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A simple quantitative method for assessing animal welfare outcomes in terrestrial wildlife shooting: the European rabbit as a case study

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Abstract

*Shooting is widely used to reduce the abundances of terrestrial wildlife populations, but there is concern about the animal welfare outcomes ('humaneness') of these programmes. Management agencies require methods for assessing the animal welfare outcomes of terrestrial wildlife shooting programmes. We identified four key issues in previous studies assessing the animal welfare outcomes of shooting programmes: (i) biased sampling strategies; (ii) no direct ante mortem observations; (iii) absence of quantifiable parameters for benchmarking; and (iv) no evaluation of explanatory variables that may cause adverse welfare outcomes. We used methods that address these issues to assess the welfare outcomes of a European rabbit (*Oryctolagus cuniculus*) shooting programme in south-eastern Australia. An independent observer collected ante mortem (distance, timing and outcome of each shot fired) and post mortem (locations of bullet wounds) data. The ante mortem data were used to estimate three critical animal welfare parameters: apparent time to death (ATTD); instantaneous death rate (IDR); and wounding rate (WR). The post mortem data were used to evaluate the location of bullet wounds relative to the Australian national standard operating procedure (SOP). For rabbits, the mean IDR was 0.60, ATTD was 12 s and WR was 0.12. A large proportion of rabbits (0.75) were shot in the cranium or thorax, as required by the SOP. Logistic regression indicated that the proportion of rabbits wounded and missed increased with shooting distance. Hence, reducing shooting distances would increase the humaneness of European rabbit shooting programmes. Our approach enables the animal welfare outcomes of terrestrial shooting programmes to be independently quantified.*

Keywords: *animal welfare, European rabbit, hunting, instantaneous death rate, time to death, wounding rate*

Introduction

The shooting of wildlife using firearms (also called 'culling', 'hunting', 'gunning' and 'cropping') is a common management activity, particularly for populations considered overabundant (eg Lewis *et al* 1997; McLeod *et al* 2011; Warburton *et al* 2012). However, there is ongoing concern about the animal welfare outcomes (or 'humaneness') of wildlife shooting programmes (Bateson & Bradshaw 1997; Butterworth & Richardson 2013). Wildlife management agencies must ensure that shooting programmes are humane or future options for shooting will be restricted (eg Nimmo & Miller 2007; Warburton & Norton 2009).

The importance of maintaining high standards of animal welfare in wildlife management has been emphasised by recent reviews (Mellor & Littin 2004; Warburton & Norton 2009; Littin 2010; Warburton *et al* 2012). In an effort to improve animal welfare outcomes for wildlife management, a number of studies have attempted to rank the humaneness of wildlife removal methods (Sharp & Saunders 2011; Beausoleil & Mellor 2014; Littin *et al* 2014). These studies have emphasised the importance of quantifiable, benchmarked parameters to allow the welfare outcomes of alternative control methods to be objectively ranked. While there are much existing data to inform such approaches for the use of toxins and traps, there are little quantitative data available for shooting methods. Currently, there is not a method that agencies can use to robustly monitor and report (eg to funding agencies and other stakeholders) the animal welfare outcomes of terrestrial wildlife shooting programmes.

The two key factors used in the ranking of welfare outcomes for killing methods are the duration and intensity of suffering experienced by animals (Mellor & Littin 2004; Littin *et al* 2014). Although measuring the intensity of suffering is subjective, the average duration of suffering for killing methods has been defined as the time from the onset of a painful or stressful stimuli or insult to permanent insensibility (Newhook & Blackmore 1982). Without quantifying duration of suffering, comparing the animal welfare outcomes of wildlife shooting programmes is difficult due to the multiple methods and definitions used to assess humaneness (Daoust *et al* 2014). This deficiency has been highlighted by recent contention surrounding animal welfare outcomes in harp seal (*Pagophilus groenlandicus*) shooting programmes (Daoust & Caraguel 2012; Butterworth & Richardson 2013; Daoust *et al* 2014).

An appropriate template for simplifying the assessment of welfare outcomes for terrestrial hunting methods through benchmarked parameters comes from studies of duration of suffering in cetaceans (eg Knudsen 2005), as demonstrated by Hampton *et al* (2014). Killing methods for cetaceans involve similar ballistic injuries to terrestrial shooting and have been intensively studied for more than 30 years. There is now wide acceptance of the parameters that must be measured and how those parameters are measured in the field (Knudsen 2005; Brakes & Donoghue 2006; Gales *et al* 2008). The framework for comparing cetacean killing methods relies on the quantification of four key parameters: struck-and-lost rate; mean time to death (TTD); instantaneous death rate (IDR); and the anatomical location of shots. Struck-and-lost rate, usually called wounding rate (WR) in terrestrial wildlife shooting studies (Stormer *et al* 1979; Hampton *et al* 2014), is the estimated proportion of animals shot but not killed.

