Aerial culling feral fallow deer with shotguns improves efficiency and welfare outcomes

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Flinders University

LANDSCAPE SOUTH AUSTRALIA LIMESTONE COAST

Government of South Australia
Department of Primary Industries and Regions

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Executive Summary

Feral deer abundance in Australia has increased from 200,000 in 2000 to around 2 million individuals by 2021. Their adverse ecological and economic impacts are now severe and, if left uncontrolled, their economic costs will exceed billions of dollars annually within 30 years. Aerial culling can be an effective means for removing large numbers of feral vertebrates, including goats, pigs, and deer, from inaccessible areas.

Landholders have been culling feral deer since they were first introduced, and the Government of South Australia has been doing helicopter-based culling (hereafter 'aerial culling') of feral deer for more than 15 years. Despite these programs, feral deer populations have continued to grow.

Firearms used in aerial culling vary among jurisdictions and must comply with local requirements. In New South Wales, the Feral Animal Aerial Shooting Team used high-powered, centre-fire rifles to shoot feral deer in their aerial culling programs; the same methods were used in South Australia until 2021, whereas the New Zealand Government uses shotguns in aerial culling of feral deer. In Australia, it is common for shotguns to be used in the aerial culling of goats and pigs, but not deer. Because fallow deer (*Dama dama*) is a relatively small-bodied cervid (similar in size to goats and pigs), we posit that incorporating shotguns into the culling program targeting this species could increase efficiency and improve animal welfare outcomes. Specifically, we predicted that a program using a shotgun (compared to rifle-only programs) would:

- increase the efficiency of the program, and
- improve welfare outcomes for target animals by
    - reducing the time between the first shot and death,
    - shortening pursuit times,
    - and increasing the likelihood of multiple projectiles penetrating the thorax of target animals, leading to more fatal injuries of vital organs, thereby minimising time until death.

This aerial-culling trial targeted fallow deer, which is the most abundant feral deer species in South Australia, was done in the Limestone Coast, South Australia in October 2022. The aerial crew configuration included a primary shooter equipped with Benelli M2 semi-automatic shotgun with a red-dot scope and a custom choke at full extension (equivalent to "extra-full" choke constriction. A secondary shooter was armed with a Wedgetail WT25 semiautomatic .308-calibre rifle equipped with a thermal scope and a variety of ammunition. In addition to the pilot, a thermographer was included in the crew to operate a high-resolution Vayu HD thermal-imaging camera and a high-powered laser to help the secondary shooter locate feral deer in forested areas. Each deer was shot at least twice, and the kill confirmed audibly by two crew members before moving to another target.

Of the 611 deer culled during the program, we reviewed video and audio records of 104 to record the efficiency and humaneness of the program. We collected information on the number of shotgun and rifle rounds fired per animal, the time between first shot and confirmed death, and pursuit time. We also did field autopsies of 20 individuals to assess the severity and lethality of wounds inflicted with shotgun pellets.

A total of 383 shotgun rounds and only 10 rifle rounds were used on 104 fallow deer assessed in this study. The mean ± standard error time between first shot and confirmed kill was 11.1 ± 0.7 seconds. Individual deer, or the first deer shot in a group, had the longest mean time between first shot and

confirmed kill, but this interval decreased with subsequent individuals culled in the targeted group, and the maximum time recorded between first shot and a confirmed kill for any deer was 35.9 seconds. Mean pursuit time between detection and a confirmed kill was 49.5 ± 3.4 seconds. Pursuit time increased with subsequent deer controlled within a group, and maximum pursuit time for any individual was 159.0 seconds. All autopsied animals had received lethal wounds, with 100% receiving lung-penetrating damage and 70% also receiving heart-penetrating damage.

We compared these results with published and unpublished data from other aerial-culling programs for feral deer in South Australia since 2009. Based on this comparison, we conclude that aerial culling for fallow deer using a shotgun is more efficient than exclusively using a semi-automatic .308-calibre rifle. The thermal-imaging equipment also increased the efficiency of the cull. Using a shotgun reduced the time between first shot and confirmed death and pursuit times relative to other programs in the same region. Reducing these intervals also minimises stress, and enhances animal welfare outcomes for culled deer. We also confirmed the suitability of shotguns for lethally culling fallow deer by observing that all targeted individuals had lethal wounds from shotgun pellets.

Introduction

Feral deer are some of Australia's worst emerging pest species. The total number of deer in Australia is estimated to have increased from 200,000 in 2000 to around 2 million animals by 2021 (i.e., a ten-fold increase). Their impacts are now severe and include damage to native plants, competition with native animals, economic losses to primary industries (crops, pastures, horticulture, plantations) (Bradshaw et al. 2021), and human safety risks from vehicle collisions. Feral deer are also potential reservoirs and vectors of exotic animal diseases, such as foot-and-mouth disease. If left uncontrolled, the economic impacts of feral deer are expected to cost billions of dollars annually within 30 years (BDO EconSearch 2022; Frontier Economics 2022).

Australia has six species of feral deer — fallow (*Dama dama*), red (*Cervus elaphus*), hog (*Axis porcinus*), chital (*A. axis*), rusa (*C. timorensis*), and sambar (*Rusa unicolor*); apart from hog deer, all species occur in South Australia (Centre for Invasive Species Solutions 2022a). The Government of South Australia has supported helicopter-based shooting programs (hereafter 'aerial culling') of feral deer for over 15 years, but the populations have continued to increase. In the last three years, aerial culling programs have removed about 3,000 feral deer per annum (BDO EconSearch 2022). In addition to aerial culling, control programs have used ground shooting by professional marksmen, ground shooting by volunteers and landholders, and commercial harvesting operations (PIRSA 2022). Recreational hunting and culling by private landholders are estimated to remove around 8,300 feral deer annually. With all control approaches combined, approximately 11,300 feral deer are removed per annum from South Australia (BDO EconSearch 2022).

A large proportion of the population of feral deer must be removed each year to drive a population decline. For example, at least 34% of the population of fallow deer must be removed each year just to stop population growth; even higher proportions for other deer species (hog: 52%; chital: 49%; rusa: 46%; sambar: 40%; Hone *et al*. 2010). It is increasingly evident that large-scale, intensive, and coordinated control programs are necessary to drive population declines of feral deer.

Aerial culling can be an effective means for removing large numbers of feral deer (e.g. Husheer and Robertson 2005; Bengsen *et al.* 2022) and feral pigs (Cox *et al.* 2022) during brief periods in vast, remote, and inaccessible landscapes. The firearms used in aerial culling vary among jurisdictions and must comply with local requirements. In New South Wales, aerial culling programs use high-powered, centre-fire rifles to shoot feral deer (Sharp & Saunders 2022), whereas shotguns are routinely used by the New Zealand Government for aerial culling feral deer (e.g., Forsyth *et al.* 2013). In Australia, it is common for shotguns to be used in the aerial culling of goats and pigs (Centre for Invasive Species Solutions 2022b, c). Government programs across Australia are now trialling different combinations of firearms for different terrain and species of deer to improve continuously the efficiency of culling and the welfare outcomes for target animals (e.g., Hampton *et al*. 2022).

Adopting new technologies will potentially enhance the efficiency of aerial programs and welfare outcomes. Thermal-imaging technology is increasingly being incorporated into aerial culling to detect, track, and shoot feral deer. Cox *et al*. (2022) demonstrated improvements in efficiency and welfare outcomes for culled deer when using thermal technology, including reducing the time the helicopter crew spent searching for target animals. In that trial, new crew configurations were also adopted — the personnel included a thermographer to operate a high-resolution, thermal-imaging camera. The thermographer was positioned in the back-left of the helicopter and operated a Vayu HD thermal camera to detect deer and confirm death after the animal was shot at least twice. The thermographer quickly identified and located any wounded deer, including in forested areas, enabling rapid follow-up to maximise welfare outcomes. The shooter was located to the left of the pilot and was furnished with a semi-automatic, .308-calibre rifle fitted with a thermal scope and a pair of thermal binoculars.

