CSIRO PUBLISHING

SPECIAL ISSUE | RESEARCH PAPER
https://doi.org/10.1071/WR22117

WILDLIFE RESEARCH

Characterising a unique recreational hunting method: hound hunting of sambar deer (*Cervus unicolor*) in Victoria, Australia

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Handling Editor:
Graham Nugent

ABSTRACT

Context. Scent-trailing dogs ('hounds') are used to hunt introduced sambar deer (*Cervus unicolor*) in south-eastern Australia, but little is known about this recreational hunting technique. **Aim.** The aim of this study was to characterise hound hunting of sambar deer in Victoria, Australia. Our study had three objectives as follows: (1) to report the hunting success of the technique; (2) to estimate pursuit times and distances; and (3) to investigate the landscape features associated with kill sites. **Methods.** Data were collected from four hound-hunting crews during 2020–2021. GPS data from collars fitted to hounds were used to quantify hunt duration (min) and hunt distance (m). Logistic regression was used to estimate the effects of deer sex and hound pack size on the probability of hunting success. We used a Bayesian multinomial regression resource selection function (RSF) to identify the characteristics of sites where deer were killed (elevation, aspect, and distances to water and roads). **Key results.** The four hunting teams ranged in size from 2 to 10 people and from one to eight hounds. Of 136 hunts, most (88%) harvested a deer, with pursued deer escaping on the other 12% of occasions. Pursuit times and distances were highly variable, with pursuit time >60 min for 46% of hunts and pursuit distance >5 km for 30% of hunts. The probability of killing a pursued male and female deer were similar, and there was not a positive relationship between pack size and hunt success. The RSF showed that both male and female deer were more likely to be killed on steeper slopes and closer to roads. **Conclusions.** Successful hound hunting of sambar deer involves pursuits of considerable duration and requires a network of roads, with geographical features associated with deer kills sites being related to hunter access. **Implications.** Hound hunting may be a useful wildlife management tool for land managers, but further studies are needed to assess its efficacy for achieving management goals.

Keywords: animal welfare, anthropogenic impacts, domestic animals, human dimensions, introduced species, population control, stress, wildlife management.

Received: 29 June 2022
Accepted: 3 November 2022
Published: 9 December 2022

Cite this:
Hampton JO *et al.* (2023)
Wildlife Research, **50**(8–9), 657–668.
doi:10.1071/WR22117

Introduction

There is an increasing need to manage the undesirable impacts of wild deer (family Cervidae) in Australia (Davis *et al.* 2016; Forsyth *et al.* 2017). Currently, there are few methods available for deer impact mitigation in Australia, and most programs rely on lethal control, with shooting being the most common method of killing. Deer are subject to several forms of population control, all being based on lethal shooting. These include commercial harvesting on agricultural land (Watter *et al.* 2020), aerial shooting (Bengsen *et al.* 2022; Hampton *et al.* 2022*a*), professional ground-based culling (Comte *et al.* 2022*a*), and recreational hunting (Moloney *et al.* 2022). Recreational hunters kill large numbers of deer annually in Australia (Moloney *et al.* 2022) and New Zealand (Kerr and Abell 2014). For example, approximately 40 000 licensed hunters reported killing approximately 174 000 deer in the state of Victoria during the 2019 calendar year, the most recent calendar year not severely affected by COVID-19 restrictions (Moloney and Hampton 2020). The deer species most commonly harvested by recreational hunters in Victoria is the sambar deer (*Cervus unicolor*), accounting for approximately 131 000 (75%) of the deer harvested in 2019 (Moloney and Hampton 2020).

The sambar is Australia's largest deer species (mean live mass of 140 kg for females, 220 kg for males; Harrison 2010; Leslie 2011). It is native to the Indian subcontinent but has established non-native populations in Australia and New Zealand (Long 2003). A large and increasing population of sambar deer occurs in eastern Victoria (Forsyth *et al.* 2018; Watter *et al.* 2020; Moloney *et al.* 2022), primarily inhabiting native *Eucalyptus* forests (Gormley *et al.* 2011; Comte *et al.* 2022*b*; Forsyth *et al.* in press).

Two main methods are used to recreationally hunt sambar deer in Victoria. Stalking, as for deer species globally (Aebischer *et al.* 2014), involves hunting of deer by hunters on foot. This method accounted for 81% of the 2019 Victorian sambar deer harvest (Moloney and Hampton 2020). The other recreational hunting method involves the use of a pack of purpose-trained domestic dogs (*Canis familiaris*) ('hounds') to facilitate hunting (Game Management Authority 2014). 'Hound hunting' of sambar deer relies on dogs to scent-trail, follow and bail sambar deer to allow strategically positioned hunters to shoot the deer (Game Management Authority 2014). In 2019, 19% of the recreational sambar deer harvest (i.e. 25 000) was taken by this method (Moloney and Hampton 2020). Hound hunting is allowed only for sambar deer and only in the state of Victoria (Game Management Authority 2014), where it has been practiced for more than a century (Mason 2008). Hound hunting is thought to be more effective than stalking in heavily timbered and steep forest, particularly in those with a dense understorey (Bentley 1957).

Hound hunting of sambar deer in Victoria is contentious. Pursuits of deer on public land may be visible and audible to other public land users, and hounds sometimes stray into prohibited areas. Animal welfare concerns, as for other hunting methods relying on the use of dogs (Orr *et al.* 2019), include those affecting the hounds, the deer they pursue, and any other non-target wildlife they chase or attack. Previous accounts of hound hunting indicated that the pursuit ('chase') phase of hunts can last up to 2.5 h (Bentley 1957; Mason 2008; Harrison 2010). Beyond these anecdotal accounts, we are not aware of any empirical data characterising this hunting method.