Time to insensibility (eg Newhook & Blackmore 1982) is the ideal measure for estimating duration of suffering for physical killing methods, but TTD is widely accepted as the most practical measure for field studies (Lewis *et al* 1997; Hampton *et al* 2014), and is the key parameter of interest in discussions of animal welfare outcomes for cetacean killing methods (Knudsen 2005; Gales *et al* 2008). The importance of time to insensibility (TTD) as a welfare measure has been recognised by recent studies of lethal toxins (eg Gregory *et al* 1998; Henderson *et al* 1999; Marks *et al* 2004; Cowled *et al* 2008), trapping (eg Warburton *et al* 2000; Iossa *et al* 2007) and other killing methods (eg Ludders *et al* 1999). Time to death, however, is not considered an appropriate welfare measure, in isolation, for toxins, trapping and other killing methods where animals become unconscious some time before death (Littin *et al* 2014).

A method for estimating TTD that relies upon close visual observation, but not physical palpation to confirm death or insensibility that was developed for large animals in abattoirs (eg Grandin 2010) has been since applied to cetacean harvesting (eg Gales *et al* 2008) and wildlife shooting (eg Hampton *et al* 2014). A practical definition of TTD using this method for the shooting of terrestrial wildlife is the interval between the first shot being fired at an animal and the moment the animal falls and does not move (Lewis *et al* 1997; Knudsen 2005; Parker *et al* 2006; Cockram *et al* 2011). This methodology measures apparent time to death due to the inability of the observer to assess physiological responses from a distance (see Hampton *et al* 2014), as opposed to methods requiring physical handling and palpation of small animals (eg Warburton *et al* 2000).

IDR is the proportion of animals for which TTD is zero, to the extent to which TTD can be accurately quantified. In addition to measuring IDR, the parameter re-shooting rate (RSR) has been quantified in some studies as the proportion of animals receiving multiple shots. While the observation of re-shooting has been used to infer slow TTDs in some studies (eg harp seals; Butterworth & Richardson 2013), re-shooting of all animals, regardless of signs of life, is often routinely practiced during shooting programmes (Knudsen 2005; Daoust *et al* 2014; Hampton *et al* 2014). The mandatory requirement for at least two shots per animal in aerial shooting programmes conducted in Australia (Sharp 2011) highlights the problem of using RSR as a useful animal welfare parameter.

Surprisingly few terrestrial studies have followed the established cetacean template of combining ante and post mortem data for the accurate estimation of key parameters (but see Hampton *et al* 2014). Much of the data relevant to assessing the animal welfare outcomes of shooting programmes have come from research designed to increase hunting efficiency (eg Sjare & Stenson 2002; Parker *et al* 2006; Noer *et al* 2007) or meat quality (Hoffman 2000). There are two main reasons why terrestrial wildlife shooting studies have not collected data that enable meaningful benchmarking. First, many studies have presented data collected opportunistically (so-called 'convenience sampling'; Anderson 2001) rather than in designed studies (eg Cockram *et al* 2011; Defra 2013). The animals sampled opportunistically may have been biased by shooter selection (eg Bradshaw & Bateson 2000; Parker *et al* 2006) or by selection of video recordings (eg Butterworth & Richardson 2013). Second, few studies have performed ante mortem observations and hence collected TTD data for terrestrial wildlife shooting programmes (Knudsen 2005).

In the absence of ante mortem observations, some studies have attempted to use post mortem examination to infer duration of suffering (eg RSPCA Australia 2002). However, estimates of IDR or TTD based on post mortem information alone must be interpreted cautiously. The methodical approach of Urquhart and McKendrick (2003, 2006) provides the most objective and repeatable technique for describing post mortem pathology induced by shooting, but the authors rejected the approach of retrospectively assessing the TTD for culled animals based on the anatomical distribution of bullet-wound tracts alone. An additional problem inherent in many post mortem studies is the examination of carcases *ex situ* (ie when presented by shooters at collection or processing depots). The selection of animals presented by the shooter may severely bias the findings of such studies. Many such studies (eg RSPCA Australia 2002; Urquhart & McKendrick 2003) have also examined processed rather than whole carcases, limiting the amount of information that could be gathered about bullet-wound locations.

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Several studies attempting to assess extent of suffering have measured glucocorticoid levels to infer humaneness in wildlife shooting programmes (eg Cockram *et al* 2011). As glucocorticoid levels reflect responses to chronic stress (but not peracute processes; Mormède *et al* 2007), this approach may be useful in programmes in which animals are disturbed prior to shooting, or if there is an extended pursuit phase (Bateson & Bradshaw 1997). For hunting methods relying on surprise rather than pursuit, such as spotlight shooting, glucocorticoid levels have been shown to be inapplicable in many species (eg Marks 2010), including the European rabbit (*Oryctolagus cuniculus*; Jacobson *et al* 1978; Hamilton & Weeks 1985).

