of killed animals rendered immediately insensible; Hampton *et al.* 2015), excluding the four animals that were first missed but then rendered immediately insensible, was hence 96%. Two kangaroos were observed to be non-fatally wounded and escaped, hence 'wounding rate' (Hampton *et al.* 2015) was 0.6%.

The number of kangaroos shot and killed before shooting teams collected them and performed post-mortem inspections ranged from 1−7 animals (**Table 3**). On a single occasion, a shot and killed kangaroo could not immediately be found by the shooting team. This animal was located approximately two hours after shooting. Shooting teams confirmed the sex and species of all shot kangaroos, and inspected the pouches of all shot female kangaroos for pouch young.

1.3.3. Post-mortem examination

Shot animals

Of the 322 kangaroos that were shot and killed, all were found by the shooting teams. Hence, 322 animals were available for post-mortem examination. The sex ratio of the shot animals was female-biased (70:30). Sub-adult animals (undeveloped testicles in males and undeveloped mammary glands in females) represented 29% of shot kangaroos (*n*=93) with 71% (*n*=229) of shot kangaroos classified as adults.

All but three examined animals (99%; *n*=319) had a single bullet wound tract, while three animals displayed two bullet wound tracts. One of the kangaroos that was shot twice was initially shot in the lower jaw (mandible) and was subsequently shot in the cranium. The other kangaroos that were shot twice were initially shot in the lower jaw (mandible) and was subsequently shot in the thorax (as per the COP). Of the 324 bullet wound tracts examined, 93% (*n*=320) affected the brain while 7% (*n*=24) did not. Bullet wound tracts outside the brain affected the anterior ventral neck, the anterior central neck (first and second cervical vertebrae), the orbit (eye socket), the pinna (external ears) and the thorax.

Pouch young

A total of 165 adult female kangaroos were inspected for the presence of pouch young. Of these adult female animals, 161 (98%) had one pouch young present, while four (2%) adult females had no pouch young present. No females were observed with more than one pouch young. Of pouch young detected, 76% (*n*=122) were unfurred and 24% (*n*=39) were furred. The vast majority of pouch young (99%) were euthanased via blunt trauma, and two very small pouch young were decapitated using the 'thumb and forefinger' decapitation method described by McLeod and Sharp (2014). When blunt trauma was used, a solid board was placed under 75% (*n*=121) of pouch young. However, a board was not used for the other

25% (n=40) of pouch young, constituting all of the pouch young processed by one shooter on one night of observations.

Table 3. Summary of logistics for post-mortem collection of eastern grey kangaroos (*Macropus giganteus*) culled via non-commercial shooting in peri-urban conservation estate in the ACT and NSW, May–June 2017.

Number of kangaroos killed before collection	Frequency (*n*)
1	61
2	96
3	48
4	60
5	30
6	12
7	14
Not recovered immediately*	1

* This kangaroo was recovered by the shooting team approximately two hours after shooting.

The shooting teams were observed to check all euthanased pouch young to confirm death immediately after euthanasia procedures had been performed. No previously undetected pouch young were found by the independent observers and no pouch young were found to be alive after euthanasia procedures had been performed.

1.4. Discussion

1.4.1. Compliance with the Code of Practice

The kangaroo culling operation was observed to be compliant with all aspects of the COP for the non-commercial shooting of kangaroos.

The firearms, ammunition and shooting procedures used to target kangaroos met the requirements of the COP. The majority (94%) of shots fired struck kangaroos. Of kangaroos that were killed, 97% were rendered immediately insensible from the first shot fired at them. The majority (93%) of bullet wound tracts in killed kangaroos caused gross ballistic pathology to the brain. For kangaroos not rendered immediately insensible, either repeat shooting or blunt trauma were used as follow-up killing methods. Both approaches are allowed under the COP, which states “In circumstances where, for dispatch of an injured kangaroo or wallaby, a shot to either the brain or heart is impractical or unsafe (such as when the animal is moving but not able to stand), a heavy blow to the base of the skull with sufficient force to destroy the brain (see Schedule 2) is permissible.” (Commonwealth of Australia 2008: pg. 12). The approaches taken to injured kangaroos were consistent with the COP, which states “Where an individual kangaroo or wallaby is injured, no further animals can be shot until all reasonable efforts have been made to locate and kill the injured animal” (Commonwealth of Australia 2008: pg. 8).