Management of recreational hunting requires understanding of the impacts of hunting for individual animals (Hampton and Hyndman 2019; Græsli *et al.* 2020). Accordingly, for most recreational hunting activities, published studies typically report basic metrics characterising the hunting methods used and their outcomes. Such metrics include the frequency of hunts that result in a deer being killed (Bradshaw and Bateson 2000), and the landscape features associated with successful hunts (Rowland *et al.* 2021). Furthermore, many studies have quantified metrics related to the fates of individual hunted deer, including average duration and distance of pursuit (Cederlund and Kjellander 1991).

Here, we provide the first evaluation of using hounds to hunt sambar deer in Victoria, Australia. Our preliminary study had three objectives as follows: (1) to report the hunting success of the technique; (2) to estimate the pursuit times and distances; and (3) to investigate the landscape features associated with kill sites. Further, the findings were intended to provide initial evidence regarding the strengths and weaknesses of hound hunting as a management tool for deer in Australia.

Materials and methods

Study areas and timing

Our study was conducted at four areas in eastern Victoria (Fig. 1) during April–November, the legal hound hunting season (Game Management Authority 2014), in 2020 and 2021. The four areas include the Highlands–Southern Falls and Highland–Northern Falls bioregions and contain a wide variety of floristic communities. Wet sclerophyll forests, characterised by *Eucalyptus* spp., *Acacia dealbata* and *Pomaderris aspera* with an understorey of *Comprosma quadrifida*, *Correa lawrencia* and *Pittosporum bicolor*, dominate the region (Costermans 1981). Several species

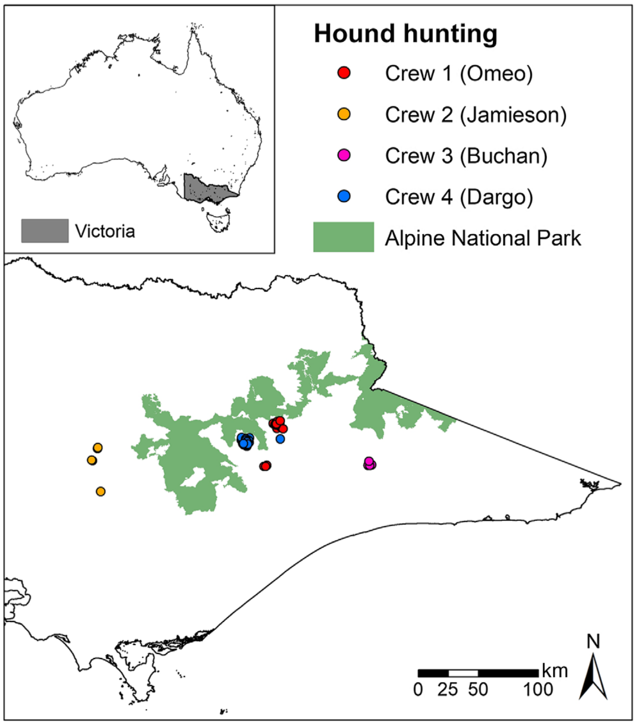

Fig. 1. Map of sites used to collect data on recreational hound hunting of sambar deer (*Cervus unicolor*) in eastern Victoria, Australia, in 2020–2021.

of introduced ungulates are sympatric with sambar deer in eastern Victoria, including fallow deer (*Dama dama*), red deer (*Cervus elaphus*) and feral goats (*Capra hircus*). However, none of those species is as widespread or abundant as is sambar deer (Forsyth *et al.* 2015). Dingoes/wild dogs (*Canis familiaris*) commonly eat sambar deer (Forsyth *et al.* 2018), but the extent to which this is by scavenging carcasses (Forsyth *et al.* 2014) or preying on calves and juveniles (Forsyth *et al.* 2019) is unknown. The climate is temperate with winter-dominant, but variable, average annual rainfall between 400 mm and 1500 mm across the region (Bureau of Meteorology 2021). Mean summer temperatures (December to February) vary from 23°C to 27°C and mean winter temperatures (June to August) vary from 13°C to 16°C (Bureau of Meteorology 2021).

Hunting regulations

Several procedural documents govern hound hunting in Victoria (Game Management Authority 2014). Current regulations stipulate that hounds be of the following three recognised breeds: beagles, bloodhounds, and harriers (Game Management Authority 2014). The laws stipulate a maximum pack size of five hounds but allow the use of up to three additional pups (i.e. dogs under 12 months of age) in training. A maximum of 10 human hunters is allowed with each hound pack. Participants are also required to pass a hound-hunting test, which assesses hunters' knowledge of relevant legislation (Game Management Authority 2014). To minimise exhaustion of pursued deer, it is not permitted to use a second team of scent-trailing hounds on a deer's trail if the first team fails to locate the deer or loses the deer's trail (Bureau of Animal Welfare 2017).

The same minimum rifle calibre and bullet mass prescriptions apply as for other forms of sambar deer hunting in Victoria, i.e. a rifle with a minimum calibre of 0.270 (6.85 mm) and a minimum projectile mass of 130 grains (8.45 g) (Hampton *et al.* 2022*b*). Although not being legal requirements, hunters are encouraged to harvest and carry out as much meat as possible from the carcasses of deer killed via hound hunting, and to not leave carcasses in waterways (Game Management Authority 2014). All contributing hunting crews were assumed to have complied with these prescriptions after being explicitly asked whether they were aware of, and would comply with them, with the awareness that the data that they provided could show violations if they had occurred.