The animal welfare outcomes of wildlife shooting programmes are likely to be a function of shooter performance, shooting distance, rifle calibre and projectile characteristics (Parker *et al* 2006; Caudell 2013; Hampton *et al* 2014). Understanding how potential explanatory variables affect the probability of an animal being killed, wounded or missed could substantially improve animal welfare outcomes (Cockram *et al* 2011). Ante mortem observations by independent observers have allowed the elucidation of explanatory variables affecting animal welfare outcomes for marine mammal killing (Daoust & Caraguel 2012), helicopter shooting (Hampton *et al* 2014) and non-lethal capture (Jacques *et al* 2009) operations. However, few studies have attempted to evaluate the effect of such variables in ground-based, terrestrial wildlife shooting programmes (Lewis *et al* 1997). The collection of such data has the potential to improve animal welfare outcomes through the modification of the standard operating procedure (SOP) governing the shooting programme (eg by imposing a maximum shooting distance).

Here, we apply the cetacean animal welfare assessment template to a terrestrial wildlife species, the European rabbit. The European rabbit has a wide global distribution (Thompson & King 1994) and is commonly controlled by shooting (Williams *et al* 1995; Reddiex *et al* 2006; Sharp 2012). There is a detailed understanding of rabbit physiology and parameters that affect animal welfare (eg Hamilton & Weeks 1985; Hattingh *et al* 1986; Liste *et al* 2009). The European rabbit was deliberately introduced to Australia and is now managed as a pest because of its impacts on agriculture and native biodiversity (Williams *et al* 1995). A national standard operating procedure (SOP) for shooting rabbits stipulates that rabbits should be shot, with the aid of a spotlight, in the cranium or thorax with a rifle of a minimum .22 calibre at distances not exceeding 80 m (Sharp 2012). The SOP specifies that any animal detected as wounded after initial shooting should be subjected to repeat shooting as quickly as possible until death is confirmed (Sharp 2012). Our study had two objectives. First, to apply the ante and post mortem cetacean assessment template to a European rabbit shooting programme in south-eastern Australia. Second, to identify explanatory factors contributing to rabbits being wounded rather than killed.

Materials and methods

Field studies

We conducted our study on a livestock grazing property near Melbourne, Victoria, south-eastern Australia (37°40' S, 144°20' E). The property had a long history of high rabbit densities but prior to our study had only been subject to occasional recreational shooting. The shooting programme was conducted on four moonless nights in April–May 2012. These months were chosen to minimise the proportion of juvenile rabbits present (Williams *et al* 1995). Shooting commenced within 30 min of darkness. A Toyota® Landcruiser® single-cab tray-back utility four-wheel drive vehicle (Toyota, Toyota City, Japan), with the shooter and spotlighter standing in the tray, was driven at 5−10 kph through the property with the spotlight (100 Watt, 240-mm diameter spotlight, Lightforce®, Hindmarsh, Australia) sweeping back and forth over an arc of 180° but concentrating on the area in front of the vehicle. The vehicle was stopped at the shooter's command when a stationary rabbit was sighted and within 80 m. The shooter only fired when the rabbit was considered within 'ethical range' (ie would humanely kill the target with a low probability of missing; Caudell *et al* 2009), but this was always < 80 m (see below). At no time was shooting undertaken from a moving vehicle or at a moving animal. Following Sharp (2012), the spotlight was trained on the target animal and its thorax or cranium was shot at by the shooter.

The shooter was an experienced marksman equipped with a Brno® Model 1 .22 calibre Long Rifle (Zbrojovka Brno, Brno, Czech Republic), fitted with a Tasco® World Class 3−9 ×40 telescopic sight (Tasco Holdings Inc, Miramar, USA). Winchester® Power-Point® 40 grain (1280 FPS) copper-plated hollow point .22 Long Rifle ammunition (Winchester Australia Ltd, Moolap, Australia) was used. The rifle was zeroed at 50 m prior to shooting. Animals were shot at as they presented themselves such that no intentional selection for size occurred.

Ante mortem observations were made by an independent observer who stood beside the shooter and recorded the number of shots fired at each animal, the incidence of shots which missed or wounded animals and the number of seconds elapsed between the first shot to hit the animal and the moment the animal fell and did not move (TTD), as per convention (Lewis *et al* 1997; Knudsen 2005; Parker *et al* 2006; Cockram *et al* 2011; Hampton *et al* 2014). Because this methodology does not permit ante mortem palpation of physiological responses (*sensu* Warburton *et al* 2000), insensibility due to neurotrauma could be confused with death (Hampton *et al* 2014). However, the methodology provides an accurate estimate of time to insensibility and hence duration of suffering (Knudsen 2005). We therefore designated this parameter 'apparent time to death' (ATTD). Animals were subjected to physical examination no more than 30 s after ATTD to confirm death via testing palpebral reflexes. Times were recorded to the nearest second using a stopwatch. The distance from the shooter to the rabbit was

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measured with a Leupold® RXTM II Digital Rangefinder (Leupold and Stevens Inc, Beaverton, USA). The dead rabbit was placed in a uniquely identified plastic bag and refrigerated overnight at 4°C.