One kangaroo was shot and assumed killed but was not recovered (found) for approximately two hours by the shooting team during observations. This kangaroo was an adult male, and hence did not have pouch young, but the animal’s sex was not known until the body was found. The COP states that “shot female kangaroos must be examined for pouch young immediately after shooting” (Commonwealth of Australia 2008: pg. 8). Other studies have observed a low frequency of shot kangaroos not being recovered by shooting teams, including those of McLeod and Sharp (2014) and Hampton and Forsyth (2016).

The majority (98%) of adult female kangaroos shot had pouch young, but most pouch young (76%) were unfurred, and hence were not considered sentient. For pouch young euthanasia, the use of blunt trauma and decapitation were compliant with the COP.

1.4.2. Animal welfare outcomes

The percentage of kangaroos rendered immediately insensible (IDR; 96%) was higher than for most published studies of wildlife shooting (e.g. 93%, Lewis *et al.* 1997; 60%, Hampton *et al.* 2015), and was similar to that observed for the same management program in 2015 (IDR 98%; *n*=139; Hampton 2016). The non-fatal wounding and escape of animals occurs with nearly all examined shooting methods (Hampton *et al.* 2015), including kangaroo shooting (McLeod and Sharp 2014) and 0.6% of kangaroos were observed to be non-fatally wounded in this study. For comparison, McLeod and Sharp (2014) reported an incidence of 0.3% for non-fatal wounding of kangaroos during commercial shooting. It should be noted that it can be difficult to distinguish minor non-fatal wounding from missed shots in field studies (Pierce *et al.* 2015), particularly with night-time shooting methods. This inherent difficulty can lead to uncertainty regarding whether animals have suffered minor non-fatal wounds or have been missed (DEFRA 2014).

1.5. Conclusions

Independent assessment of this shooting program indicated that animal welfare outcomes were comparable to other professional shooting programs. When kangaroos were shot at, the COP for non-commercial kangaroo shooting was complied with in all aspects. A minority of animals were missed, non-fatally wounded, and shot in anatomical locations other than the cranium, as occurs with nearly all shooting methods.

The shooting technique and equipment used were not uniform for all operators, as different firearm calibres and projectiles, illumination approaches, and pouch young euthanasia methods were employed. Consequently, variables associated with the occurrence of adverse animal welfare events (e.g. kangaroos not being rendered immediately insensible) were not obvious from these descriptive analyses alone, but statistically significant associations could be elucidated through multivariable modelling approaches. Modelling has allowed identification of important manipulable variables (e.g. identity of shooters) for aerial shooting programs (Hampton *et al.* 2017), facilitating refinement of procedures. This approach was used in Part 2 of this report.

1.6. Recommendations

From field observations and descriptive analyses, the following recommendation is made:

1. For continuing compliance with the COP, currently used shooting protocols should be maintained.

PART 2: ANALYSIS OF EXPLANATORY VARIABLES

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2.1 Background

This section presents the results of analyses of animal welfare data derived from the Australian Capital Territory kangaroo management program in in 2017. The objective of the analyses was to determine if explanatory variables were associated with adverse animal welfare outcomes. This allowed inferences on the causes (if any) of adverse outcomes.

2.2 Methods

Shooting outcomes from field observations (Part 1 of this report) were dichotomised into those that produced adverse animal welfare events and those that did not. Compliance with the COP (Part 1) was not considered. Shooting outcomes were dichotomised two ways:

1. All data: Kangaroos experiencing immediate insensibility or not and includes all missed shots (n = 338).
2. Killed data: Kangaroos experiencing immediate insensibility or not but not including kangaroos that escaped (n = 322).