Hunting methods

Hound hunting consists of the following three components: (1) finding fresh deer scent trails by driving four-wheel drive (4WD) tracks, hereafter 'roads', with hounds being restrained on the back of vehicles; (2) scent-trailing of deer by hounds, which we term the 'chase' component; followed by (3) shooting of bailed or pursued deer by hunters (Mason 2008). The composition of the recreational hunters in each crew on any given hunt is flexible, depending on availability. The hounds used in a given hunt are generally owned by one or more of the hunters present (Game Management Authority 2014). Scent trails are found by driving roads with hounds in vehicles and stopping when hounds vocalise, indicating that they have detected the scent of a deer. The hounds are then released from their vehicle, their GPS collars are activated, and they are released from restraint. Hunters are deployed according to the terrain and track network; typically hunters will follow the hounds on foot or drive to a strategic location where a game trail intersects a road. All hunters carry a hand-held GPS unit linked to the GPS collars worn by their hounds, to enable them to visualise the location of all hounds and to move to strategic shooting locations.

Hound-hunting crew recruitment

We used our professional and private networks to identify hound hunters likely to be willing to be involved in our study. We disproportionally targeted hunters who were members of one organised recreational hunting association, the Australian Deer Association. We selected which crews to approach on the basis of geographic separation in their hunting areas. We approached four crews and all agreed to participate in the study. The four areas hunted by the four crews were Omeo (Crew 1), Jamieson (Crew 2), Buchan (Crew 3) and Dargo (Crew 4; Fig. 1).

Field data collection

Participating crews collected the following data from each hunt on paper data sheets: (a) date of hunt; (b) number of hunters; (c) number of hounds (adults and pups); (d) outcome of hunt (deer escaped without wounding, wounded (shot but escaped) or killed; Hampton *et al.* 2022*c*); (e) shot distance (the straight-line distance between the shooter and the deer at the time of shooting, measured by GPS or range finder; Hampton *et al.* 2022*b*); (f) number of shots; (g) sex of deer killed (from external genitalia and from the presence of antlers); (h) estimated age of deer killed (adult or juvenile based on mass and, for males, antler characteristics); and (i) the latitude and longitude of the site at which deer were killed ('kill site'), recorded from the crews' hand-held GPS units.

Hound telemetry devices

We also collected data from a telemetry collar worn by the 'lead hound' (the dominant dog in each pack as designated by the hunters) in each hunt. Hunters used Garmin Astro GPS collars (Fig. 2) and hand-held GPS units (Sepúlveda *et al.* 2015) as part of a 'handheld tracking

Fig. 2. Adult male sambar deer (*Cervus unicolor*) bailed by hounds during recreational hound hunting in eastern Victoria, Australia. Photograph credit: P. Boag.

system for sporting dogs' (Garmin, KS, USA). Collars weighed 260 g (1–3% of the body weight of a typical adult hound). Information collected from tracking collars was restricted to factory-standard 'hunt metrics' supplied by the Garmin Astro system. Two metrics were recorded from the 'lead hound' for each hunt. The first was 'hunt distance', derived from a track log generated by the GPS collar recording a location every 5 s, which we designated 'chase distance' (i.e. the total distance the dog travelled during a hunt, km). The second was 'hunt time', which we designated 'chase time' (CT, min). This was the interval between the start of a hunt, the onset of the second phase of the hunt when hounds are released from a vehicle and begin to scent-trail a deer, and that deer being killed or the hunt being abandoned (Cederlund and Kjellander 1991; Vaughan and Inman 2002).

Data analysis

Expected values for key variables including chase distance, shot distance, number of hunters in a crew, number of hounds in a pack, and number of deer harvested were described using arithmetic means and standard deviations. We used Bayesian logistic regression to estimate the probability of successfully killing a deer across all hunts. We also used Bayesian logistic regression to estimate the effects of deer sex and hound pack size on the probability of success. For this model, we specified separate intercepts for deer sex and a common slope for the effect of pack size. Pack size was centred on the minimum pack size of one hound to aid interpretation of the slope parameter because a pack size of zero hounds has no inherent meaning. Ten cases (7.2%) with missing covariate data were discarded. Logistic regression models were fitted using JAGS (Plummer 2003) via the runjags package (ver. 2.0.4-6) (Denwood 2016) in the R statistical environment (R Core Team 2020). Parameters were estimated using four chains of 10 000 Markov-chain Monte Carlo (MCMC) draws after discarding 5000 burn-in draws.

We used a Kaplan–Meier cumulative hazard model (Kaplan and Meier 1958) to estimate CT for successful and unsuccessful hunts after discarding two cases (1.4%) with missing covariate data. Estimates and confidence intervals were calculated using the survival package (Therneau 2020) in the R statistical environment (R Core Team 2020). We used logistic regression to estimate the proportion of chases that lasted <60 min or <5 km.

Kill-site characteristics

We used a Bayesian multinomial regression resource-selection function (RSF; Diefenbach et al. 2005) to identify the characteristics of kill sites for the two hunting crews for which we had >15 kill sites (i.e. Omeo and Dargo). For each area, we used a Bayesian multinomial regression with male and female kill sites as two independent used resources. We then defined the available resources by generating random points (three times the number of kill sites) within a buffer around each known kill site (Northrup et al. 2013) to achieve representative coverage of the available landscape (Fig. 3). In the absence of predefined boundaries for the hound hunting activity, we selected the buffer size for the available resources as the maximum nearest neighbour distance among all kill sites in each area (i.e. 1802 m in Omeo and 2324 m in Dargo).