Post mortem investigations were performed by an experienced veterinarian the morning after shooting (ie within 8–12 h of death). Sex was determined by inspection of external genitalia and the animal's mass was measured using a Pesola® Model 42500 Medio-line 2,500 (± 10) g spring scale (Pesola, Baar, Switzerland). Gross pathology of vital and non-target organs attributable to bullet-wound tract injuries were recorded following the principles of Hollerman *et al* (1990) and Di Maio (1999). Locations of bullet wounds in the carcase were recorded following the methodology of Urquhart and McKendrick (2003, 2006), assigning bullet-wound tracts to the anatomical zone displaying the most damage. However, our study differed from that of Urquhart and McKendrick (2003) in that whole animals, rather than processed carcases, were examined. Specifically, evidence of pathology to the thorax (ie heart and lungs), cranium, cervical spine, limbs and abdomen was recorded.

The rabbits used in this study were shot as part of ongoing pest animal management activity. Under Australian law, Institutional Animal Ethics Committee approval was not required for this study because it was an audit of outcomes for animals culled for management purposes.

Statistical analysis

The following four animal welfare parameters were estimated: ATTD (ie the time interval [s] from the first shot being fired to when the rabbit collapsed to the ground and did not move); WR (ie the proportion of animals that were hit and not recovered); killing efficacy (ie the proportion of targeted animals that were killed); and IDR (ie the proportion of killed animals for which ATTD was zero). ATTD could not be reported for those animals that escaped wounded. Means and 95% confidence intervals (CIs) are reported for all four parameters as decimal rates rather than percentages. ATTD data were also presented graphically as a Kaplan-Meier survival estimate (1958) using Graphpad Prism version 4.0 (Graphpad Software, San Diego, USA).

We next modelled the effects of variables potentially affecting the outcome of each shot. There are three possible outcomes for a shot fired at a rabbit: (i) hit and killed (*Killed*); (ii) hit and not killed (*Wounded*); or (iii) missed (*Missed*). If p^H is defined as the probability of hitting a rabbit with a shot, and p^K is the probability of killing the rabbit given it was hit, the probabilities for the three possible outcomes for each shot are:

$$Killed = p^H \times p^K$$

$$Wounded = p^H (1-p^K), \text{ and}$$

$$Missed = (1-p^H)$$

Following a shot, any rabbit that was wounded or missed can escape (*Escape*) with probability p^E, which may be different depending upon whether it was wounded or not. Rabbits that escape are no longer available to be shot at subsequently, while those that do not escape may be shot at again. A rabbit could be shot at multiple times, and the sequence of observed outcomes was used to determine the probability of observing that sequence. For example, suppose a rabbit was missed with the first shot, wounded with the second shot and killed with the third shot, the sequence of outcomes is *Missed* × *Wounded* × *Killed*. Using the probabilities defined above, the probability for this sequence of events would be:

$$(1-p^H)\,(1-p^E)\,(1-p^K)\,(1-p^E)\,p^H p^K$$

Note that the fact the rabbit did not escape between shots (with probability $1-p^E$) is implied by the fact that a subsequent shot was taken. As a second example, suppose a rabbit was wounded with the first shot, missed by the second shot, and then managed to escape before a third shot could be made then the sequence of outcomes is *Wounded* × *Missed* × *Escape*. The probability for this sequence is:

$$p^H (1-p^K)\,(1-p^E)\,(1-p^H)\,p^E$$

Potential factors affecting each component probability (eg distance from the shooter and whether the rabbit was wounded by a previous shot) can be evaluated using methods analogous to logistic regression. For both p^H and p^K, two factors were considered; distance from the shooter and whether or not the rabbit was wounded by a previous shot. From this, there are four possible models for each of these probabilities. For example, for p^H these models could be denoted as:

- p^H(.) = probability the same for all distances and wounding has no effect;
- p^H(distance) = probability changes with distance, wounding has no effect;
- p^H(wounded) = probability same for all distances, wounded animals have different probability; and
- p^H(distance + wounded) = distance and wounding both have an effect, with the effect of distance being the same for wounded and unwounded rabbits (ie no interaction term for distance and wounding).

For p^E, two models were considered; p^E(.) and p^E(wounded) (similar interpretations to above). By considering different combinations of factors for each component, 32 possible ('candidate') models can be fit to the data (Table 1) and the component probabilities and logistic regression parameters can be estimated using maximum likelihood methods (Williams *et al* 2002). All 32 candidate models were assessed using information theoretic approaches to determine which models were best supported by the ante mortem data (Burnham & Anderson 2002), using Akaike's Information Criterion corrected for small sample size (AICc; Burnham & Anderson 2002). Model selection weights (w_i) were computed from the AICc values and we used model-averaging to obtain overall estimates of each probability (Burnham & Anderson 2002). These model-averaged parameter estimates were used to illustrate the effects of shooting distance and whether a rabbit had been wounded on the probabilities of (i) hitting, and (ii) killing rabbits. All analyses were performed with R version 2.12.0 (R Development Core Team 2010).