The South Australian Government and regional Landscape Boards recently started a program to reduce populations of feral deer in South Australia. The program focuses on coordinating landscape-scale aerial culls. The program seeks to deliver the most efficient and humane approach to aerial controls. In that context, a recent aerial culling program trialled a similar crew configuration and the same advanced thermal technology as used in Cox *et al.* (2022), but with the addition of a second shooter using a shotgun. Shotgun trials for aerially culling feral deer are also occurring in New South Wales and the Australian Capital Territory (Hampton *et al.* 2022).

We recently trialled shotguns during an aerial culling program for fallow deer to test the efficiency and animal welfare benefits of incorporating shotguns into these operations. We collected data to assess the efficiency and animal welfare outcomes of this approach based on several predictions. Following Hampton et al. (2022) and Cox et al. (2022), we hypothesised that time between the first shot and confirmed death, pursuit time, and number of thorax-penetrating projectiles could be reduced by using shotguns instead of centre-fire rifles. Specifically, we predicted:

- increased efficiency of the program measured by a relative reduction in the time required to kill a target number of individuals, and
- improve welfare outcomes for target animals via
    - reduced time between first shot and confirmed death,
    - shortened pursuit times, and
    - increased likelihood that multiple projectiles penetrate the thorax of target animals, leading to more fatal injuries of vital organs, thereby minimising time until death.

Methods

Program location and target species

The aerial culling program occurred in October 2022 and covered 20,000 ha of private property in the Limestone Coast region about 300 km southeast of Adelaide, South Australia (Figure 2).

The program targeted fallow deer, which is the most abundant deer species of South Australia. Fallow deer are small-bodied deer, with adult females weighing 35–55 kg and adult males weighing 50–97 kg (Centre for Invasive Species Solutions 2022d); for comparison, sambar deer, Australia’s largest deer, have female and male body masses of around 230 kg and 300 kg, respectively (Centre for Invasive Species Solutions 2022e). We reasoned that the small size of fallow deer would increase the likelihood of shotgun pellets penetrating the thorax compared to larger-bodied species.

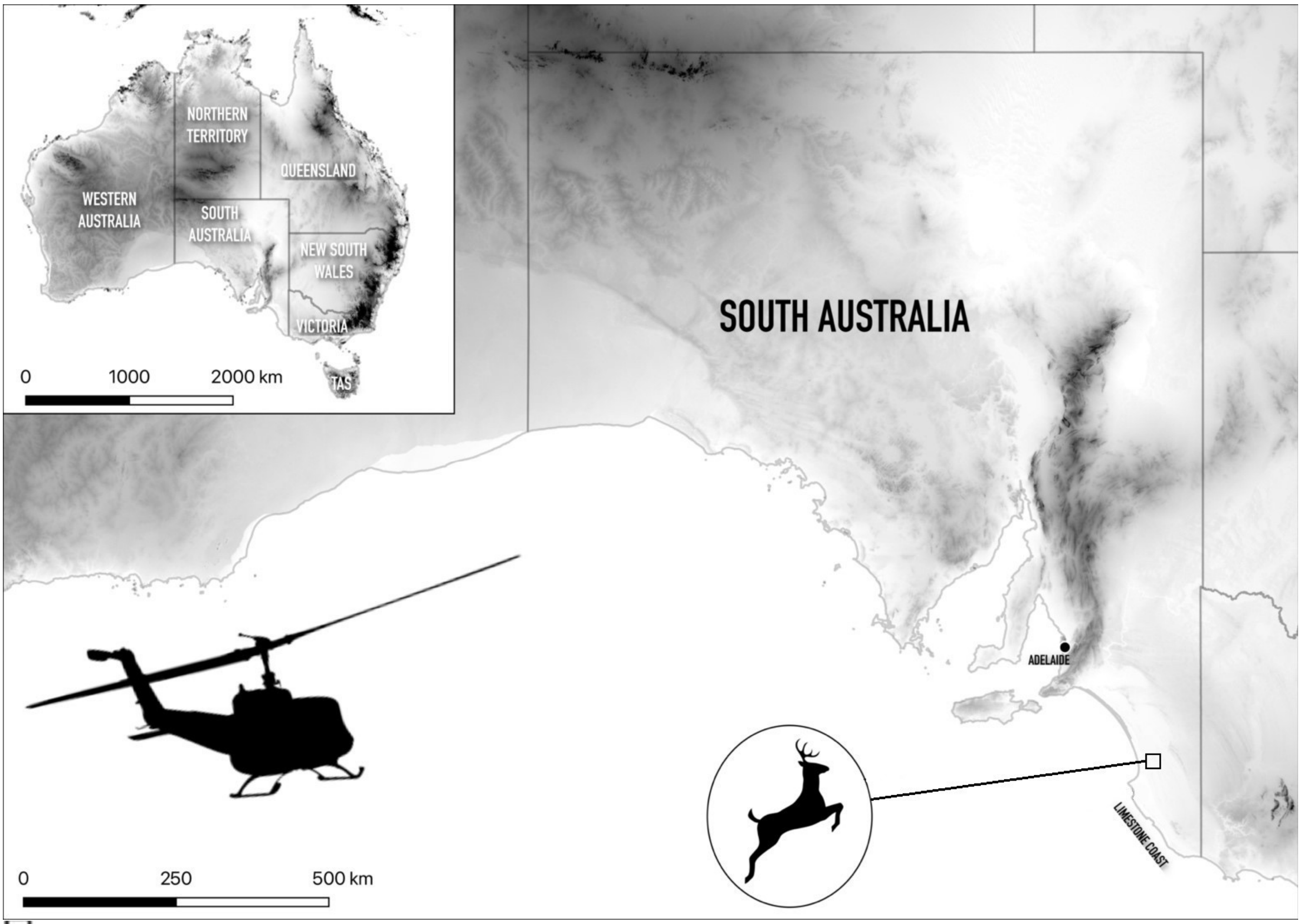

Figure 1. Location of the aerial culling trial for feral deer on the Limestone Coast in the southeast of South Australia.

Firearms, ammunition, crew configuration

One shooter (hereafter, the 'primary' shooter) was equipped with Benelli M2 semi-automatic shotgun with a custom choke at full extension that created a pellet spread of 25 cm at a distance of 20 m and 45 cm at 30 m. The primary shooter used a shotgun fitted with a red-dot scope (Sightron S30-5 and Aimpoint 9000L^{TM}) for all targets within 30 m. The shotgun had a 12-shell tube magazine and was loaded with GB SSG 21-pellet buckshot and Winchester Super-X 16-pellet buckshot. The projectiles in the 16-pellet SSG cartridges have an average weight of 2.3 g, with a total payload of 36 g. The projectiles of the 21-pellet SSG cartridges have an average weight of 1.8 grams, with an average total payload of 37 g. From previous programs, the professional shooters did not observe any differences in the performance of the different rounds of buckshot, so both round types were mixed into the primary shooter's ammunition bags; we did not distinguish our collected data by ammunition type. The primary shooter was located in the rear right-hand side of the helicopter behind the pilot (Figure 1).

The secondary shooter used a Wedgetail WT25 semi-automatic, .308-calibre rifle with a variety of ammunitions. The secondary shooter was located next to the thermal camera operator ('thermographer'; see Figure 1). The thermographer used a high-powered laser to assist the secondary shooter to locate feral deer in forested areas. The .308-calibre rifle was also equipped with a thermal scope (Pulsar Trail 2 LRF XQ50), so wounded deer in forested areas could be located quickly for follow-up shots and so that the thermographer could confirm death.