We characterised the resources (used and available) in both areas by using the following six environmental covariates (spatial resolution 100 × 100 m): elevation (m above sea level); slope (degrees); woody vegetation cover (1–100%); distance to road (m); distance to watercourse (m); sin(aspect) → west–east, and; cos(aspect) → south–north. Further details on these environmental covariates, including their sources, are provided in Supplementary material Table S1. The 1-ha spatial resolution was chosen because it approximated typical 'flight distances' between where deer of the size of sambar are shot and where they fall (Stokke et al. 2018; Hampton et al. 2022b). Pearson correlation coefficients indicated that none of these six covariates was significantly correlated at either the Omeo or Dargo areas (Table S2). Hence, we used all six covariates in our analyses. For each of the two models (Omeo and Dargo), we ran three MCMC chains with 5000 adaptation runs and 5000 burn-in runs for a total sample size of 50 000. We assessed the mixing of the MCMC chains visually and with the Gelman–Rubin diagnostic (R; Gelman and Rubin 1992).

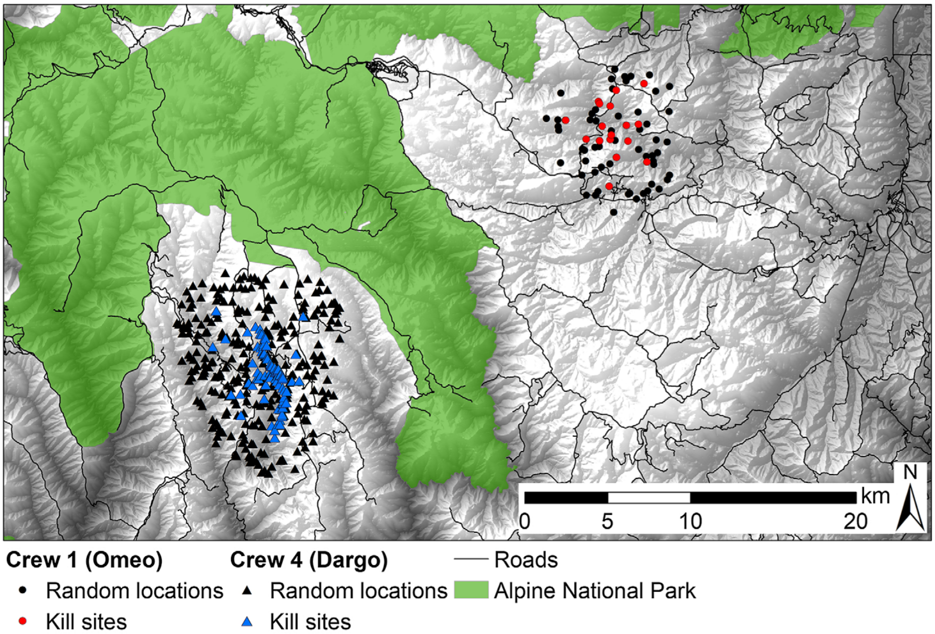

Fig. 3. Map showing kill sites for sambar deer (*Cervus unicolor*) killed via recreational hound hunting in eastern Victoria, Australia, in 2020–2021, with random locations used for a resource-selection function.

Results

Data scope

The four hunting crews collected data from 136 chases on 60 hunting days. Crew sizes varied from 2 to 10 hunters, and hound pack sizes varied from one to eight (including pups). Mean crew size was 7.60 (s.d. = 2.48) for hunters and 3.43 (s.d. = 1.44) for hounds (Table 1). In total, 122 deer were killed but two deer were shot when opportunistically encountered in the forest rather than having been pursued by hounds, and were excluded from the analysis. Hence, the mean number of sambar deer harvested per crew per hunting day was 1.93 (s.d. = 1.31, range 0–5). There were no instances in which more than one deer was harvested by the one hunting crew from a single chase. The majority (72%) of killed deer were adults, with a male:female sex ratio of 51:49. Mean shooting distance was 39 m (s.d. = 31 m), with the majority of shots from <50 m (Fig. 4). The frequency of more than one shot being fired at a deer was 0.32 (95% credible interval = 0.24, 0.40; Table 2), with the mean number of

Table 1. Arithmetic mean and standard deviation of variables describing key characteristics of 136 hound hunts for sambar deer (*Cervus unicolor*) in eastern Victoria, Australia, in 2020–2021.

Variable	Mean	s.d.
Number of hounds	3.43	1.44
Number of hunters	7.60	2.48
Chase distance (km)	4.81	4.77
Shooting range (m)	38.66	31.22
Number of deer killed per day	1.93	1.31
Number of deer killed per hunt	0.91	0.28
Number of shots fired per hunt	1.32	0.79

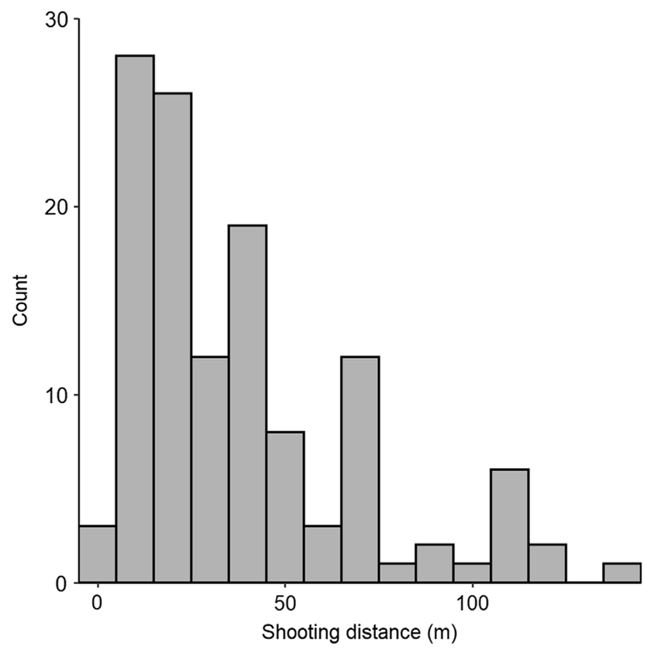

Fig. 4. Histogram of shooting distances used for killing sambar deer (*Cervus unicolor*) during recreational hound hunting in eastern Victoria, Australia, in 2020–2021.