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Table 1 Model selection information for the 32 candidate models explaining the outcomes of a European rabbit (*Oryctolagus cuniculus*) shooting programme in south-eastern Australia (April–May 2012).

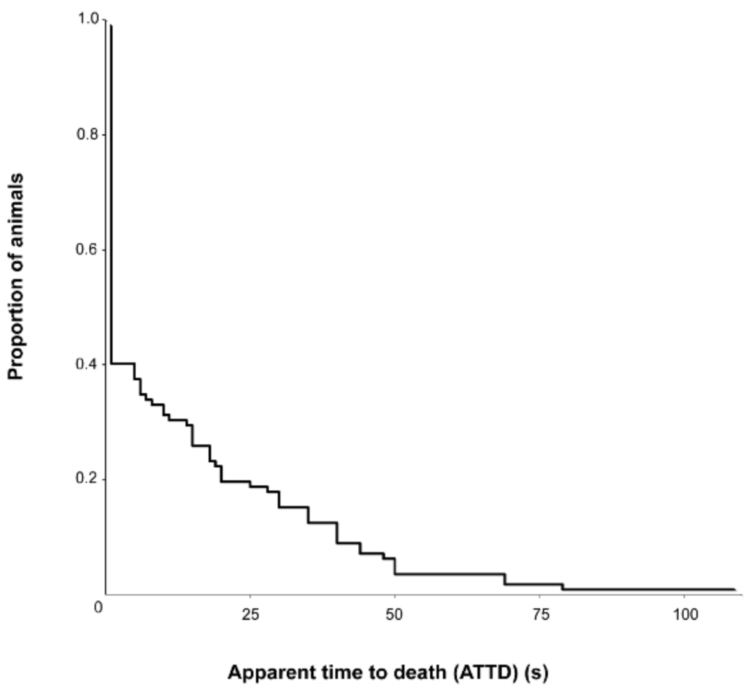
Model	LL[†]	K[‡]	AICc[§]	ΔAICc[#]	w_i*
p^H(.), p^K(dist+wounded), p^E(.)	267.54	5	545.08	0.00	0.17
p^H(dist), p^K(dist+wounded), p^E(.)	266.57	6	545.14	0.07	0.17
p^H(.), p^K(dist+wounded), p^E(wounded)	266.91	6	545.81	0.73	0.12
p^H(dist), p^K(dist+wounded), p^E(wounded)	265.94	7	545.88	0.80	0.11
p^H(wounded), p^K(dist+wounded), p^E(.)	267.54	6	547.08	2.00	0.06
p^H(dist+wounded), p^K(dist+wounded), p^E(.)	266.56	7	547.12	2.04	0.06
p^H(wounded), p^K(dist+wounded), p^E(wounded)	266.91	7	547.81	2.73	0.04
p^H(dist+wounded), p^K(dist+wounded), p^E(wounded)	265.93	8	547.85	2.77	0.04
p^H(.), p^K(wounded), p^E(.)	270.15	4	548.29	3.21	0.03
p^H(dist), p^K(wounded), p^E(.)	269.18	5	548.36	3.28	0.03
p^H(.), p^K(wounded), p^E(wounded)	269.51	5	549.03	3.95	0.02
p^H(dist), p^K(wounded), p^E(wounded)	268.55	6	549.09	4.02	0.02
p^H(wounded), p^K(wounded), p^E(.)	270.14	5	550.29	5.21	0.01
p^H(dist+wounded), p^K(wounded), p^E(.)	269.16	6	550.33	5.25	0.01
p^H(.), p^K(dist), p^E(.)	271.20	4	550.40	5.32	0.01
p^H(dist), p^K(dist), p^E(.)	270.23	5	550.46	5.39	0.01
p^H(wounded), p^K(wounded), p^E(wounded)	269.51	6	551.02	5.95	0.01
p^H(dist+wounded), p^K(wounded), p^E(wounded)	268.53	7	551.06	5.99	0.01
p^H(.), p^K(dist), p^E(wounded)	270.57	5	551.13	6.05	0.01
p^H(dist), p^K(dist), p^E(wounded)	269.60	6	551.20	6.12	0.01
p^H(wounded), p^K(dist), p^E(.)	271.20	5	552.40	7.32	0.00
p^H(dist+wounded), p^K(dist), p^E(.)	270.22	6	552.43	7.36	0.00
p^H(wounded), p^K(dist), p^E(wounded)	270.56	6	553.13	8.05	0.00
p^H(dist+wounded), p^K(dist), p^E(wounded)	269.58	7	553.17	8.09	0.00
p^H(.), p^K(.), p^E(.)	273.98	3	553.96	8.88	0.00
p^H(dist), p^K(.), p^E(.)	273.01	4	554.03	8.95	0.00
p^H(.), p^K(.), p^E(wounded)	273.35	4	554.69	9.62	0.00
p^H(dist), p^K(.), p^E(wounded)	272.38	5	554.76	9.68	0.00
p^H(wounded), p^K(.), p^E(.)	273.98	4	555.96	10.88	0.00
p^H(dist+wounded), p^K(.), p^E(.)	273.00	5	556.00	10.92	0.00
p^H(wounded), p^K(.), p^E(wounded)	273.35	5	556.69	11.61	0.00
p^H(dist+wounded), p^K(.), p^E(wounded)	272.37	6	556.73	11.65	0.00

