Effectiveness of toxic baiting for the control of canines and felines

Authors: Yong Zhi Foo[1], Daniel W. A. Noble[2], Patrick L. Taggart[3,4,5]*

Affiliations:

[1] Centre for Evolutionary Biology, School of Biological Sciences, University of Western Australia, 35 Stirling Hwy, Crawley 6009, WA, Australia

[2] Division of Ecology and Evolution, Research School of Biology, Australian National University, Canberra, ACT, Australia

[3] Vertebrate Pest Research Unit, Department of Primary Industries NSW, Queanbeyan, New South Wales, Australia

[4] School of Animal and Veterinary Sciences, The University of Adelaide, Roseworthy, South Australia, Australia

[5] School of Biological, Earth and Environmental Sciences, University of New South Wales, Sydney, New South Wales, Australia

* Correspondance: patrick.taggart@bushheritage.org.au

Highlights

- Baiting increased the probability of predator death by 36% relative to control plots.
- Higher bait densities along tracks achieved greater predator knockdown.

- No effect of predator family, canine Vs feline, on baiting effectiveness.
- No effect of bait matrix or repeat bait application in short time period on baiting effectiveness.
- Many accepted baiting practices have little empirical support, and are premature given available evidence.

ABSTRACT

Toxic baiting is used for the lethal control of mammalian predators. It is easily applied over large areas and can be highly effective, but also receives significant criticism. We conducted a meta-analysis of the efficacy of lethal baiting for the feral cat, red fox and dingo; our outcome of interest was predator survival. Our dataset contained 125 effects from 35 studies, comprising 1560 individuals tested. Overall, baiting increased the probability of predator death by 36% relative to control plots. However, this effect was stronger (46% increased probability of death) when baits were distributed along tracks relative to across areas (probability of death comparable for baited and unbaited areas). We found no evidence that baiting was more effective at reducing canine relative to feline populations. We additionally found no evidence that Eradicat® achieved greater cat death than other baits. Higher bait densities achieved greater predator knockdown when baits were distributed along tracks, but not when baits were distributed across areas. We found no evidence that repeat bait applications over short periods of time achieve greater population reduction than single bait applications; this was consistent across both design types. Similarly, we found no evidence for an effect of bait matrix (fresh meat, dry processed bait, mixture) for either design type. Our study shows that many accepted baiting practices and perceptions have little empirical support, and are premature given the available sparse evidence. Further, rigorous research is of high priority in this field.

Keywords

Lethal; population; bait; pest; management; control

INTRODUCTION

Baiting is one of the most frequently used techniques for the control and management of invasive species, particularly mammals (Taggart et al. 2023a). For example, over one third of global cat eradication programs rely heavily on baiting (Nogales et al. 2004; Campbell et al. 2011), and 75-85% of lethal fox and dingo/dog control in Australia is achieved through baiting (West & Saunders 2003; Reddiex et al. 2006). Baiting can be highly effective at controlling a target animal population. For this reason, it is frequently used to manage wildlife populations *in situ*. Most commonly, it is used to deliver toxins for the lethal control of target individuals or populations (Taggart et al. 2023a). The high frequency of baiting programs can be, in part, attributed to its easy and often cost-efficient application (Thompson & Fleming 1991). Toxic predator baits are produced both commercially and made in-house by practitioners, and then distributed by researchers, government officials, industry, or private individuals (Allen et al. 2013; Bengsen 2014). Baiting applications can occur across vast spatial scales, exceeding multiple thousand square kilometers, and they are often the only method of predator control that can be successfully applied at these scales (Taggart et al. 2023a).

While lethal predator baiting programs have been shown to be effective at reducing the economic and biological/environmental costs of invasive species they can also be controversial. Compassionate conservationists follow the guiding principles of *first do no harm, individuals matter, inclusivity, and peaceful coexistence*. They advocate for the intrinsic value of all wildlife, irrespective of their abundance, nativeness or impacts, and are accordingly opposed to lethal control in any form (Sherley 2007; Wallach et al. 2015). Toxic baiting also has the potential for unintended consequences. Non-target species can consume baits and experience lethal impacts, although population level impacts of toxic predator baiting on non-target species are difficult to demonstrate (Glen et al. 2007). Some additionally argue that the lethal control of canine predators, predominately achieved through baiting, contributes to the release of smaller mesopredators that have more significant detrimental impacts on native flora; others argue it has changed entire ecosystems, including fauna and flora assemblages and vast land forms (Johnson et al. 2014; Lyons et al. 2018; Mills et al. 2021).

Lethal predator baiting requires a series of successive steps (Bengsen et al. 2008; Fancourt et al. 2021); 1) the predator must be able to find a bait; 2) access the bait; 3) be sufficiently attracted to consume the bait; and 4) the bait must then have a sufficient quantity of toxin to be lethal. The optimisation of this process has substantial applied benefits for anyone with an interest in lethal predator baiting, irrespective of if they are advocates or critics. For example, refining and optimising the minimum density at which baits should be distributed in the environment to achieve a given population reduction can save on labour costs for those aiming to lethally control feline or canine populations. Similarly, reducing the number of baits distributed in the environment is also of interest to those aiming to minimise possible impacts on non-target species. The optimisation of many other aspects of the baiting process, such as the bait matrix, the frequency of bait application/distribution, and bait presentation also have applied value for both advocates and critics of lethal predator baiting. Nonetheless, we lack a systematic and quantitative framework that evaluates baiting programs to understand their impacts on predator control or the factors explaining their success. Such a synthesis can provide important insight to help modify programs in positive ways for better outcomes – both ethically and biologically.

Here, we conducted a meta-analysis to better understand the process and effectiveness of lethal baiting of feline and canine populations. Meta-analysis enables the collation of many individual study effects that vary in size and direction, but fundamentally address an equivalent question. In this way, meta-analysis facilitates the identification of an average effect, a quantification of the variability of effects across studies, and factors (moderators) that explain such variation. With this in mind, and in the context of lethal predator baiting, we addressed five main questions; 1) does baiting work to lethally control predators, and if so, how well? 2) Does the effectiveness of baiting differ for canines and felines? 3) Do higher bait densities achieve greater lethal predator control? 4) Do repeated bait applications within a short period of time achieve greater predator control relative to single bait applications? And 5) does the bait matrix influence the effectiveness of the baiting program?

Methods

In the reporting of our methods we follow the *MeRIT* guidelines (Nakagawa et al. 2023).

Identification of literature

A previous study recently published a systematic review of baiting within the fields of conservation and pest management; for a detailed description of their literature search see Taggart et al. (2023a). Briefly, they systematically searched titles and abstracts contained within Web of Science and Scopus. Their search string contained four main terms, the first focused on capturing baiting studies, the second focused on capturing studies within the fields of conservation or pest management, the third focused on capturing field studies as opposed to laboratory or simulation studies, and the last search term was constructed to remove common themes that were not of interest. They then supplemented their systematic searches in both Web of Science and Scopus with an equivalent search in Google Scholar to capture grey literature. This systematic search identified 65 canid and felid baiting studies of relevance to our meta-analysis. Using these 65 studies, PLT conducted backward and forward snowballing to identify additional relevant studies. Snowballing was conducted on 15th March 2022. This process was aided by Citation Chaser (Haddaway et al. 2022), which captures both published and grey literature, with backward and forward snowballing conducted manually for any articles that did not contain a DOI. Snowballing obtained a list of 2,232 references. PLT then identified 364 of these to be duplicates in Endnote and a further 121 to be duplicates in Rayyan (Ouzzani et al. 2016). PLT conducted title and abstract screening of the remaining 1747 papers in Rayyan and identified a further 37 for consideration in our meta-analysis. This gave a total of 102 papers for consideration in our meta-analysis (Figure 1).