Several explanatory variables were collected. These explanatory variables were considered potentially important to the occurrence of adverse outcomes or might have been confounders any observed statistical relationship. These included:

1. Individual shooter (categorical data: 7 shooters)
2. Individual driver (categorical data: 5 drivers)
3. Agency of shooter (categorical data: 3 agencies)
4. Agency of driver (categorical data: 2 agencies)
5. Site (categorical data: 2 sites)
6. Cumulative # animals targeted that night by shooter (continuous)
7. Cumulative # animals targeted since a food break (continuous)
8. Time of night when shooting occurred (categorical data: 4 'sessions')
9. Illumination (categorical data: 2 technologies)
10. Optics (categorical data: 2 technologies)
11. Firearm calibre (categorical data: 2 technologies)
12. # animals shot before collection (continuous)*
13. Sex (categorical data: 2 sexes)*
14. Age (categorical data: 2 age classes)*
15. Night of the operation (continuous)
16. Consecutive nights of shooting (1^{st}, 2^{nd} night etc.)

* Incomplete data for the n = 338 database.

Uni-variable description and bi-variable analyses were conducted to describe both variables and the outcome of interest and to look at crude measures of association between explanatory variables and the outcome immediate insensibility. The crude (uncontrolled) association between bivariable explanatory variables and the outcome (immediate insensibility) was examined by creating simple logistic regression models of immediate insensibility against the explanatory variable in question, and exponentiating the estimated co-efficient to estimate the odds ratio. In the case of variables with multiple categories, a simple contingency table and fisher exact test was conducted.

Multivariable models were implemented to test for associations between explanatory variables and the outcome of immediate insensibility whilst controlling for potentially confounding variables. Multivariable models were implemented as generalised linear models with a log odds link function. Several models were implemented, with each model representing a plausible *a priori* hypothesis. The models were assessed using information theoretic approaches to determine which models (hypotheses) were most supported by the data (Burnham and Anderson 2002; Burnham *et al.* 2011). The fit of the most supported model was examined using standard statistical approaches.

Two data sets were analysed separately. In the first analyses, ‘All data’ was used to implement Hypotheses 1−6, although hypothesis 6 (multivariable model) did not include sex or age. In the second analyses, ‘Killed data’, was used to implement hypotheses 1−7.
The following *a priori* hypotheses were implemented as appropriate multivariable logistic regression models:

Hypothesis 1: Shooter skill
The skill of an individual shooter influences the likelihood of immediate insensibility, but is affected by the calibre of the rifle, the illumination and the optics used:
$$\log_e \frac{P}{1-P} = B_0 + B_1 Shooter + B_2 Calibre + B_3 Illumination + B_4 Optics$$
where P= probability of outcome

Hypothesis 2: Rhythm
Shooters are most likely to make bad shots before they ‘get their eye in’. This will be influenced by the number of animals shot that night, the number shot since a break and the number of shooting sessions that night (most likely to miss when starting each night and each session):
$$\log_e \frac{P}{1-P} = B_0 + B_1 Kangaroos\ shot + B_2 Kangaroos\ since\ break + B_3 Sessions$$

Hypothesis 3: Fatigue
The opposite of rhythm. Shooters are most likely to make bad shots as the number of animals shot that night increase, in later sessions and as the number of animals shot since a break increase. This may be confounded by temperature:
$$\log_e \frac{P}{1-P} = B_0 + B_1 Kangaroos\ shot + B_2 Kangaroos\ since\ break + B_3 Sessions + B_4 Temperature$$

Hypothesis 4: Technology
The equipment used is the most important effect on immediate insensibility. Affected by calibre, illumination and optics:

$$\log_e \frac{P}{1-P} = B_0 + B_1 Calibre + B_2 Illumination + B_3 Optics$$

Hypothesis 5: Animal naivety
Animals get wary of shooters and are harder to shoot as they are exposed for longer. Influenced by the night of the operation and the number of consecutive nights of shooting:

$$\log_e \frac{P}{1-P} = B_0 + B_1 Cummulative\ Night + B_2 Consecutive\ nights$$

Hypothesis 6: Multivariable
All variables have an influence on outcomes and hence all variables are included into a single model:

$$\log_e \frac{P}{1-P} = B_0 + B_1 Cuumulative\ Night + B_2 Consecutive\ nights + B_3 Sex + B_4 Age + B_5 Calibre + B_6 Illumination + B_7 Optics + B_8 Temperature + B_9 Kangaroos\ shot + B_{10} Kangaroos\ since\ break + B_{11} Sessions + B_{12} Shooter$$

Note, that for all data, no sex and age variable was include in the multivariable model as this data was incomplete as some kangaroos were not killed and could not be examined.