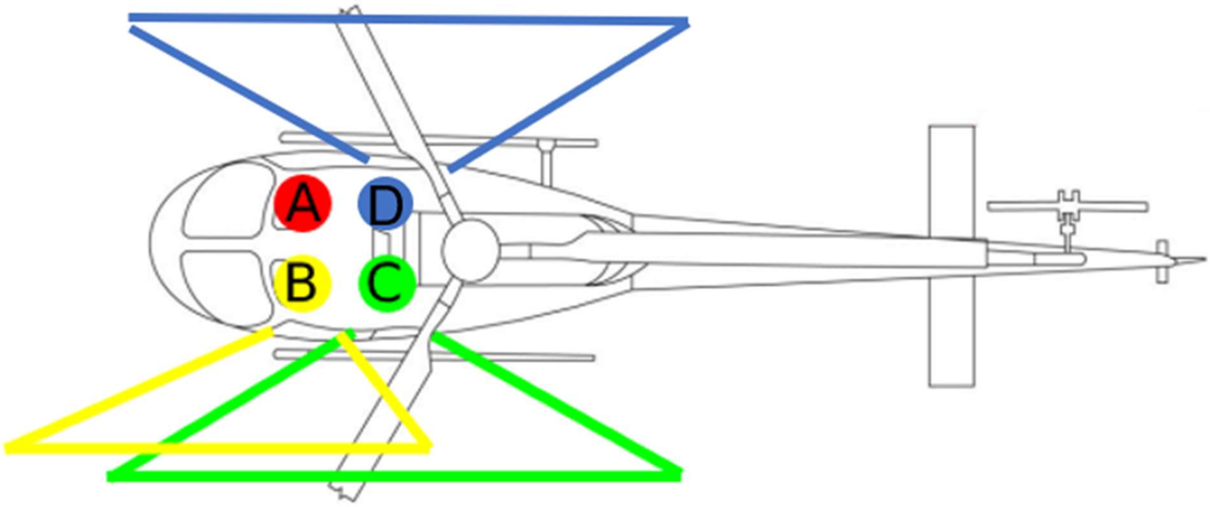

Figure 2. Seating configuration of the personnel in the helicopter*:* (A) pilot, (B) secondary shooter with rifle and thermal scope, (C) thermographer, and (D) primary shooter with shotgun and red-dot scope. Yellow and blue polygons show the indicative field of view for the shooters, and the green polygon shows the field of view for the thermographer.

The program had a deliberate ‘overkill policy’, which mandated that each deer was shot at least twice and the kill confirmed by two crew members before moving to another target.

Data collection and analyses

Flight times were recorded using two sources: (1) by the thermographer, and (2) using a GoPro 3 camera. The thermographer used a Vayu HD uncooled microbolometer array with the Blackmagic Video Assist and Panasonic GH5 4K video camera. The GoPro 3 camera was mounted to the rear firewall of the helicopter and programmed to record continuously the activities of all personnel in the helicopter and most of their field of view (Figure 3). Both systems recorded flight audio.

We modified the methodology and analyses described in Cox *et al*. (2022) by instead reviewing video footage of the first four hours of flight time on 2, 4, and 5 October 2022 to record:

- number of rounds: number of shotgun and rifle rounds fired per animal),
- time between first shot with a shotgun and confirmed death: time taken between the first shot fired at the target with a shotgun and a confirmed kill (with shotgun or rifle). At least two helicopter personnel confirmed time of death based on:
    - the thermographer observing a complete absence of movement as well as hotspots visible on the thermal camera indicating that the thorax (heart and/or lungs) had been pierced, and
    - a complete absence of movement confirmed by the helicopter pilot and the secondary shooter.

- Pursuit time: duration between first detection of the target and confirmation of its death. If a deer stayed with its group under pursuit, pursuit time was cumulative for each consecutive deer (i.e. the last deer in the group killed was recorded as being pursued while the other deer were culled). If the group dispersed and a subset of that group had to be re-located, pursuit timer was re-started upon relocation of the next group.

Figure 3. Seating configuration of the personnel in the helicopter, their fields of view, and four deer being pursued (identified by red circles).

Generalised linear models

To test which components of an individual kill explained the most variation in the time from the start of the pursuit to the kill, we constructed a series of generalised linear models using the *glm* function in the `stats` R library (R Core Team 2022). Here, we tested whether the time between first and last/kill shots, number of rounds fired, and group size explained variation in the time from the start of the pursuit to the kill (with a shotgun). We applied a Gamma error distribution and a log link-function, and scaled the response and explanatory variables (except group size) using the *scale* function in R. We contrasted a total of eight models, including the three additive main effects, all combinations of two additive effects, single effects, and the intercept-only model. We compared the relative probability of the five models per response variable using Akaike's information criterion corrected for small sample size (AIC_c) (Burnham & Anderson 2002). The bias-corrected relative weight of evidence for each model, given the data and the suite of candidate models considered, was the AIC_c weight (the smaller the weight, the lower its contribution to parameter estimates) (Burnham and Anderson 2002). We also calculated the percent deviance explained (%DE) as a measure of goodness of fit. We examined model diagnostics using the *check_model* function in the `performance` R library (Lüdecke *et al*. 2021). All data and R code are available at https://github.com/cjabradshaw/deerCullShotgun.

Field autopsies to assess shotgun damage

Following morning flights on 4 and 5 October 2022, 20 deer carcasses were located. Field autopsies were done to collect information on the penetration characteristics of shotgun pellets and organ damage.

Shotgun pellet penetration and spread were determined by cutting and peeling back the pelt and assessing the external muscle tissue for bruising and penetration of shotgun pellets on both the impact and exit sides. The number of projectiles that impacted the thorax was recorded for each carcass.

Organ damage by shotgun fire. Following inspection of the muscle tissue and sites of pellet impact, the chest cavity was opened below the sternum using a bone saw. The heart and lungs were removed and inspected for tissue damage, wound channels, bleeding, and blood coagulation to determine whether pellets penetrated the heart and/or the lungs. The heart and lung were dissected to establish the extent of the wounding by shotgun pellets, if not obvious externally. The chest cavity was inspected for pooling of blood.

Results

Aerial culling

The program on the Limestone Coast operated 1–7 October 2022. From 26.3 hours of flight time (Table 1), a total of 611 feral deer were culled (= 23 deer $hour^{-1}$ = 1 deer 155 $seconds^{-1}$.

Table 1. Daily number of engine hours recorded during the aerial cull of deer on the Limestone Coast from 1–7 October 2022.

date	flight time (hours)
01/10/2022	1.5
02/10/2022	4.0
03/10/2022	4.1
04/10/2022	8.4
05/10/2022	1.2
06/10/2022	5.3
07/10/2022	1.8
daily average ± s.e.	**3.8 ± 1.0**

Shotgun results

We reviewed the footage for 104 fallow deer killed with shotguns (*n* = 96) and with a shotgun-rifle combination (*n* = 8). A total of 383 shotgun rounds and 10 rifle rounds were shot.

Mean ± standard error (s.e.) time between first shot and confirmed kill was 11.1 ± 0.7 seconds (*n* = 104 deer). Individual deer, or the first deer shot in a group had the greatest mean time between first shot and confirmed kill, but this time decreased with subsequent targeted individuals in the group (Figure 4). The maximum time recorded between first shot and a confirmed kill for any deer was 35.9 seconds.

Mean pursuit time (between detection and confirmed kill) was 49.5 ± 3.4 seconds (*n* = 104). Pursuit time increased with subsequent deer shot within a group (Figure 4). The maximum pursuit time for any deer was 159.0 seconds (summary data in Table 2).