p^H = probability of hitting a rabbit with a shot;
p^K = probability of killing the rabbit given it was hit;
p^E = probability of a rabbit escaping after it was shot at;
dist = shot distance (m);
wounded = rabbit was hit but not killed by a previous shot;
[†] Log-likelihood; [‡] number of estimated parameters;
[§] Akaike Information Criterion;
[#] difference between the Akaike Information Criterion for each model and that of the most parsimonious model;
* model weight.

Table 2 Summary of ante mortem data collected during an assessment of the animal welfare outcomes of a European rabbit (*Oryctolagus cuniculus*) shooting programme in south-eastern Australia (April–May 2012).

Category	Sample size (n)	Probability (95% CI)
Number of animals shot at	141	–
Number of animals hit	127	–
Number of animals killed	112	0.79 (0.72–0.86)
Number of animals killed one shot	67	0.48 (0.39–0.56)
Number of animals killed post-wounding	27	0.19 (0.13–0.27)
Number of animals escaping wounded	15	0.11 (0.06–0.17)
Number of animals killed after missed shot(s)	18	0.13 (0.08–0.19)
Number of animals escaping unwounded	14	0.10 (0.06–0.16)

Figure 1



Kaplan-Meier survival estimate corresponding to time-to-event data for apparent time to death (ATTD) for European rabbits (*Oryctolagus cuniculus*) subjected to a shooting programme in south-eastern Australia (April–May 2012).

Results

Ante mortem

A total of 141 rabbits were shot at during the four nights of our study (Table 2). The mean shooting distance was 28 (95% CI; 26–30) m, with the longest shot 64 m. The mean number of shots fired at a rabbit was 1.5 (95% CI; 1.3–1.6), but a large proportion (0.76) of rabbits were killed with one shot. The probability of rabbits escaping unwounded was 0.10 (95% CI; 0.06–0.16), escaping wounded was 0.11 (95% CI; 0.06–0.17), and killed was 0.79 (95% CI; 0.72–0.86). The probability of rabbits being killed instantaneously was 0.48 (95% CI; 0.39–0.56), killed after a missed shot was 0.13 (95% CI; 0.08–0.19) and killed after being wounded was 0.19 (95% CI; 0.13–0.27).

The ATTD ranged from 0 to 90 (mean = 12, 95% CI = 8–16) s and the proportion of animals having an ATTD of 0 s was 0.60 (95% CI; 0.50–0.69; Figure 1). Hence, the IDR was 0.60 (95% CI; 0.50–0.69). The WR was 0.12 (95% CI; 0.07–0.19), and killing efficacy was 0.79 (95% CI; 0.72–0.86).

There was considerable model selection uncertainty in our analysis of the variables affecting the probabilities of rabbits being hit, wounded or escaped, with no one model overwhelmingly supported ($w_i \leq 0.17$; Table 1). There was not strong evidence that shooting distance had a significant effect on the probability of hitting a rabbit, although model-averaged estimates indicate a small decline with increasing distance (Figure 2). However, there was strong evidence that shooting distance had a significant effect on the probability of killing a hit rabbit (conditional on the rabbit being

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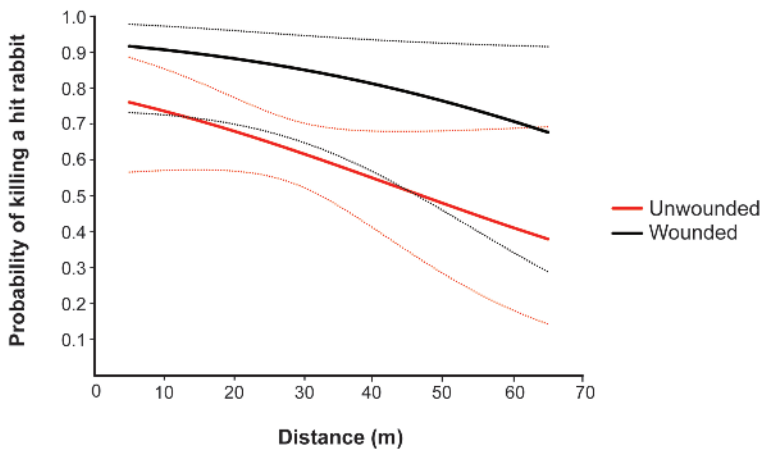
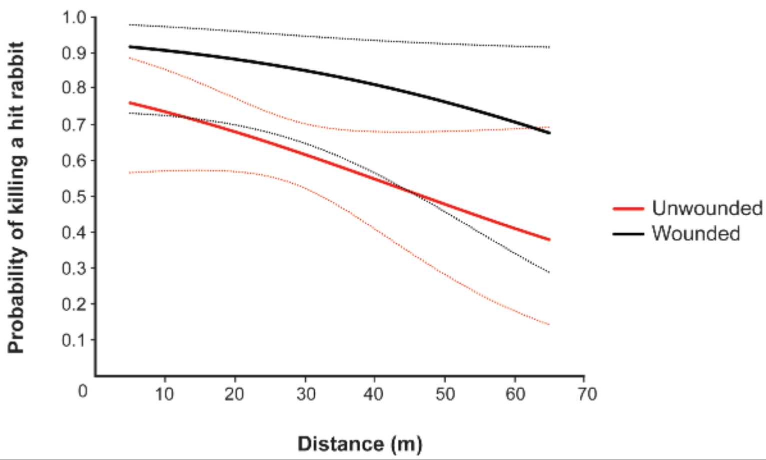
Figure 2