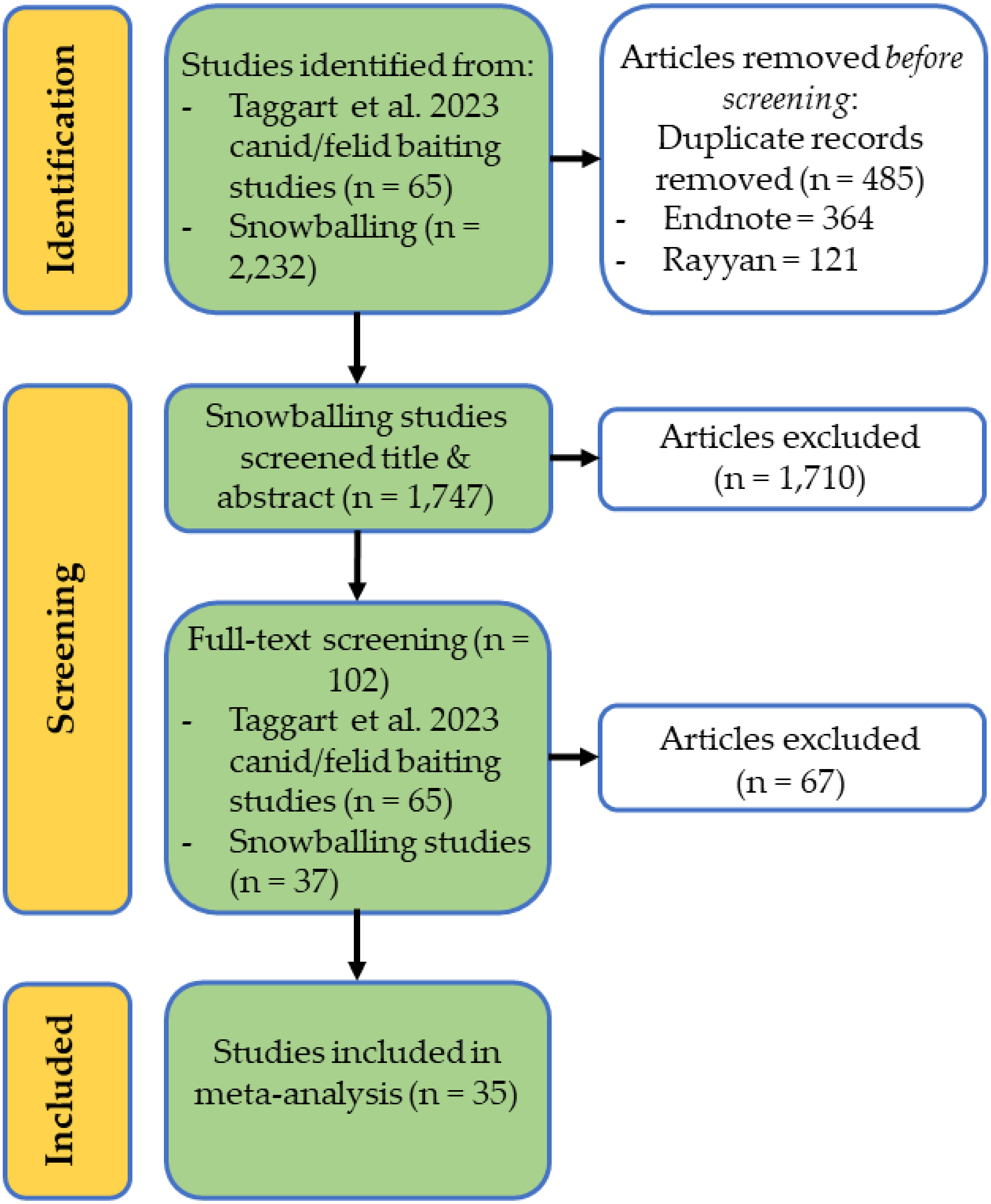

Fig. 1. Modified PRISMA diagram showing the search process and the number of article/reports considered at each step (orange boxes). For each step, green boxes represent articles/reports included and unfilled boxes represent articles/reports excluded.

Inclusion criteria and full text screening

Inclusion criteria were discussed and agreed upon by all authors. To be included in our meta-analysis studies had to: 1) distribute toxic baits for the lethal control of feral cats (*Felis catus*), foxes (*Vulpes vulpes*) or Dogs/Dingoes (*Canis lupus familiaris*/*Canis lupus dingo*) in a defined area or transect; and 2) have tracked a known number of individuals prior to and post baiting; or 3) explicitly state the number of individual animals present prior to and after baiting. We made one exception to these criteria Algar et al. (2007), who explicitly stated the number of individual feral cats present prior to baiting and the number of baits taken. We focused on studies quantifying individual animals as best possible to avoid debate over the value and credibility of population indices (Hayward & Marlow 2014; Hayward et al. 2015). Studies frequently did not demonstrate with absolute certainty that all individuals had died specifically due to the consumption of a toxic bait, such as through laboratory confirmation of 1080 in deceased animals. Rather, most studies made the assumption that if animals were alive immediately prior to baiting, and died soon after the baiting event, then their death was due to toxic bait consumption. Here we made this same assumption - i.e. deaths of predators after baiting events were attributed to the lethal impacts of the baiting event.

Full-text screening was conducted by YZF. We excluded 62 papers during the full-text screening process that did not meet our inclusion criteria, typically because they did not demonstrate with confidence that there was a known number of individuals prior to or after baiting. This gave a total of 35 papers from which data were extracted.

Data extraction

Data extraction was predominately conducted by YZF, with assistance form PLT. All information was extracted at an equivalent level to which authors reported baiting impacts on predator survival. For example, some studies distributed baits on a single occasion and quantified the impact on predator survival in association with this single event, but other studies distributed baits on multiple occasions within a short period of time or replenished all taken/missing baits before quantifying the impact on predator survival;

information for these studies was accordingly extracted at these different reporting levels. This difference in reporting/data capture and extraction was captured and accounted for in analysis through the use of a repeat baiting moderator that indicated if a single or multiple bait applications (within a short period of time) had occurred prior to estimating impacts on predator numbers. In this context, authors were said to have employed repeat baiting if any additional baits were deployed/distributed shortly after a main initial deployment; this included the daily replacement of taken/missing baits and the complete replacement/re-distribution of all baits. For each paper we additionally extracted information pertaining to: authors affiliations, year of publication, target species/predator, toxin used, toxin concentration and total volume, bait matrix, bait brand, time between repeat bait applications, method of bait distribution, bait density, duration of baiting, study area, temperature and rainfall. Our final raw dataset can be found at *open_source_respository_to_be_inserted_after_review*.

Outcomes

We focused on two major outcomes, the number of individuals killed and the proportion of individuals that took the bait. Measures were included only when they clearly reported on the number of individuals pre and post experiment. Examples included the number of radio-collared individuals alive pre and post baiting, the number of individuals identified by pelage pre and post baiting, the distinct number of genotypes pre and post baiting, and the number of feral cats that took baits out of a total number of individuals known to be alive prior to baiting.

Effect size calculation

We used the log odds (i.e. log(number of baiting success/number of baiting failures)) as our effect size in meta-analytic models. Zero values (i.e., zero successes) are problematic for the calculation of log odds ratios, so a small adjustment of 0.5 was added to any zero value to ensure that the log odds was defined. As such, any result on the efficacy of baiting is likely conservative. Given that only 16 effects contained both experimental and control groups, we were unable to use traditional contrast-based meta-analysis approaches, which require data from both groups to calculate effect size (e.g. log odds ratio). Therefore, we used a long form armed-based approach instead, where each row of data, or entry, is represented by the odds (natural logarithm) of baiting success of an individual treatment/control group.