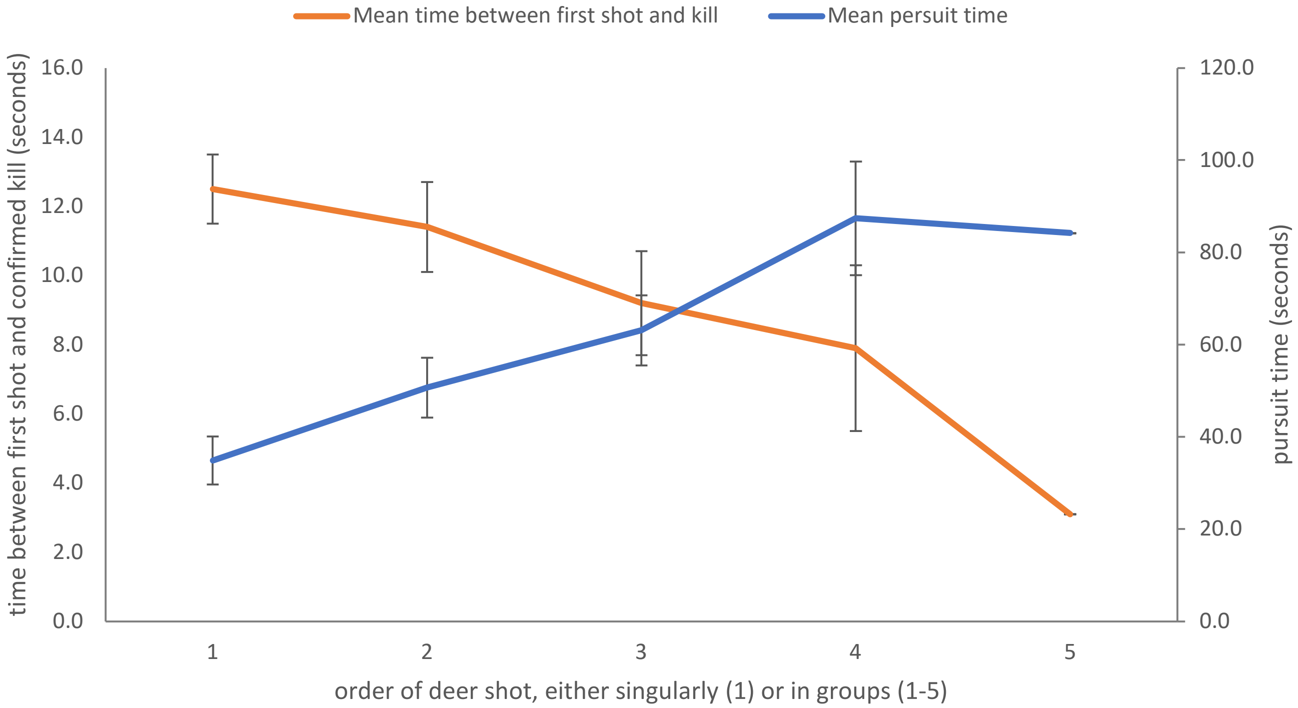

Figure 4. Mean ± s.e. time between first shot and confirmed kill (left *y*-axis) and mean ± s.e. pursuit time between first detection and confirmed kill (right *y*-axis).

Table 2. Summary statistics from analyses of footage of 104 deer killed involving a combination of firearms, a secondary shooter, and thermal-imaging technology.

summary statistic	order of deer shot[a]						
	first	second	third	fourth	fifth[b]	total	mean
sample size (deer)	45	29	21	8	1	104	-
shotgun rounds fired	169	114	64	34	2	383	-
mean ± s.e. shotgun rounds $deer^{-1}$	3.8 ± 0.3	3.9 ± 0.3	3.0 ± 0.4	4.3 ± 0.6	2.0	-	3.7 ± 0.2
rifle rounds fired	4	6	-	-	-	10	1.3
min/max time between first shot with shotgun and confirmed kill (seconds)	2.9/35.9	2.6/32.0	2.6/33.2	4.0/14.1	3.1/NA	-	-
mean ± s.e. time between first shot with shotgun and confirmed kill (seconds)	12.5 ± 1.0	11.4 ± 1.3	9.2 ± 1.5	7.9 ± 2.4	3.1	-	11.1 ± 0.7
min/max pursuit time (seconds)	13.9/83.1	16.0/89.4	14.5/120.2	46.3/159.0	84.2/NA	-	-
mean ± s.e. pursuit time (seconds)	34.9 ± 5.2	50.7 ± 6.5	63.1 ± 7.6	87.4 ± 12.3	84.2	-	49.5 ± 3.4

[a] first deer includes isolated individual deer as well as the first deer targeted within a group; data also collected for subsequent deer shot from the same group for up to five deer.

[b] sample size = 1, no standard error calculated.

Generalised linear models

There was a positive effect of deer group size and number of shotgun rounds fired on the total time elapsed since start of pursuit to death (Table 3). These two variables explained ~ 43% of the variation in the response. However, there was no evidence for an effect of the time between the first and last shot and total time elapsed since start of pursuit to death.

Table 3. Generalised linear model results testing the effects of time between first and last/kill shots (*t1stLast*), number of rounds fired (*rnds*), and group size (*grpSize*) on the time from the start of the pursuit to the kill with a shotgun (response). k = number of model parameters; ℓ = -log likelihood; AIC_c = Akaike's information criterion corrected for small sample size; $wAIC_c$ ≈ model probability; %DE = percent deviance explained.

model	k	ℓ	AIC_c	$wAIC_c$	%DE
~grpsize+rnds	3	-24.770	57.945	0.529	42.7
~t1stLast+grpSize+rnds	4	-23.859	58.330	0.436	43.7
~t1stLast+grpSize	3	-27.489	63.383	0.035	39.7
~grpSize	2	-32.480	71.201	0.001	33.8
~rnds	2	-50.879	107.997	<0.001	6.9
intercept-only	1	-54.745	113.610	<0.001	-
~t1stLast+rnds	3	-50.356	109.116	<0.001	7.8
~t1stLast	2	-54.603	115.446	<0.001	0.3

Autopsy to assess shotgun damage

A total of 20 carcasses were recovered and autopsied within 6 hours of being culled; all carcasses had received shotgun wounds only. Pellets had penetrated the thorax of all deer autopsied. The total number of pellets that had penetrated the thorax of 20 deer was 116 (5.8 ± 0.6 pellets animal^{-1}; range: 3–13 pellets animal^{-1}).

All 20 animals autopsied had lethal lung-penetrating wounds, and 14 (70%) also had lethal heart-penetrating wounds. The wounds and their classification are shown in Figures 5-9.