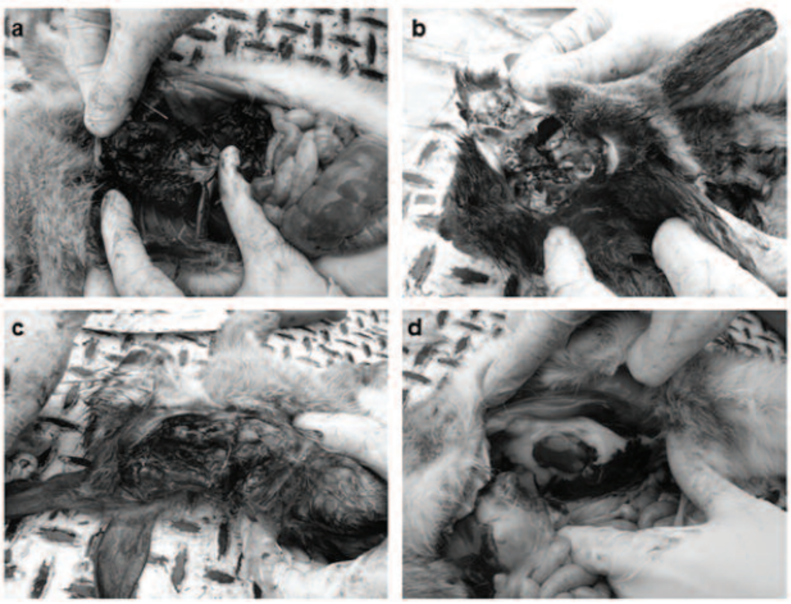
Fitted relationships (mean and 95% confidence limits) between shooting distance and the probability of hitting a European rabbit (*Oryctolagus cuniculus*) during a shooting programme in south-eastern Australia (April–May 2012).

Figure 3



Fitted relationships (mean and 95% confidence limits) between shooting distance and the probability of killing a European rabbit (*Oryctolagus cuniculus*) that was or was not wounded during a shooting programme in south-eastern Australia (April–May 2012).

Figure 4



Examples of pathology to the (a) thorax, (b) cranium, (c) cervical spine and (d) abdomen from European rabbits (*Oryctolagus cuniculus*) shot with 40 grain hollow point .22 Long Rifle calibre bullets in south-eastern Australia in April–May 2012.

hit), with the probability declining with increasing distance (Figure 3). The probability of the rabbit being killed (conditional on being hit) was much higher if the rabbit was wounded (Figure 3), but the probability of an unwounded (0.31, 95% CI = 0.20–0.45) or wounded (0.27, 95% CI = 0.18–0.39) rabbit escaping was similar.

Post mortem

Similar numbers of male (n = 60) and female (n = 52) rabbits were shot. Mean body mass (sexes combined) was 1.70 (95% CI = 1.65–1.75) kg. The proportions of rabbits with bullet-wound trauma to anatomical zones were as follows: thorax, 0.68 (95% CI; 0.58–0.76; Figure 4[a]); cranium, 0.06 (95% CI; 0.03–0.12; Figure 4[b]); cervical spine, 0.30 (95% CI; 0.22–0.40; Figure 4[c]); abdomen, 0.35 (95% CI; 0.26–0.44; Figure 4[d]); and limbs, 0.30 (95% CI; 0.22–0.40). The proportion of killed rabbits with bullet-wound tracts in either the thorax (Figure 4[a]) or cranium (Figure 4[b]), as per Sharp (2012), was 0.75 (95% CI; 0.66–0.83).