Moderators

Due to the relatively low number of effect sizes within each data set (track/road vs. area based studies), we limited the number of moderators included in models to only those considered to be the most important based on biological plausibility. These were bait matrix (3 levels - fresh meat bait, dry processed sausage bait, mixed), predator family (2 levels - canines vs felines), repeat bait applications (2 levels - single versus repeated), and bait density. We also recorded the year of publication, to examine potential time-lag bias (i.e. tendency for studies with large effects to be published earlier - see details below).

Data analysis

All analysis was conducted in R version (4.2.2) (Team 2023) and plots created in *ggplot2* (vers. 3.4.4, Wickham 2016) by YZF. We fitted multilevel meta-analytic and multilevel meta-regression models run using the `rma.mv()` function within the *metafor* package (vers. 4.4.0, Viechtbauer 2010).

We first tested for an overall effect of baiting on the log odds of predator death. We included baiting treatment (treatment vs. control) as a fixed effect. Our data contained several potential sources of non-independence that we controlled for by including the corresponding random effect. In total, there were four random intercepts: paper identity, study identity (some papers might have multiple studies), effect size identity (for identifying the pairs of treatment and control group comparisons), and entry ID (individual treatment or control effect) as random intercepts. Random intercepts that did not account for any heterogeneity (i.e. > 0%) were dropped from the final model. We report on measures of I^2, which quantify the proportion of variation explained by specific random effects relative to total heterogeneity (excluding sampling variance). Given that we conducted an arm-based analysis we also included random slopes for baiting treatment within each paper identity and effect size identity. We also assumed that the within-study variance was not constant between the control and treatment groups by estimating separate within study variances. Due to baits being distributed either along tracks, trails and roads, or across areas (spatial polygon), and there being no accepted method of comparing these two designs, we split our data in two for all downstream analyses. Accordingly, we conducted equivalent analyses for both track/road and area-based studies. We conducted the moderator analyses on just the treatment group data, after removing all control group data. Therefore, the moderator analyses represent how the treatment group results varied depending on the moderators.

Publication Bias

We ran two analyses to detect potential publication bias: 1. small study effects, where effect sizes from studies with small sample sizes are over-estimated (hereafter referred to as the small study bias) and 2. time lag bias (i.e. when initial findings are dominated by studies reporting larger effects). For small study bias, we entered the effect sizes' standard error as a moderator (*sensu* Taggart et al. 2023b). For time lag bias, we entered the year of publication (centered) as a moderator. Both moderators were entered simultaneously in a multilevel multiple regression with paper ID and effect size ID included as random factors. For the track/length baiting studies, we also included bait density to control for heterogeneity in effect sizes due to the moderator.

Results

Data description

Our final dataset contained 35 papers, that provided a total of 125 effects. Of these 125 effects, 16 contained both experimental and control groups, and 109 had only an experimental group. Sixty-eight effects came from track/road based studies, 49 from area based studies, and 8 studies could not be classified as either design type. Ninety-two effects related to the baiting of feral cats, 14 to fox baiting and 19 to dingo/dog baiting. Overall, 111 effects came from mainland Australia, 9 from 5 different Australian islands, 4 from mainland New Zealand and 1 from a Galapagos island. Together, 1560 individuals were tested.

Details of the specific bait used, or methods employed, were often incomplete (Table 1). Nonetheless, based on the available details, when feral cats were targeted in baiting, dry/processed baits were by far the dominant bait base used. A large proportion of these dry/processed baits used to target feral cats were Eradicat, but bait brand information was not provided for approximately half of all feral cat effects. Most baits targeting feral cats were surface laid, and a greater proportion were distributed on-ground as opposed to via air. When foxes were targeted in baiting, dry/processed baits were again the dominant bait base used. Some of these dry/processed baits were Foxoff, but bait brand information was not provided for approximately half of all fox effects. Fox baits were typically buried or tethered and were largely distributed on-ground. In contrast to feral cats and foxes, when dingoes/dogs were targeted in baiting fresh meat was the dominant bait base. This was typically red meat that was surface laid and distributed by air.

Table 1. Summary of baiting methods used by species targeted.

		Feral cat (number of effects (proportion of total effects))	Red Fox (number of effects (proportion of total effects))	Dingo/dog (number of effects (proportion of total effects))
Bait base	Dry/processed	82 (0.89)	11 (0.79)	2 (0.11)
	Fresh meat	6 (0.07)	3 (0.21)	12 (0.63)
	Mixture (dry & fresh)	0 (0.00)	0 (0.00)	5 (0.26)
	Whole animal carcass	4 (0.04)	0 (0.00)	0 (0.00)
	Total effects	92	14	19
Bait brand	Bait-tek	2 (0.02)	0	0 (0.00)
	Curosity	4 (0.04)	0 (0.00)	0 (0.00)
	Eradicat	29 (0.32)	0 (0.00)	1 (0.05)
	Foxoff	0 (0.00)	3 (0.21)	0 (0.00)
	Oakleigh	1 (0.01)	0 (0.00)	0 (0.00)

		Feral cat (number of effects (proportion of total effects))	Red Fox (number of effects (proportion of total effects))	Dingo/dog (number of effects (proportion of total effects))
	Pedastop fresh red meat	1 (0.01)	0 (0.00)	0 (0.00)
	Pedastop fresh white meat	1 (0.01)	0 (0.00)	0 (0.00)
	In-house fresh animal carcass	4 (0.04)	0 (0.00)	0 (0.00)
	In-house fresh fish	1 (0.01)	0 (0.00)	0 (0.00)
	In-house mixture (dry & fresh)	0 (0.00)	1 (0.07)	0 (0.00)
	In-house fresh red meat	3 (0.03)	4 (0.29)	11 (0.58)
	In-house other	1 (0.01)	0 (0.00)	4 (0.21)
	Information not provided	45 (0.49)	6 (0.43)	3 (0.16)
	Total effects	92	14	19
Bait presentation	Buried	2 (0.02)	3 (0.21)	0 (0.00)
	Buried & tethered	0 (0.00)	2 (0.14)	0 (0.00)
	Physical bait station	2 (0.02)	0 (0.00)	0 (0.00)
	Surface laid	31 (0.34)	2 (0.14)	15 (0.79)
	Suspended	1 (0.01)	0 (0.00)	0 (0.00)
	Tethered	0 (0.00)	4 (0.29)	4 (0.21)
	Information not provided	56 (0.61)	3 (0.21)	0 (0.00)
	Total effects	92	14	19
Bait distribution method	Aerial deployment	34 (0.37)	2 (0.14)	14 (0.74)
	On-ground deployment	56 (0.61)	12 (0.86)	5 (0.26)
	Aerial & on-ground deployment	1 (0.01)	0 (0.00)	0 (0.00)
	Information not provided	1 (0.01)	0 (0.00)	0 (0.00)
	Total effects	92	14	19

How effective is baiting?