Table 2. Probability of various hunt outcomes as estimated by Bayesian analysis from recreational hound hunting of sambar deer (*Cervus unicolor*) in eastern Victoria, Australia, in 2020–2021.

Outcome	*n*	*P* (outcome)	95% credible interval
Deer killed	136	0.88	0.83, 0.93
No deer killed	136	0.12	0.07, 0.17
Deer shot at more than once	136	0.32	0.24, 0.40
Chase time >60 min	136	0.46	0.38, 0.55
Chase distance >5 km	131	0.30	0.22, 0.38

shots fired at each deer chased being 1.32 (s.d. = 0.79; Table 1).

Hunting success

The overall probability of success across all 136 hunts was 0.88 (95% credible interval [CrI] = 0.83, 0.93; Table 2). Twelve hunts (8.8%) concluded with deer escaping without shots being fired at them when pursuits were abandoned or hounds lost their trail. No deer were reported as having escaped wounded after shooting. Four deer (2.9%) were shot at, missed and escaped (i.e. escaped unwounded, see Hampton *et al.* 2022*b*). Mean hound hunter efficiency was 0.35 (s.d. = 0.34) deer harvested per hunter per hunting day. Logistic regression showed no evidence of a difference in the probability of hunting success between female (0.92, 95% CrI = 0.79, 0.99) and male (0.88, 95% CrI = 0.73, 0.97) deer for a chase, using a single hound. The probability of a positive relationship between hunting success and the number of hounds used (i.e. $\beta > 0$) was only 0.54. Hence, each additional hound, up to a maximum of seven hounds (including pups), had no discernible effect on the odds that a chase would be successful (odds ratio = 1.04, 95% CrI = 0.65, 1.58).

Chases

Tracking data from GPS collars on lead hounds indicated that most chases (70%, 95% CrI = 62, 78%) were <5 km in length, although some were >20 km (Fig. 5). Logistic regression indicated that a small majority of chases (54%, 95% CrI = 45, 62%) lasted less than 60 min (Table 2 and Fig. 6). The Kaplan–Meier survival model showed that unsuccessful hunts lasted longer, on average (median chase time = 108 min, 95% CI = 90, 330 min), than did successful hunts (median chase time = 45 min, 95% CI = 40, 65 min; Fig. 6).

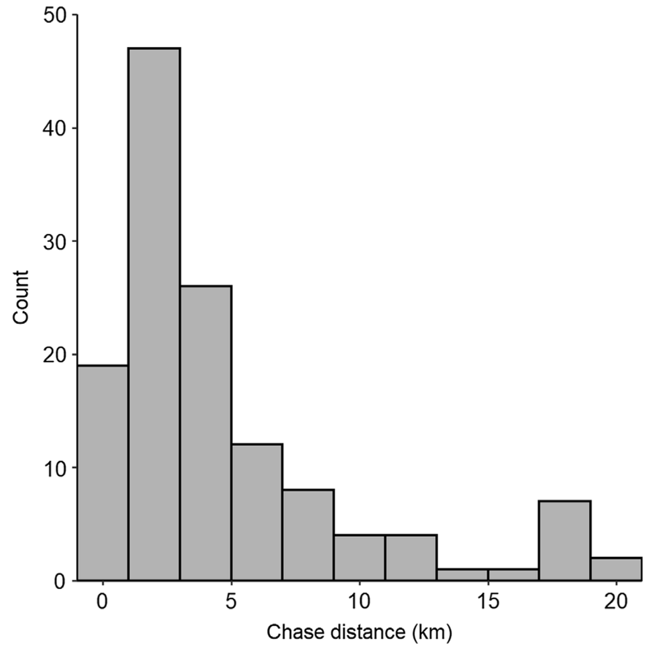

Fig. 5. Histogram of chase distances for sambar deer (*Cervus unicolor*) during recreational hound hunting in eastern Victoria, Australia, in 2020–2021.

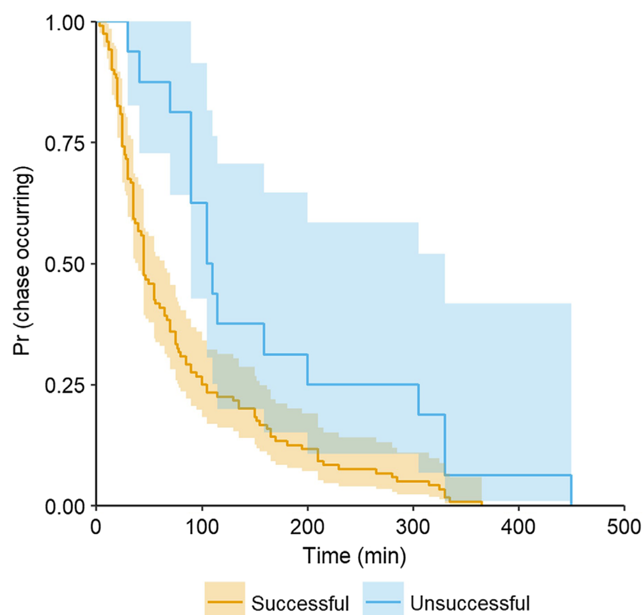

Fig. 6. Kaplan–Meier survival curves showing the probability (Pr) of different chase durations for sambar deer (*Cervus unicolor*) during successful and unsuccessful recreational hound hunts in eastern Victoria, Australia, in 2020–2021.