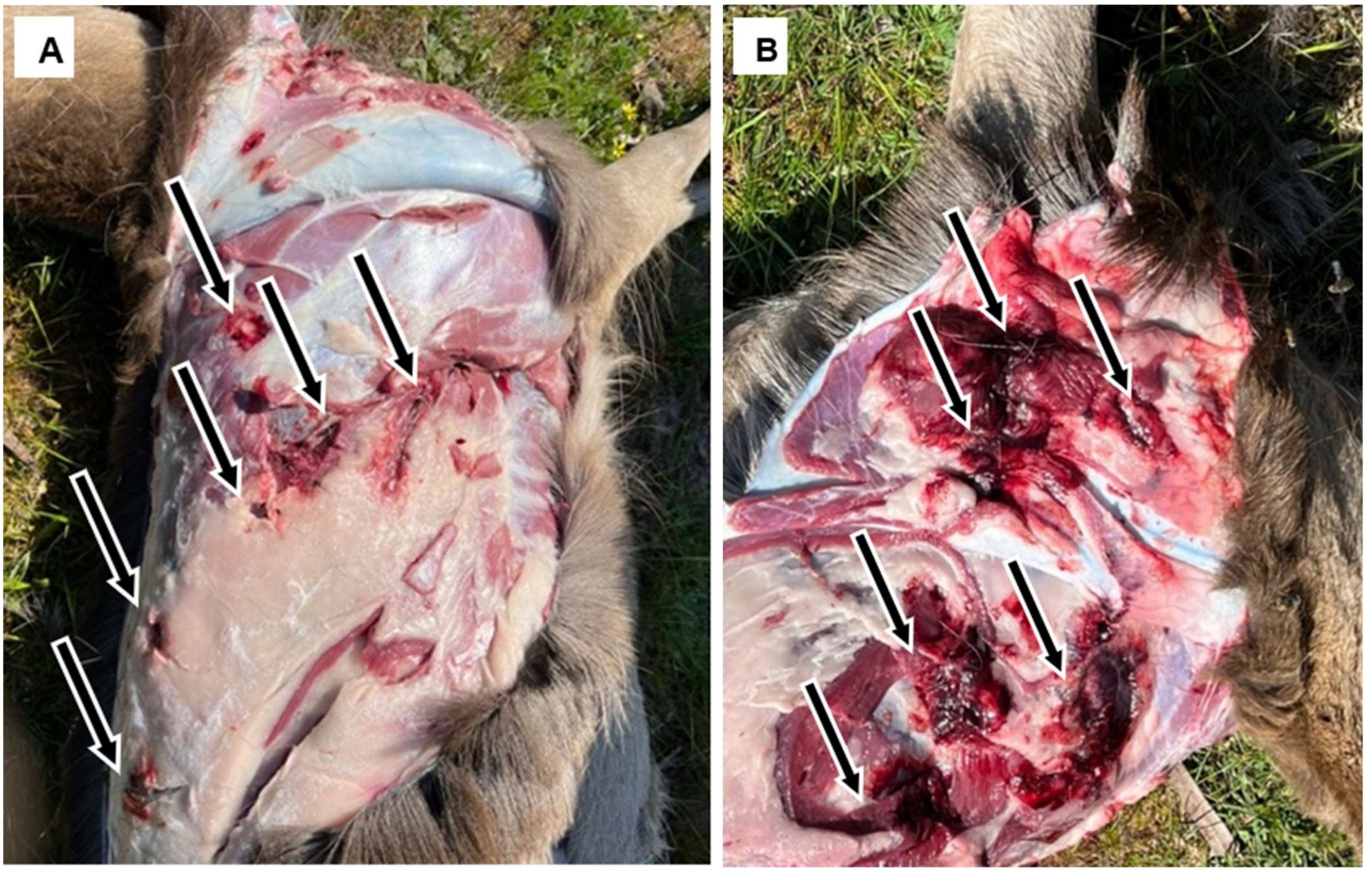

Figure 5. Deer VI, controlled with shotgun; pelt is removed to show the difference between shotgun-pellet wounds on the entry (A) and exit (B) sides of the carcase. Arrows indicate the wounds described in each image: (A) entry wounds with minimal bruising or bleeding; (B) exit wounds with extensive bleeding, bruising, and coagulation of blood.

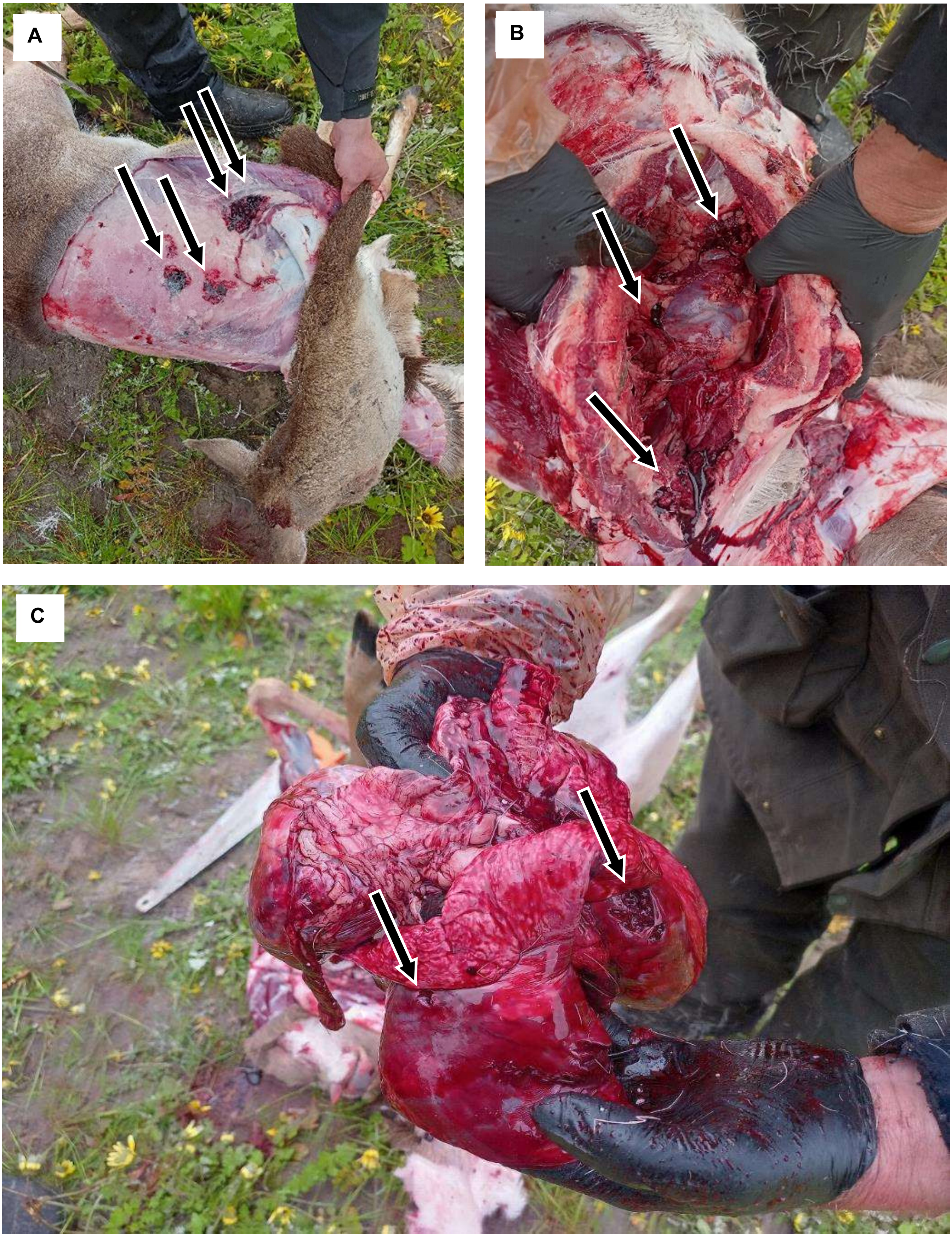

Figure 6. Deer XV, showing typical wounds and mode of death for fallow deer culled with shotguns in this trial. Arrows point to wounds described in each image: (A) four thorax-penetrating pellet entry wounds, showing bleeding and bruising at the end of the wound channel; (B) chest cavity with old oxygenated, congealing blood in multiple areas around the heart and lungs; (C) example of removed heart and lungs with penetrating wounds to the lungs.