The overall risk of dying in a baited area was 51.67% (95% CI: 40.73, 62.46), and was significantly higher (*p* value = 0.01) than the risk of dying in a control area, 16.10% (95% CI: 5.05, 40.91) (Figure 2). However, we found a significant interaction between baiting treatment and design (estimate (contrast - log(odds)): -2.27; 95% CI: -3.75, -0.79; *p* value: <0.01), indicating that the effect of baiting was stronger when baits were distributed along tracks and roads compared to across areas (Figure 2). Comparing effect sizes derived from track/road and area distribution studies, we found that there was a significant effect of baiting on survival when baits were distributed along tracks/roads (estimate (contrast - log(odds)): 3.03; 95% CI: 2.00, 4.05; *p* value = <0.01), but not when baits were distributed across areas (estimate (contrast - log(odds)): 0.72; 95% CI: -0.46, 1.90; *p* value = 0.23) (Figure 2). However, we noted that the mean risk of dying within the baited/treatment group was approximately equivalent for track/road and area distribution studies, and available data for unbaited areas was sparse (only 5 effects). Given that both the random intercepts of study identity and entry identity did not account for any of the variation in effects (i.e. > 0), we retained only the two random slopes in the above analyses.

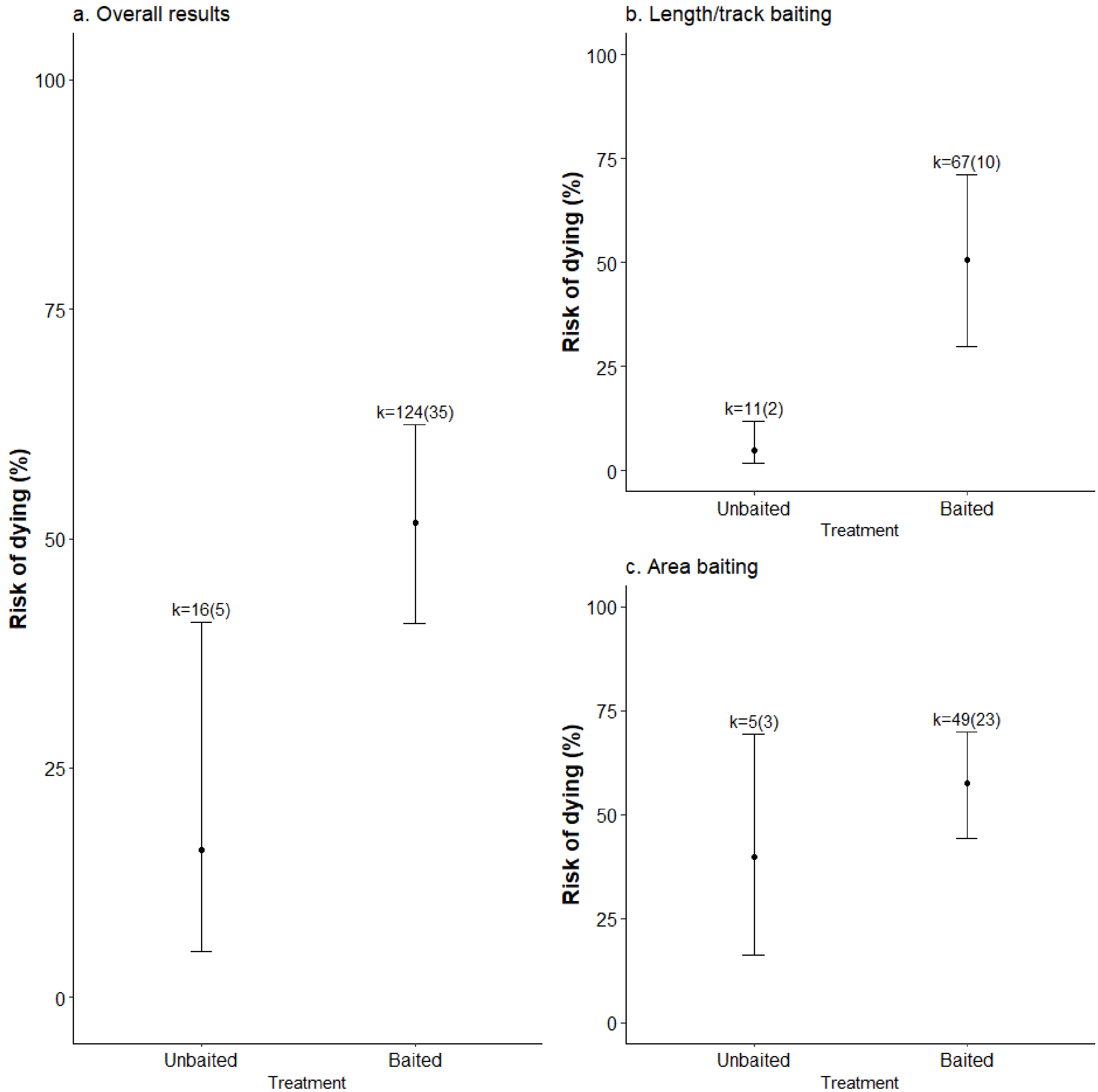

Fig. 2. Marginal means and 95% confidence interval of the risk of dying for baited vs unbaited plots for (a) overall results, (b) track/road distribution studies, and (c) area distribution studies. k refers to the number of effect sizes and number of papers in parenthesis.

Table 2. Model parameter estimates for moderators in track/road based studies. For categorical moderators' parameter estimates are based on estimated marginal means. For the only continuous moderator, bait density, we presented the estimate from the metaregression model.

Moderator	Estimate (ln odds)	SE	95% CI lower (ln odds)	95% CI upper (ln odds)	Risk of dying (%)	95% CI lower (%)	95% CI upper (%)
Bait density (centered)	0.06	0.02	0.02	0.11			
Predator							
Canine	0.09	0.31	-0.53	0.70	52.18	37.09	66.89
Feline	0.06	1.44	-2.76	2.89	51.59	5.96	94.72
Bait matrix							
Dried	0.11	1.07	-1.98	2.20	52.69	12.10	90.01
Mix	-1.67	2.01	-5.61	2.26	15.82	0.37	90.57
Fresh	0.44	1.51	-2.52	3.39	60.80	7.47	96.75
Repeated baiting							
No	-0.05	1.00	-2.02	1.91	48.63	11.74	87.07
Yes	1.12	2.11	-3.01	5.26	75.47	4.70	99.48

Table 3. Model parameter estimates for moderators in area-based studies. For categorical moderators' parameter estimates are based on estimated marginal means. For the only continuous moderator, bait density, we presented the estimate from the metaregression model.

Moderator	Estimate (ln odds)	SE	95% CI lower (ln odds)	95% CI upper (ln odds)	Risk of dying (%)	95% CI lower (%)	95% CI upper (%)
Bait density (centered)	0.00	0.01	-0.01	0.02			
Predator							
Canine	0.01	0.16	-0.31	0.33	50.20	42.32	58.07
Feline	0.56	0.66	-0.73	1.85	63.58	32.42	86.40
Bait matrix							

Moderator	Estimate (ln odds)	SE	95% CI lower (ln odds)	95% CI upper (ln odds)	Risk of dying (%)	95% CI lower (%)	95% CI upper (%)
Dried	0.43	0.53	-0.62	1.47	60.50	35.03	81.32
Fresh	0.57	0.87	-1.14	2.29	63.97	24.28	90.77
Repeated baiting							
No	0.47	0.53	-0.56	1.51	61.63	36.35	81.88
Yes	0.39	0.82	-1.22	1.99	59.58	22.82	88.02

I^2 values revealed a high proportion of heterogeneity, I^2_{Total}: 71.87%, with most variation being explained by the specific paper and effect size (i.e. more than 0%, Table 4). A high proportion of heterogeneity was also observed in models analyzing track/road and area baiting studies separately, with I^2_{Total} being 56.48% for track/road baiting studies and 72.65% for area baiting studies, suggesting moderators could be driving some of the heterogeneity.

Table 4. Proportion of effect size heterogeneity for the treatment groups at the different random effect levels and overall (i.e., total, which excludes sampling variance)

Random effect	I2 (%)
Total	71.87
Paper id	57.70
Effect size id	14.17
Study id	0.00

Does the effectiveness of baiting differ for canines and felines?