Hypothesis 7: Animal factors
Sex and age may influence outcomes (e.g. large adult males less likely to be killed).
This hypothesis is only applicable to outcome 2, Kangaroos experiencing immediate insensibility or not but not including missed shots (*n* = 322):

$$\log_e \frac{P}{1-P} = B_0 + B_1 Sex + B_2 Age$$

2.3 Results

2.3.1 Analysis 1: 'All data'

Note: This does *not* include sex and age data, but records all kangaroos that were shot or escaped.

Descriptive analysis
The following descriptive analysis is presented to understand the distribution of each variable and to allow error checking. **Table 4** describes the continuous variables. **Table 5** describes the categorical variables.

Table 4: Descriptive statistics for each explanatory variable in the models.

Variable	Minimum	Quartile 1	Median	Mean	Quartile 3	Maximum
Adverse event	Prevalence = 0.0858 (95% CI: 0.056−0.116)					
Minimum temperature (°C)	-5.100	-4.500	-4.250	-3.442	-2.900	-0.700
Cumulative night of shooting	6	7	9	10.850	16	18
Consecutive nights of shooting	1	1	2	2.213	3	5
Cumulative kangaroos shot in night	1	10	23	27.990	44	72
Cumulative kangaroos shot since break	1	5	10	10.87	15	33

Bi-variable analysis

The bi-variable analysis explores the relationship between the outcome (adverse events) and each explanatory variable (**Table 6**). An odds ratio of 1 implies there is no relationship between the explanatory variable and the outcome, but should be interpreted for statistical significance by examining the 95% confidence intervals. 95% Confidence intervals that contain 1 indicate a non-significant relationship between the outcome and explanatory variable.

It is important to note that these are uncontrolled variables. The relationship identified may be confounded by other variables. This is generally dealt with in the multivariable modelling section below.

Table 5: Distributions of categorical explanatory variables.

Shooter ID:

Shooter ID	Number of nights
1	33
2	23
3	22
4	70
5	69
6	72
7	49

Sex:

Sex	Number
F	NA
M	NA
Missing data (escaped)	NA

Age:

Age	Number
Adult	NA
Sub-adult	NA
Missing data (escaped)	NA

Calibre:

Calibre	Number
1	217
2	121

Illumination:

Illumination type	Number
Infra-red	208
White light	130

Optics:

Optics type	Number
C	9
S	329

Table 6: Uncontrolled relationship between adverse events and explanatory variable as quantified by odds ratio (note: sex and age are missing as these were not recorded for all animals as some escaped).

Variable	Odds ratio (95% CI) or Fisher exact test
Minimum temperature (°C)	1.1231 (0.8862–1.4080)
Cumulative night of shooting	0.8777 (0.7800–0.9679)
Consecutive nights of shooting	0.8146 (0.5786–1.0929)
Cumulative kangaroos shot in night	0.9963 (0.9769–1.0150)
Cumulative kangaroos shot since break	1.0384 (0.9855–1.0920)
Shooter ID	$\chi 2 = 30.22$, df = 6, $p<0.001$ Shooter ID: Adverse event: 1 2 3 4 5 6 7 0 32 15 22 60 64 70 46 1 1 8 0 10 5 2 3
Calibre	0.3466 (0.1143-0.8639) Calibre: Adverse event: 1 2 0 193 116 1 24 5
Illumination	1.1426 (0.5156-2.4601) Light type: Adverse event: IR W 0 191 118 1 17 12
Optics	0.1716 (0.0426-0.8494) Optics: Adverse event: C S 0 6 303 1 3 26

Multivariable modelling

The multivariable modelling is summarised in a table where all models representing the various hypotheses are ranked from most supported to least supported (**Table 7**). The Akaike weight (probability) and AICc differences (Δ) allow consideration of which are the most supported models. In general terms, a delta of less than 4−7 indicates that the model has some support (Burnham *et al.* 2011).