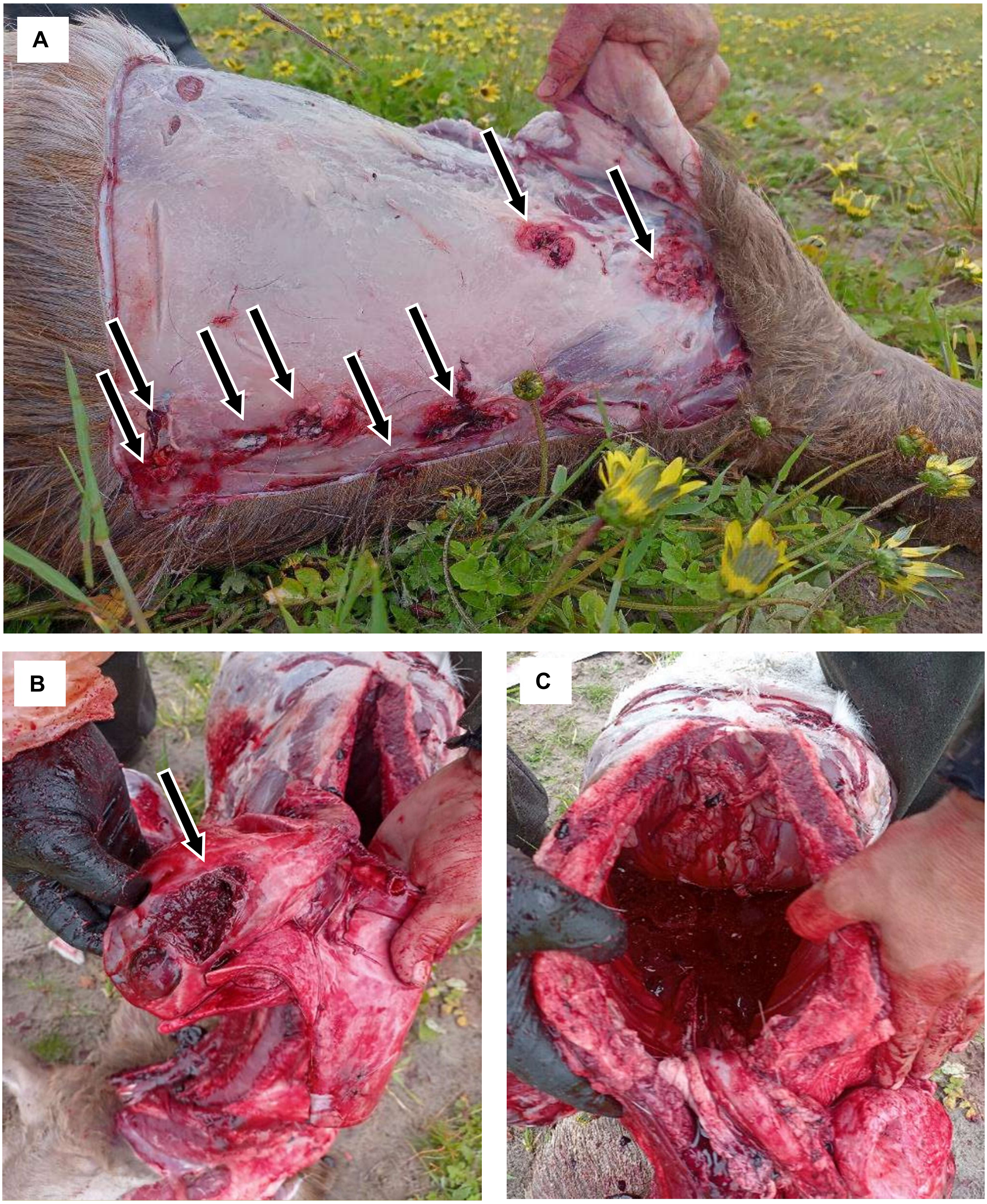

Figure 7. Deer IX, showing typical wounds and mode of death for fallow deer culled with shotgun in this trial. Arrows point to wounds: (A) eight pellet entry wounds across the side and back of this fallow deer; (B) damage to lung tissue with blood clotting inside the lungs; (C) blood pooling in the chest cavity, following removal of the heart and lungs; bleeding is from the wounds to the heart, lungs, and other tissue.

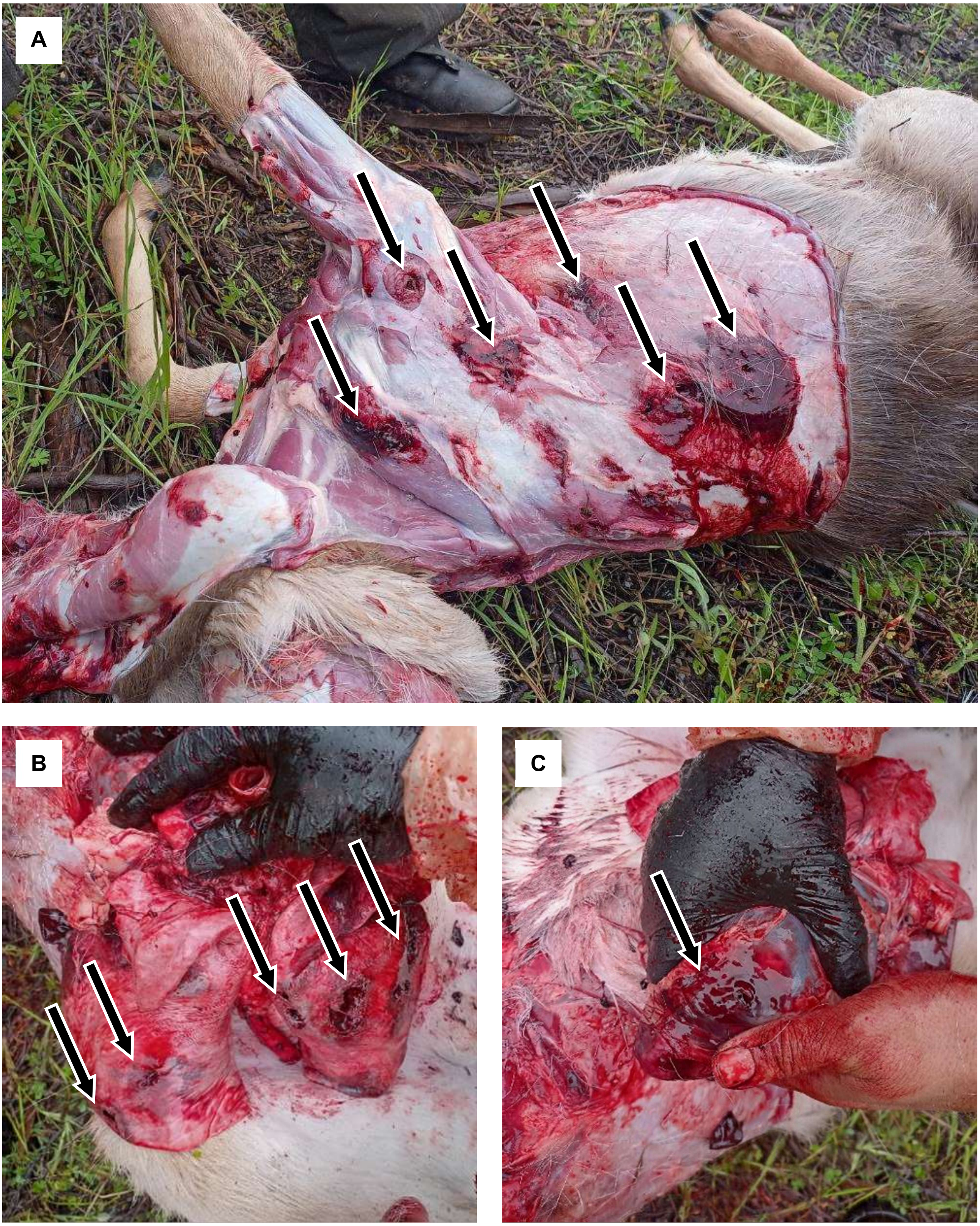

Figure 8. Deer XII, showing typical wounds and mode of death for fallow deer culled with shotgun in this trial. Arrows point to wounds: (A) six pellet exit wounds on the thorax, showing blood loss, bruising, and clotting; (B) multiple penetrating wounds to the lungs; (C) bleeding from a penetrating wound to the heart.