We found no evidence that baiting was more effective at reducing canine relative to feline survival, after controlling for bait density, repeat bait applications and bait matrix (p value for length based studies = 0.99, p value for area based studies = 0.37) (Table 2 & 3, Figure 3 & 4).

In 78% of studies where feral cats were targeted in baiting and the brand of bait could be identified, the authors used Eradicat® baits. We therefore also tested, post-hoc, if Eradicat® achieved a greater probability of feline death relative to other bait brands/types. We found no evidence to support this (*p* value = 0.40). For area distribution studies, there was no difference in the probability of feline death when Eradicat® was distributed (risk of dying: 61.52%; 95% CI: 43.08, 77.15), compared to if another bait brand/type was used (risk of dying: 46.64%; 95% CI: 20.80, 74.42). There was insufficient information available to enable an equivalent test for track/road distribution studies.

Do higher bait densities achieve greater lethal predator control?

Higher bait densities achieved a greater risk of predator death when baits were distributed along tracks/roads (estimate (log odds)= 0.06; 95% CI: 0.02, 0.11; *p* value = < 0.01) (Table 2, Figure 3). This was after controlling for predator family, repeat bait distribution and bait matrix. For each additional bait distributed per km, the odds (log) of predator death increased by 0.06. However, the same effect did not hold when baits were distributed across areas (estimate (log odds) = <0.01; 95% CI: -0.01, 0.02; *p* value = 0.94), although the range in bait densities for area distribution studies was limited (Table 3, Figure 4).

Do repeated bait applications achieve greater predator control relative to single bait applications?

We found no evidence that repeat bait applications, within a short period of time, achieved greater predator control (Table 2 & 3, Figure 3 & 4). This was after controlling for predator family, bait density and bait matrix. This lack of an effect was consistent across studies distributing baits along tracks/roads and across areas (*p* value for track/road distribution studies = 0.41, *p* value for area distribution studies = 0.89). When the interval between repeat bait applications was reported, the mean interval was 5 (range: 1, 18) days.

Does the bait matrix influence the effectiveness of baiting?

We found no evidence that bait matrix influenced the risk of predator death (Table 2 & 3, Figure 3 & 4). This was after controlling for predator family, bait density and repeat bait applications. This lack of an effect was consistent across studies that distributed baits along tracks/roads and across areas (p value for track/road distribution studies = 0.41, p value for area distribution studies = 0.52).

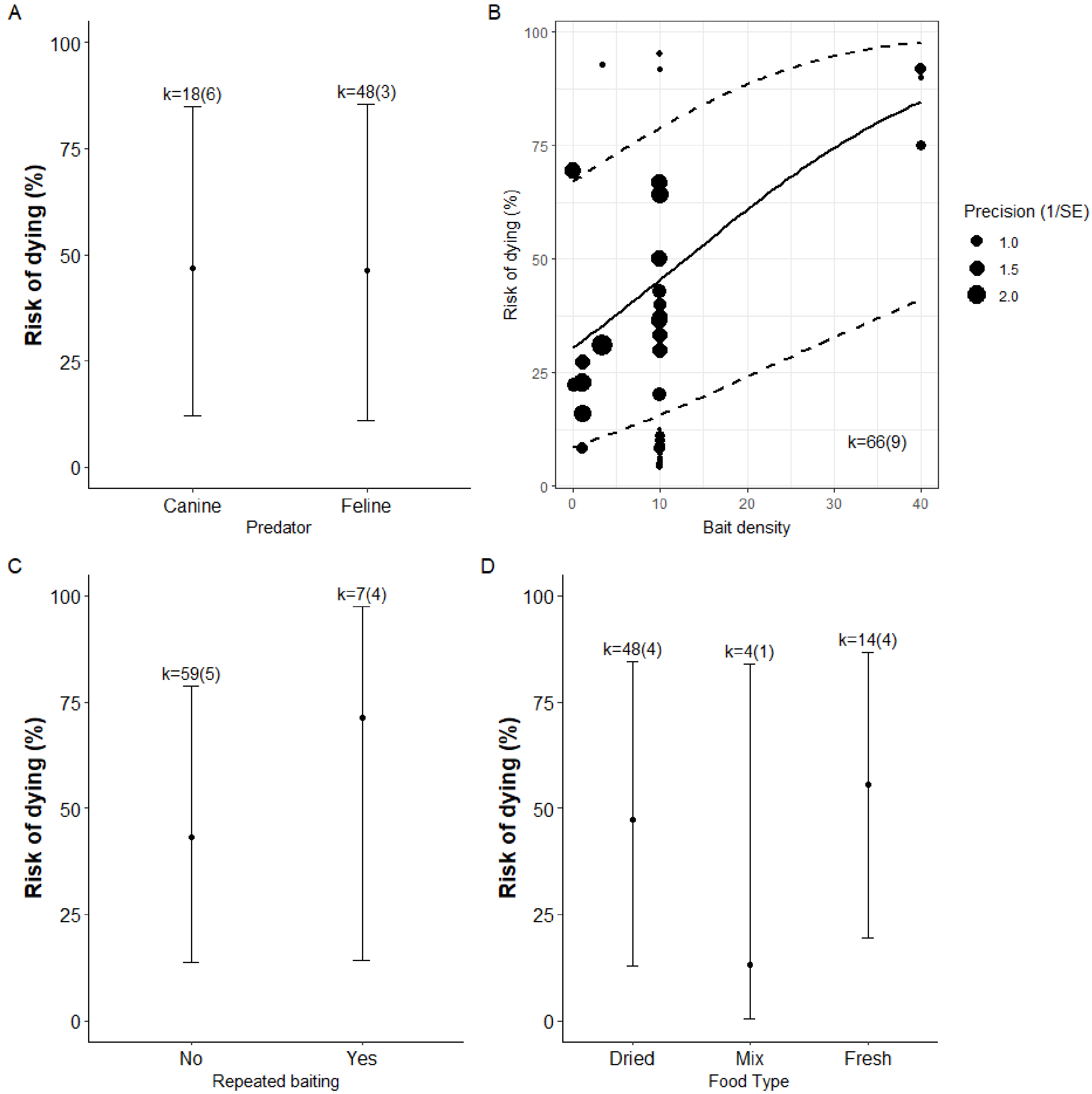

Fig. 3. Moderator effects on the effect of baiting in track/road distribution studies. Each categorical moderator plot (A, C, D) includes the estimated marginal mean effect size (circle) and 95% confidence interval (error bars around the mean effect size). (B) shows the continuous relationship between log odds effect size and bait density. Size of each point corresponds to the precision (inverse of standard error). k refers to the number of effect sizes and number of papers in parenthesis.