Table 7: Akaike information criterion (AIC) values and other model comparison parameters for model selection using information theoretic approaches (Burnham and Anderson 2002; Burnham *et al.* 2011). The probability of the multi-variable and single variable shooter skill models are high and clearly the data support either of these models. There is a small amount of support for the MV multivariable model (model containing all parameters) although this support is mostly due to the inclusion of explanatory variables for shooter. Models are listed in AIC ranked order for each hypothesis.

Model	Parameters (K)	Bias corrected AIC (AICc)	AICc differences (Δ)	Probability (Akaike weight)
MV* Shooter skill	**5**	**186.8**	**0**	**0.499**
SV Shooter skill**	**2**	**187.2**	**0.39**	**0.411**
MV Multivariable	**11**	**191.3**	**4.49**	**0.053**
MV Animal Naivety	3	193.6	6.85	0.016
SV cumulative night of shooting	2	194.8	7.98	0.009
SV Calibre	2	196.6	9.84	0.004
MV Technology	4	197.1	10.28	0.003
SV Optics	2	197.4	10.58	0.003
SV Cumulative kangaroos shot since break	2	199.9	13.1	0.001
SV Consecutive nights of shooting	2	200.1	13.33	0.001
SV minimum temperature	2	201	14.17	0
SV Cumulative kangaroos shot in night	2	201.8	14.99	0
SV illumination	2	201.8	15.02	0
MV Rhythm	4	204.6	17.84	0
MV Fatigue	5	206.2	19.43	0

*Multivariable model
**Single variable model

Where several models have some support, it is useful to model average to assist inferences and prediction (Grueber *et al.* 2011). In more detail, the value of the co-efficients from each of the explanatory variables can estimated with weighting from several models based on their level of support. Conditional estimates are useful for prediction. A conditional estimate is produced when setting all other parameters to their mean. **Table 8** presents model averaged predictions.

Table 8: Conditional averages of model coefficients across all models.

Coefficient	Estimate (eB)	Std. Error	Adjusted SE	z value	Pr (>|z|)
(Intercept)	0.2840	1062.8933	1066.8782	0.0010	0.9991
Shooter (2 cf. 1)	**20.3989**	**1.3815**	**1.3851**	**2.1770**	**0.0295**
Shooter (3 cf. 1)	0.0000	1429.6335	1434.8999	0.0100	0.9918
Shooter (4 cf. 1)	9.7404	1.2873	1.2911	1.7630	0.0779
Shooter (5 cf. 1)	5.2403	1.4356	1.4397	1.1510	0.2499
Shooter (6 cf. 1)	0.9143	1.2432	1.2478	0.0720	0.9427
Shooter (7 cf. 1)	2.0870	1.1774	1.1818	0.6230	0.5336
Calibre (2 cf. 1)	1.6×10^{25}	7865.4639	7894.9549	0.0080	0.9937
Illumination (W cf. IR)	2.0157	697.8126	700.4288	0.0010	0.9992
Optics (S cf. C)	0.0000	2152.5513	2160.6221	0.0090	0.9929
Cumulative night of shooting	0.0072	701.6368	704.2675	0.0070	0.9944
Consecutive nights of shooting	33.9796	437.4148	439.0549	0.0080	0.9936
Cumulative roos shot that night	**1.1401**	**0.0646**	**0.0648**	**2.0240**	**0.0430**
Cumulative roos shot since break	0.9000	0.0621	0.0623	1.6920	0.0907
Session (2 cf. 1)	**0.0211**	**1.6046**	**1.6105**	**2.3970**	**0.0165**
Session (3 cf. 1)	**0.0016**	**3.1237**	**3.1353**	**2.0610**	**0.0393**
Session (4 cf. 1)	**0.0002**	**3.6815**	**3.6952**	**2.2690**	**0.0233**
Minimum temperature (°C)	0.0119	500.1930	502.0684	0.0090	0.9930