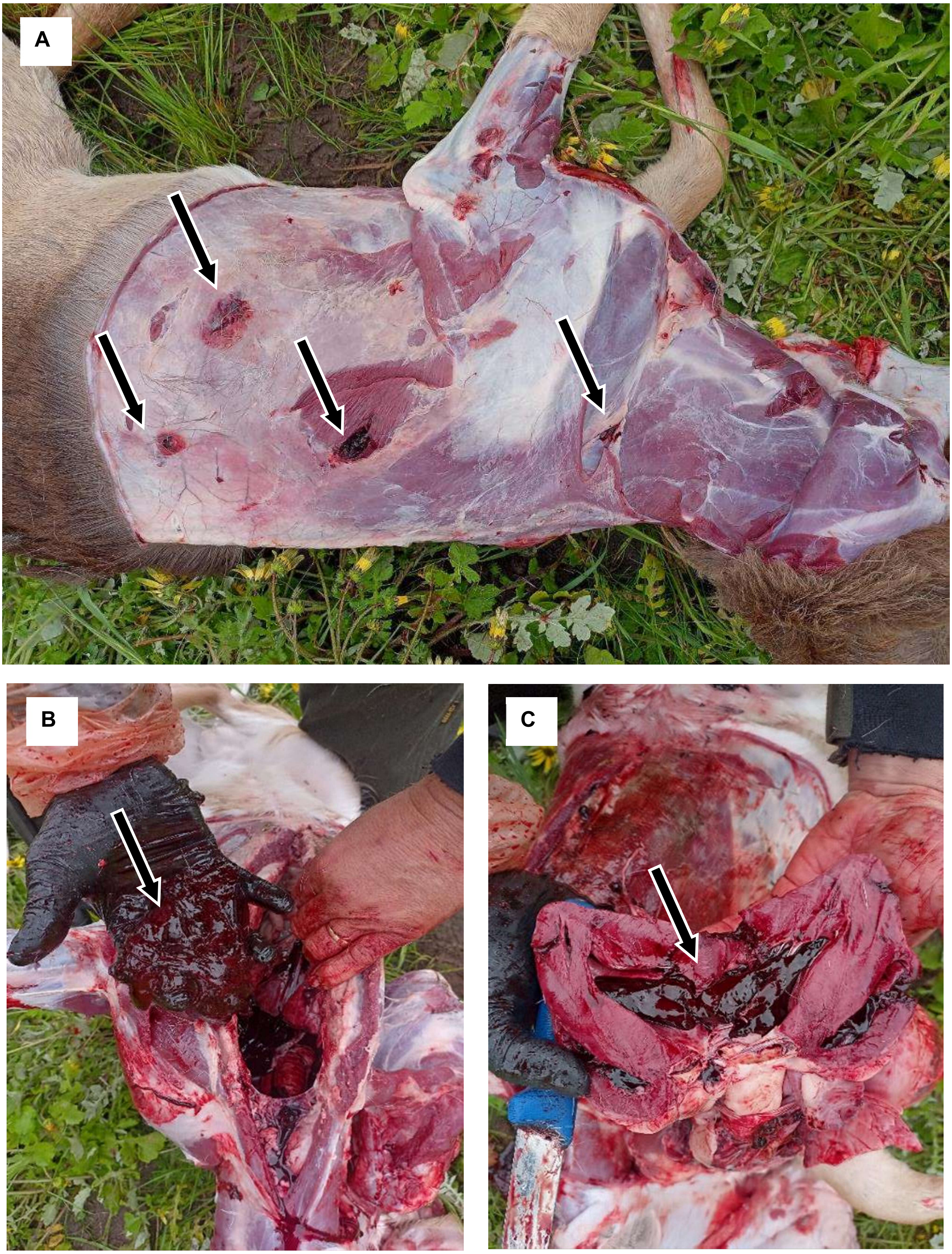

Figure 9. Deer XIV, showing typical wounds and mode of death for fallow deer culled with shotgun in this trial. Arrows point to: (A) four thorax-penetrating entry wounds; (B) blood clot from pooling of blood in chest cavity; (C) dissection of heart showing clotting of blood along a wound channel.

Discussion

Efficiency of the aerial culling programs

Our first prediction was that that aerial culling of fallow deer with a shotgun would increase the efficiency of the program. In this trial we used the same pilots, aircraft, thermal technology, and crew configuration (for the pilot, camera operator and the shooter with the rifle), as in Cox *et al*. (2022) for feral pig and deer control. Both programs used thermal imaging to locate animals and confirm that they were dead. The only difference was that our trial included a shooter armed with a shotgun sitting behind the pilot. The shotgun was able to deliver a rapid, lethal shot because the pattern spread of the pellets at a range of 10–30 m made each shot likely to hit and incapacitate the target. When compared to other programs, using shotguns was the most-efficient method compared to any program in the Limestone Coast (Table 4; Fig. 10). Relying on a single shooter armed with a rifle was the least-efficient (i.e., 8–10 deer $hour^{-1}$), adding thermal equipment improved efficiency for single shooters (12 deer $hour^{-1}$), but using two shooters, thermal equipment, and a combination of firearms (including shotguns) was the most efficient (23 deer $hour^{-1}$). We also note that .308-calibre rifles and/or further research on shotguns may be required in places with different deer densities, or where the canopy cover or terrain result in shot distances >30 m. Our findings are relevant to aerial culling programs in areas with similar deer densities, canopy cover and terrain to the Limestone Coast region of South Australia.

Table 4. Comparison metrics between this study and other aerial culls in the Limestone Coast. Efficient rank (1 = highest; 5 = lowest) is based on the relative values of deer culled $hour^{-1}$.

trial	method	flight hours	deer culled	deer culled $hour^{-1}$	efficiency rank
Limestone Coast, 2022 – this trial	second shooter with shotgun and thermal equipment	26.3	611	23	1
Limestone Coast, 2022	one shooter, rifle only	83.4	630	8	5
Limestone Coast, 2021 – Cox *et al*. (2022)	one shooter, rifle only; first trial of thermal equipment	15.5	188	12	2
Limestone Coast, 2019 – Bengsen *et al.* (2022)	one shooter, rifle only	2.6	27	10	3
Limestone Coast, 2009-2018– unpublished data, Limestone Coast Landscape Board	one shooter, rifle only, thermal binoculars may be used, n = 21 programs	947	8,074	8	4