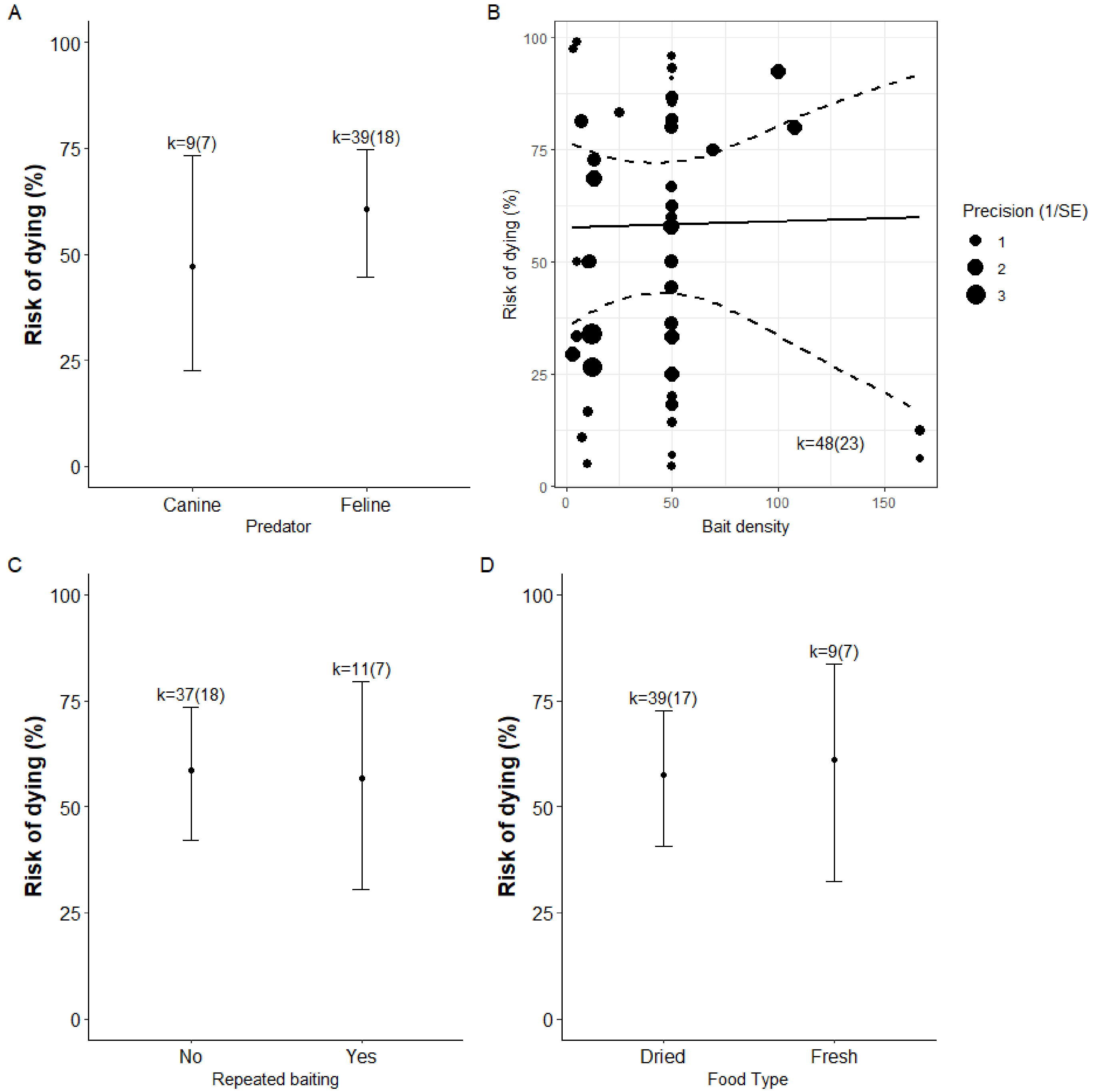

Fig. 4. Moderator effects on the effect of baiting in area-based studies. Each categorical moderator plot (A, C, D) includes the estimated marginal mean effect size (circle) and 95% confidence interval (error bars around the mean effect size). (B) shows the continuous relationship between log odds effect size and bait density. Size of each point corresponds to the precision (inverse of standard error). k refers to the number of effect sizes and number of papers in parenthesis.

Publication bias

Both small study bias and time lag bias (Figure 5) tests were non-significant for both track/road and area baiting studies (*p* values: 0.37 to 0.80).

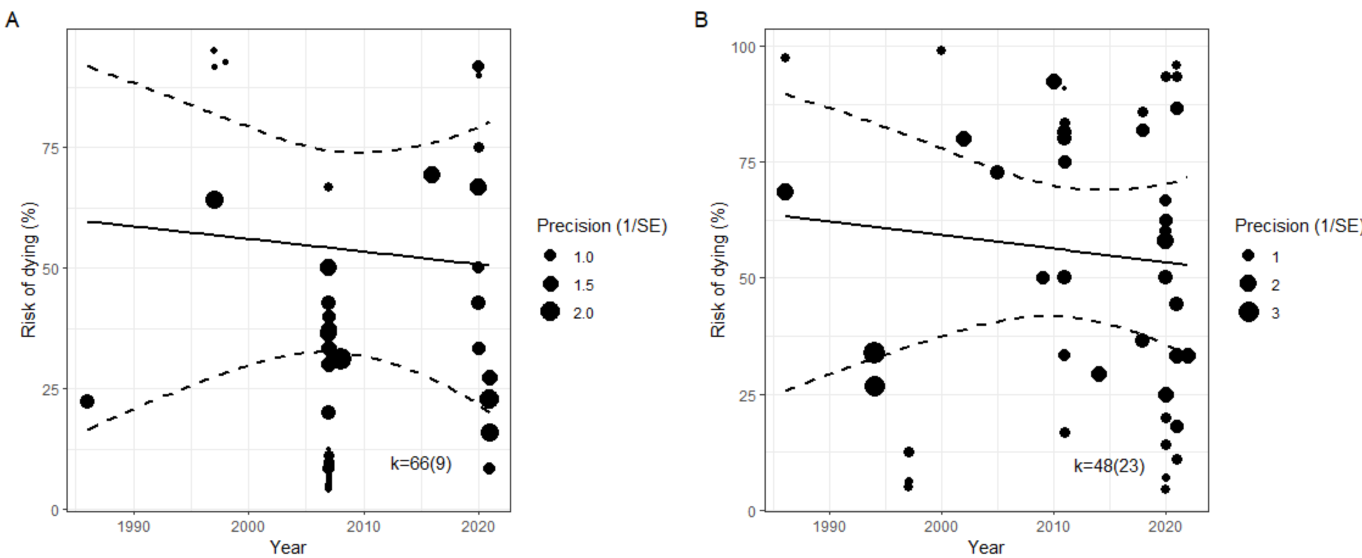

Fig. 5. Relationship between effect size and year of publication for (A) track/road and (B) area baiting studies. Size of each point corresponds to the precision (inverse of standard error).k refers to the number of effect sizes and number of papers in parenthesis.

Discussion

Toxic baiting is a major method used for the lethal control of feral cats worldwide, and the dominant method used for the lethal control of red foxes and dingos/dogs in Australia (West & Saunders 2003; Nogales et al. 2004; Reddiex et al. 2006; Campbell et al. 2011). Toxic baiting can be applied over large areas with relative ease and can be highly effective. However, the practice of toxic predator baiting is also subject to intense criticism for a range of reasons. Given the frequency and scale at with which toxic baiting is applied, its possible lethal outcomes for target and non-target animals, and the strong perceptions and emotions that it evokes, it is critical that baiting practices are founded in robust scientific evidence.

Here, we conducted the first meta-analysis of the efficiency of toxic baiting for the control of feral cats, red foxes and dingoes/dogs. Using predator survival as our outcome variable of interest, we assessed the evidence for key perceptions and routinely accepted standard baiting practices. Our intention was to optimise the baiting process to simultaneously achieve positive outcomes for baiting advocates and critics alike, as we recognised that there will be situations where baiting is the only, or most appropriate control method, but nonetheless should be conducted in an optimal and scientifically robust manner.