Model fit

The most supported model, multivariable (MV) Shooter Skill model, was examined for model fit. A likelihood ratio test of the MV Shooter Skill model verse an intercept-only model revealed that the MV Shooter Skill model fitted better than the intercept-only model (H0 = Reduced model is true; HA = Current model is true; χ^2 = 27.5326, df = 7, p = 0.0003). The R^2 was 0.16. This means that approximately 16% of the variability in the data is explained by the data. These indicate that the model fits the data moderately well, but that there are variables that explain much of the data that are not included in the data.

Several coefficients are significant including Shooter 2 cf. Shooter 1 (and marginally Shooter 4 cf. Shooter 1). This indicates that Shooter 2 had more adverse outcomes than shooter 1, whereas 3, 5, 6 and 7 were all not statistically significantly different to Shooter 1. Shooter 4 was trending towards a poorer outcome than shooter 1. Shooter 2 had an odds ratio of

20.3989, indicating 20.3989 times the odds of an adverse outcome than shooter 1 (or practically, shooter 3−7).

In addition, as the number of kangaroos shot increases each night, the likelihood of an adverse outcome increases marginally. That is, the odds ratio is 1.14 indicating that there is a 0.14 increase in the odds of an adverse outcome in roos shot in later sessions
In contrast, cf. session 1, sessions 2−4 were all significantly less likely to have roos shot with adverse outcomes.

2.3.2 Analysis 2: 'Killed data'

Note: This *does* include sex and age data, and records all kangaroos that were shot (*n* = 322), but not those that escaped.

Descriptive Analysis
The following descriptive analysis is presented to understand the distribution of each variable and to allow error checking. **Table 9** describes the continuous variables and **Table 10** shows the distribution of categorical variables.

Bi-variable Analyses
As described above (**2.3.1**), the bi-variable analysis explores the relationship between the outcome (adverse events) and each explanatory variable. Odds ratios enumerate this relationship (**Table 11**). These are uncontrolled variables. The relationship identified may be confounded by other variables. This is generally dealt with in the multivariable section.

Multivariable Modelling
The multivariable (MV) modelling presents a table where all models representing the various hypotheses are ranked from most supported to least supported (**Table 12**). The Akaike weight (probability) and AICc differences (Δ) allow consideration of which are the most supported models. In general terms, a delta of less than 4−7 indicates that the model has some support (Burnham *et al.* 2011).

Where several models have some support, it is useful to model average to assist inferences and prediction (Grueber *et al.* 2011). In more detail, the value of the co-efficients from each of the explanatory variables can estimated with weighting from several models based on their level of support. Conditional estimates are useful for prediction. A conditional estimate is produced when setting all other parameters to their mean. **Table 13** presents model averaged predictions.

Table 9: Descriptive statistics for each explanatory variable in the models.

Variable	Minimum	Quartile 1	Median	Mean	Quartile 3	Maximum
Adverse event	Prevalence = 0.0404 (95% CI: 0.0189-0.0619)					
Minimum temperature (°C)	-5.100	-4.500	-4.200	-3.446	-2.900	-0.700
Cumulative night of shooting	6	7	9	11.0100	16	18
Consecutive nights of shooting	1	1	2	2.252	3	5
Cumulative kangaroos shot in night	1	10	24	28.2300	44	72
Cumulative kangaroos shot since break	1	5	10	20.7800	15	33

Table 10: Distributions of categorical explanatory variables

Shooter ID:

Shooter ID	Number of nights
1	33
2	17
3	22
4	65
5	65
6	71
7	49

Sex:

Sex	Number
F	225
M	97

Age:

Age	Number
Adult	239
Sub-adult	83

Calibre:

Calibre	Number
1	202
2	120

Illumination:

Illumination type	Number
Infra-red	199
White light	123

Optics:

Optics type	Number
C	7
S	315

Table 11: Uncontrolled relationship between adverse events and explanatory variable as quantified by odds ratio.