Spatial distribution of kill sites

We performed RSF for deer killed in Omeo, *n* = 19 (hound-hunting Crew 1 in Fig. 1) and Dargo, *n* = 89 (hound-hunting Crew 4 in Fig. 1). The spatial distribution of kill sites in our study varied both between sites and between sexes. In Omeo, hound hunters killed 8 male and 11 female sambar deer. There, hunters were more likely to kill male deer on steep westerly slopes with high levels of

Table 3. Posterior distribution of model parameters for resource-selection function used to characterise the spatial distribution of killing sites of sambar deer (*Cervus unicolor*) from recreational hound hunting in Omeo, eastern Victoria, Australia, in 2020–2021.

Parameter	Mean	Median	Mode	lHDI	uHDI	s.d.	*R*	ESS
Male sambar deer								
Intercept	−14.056	−13.195	−13.139	−37.330	2.784	10.014	1.124	138
Elevation	0.000	−0.001	−0.010	−0.016	0.018	0.008	1.114	198
Slope	0.341	0.328	0.271	0.097	0.665	0.144	1.008	1121
Woody cover	0.093	0.089	0.103	0.016	0.195	0.044	1.010	666
Distance to roads	−0.003	−0.003	−0.002	−0.008	0.000	0.002	1.007	1796
Distance to watercourses	−0.016	−0.015	−0.019	−0.042	0.007	0.013	1.017	3533
Easterly aspect	−3.462	−3.311	−2.888	−6.594	−1.151	1.392	1.006	1378
Northerly aspect	0.108	0.118	1.228	−1.420	1.561	0.755	1.000	44 222
Female sambar deer								
Intercept	−0.092	0.009	11.549	−11.637	10.721	5.781	1.010	227
Elevation	−0.004	−0.004	−0.011	−0.014	0.007	0.005	1.009	234
Slope	−0.042	−0.041	−0.109	−0.192	0.101	0.075	1.001	4760
Woody cover	0.023	0.021	0.023	−0.015	0.076	0.023	1.000	1728
Distance to roads	−0.001	−0.001	−0.001	−0.002	0.001	0.001	1.000	20 892
Distance to watercourses	0.009	0.009	0.010	−0.004	0.023	0.007	1.002	1654
Easterly aspect	−0.911	−0.895	−1.045	−2.153	0.235	0.604	1.000	22 097
Northerly aspect	−0.301	−0.282	−1.003	−1.577	0.869	0.620	1.000	28 627

lHDI and uHDI represent the lower and upper limits of the 95% credible intervals, *R* is the Gelman–Rubin diagnostic, and ESS is the estimated sample size.

woody vegetation (Table 3). Male deer were also more likely to be killed near roads. Opposingly, given the same available landscape as for males, there was no evidence of habitat associated with kill sites of female deer. In Dargo, hunters killed 50 male deer and 43 female deer and kill sites for both sexes showed a similar association with habitat. Sambar deer were more likely to be killed on steep slopes and near roads (Table 4).

Discussion

This is the first study quantifying recreational hound hunting of sambar deer in Victoria, Australia. We found that deer were harvested in the majority of hunts. Chase times and distances were highly variable, and deer were more likely to be killed on steep slopes, in areas with woody vegetation cover, and close to roads.

Relative to other published methods relying on the use of dogs to pursue hunted deer, sambar deer hound hunting was relatively efficient, with 88% of hunts resulting in the harvest of a deer. This was markedly higher than the 46% ($n = 170$) observed for hound hunting of red deer (*Cervus elpahus*) in the United Kingdom (Bradshaw and Bateson 2000). However, this measure of efficiency reflects only the success of each hunting crew, not individual hunters. The mean hound hunter success rate in our study (0.35 deer harvested per hunter per hunting day) was less than that estimated for all hound hunters in Victoria (0.45) in 2019 (Moloney *et al.* 2022), and was considerably lower than the efficiency of all deer hunting (including stalking; 0.50) estimated for the same year (Moloney and Hampton 2020). Caley and Ottley (1995) reported identical hunting success (88%) for use of hunting 'pig' dogs to capture feral pigs (*Sus scrofa*) in Northern Territory, Australia. That study reported a significantly male-biased harvest, but analysed data from one-dog team (Caley and Ottley 1995), whereas we examined data from four independent teams.

Sambar deer were more likely to be killed on steep slopes, near roads and in woody cover. The non-random distribution of deer kill sites is likely to be a characteristic of the hunting method rather than of sambar deer distribution. Conversations with the four hunting crews indicated that the proximity to roads is likely to reflect the use of roads by hunters to approach and shoot deer that are bailed by hounds. Finding a positive association between kill sites and the presence of roads is consistent with hunters using vehicles to position themselves for strategic shots along deer escape routes (Steyaert *et al.* 2016). It may also reflect the use of roads as a (presumably) faster way to find deer-scent trails than is looking for scent trails on foot. Accessibility has been associated with increased hunting success for recreational deer hunters in the United States (Lebel *et al.* 2012; Rowland *et al.* 2021). The positive association of steep slopes with the

Table 4. Posterior distribution of model parameters for resource-selection function used to characterise the spatial distribution of killing sites of sambar deer (*Cervus unicolor*) from recreational hound hunting in Dargo, eastern Victoria, Australia, in 2020–2021.