Baiting consistently reduces predator numbers

Overall, baiting increased the risk of predator death by 35.5739% relative to no baiting, suggesting that it is an effective method of population control in certain contexts. However, baiting was most effective when baits were distributed along tracks, trails and roads, increasing the risk of predator death relative to no baiting to 45.9465%. These estimates should both be considered conservative given we had a large number of effects where no mortality occurred in the control group; for analytical purposes these 0’s were adjusted to 0.5. In contrast, we found little difference in the risk of predator death between baited and unbaited areas. However, we noted that the mean risk of dying within the baited/treatment group was approximately equivalent for track/road and area distribution studies, and that the available data for unbaited areas was sparse (only 5 effects). Hence, it is possible that the lack of effect observed for area distribution studies was partially driven by high uncertainty in the control group estimate. Similarly, for track/road distribution studies, a large number of effects came from a single study, Algar et al. (2007), and it is unclear if reductions in predator survival in track/road studies represent a general reduction in survival for the broader population, or only a reduction in the survival of animals that preferentially use tracks/roads.

Track and road baiting programs may be more effective because cats, foxes and dingoes preferentially travel along tracks and trails, or similar landscape features that improve movement efficiency and prey detection through the landscape. For example, the placement of camera traps on roads increases rates of detection for all species relative to off road cameras (Read et al. 2015; Geyle et al. 2020; Wysong et al. 2020b), and GPS tracking studies show preferential use of roads and similar linear features by felids and canines (Robley et al. 2010; Bischof et al. 2019; Wysong et al. 2020a). Our results are therefore logical and consistent with literature describing the spatial movements of these predators.

Based on the currently available evidence, land managers wishing to maximise predator population reduction, or minimise excess baits distributed, may focus their efforts on track/road-based bait distribution. While aerial bait distribution may have cost or practical benefits at large scales, its efficiency is less certain (Thompson & Fleming 1991). Land managers must also consider the duration over which predator populations are intended to be reduced to realise meaningful reductions in predator damage. Even when baits are distributed along tracks, tails and roads, the average risk of predator death achieved from baiting is below annual maximum population growth rates for all of feral cats, foxes and dingoes (Hone et al. 2010, 2017). Therefore, assuming predator populations are increasing at their maximum annual growth rates, we would expect populations to continue to increase through time if not subject to further and ongoing control. While predator death was our outcome of interest here, we acknowledge that reductions in populations do not always reduce predator impacts (Campbell et al. 2019).

Baiting is as effective for felines as it is for canines

Our results suggest baiting may be an equally effective management tool for felines and canines. However, additional studies are needed to improve precision in our estimates. Felids are generalist, opportunistic ambush predators, with the domestic/feral cat being no exception (Woinarski et al. 2019). They are typically said to be visually driven and to prefer fresh meat (Kitchener et al. 210AD; Bradshaw et al. 1996). For these reasons they are anecdotally suggested to be reluctant to scavenge and consequently less amenable to control via baiting. In contrast, dingoes and foxes are well documented scavengers (Allen 2010; Forsyth et al. 2014; Spencer & Newsome 2021). However, our results do not support these expectations.

One explanation for baiting appearing to be equally effective for felines as it is for canines would be if a majority of feline studies distributed Eradicat® baits which are said to be superior to other bait brands for feral cat control (Algar et al. 2007). Eradicat® is a manufactured sausage bait specifically designed for uptake by feral cats and may help to overcome their supposed reluctance to scavenge or consume baits. Indeed, in 78% of studies where feral cats were targeted in baiting and the brand of bait could be identified, the authors had used Eradicat® baits. However, for studies where baits were distributed across areas, we found no evidence that Eradicat® baits did achieve greater feline knockdown relative to other bait types, and data was too sparse to enable an equivalent comparison for track/road distribution studies. This suggested that the use of superior Eradicat® baits were unlikley to be the reason why reductions in survival achieved with baiting were largely indistinguishable for canines and felines.

Alternatively, due to the perception that feral cats are reluctant to scavenge or consume baits, practitioners may make additional, concerted efforts to deploy baits at times when alternate prey abundance is expected to be low, increasing the probability that cats do take baits when they are available (Algar et al. 2007; Christensen et al. 2013). Although, effective canine baiting methodology also considers the availability of alternate prey, the timing of bait deployments are viewed to be less critical to baiting success. Irrespective of why the baiting of feral cats may be equally effective to that of canine baiting, our results suggest that this could be the case.

Higher bait densities achieve greater predator knockdown

Our results demonstrate that higher bait densities do achieve a greater risk of death when baits are distributed along track/roads. Although, we could not demonstrate an equivalent effect for studies distributing baits more broadly across areas, we note that the range in bait densities for area distribution data was limited. The ability of predators to find baits in the environment is one of the key steps in the baiting process (Bengsen et al. 2008; Fancourt et al. 2021) and hence greater bait densities should be related to population reduction. Although we did not test for non-linear relationships due to sparse data, we hypothesised that the relationship between bait density and the risk of predator death is non-linear and likely follows some form of effort-outcome relationship where at high bait densities, the population reduction achieved per additional unit of baiting diminishes (Hone et al. 2017).

Although others have shown a positive relationship between bait density and population reduction, and suggest that higher densities do achieve greater population control (Ballard et al. 2020), the relationship is unlikely to be this clear-cut. Indeed, Rees et al. (2023) present data that provide support for a non-linear relationship, suggesting that 2-3 fold increases in bait density may have limited impact on population reduction.

Repeat bait applications do not achieve greater predator knockdown compared to single applications

We found no evidence that repeated bait applications within a short period of time achieved greater predator knockdown relative to single applications. There are a number of possible reasons why this may be the case.

Due to individual behavioural differences, not all predators within populations will consume baits and hence not all predators within a given population will be susceptible to baiting. This may arise due to predator populations being repeatedly exposed to baiting for prolonged periods enabling individuals to develop an aversion to baits if they have experienced sub-lethal impacts previously, or due to other inherent individual differences in animal personalities (Wolf & Weissing 2012). For example, some foxes are known to cache baits, and if cached baits are consumed once the 1080 has degraded to sub-lethal levels, foxes can develop bait aversion (Saunders et al. 1999). If foxes then associate this illness with the bait, individuals learn to avoid baits in subsequent encounters. This effectively reduces the number of foxes susceptible to baiting. In a similar manner, individual cats and dingoes are also known to, at times, avoid baits (Allen et al. 1996; Ratcliffe et al. 2010), however the exact reason for such avoidance behaviours are not always known. For any bait application, there will therefore only be a proportion of the population that are susceptible and likely to consume baits when they are encountered. Single bait applications likely kill the majority of bait-susceptible predators, with subsequent applications shortly after being of limited benefit among largely wary individuals.

The lack of a repeat baiting effect may also be due to baited areas being small or repeat baiting events being too far spaced in time. Rapid immigration into small baited areas may negate carry-over effects from one bait application to another a short time after (Gentle et al. 2007). Such an explanation is supported by findings from Greentree et al. (2000), and also by Molsher (1999) who found that local fox abundance did not decline even when baits were applied monthly. Palmas et al. (2020) also found that following a 44% reduction in local feral cat abundance, the population rapidly recovered to pre-control abundance within three months due to rapid compensatory immigration. Similarly, repeated bait applications may be too far spaced in time, giving predator populations time to recover prior to subsequent bait applications. However, this is an unlikely explanation here given repeat bait applications were typically only approximately 5 days apart (Hone 1999; Hone et al. 2010).

Here we test the difference in the risk of predator death between single bait applications and repeat bait applications within a short period of time, such as replenishing baits daily or a subsequent bait distribution one week after the first. We do not test the difference between single bait applications and repeat bait applications at any and all time points into the future. It would be expected that repeated bait applications at distant time points in the future could further contribute to predator mortality, particularly where immigration is limited; indeed may island eradications of predators employ distant, repeated bait applications.