Variable	Odds ratio (95% CI) or Fisher exact test
Minimum temperature (°C)	1.2281 (0.8737−1.7044)
Cumulative night of shooting	0.9569 (0.8316−1.0806)
Consecutive nights of shooting	1.1118 (0.7419−1.5990)
Cumulative kangaroos shot in night	1.0067 (0.9794−1.0336)
Cumulative kangaroos shot since break	1.0363 (0.9594−1.1128)
Shooter ID	$\chi^2 = 8.737$, df = 6, p = 0.1889 Shooter ID: Adverse event: 1 2 3 4 5 6 7 0 32 15 22 60 64 70 46 1 1 2 0 5 1 1 3
Calibre	0.7394 (0.1968-2.3259) Calibre: Adverse event: 1 2 0 193 116 1 9 4
Illumination	1.0117 (0.2997-3.1049) Light type: Adverse event: IR W 0 191 118 1 8 5
Optics	0.2376 (0.0364-4.6717) Optics: Adverse event: C S 0 6 303 1 1 12
Sex	1.9551 (1.2845-13.3952) (Male cf. female) Sex: Adverse event: F M 0 220 89 1 5 8
Age	1.8510 (0.5456-5.7153) Age: Adverse event: A SA 0 231 78 1 8 5

Table 12: Akaike information criterion (AIC) values and other model comparison parameters for model selection using information theoretic approaches (Burnham and Anderson 2002; Burnham *et al.* 2011). The probability of the single variable sex, animal naivety and multivariable animal factors models are highest. However, there are several other models with some level of support and it is difficult to state the data clearly support these hypotheses over others. For example, the first 13 models all have a delta (Δ) of less than 7. Models are listed in AIC ranked order for each hypothesis.

Model	Degrees of freedom	Bias corrected AIC (AICc)	AICc differences (Δ)	Probability (Akaike weight)
SV*Sex	2	107.2	0	0.357
MV** Animal Naivety	3	108.6	1.4	0.177
MV Animal factors	3	108.8	1.52	0.167
SV minimum temperature	2	111.5	4.26	0.042
SV Optics	2	111.7	4.5	0.038
SV Age	2	111.9	4.67	0.035
SV Cumulative kangaroos shot since break	2	112.1	4.85	0.032
SV cumulative night of shooting	2	112.5	5.24	0.026
SV Consecutive nights of shooting	2	112.7	5.42	0.024
SV Calibre	2	112.7	5.47	0.023
SV Cumulative kangaroos shot in night	2	112.7	5.47	0.023
SV illumination	2	113	5.72	0.021
MV Multivariable	16	114.2	6.93	0.011
SV** Shooter skill	7	114.3	7.07	0.01
MV Technology	4	115.7	8.47	0.005
MV* Shooter skill	8	116	8.77	0.004
MV Rhythm	6	117.1	9.83	0.003
MV Fatigue	7	119.1	11.89	0.001

*Single variable model
*Multivariable model

Model fit

The most supported model, single variable (SV) Sex model, was examined for model fit. A likelihood ratio test of the SV Sex model verse an intercept only model revealed that the Sex model fitted better than the intercept only model (H0 = Reduced model is true; HA = Current model is true; $\chi^2 = 5.7173$, df = 1, p = 0.0168). The R^2 was 0.061, which is relatively low and means much of the variance in the data remains unexplained by the model.

Table 13: Conditional averages of model coefficients across all models.