Parameter	Mean	Median	Mode	lHDI	uHDI	s.d.	*R*	ESS
Male sambar deer								
Intercept	0.152	0.292	2.651	−7.359	6.644	3.521	1.046	120
Elevation	−0.002	−0.002	−0.002	−0.005	0.001	0.002	1.011	406
Slope	0.059	0.059	0.049	0.015	0.103	0.022	1.004	2622
Woody cover	−0.002	−0.005	−0.015	−0.049	0.067	0.029	1.067	206
Distance to roads	−0.002	−0.002	−0.001	−0.003	−0.001	0.000	1.000	5809
Distance to watercourses	−0.001	−0.001	−0.003	−0.006	0.002	0.002	1.000	4750
Easterly aspect	−0.104	−0.104	−0.127	−0.527	0.311	0.214	1.000	67 620
Northerly aspect	0.030	0.030	−0.116	−0.546	0.605	0.294	1.001	13 120
Female sambar deer								
Intercept	0.192	0.426	1.702	−7.054	6.965	3.708	1.085	132
Elevation	−0.001	−0.001	−0.003	−0.005	0.002	0.002	1.037	437
Slope	0.097	0.096	0.103	0.049	0.148	0.025	1.011	3084
Woody cover	−0.020	−0.022	−0.038	−0.070	0.042	0.029	1.060	231
Distance to roads	−0.001	−0.001	−0.001	−0.002	0.000	0.000	1.002	4604
Distance to watercourses	−0.004	−0.004	−0.004	−0.010	0.001	0.003	1.003	8763
Easterly aspect	−0.067	−0.065	−0.141	−0.536	0.391	0.236	1.000	62 935
Northerly aspect	−0.113	−0.112	−0.232	−0.734	0.505	0.316	1.004	11 564

lHDI and uHDI represent the lower and upper limits of the 95% credible intervals, *R* is the Gelman–Rubin diagnostic, and ESS is the estimated sample size.

location of kill sites may be due to sambar deer moving more slowly up steep hills and therefore representing an easier target for the hunters (Lone *et al.* 2014). Steep slopes and dense woody vegetation could also represent an escape strategy for deer trying to outpace the chasing hounds. Another reason could be that deer feel safer on steeper slopes and in dense vegetation when chased by hounds (Bongi *et al.* 2008). A common escape strategy used by sambar deer is to cross rivers and streams (Fig. 2), apparently in an attempt to throw the hounds off their scent trail (Mason 2008), but there was no evidence of association between watercourses and kill sites in our study. This is most likely due to us analysing only kill-site location data and not the lead hounds' complete track log. Hunting prescriptions encourage the removal of meat from carcasses, and discourage hunters from leaving carcasses in waterways (Game Management Authority 2014), and this could also have influenced where hunters shot deer.

Our results suggest that there is minimal sex bias in sambar deer harvested by recreational hound hunters in Victoria. This conclusion is supported by historical records. Bentley (1957) described the activities of one Victorian hound hunting pack from 1954 to 1956 and reported that a total of 134 deer was killed, with a slightly male-biased sex ratio of 56:44. In contrast, sambar deer killed by other shooting methods in Victoria (i.e. culling, commercial harvesting and recreational stalking) had a slightly female-biased sex ratio (55:45, n = 144; Watter *et al.* 2020). We are unaware of any data on the sex ratio of *live* (as opposed to killed) sambar deer populations in Australia. If the eastern Victoria sambar deer population is female-biased, as some populations in the native range are (Ramesh *et al.* 2012), then hound hunting may involve the selective harvest of males.

Mean shooting distance was only 39 m for hound hunting, which is markedly lower than the average of 111 m recorded for ground-based shooting of the same species without the aid of hounds (Hampton *et al.* 2022*b*). This result suggests that hound hunting allows shooters to get much closer to deer than is possible through diurnal stalking or nocturnal culling (Comte *et al.* 2022*a*). The relatively high frequency of repeat shooting (>1 shot fired at a deer) of 32% for hound hunting (compared with 7–14% for stalking and culling; Hampton *et al.* 2022*b*) is likely to reflect hunters shooting at moving deer and a greater ability to take follow-up shots at deer when pursued or bailed by hounds.

Average sambar deer pursuits were of considerable length as measured by distance (>4 km) and duration (>90 min). The longest of these were >20 km (Fig. 5) and >7 h (Fig. 6) respectively. It is possible that multiple deer were involved in some hunts, allowing some deer to be chased for only a proportion of our reported chase times before escaping, whereas other deer may have been chased multiple times. Unfortunately, the data we collected could not be used to quantify these outcomes. Chase distances were lower than for other deer species studied overseas. For example, red deer hunted with hounds in the United Kingdom in the 1990s ran an average of 19 km before being killed (Bateson and Bradshaw 1997). However, the duration of stress imposed by hound hunting is considerably longer than that associated with other deer killing methods used in Australia, notably professional nocturnal vehicle-based culling of rusa deer (*Cervus timorensis*) (Hampton *et al.* 2022*c*) and aerial shooting of fallow (*Dama dama*) and chital deer (*Axis axis*) (Hampton *et al.* 2022*a*).

For most species, physiological exertion imposed over timeframes of hours raises animal-welfare concerns (Le Grand *et al.* 2019). We did not collect biological samples from sambar deer pursued by hounds, but it is likely that the physiological effects of pursuit (as measured by the concentrations of markers of exertion in blood) would be similar to those documented in red deer (Bradshaw and Bateson 2000; Gentsch *et al.* 2018) and moose (*Alces alces*) (Græsli *et al.* 2020) pursued by scent-trailing hounds.