Discussion

The methods used here provide a quantitative template for objectively assessing the welfare outcomes of terrestrial wildlife shooting programmes. We believe that research addressing animal welfare outcomes from shooting should meet the same rigorous scientific standard as other aspects of wildlife research (see also Romesburg 1981; Caudell 2013; Daoust *et al* 2014). Our approach removes several of the weaknesses and inconsistencies inherent in previous assessments of the animal welfare outcomes of terrestrial wildlife shooting programmes as mentioned earlier. First, by having an independent observer, we avoided biased sampling strategies resulting from shooter-bias in animals examined (eg Bradshaw & Bateson 2000; Parker *et al* 2006) or video analysis (eg Butterworth & Richardson 2013). Second, rather than rely solely on post mortem observations to make inferences (eg RSPCA Australia 2002; Urquhart & McKendrick 2003, 2006) we performed direct ante mortem observations. We believe that extrapolation of time to death or instantaneous death rate from post mortem information alone is unreliable (Urquhart & McKendrick 2003, 2006). Third, we quantified widely accepted animal welfare parameters and their associated uncertainties (ie with 95% confidence intervals; Knudsen 2005). Fourth, we recorded potential explanatory variables that enable factors that impact on animal welfare outcomes to be identified (*sensu* Lewis *et al* 1997).

In our study, all ante and post mortem data were collected by people independent of the shooting team. The independence of the observer and veterinarian from the shooter team provides an unbiased assessment of the programme to the management agencies and other stakeholders. The importance of independent observers for the transparent quantification of key animal welfare parameters is recognised for cetacean killing methods (Brakes & Donoghue 2006).

We assessed the animal welfare outcomes of a shooting programme that aimed to reduce the abundances of an over-abundant invasive species, the European rabbit, in south-eastern Australia. The programme followed the national protocol for shooting rabbits (Sharp 2012). We observed benchmarks for the proportion of animals escaping unwounded (0.10), shot animals escaping wounded (0.12), instantaneous death rate (0.60) and mean apparent time to death (12 s). We found that a large proportion (0.75) of animals were shot in either of the two target zones prescribed by Sharp (2012). Our analysis revealed that the probability of an animal being missed or wounded increased significantly with increasing shooting distance. There was strong evidence that the probability of killing a rabbit (if you hit it), declined with distance and was higher if the rabbit was already wounded. Our results indicate that reducing shooting distances would increase the humaneness of European rabbit shooting programmes that use the .22 Long Rifle rimfire calibre. The national protocol for shooting rabbits states that more powerful (centrefire; eg .22 Hornet®; .222 Remington®) calibres should be used for longer shooting distances (Sharp 2012). A projectile of higher power is likely to yield improved animal welfare outcomes through an increase in kinetic energy imparted to the animal (for a review, see Caudell 2013).

Our modelling approach enabled us to evaluate the influence of two variables, shooting distance and whether or not the rabbit was wounded by a previous shot, on welfare outcomes. Our modelling framework is flexible and robust, partitioning all potential shooting outcomes into their component probabilities (for further details, see Williams *et al* 2002) and using information theoretic methods (AIC) to evaluate their relationships with variables hypothesised to influence them (Burnham & Anderson 2002). The importance of other variables likely to influence welfare outcomes, for example individual shooter (Hampton *et al* 2014) and firearm calibre (Hoffman 2000), could easily be examined using this modelling approach.

The non-lethal wounding of animals is an almost inevitable outcome of a shooting programme conducted in field conditions (Knudsen 2005). From an animal welfare perspective, the escape of a wounded animal is the worst of all possible outcomes because it involves a potentially protracted, but unquantifiable, duration of suffering (Bradshaw & Bateson 2000). Comparisons between published wounding rates are difficult due to differing methodologies. The best documented wounding rates are to be found in recreational bow-hunting (eg Gregory 2005), waterfowl shooting (eg Noer *et al* 2007) and the commercial whaling industry (eg Kestin 1995). The wounding rate reported here for European rabbits (0.12) is lower than in most of those studies. The relatively small size of rabbits, and the relatively low energy of projectiles recommended for shooting them (Sharp 2012), are obvious factors limiting the instantaneous death rate of rabbits and increasing the likelihood of rabbits escaping wounded. When larger species with similar flight distances are hunted in a similar manner, with higher energy projectiles, lower wounding rates have been reported (Lewis *et al* 1997; Parker *et al* 2006).

We believe that the methods used in this study could be applied to most other wildlife shooting programmes. The Kaplan-Meier survival analysis approach (Kaplan & Meier 1958; Figure 1) would enable the efficacy of individual shooters to be

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compared within a shooting programme, as required by Defra (2013). Our methods were developed for a vehicle-based shooting programme and hence could be used to evaluate the contentious issue of the animal welfare outcomes of commercial kangaroo harvesting in Australia (RSPCA Australia 2002; McLeod & Sharp 2014). Our methods would also be applicable to evaluating the culling of badgers (*Meles meles*) in the UK (Jenkins *et al* 2010; Defra 2013).

Animal welfare implications

Our methods enable the welfare outcomes of terrestrial wildlife shooting programmes to be quantified independently of the shooter, allowing management agencies to report robustly on the animal welfare outcomes of their shooting programmes. Quantifying apparent time to death, instantaneous death rate and wounding rate, and the variables affecting welfare outcomes (eg shooting distance) may also assist the refinement of standard operating procedures, facilitating improvement in welfare outcomes for regulated terrestrial wildlife shooting programmes. Our study provides a simple template that can be applied to other ground-based terrestrial wildlife shooting programmes.

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