Coefficient	Estimate (eB)	Std. Error	Adjusted SE	z value	Pr (>|z|)
(Intercept)	0.0695	755.1000	758.1000	0.0040	0.9970
Shooter (2 cf. 1)	23623.5648	1042.0000	1046.0000	0.0100	0.9920
Shooter (3 cf. 1)	0.0000	2206.0000	2214.0000	0.0060	0.9960
Shooter (4 cf. 1)	3.2805	1.2780	1.2830	0.9270	0.3540
Shooter (5 cf. 1)	0.6374	1.6170	1.6230	0.2780	0.7810
Shooter (6 cf. 1)	0.4571	1.4300	1.4360	0.5450	0.5860
Shooter (7 cf. 1)	2.0869	1.1770	1.1820	0.6220	0.5340
Calibre (2 cf. 1)	563681537.4071	6676.0000	6703.0000	0.0030	0.9980
Illumination (W cf. IR)	196.5663	1772.0000	1779.0000	0.0030	0.9980
Optics (S cf. C)	0.0002	1711.0000	1718.0000	0.0050	0.9960
Cumulative night of shooting	0.5070	293.7000	294.8000	0.0020	0.9980
Consecutive nights of shooting	3.3602	173.7000	174.4000	0.0070	0.9940
Cumulative roos shot that night	1.0560	0.0840	0.0842	0.6470	0.5170
Cumulative roos shot since break	0.9984	0.0796	0.0797	0.0200	0.9840
Session (2 cf. 1)	0.0000	1387.0000	1392.0000	0.0120	0.9910
Session (3 cf. 1)	0.0030	4.3910	4.4030	1.3190	0.1870
Session (4 cf. 1)	0.0008	5.0960	5.1120	1.3830	0.1670
Minimum temperature (C)	0.4408	342.8000	344.2000	0.0020	0.9980
Sex (Male)	**3.9079**	**0.5887**	**0.5910**	**2.3070**	**0.0210**
Age (SA)	1.5861	0.6038	0.6061	0.7610	0.4470

Multivariable animal naivety

The second most supported model, multivariable (MV) Animal Naivety model was examined for model fit. A likelihood ratio test of the MV Animal Naivety model verse an intercept-only model revealed that the Animal Naivety model fitted better than the intercept-only model (H0 = Reduced model is true; HA = Current model is true; $\chi^2 = 6.35$, df = 2, p = 0.0417). The R^2 was 0.068, which is relatively low and means much of the variance in the data remains unexplained by the model.

It is clear that the only significant coefficient is sex, with males more likely to have adverse outcomes than females. However, other significant parameters were not evident (**Table 13**). This may be due to the small number of adverse outcomes recorded leading to low power in the analysis.

2.4 Conclusions

The dataset that included adverse outcomes as escaped kangaroos and wounded kangaroos was the most amenable to analyses and produced models that explained a moderate amount of the data variability.

Analyses of this dataset revealed that hypotheses associated with shooter identity (skill) were most supported by the data. In greater detail, it appeared that some shooters were more likely to have adverse outcomes than other shooters whilst controlling for potentially confounding variables such as calibre of rifle.

The second dataset that included only killed kangaroos was less amenable to analyses. In these analyses, it was difficult to distinguish between the various hypotheses as many had some support from the data. In addition, these models only explained a small amount of the data variability, with relatively low R^2 values. Despite this, the models that represented the sex, multivariable and animal naivety hypotheses had the most support. The only significant variable on conditional model averaging was the sex variable, with males likely to have adverse outcomes compared with females. This result likely reflects that males are more difficult to render immediately insensible because of their larger size (e.g. thicker bone structure may provide greater resistance to bullet penetration; Hampton *et al.* 2017). Similar results for male animals have been observed for other physical killing methods (e.g. captive bolt use for slaughter of livestock; Gregory *et al.* 2007).

In summary, shooter skill was most likely to affect the probability of an adverse outcome (predominantly escapes). In addition, sex was a key factor for adverse outcomes (wounding). There was no evidence that other variables such as illumination (white light vs. infra-red) affected outcomes. There are likely un-recorded variables that are responsible for much of probability of adverse outcomes. Further research is indicated to determine what these variables are as they may be amenable to manipulation, thereby reducing adverse outcomes. Shooting distance (Hampton *et al.* 2015), wind speed and the presence of fog may all influence shooting outcomes and should be examined in future studies.

Despite this, it is important to note that adverse outcomes (especially wounding) were very unlikely to occur in this data. A frequency of adverse outcomes of 4% was recorded for all killed kangaroos.

2.5 Recommendations

For refinement of animal welfare outcomes, the following recommendations are made:

1. The managing agency should examine shooter selection and training.
2. Shooters should exercise additional caution when shooting at male kangaroos.

2.6 References

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