Animal-welfare implications for hound hunting include those affecting the deer (Bradshaw and Bateson 2000), the hounds (Orr *et al.* 2019), and any non-target wildlife that may be disturbed or harassed (Allen *et al.* 2019). These animal-welfare concerns are common to any recreational hunting methods that use dogs to pursue animals (Hampton and Hyndman 2019). Our study did not attempt to elucidate outcomes for hunting dogs or non-target wildlife species, but did allow some inference regarding impacts on deer. There were no reports of non-fatal wounding in this study, likely because shooting distances were small relative to other those of deer hunting methods, and the presence of hounds permitted hunters to track wounded deer to allow repeat shooting (Gentsch *et al.* 2018). However, the presence of some 'gundogs' has been associated with an increase in the frequency of non-fatal wounding for recreational hunting of other deer species (Godwin *et al.* 2013). Non-fatal wounding does not appear to be a central animal-welfare concern for hound hunting as it is for other deer management methods, such as nocturnal shooting from vehicles (Hampton *et al.* 2022*c*). However, pursuit is likely to cause animal-welfare impacts.

Other authors have speculated that the capacity for deer to cope physiologically with being pursued by hounds is shaped by their evolutionary or individual histories (Bateson and Bradshaw 1997). In this context, sambar deer have evolved with a suite of large mammalian predators, such as, for example, tigers (*Panthera tigris*) in southern Asia (Hayward *et al.* 2012) and are likely to be harrassed or attacked occasionally by dingoes/wild dogs in contemporary south-eastern Australia (Forsyth *et al.* 2019). Although the stress experienced prior to death is likely to be significant for sambar deer hunted with hounds, the impact of hunting on chronic stress of surviving deer is unknown (Sauerwein *et al.* 2004). Bradshaw and Bateson (2000) questioned what proportion of red deer that are hunted but escape die from severe physiological injuries (i.e. exertional myopathy and hyperthermia) sustained during a hunt. Our study was unable to address this question for sambar deer. To better understand animal-welfare impacts, future studies of hound hunting could collect blood samples to measure cortisol concentrations (or other physiological stress markers; Bradshaw and Bateson 2000). Alternatively, captured sambar deer could be equipped with ruminal temperature loggers, subcutaneous heart rate loggers and GPS collars with accelerometers, as was undertaken for moose in Sweden (Græsli *et al.* 2020).

There is interest in increasing the role of Australian recreational hunters in programs aiming to reduce the undesirable impacts of sambar deer (Australian Senate 2021), but only stalkers have been involved in management programs (Comte *et al.* 2022*a*). Hound hunting could prove useful for removing sambar deer surviving after other techniques such as stalking and aerial shooting have been used. However, our results suggest that hound hunting is most likely to be useful in areas with a developed road network. Land-use types such as timber (forestry) plantations (Davis *et al.* 2017) might be amenable. However, hound hunting may be problematic to employ on public land close to adjoining private land because of the risk of hounds (and pursued deer) crossing fences into livestock grazing properties (Game Management Authority 2014). Dog-assisted hunting has been widely used to eradicate feral pigs on islands (Cruz *et al.* 2005), and was used in the final stage of red deer eradication on Secretary Island, New Zealand (Macdonald *et al.* 2019). If hound hunting was to be used to control or eradicate sambar deer in remote areas, then a track network would need to be established to facilitate the rapid movement of hunters, as was done on Secretary Island (Macdonald *et al.* 2019).

Our study had several limitations. First, our sample size was relatively small (n < 150), so our ability to robustly estimate the frequency of infrequent events such as non-fatal wounding (no occurrences were reported) was limited (Hampton *et al.* 2019). Second, we relied on data collected by hunters rather than by independent observers (e.g. Bradshaw and Bateson 2000). This could have biased our results towards underestimation of ambiguous events with negative connotations (e.g. non-fatal wounding). Third, selection of hunting crews was non-random, and it is possible that the outcomes achieved by the crews that volunteered to participate in this study may have been better than in the general hunter population. Fourth, the hunters estimated (rather than measured) the ages of deer. Last, we did not have access to the complete track logs of lead hounds, limiting our analyses to the total time and distance of the hunt and, for successful hunts, to the kill site. Hence, our inferences relating to landscape features reflect sites where hunters prefer to take shots at deer, rather than the habitat deer use during a hunt (Lebel *et al.* 2012; Comte *et al.* 2022*a*).

Conclusions

Successful hound hunting requires a network of roads, potentially limiting the usefulness of this method for controlling deer in remote areas. Hound hunting chase times and distances are long relative to those of other deer hunting methods, but non-fatal wounding was not reported.

Supplementary material

Supplementary material is available online.

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Data availability. The data that support this study are not publicly shared due to privacy reasons but may be shared upon reasonable request to the corresponding author if appropriate.

Conflicts of interest. David Forsyth is a guest Associate Editor of *Wildlife Research* but was blinded from the peer-review process for this paper. Three authors are employees of government agencies involved with the management of deer hunting activities in the state of Victoria, Australia: Jason Flesch and Simon Toop work for the Victorian Game Management Authority, and Chris Davies works for Parks Victoria. Their employment could not reasonably have interfered with the full and objective presentation of this research.

Declaration of funding. This project was funded by the Victorian Game Management Authority and the McKenzie Fellowship Program of the University of Melbourne.

Acknowledgements. This was an observational study of legally compliant recreational hunting activities and did not require Animal Ethics Committee (AEC) approval. We thank Danny Edebohls, Chris Eaton, Corey Lewis, Craig Hill and their colleagues for collecting data. We thank Zachary Powell, Barry Howlett, Bronwyn Orr and Jon Arnemo for initial discussions that led to the conception of this project. The Australian Deer Association assisted with outreach to hunters.

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