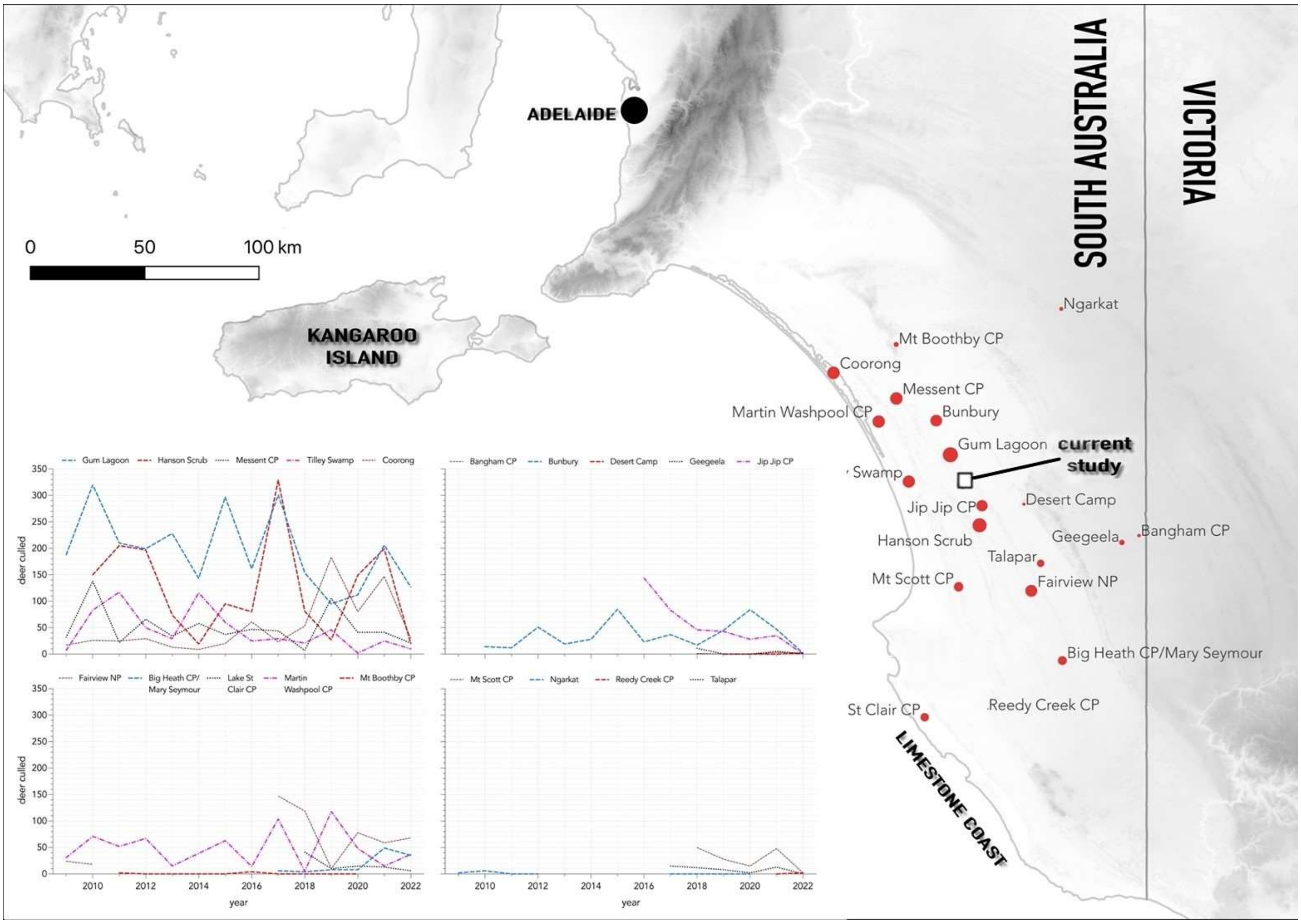

Figure 10. Map of previous deer culls in Conservation Parks (CP) and National Parks (NP) in South Australia from 2009 to 2022, with time series of cull data shown as graphed inset. Symbol size (red dots) corresponds to relative total number of deer culled from 2009 to 2022.

Time between first shot and confirmed death

Our hypothesis that using a shotgun relative to a rifle only reduces the time between the first shot taken and death of the culled deer. The results show the mean time from first shot to death was 11.1 ± 0.7 seconds (range: 2.6–35.9 seconds). Cox *et al.* (2022) recorded a mean time between first shot and confirmed death at 21.9 seconds (standard deviation = 33.2), and Hampton *et al*. (2022) reported that 95% of deer were dead within 57 seconds of the first shot. Without controlling for other factors, which might reduce time between first shot and confirmed death, a shotgun appears to reduce the time between first shot and death. However, our analyses were focused on deer that were culled in open terrain without dense vegetation. Different vegetation types, terrain, and individual skill of the shooter will all affect time to death. Collecting more data on this aspect among program types will help document time to death from the first shot for a variety of environmental conditions and firearm combinations.

Pursuit time

We hypothesised that using a shotgun compared to a rifle only in aerial culling for fallow deer would decrease pursuit times. Following Cox et al. (2022) and Hampton et al. (2022), we considered that a shorter pursuit time indicated better welfare outcomes for target animals (i.e., less time stressed during pursuit). In this study we assessed a sub-sample of deer that were controlled in open areas with shotguns fired ≤ 30 m from the target, and found that the mean pursuit time for all 104 animals was 49.5 ± 3.4 seconds. In comparison, pursuit times were 150 seconds (standard deviation = 80 seconds) (Cox *et al*. 2022) and 92–205 seconds (Hampton *et al.* 2022) in aerial culls that used a .308-calibre rifle only, with and without thermal-detection equipment, respectively. We also determined that the time from pursuit to death increased both with deer group size and the number of shotgun rounds fired. Thus, our data indicate that a shotgun appears to reduce pursuit time, but more data from studies analysing pursuit times should be collected to investigate variation arising from different vegetation types/densities.

Autopsy results

We hypothesised that using a shotgun would result in multiple projectiles penetrating the thorax of target animals, leading to a higher incidence and faster onset of fatal injuries of vital organs, thereby minimising time until death. Following Hampton *et al*. (2022), we expected that animals would suffer less if they were shot multiple times, and had at least one or more wounds in the thorax. As expected, we confirmed that the mean number of thorax-penetrating wounds per individual was higher than in some autopsies of deer culled with a rifle (Hampton *et al.* 2022). Our autopsies (Figures 5–9) indicated an average of 5.8 pellets carcase^{-1}; all carcases recorded lethal damage to either the heart or lungs. Wounds to the lungs and the pooling and/or clotting of blood in the chest cavity indicated a pneumothorax (collapse of lung) and/or a hemothorax (collapse of lung because of blood in chest cavity). The wounds to the heart probably caused rapid decrease in blood pressure, rapid loss of consciousness, and death by exsanguination. In combination, these injuries lead to hypovolemic shock, causing hypoxia, unconsciousness, and rapid death from lack of oxygen supply to the brain (Stokke *et al*. 2018). The increased number of projectiles fired compared to the rifle suggest that welfare outcomes are more desirable when using a shotgun.

Conclusions

Although a small cervid (similar in size to pigs and goats for which shotguns are regularly used), fallow deer are often difficult to shoot from a helicopter because they run quickly to escape the pursuing helicopter (pers. comm. M. Leeson and S. Boyd-Law, pers. comm., both cited in Hampton et al. 2022). This species tends to hide in dense vegetation and run fast, darting quickly from side to side when pursued, behaviours that make accurate shots difficult with a rifle, thereby increasing pursuit times and the associated stress. Relying mainly on a shotgun as the primary tool is more efficient, and therefore, more humane for aerially culling fallow deer.

While we did not present cost data from this or other programs, we confirm higher costs in this trial compared to previous ones because we employed an additional shooter, a thermographer, and a larger helicopter. While more costly despite the higher efficiency, these additions conferred safety benefits by providing shooters more opportunities to take brief breaks during each flight, to change roles when a magazine needed to be changed, and to alternate between using the shotgun and the rifle between flights. In addition, the thermographer had more opportunity to monitor welfare outcomes with the high-resolution thermal camera to confirm each deer was dead and to locate wounded deer in forested areas.

We showed that shotguns improve the welfare outcomes for culled deer compared with programs that rely solely on.308-calibre rifles, with improved welfare outcomes for the target animals as measured by reduced pursuit and times between the first shot and death. Furthermore, all deer autopsied were shot more than once, and received multiple thorax-penetrating wounds, resulting in lethal injuries to either the lungs and/or heart, and ensuring a short time until death. These findings are some of the best welfare outcomes reported from aerial culling programs in Australia to date (Hampton et al. 2022), and are relevant to aerial culling programs in areas with similar deer densities, canopy cover and terrain to the Limestone Coast region of South Australia.

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