Fresh baits are not more effective than dried baits

We found little evidence that bait matrix influenced the risk of predator death, although further studies are needed to improve precision in our estimates. This was in contrast to our prediction that fresh meat baits would achieve a greater predator knockdown, especially for canines, and is in contrast to several bait palatability trials. For example, Gentle (2005) inserted trackers into fresh meat and dry processed fox baits to assess whether they were eaten or cached following removal. He found that fresh meat baits were eaten at a vastly higher rate relative to dry processed baits. Similarly, there is some evidence that both dingoes and cats also prefer fresh meat baits (Thomson 1986; Cox et al. 2022). Increasing the attractiveness and palatability of dry processed baits has been a long, and is an ongoing, focus among those studying baiting. The lack of effect detected here may be, in part, attributable to the relatively small number of effect sizes available, compromising statistical power, and their high variability (Johnston et al. 2020; Cox et al. 2022), but nonetheless demonstrates that objective evidence for a superior bait matrix is weak.

Future directions

We are aware that the toxic baiting of predators can be a contentious issue and that there are strong perceptions regarding what works and what doesn't. Our results will be surprising to many people, and we consequently expect that our study and input data will be heavily scrutinised. We encourage this. We supply all data and code to reproduce our analysis and manuscript. Given additional data, there are a host of other variables and interactions that would be worth testing; unfortunately, the current data does not permit this. We encourage additional robust research within the predator baiting field generally, but nonetheless consider our analysis and its power respectable. In meta-analysis, when judging statistical power, it is important to consider the number of papers included, the number of effect sizes extracted, and the number of unique units (in this case individual animals) summarised. Our study summarised 35 papers, 125 effect sizes and 1560 individuals. Despite this, we found limited evidence for many standard baiting practices and perceptions.

To enable further research to contribute most effectively to the improvement of predator baiting practices, collective analyses and collective improvements in methodology, studies should focus on three main areas: 1) Tracking the fate of a known number of individuals through baiting events. Many studies present indices of population change that make quantifying the outcome of baiting challenging and difficult to compare. 2) Improved reporting and design. It is critical that researchers thoroughly report all fundamental information, including the bait brand/type, how it was presented, the concentration or amount of toxin in each bait, the density at which baits were distributed, the total area/distance over which baits were distributed, and if baits were replenished/refreshed and when this was done. However, arguably of greater importance, is the design of the baiting program itself. Adequate unbaited controls are critical, and their absence significantly limits the utility of the information gained and the conclusions that can be drawn. 3) Studies that use atypical methodologies. While regulation and legislation of baiting activities is understandably necessary, rules and regulations around how predator baiting must be conducted, result in homogeneous data. This presents challenges when attempting to make comparisons, optimise and improve methodology. We encourage researchers to seek exceptions to explore the effectiveness of baiting practices outside of routine rules and regulations - this is where improvement in methodology will be realised. We note that many of these reccomendations have been advocated for by others (Hayward et al. 2015).

We had a strong bias towards Australian studies in our analysis. Although predator baiting, especially of feral cats, is applicable worldwide (Nogales et al. 2004; Campbell et al. 2011), many predator baiting studies outside of Australia have not focused on the effectiveness of the baiting for the control of the target predator. Rather, for example, studies have described how baiting has contributed to the eradication of feral cats from an island, without reporting suitable baiting efficiency data to enable extraction for inclusion in meta-analyses. Accordingly, we encourage robust predator baiting efficiency studies outside of Australia.

Our study has focused specifically on the predators themselves and the impact baiting has on them. However, discussion of predator baiting cannot occur in the absence of consideration of lethal non-target impacts to individual animals and populations, or consideration of predator impacts and reduction in predator impacts following baiting (i.e. faunal response). Systematic and quantitative summaries of these topics would be valuable and important. Such work is additionally relevant to improving the effectiveness of baiting for the control of predators themselves. For example, high bait takes rates by non-target species have previously been suggested to be a cause of low mortality for target predators (McIlroy et al. 1986; Algar et al. 2007).

Conclusions

Our study is the most comprehensive analysis of predator baiting to date. However, it is limited to the available, suitable data, which is sparse, highly variable, and at times of poor quality. Nonetheless, based on the currently available published and readily accessible grey literature, we demonstrate that the evidence for the superiority of a number of routine and accepted baiting practices is weak. We consequently encourage all practitioners to publish their findings or make their data available for collective analyses through other means; such information enables baiting methodology to be improved for everyone – advocates and critics alike.

Author contributions:

Detailed author contributions are described throughout the methods section. Briefly, PLT conceived of the study, all authors contributed to the study design, YZF extracted the data and conducted the analysis with assistance from PLT and DWAN, PLT wrote the first draft of the manuscript with assistance from YZF and DAWN, all authors contributed to manuscript revisions and approved the final manuscript.

Conflict of interest statement:

The authors declare no conflicts of interest.

Acknowledgments:

We thank Pip Taylor and Kandarp Patel who contributed to the original systematic review of baiting that subsequently led to this study. Thank you to Ned Ryan-Schofield and anonymous reviewers for constructive feedback on our manuscript.

Data availability statement:

All data and analysis scripts will be made available open-source through GitHub after review.

References

Algar D, Angus G, Williams M, Mellican A. 2007. Influence of bait type, weather and prey abundance on bait uptake by feral cats (felis catus) on peron peninsula, western australia. Conservation Science Western Australia **6**:109–149.

Allen BL. 2010. Skin and bone: Observations of dingo scavenging during a chronic food shortage. Australian Mammalogy **32**:207–208.

Allen BL, Allen LR, Engeman RM, Leung LK. 2013. Intraguild relationships between sympatric predators exposed to lethal control: Predator manipulation experiments. Frontiers in Zoology **10**:1–18.

Allen L, Engeman R, Krupa H. 1996. Evaluation of three relative abundance indices for assessing dingo populations. Wildlife Research **23**:197–205.

Ballard G, Fleming P, Meek P, Doak S. 2020. Aerial baiting and wild dog mortality in south-eastern australia. Wildlife Research **47**:99–105.

Bengsen A. 2014. Effects of coordinated poison-baiting programs on survival and abundance in two red fox populations. Wildlife Research **41**:194–202.

Bengsen A, Leung LK, Lapidge SJ, Gordon IJ. 2008. The development of target-specific vertebrate pest management tools for complex faunal communities. Ecological Management & Restoration **9**:209–216.

Bischof R, Gjevestad JGO, Ordiz A, Eldegard K, Milleret C. 2019. High frequency GPS bursts and path-level analysis reveal linear feature tracking by red foxes. Scientific reports **9**:8849.

Bradshaw JWS, Goodwin D, Legrand-Defrétin V, Nott HMR. 1996. Food selection by the domestic cat, an obligate carnivore. Comparative Biochemistry and Physiology **114**:205–209.

Campbell G, Coffey A, Miller H, Read JL, Brook A, Fleming PJ, Bird P, Eldridge S, Allen BL. 2019. Dingo baiting did not reduce fetal/calf loss in beef cattle in northern south australia. Animal Production Science **59**:319–330.

Campbell K, Harper G, Algar D, Hanson C, Keitt B, Robinson S. 2011. Review of feral cat eradications on islands. IUCN, Gland, Switzerland.

Christensen PE, Ward BG, Sims C. 2013. Predicting bait uptake by feral cats, f elis catus, in semi-arid environments. Ecological Management & Restoration **14**:47–53.

Cox FS, M. JP, Kirby-Crowe KS, Murph EC. 2022. Field palatability and degradation of a selection of feral cat bait matrices on auckland island. New Zealand Journal of Ecology **46**:3495.

Fancourt BA, Augusteyn J, Cremasco P, Nolan B, Richards S, Speed J, Wilson C, Gentle MN. 2021. Measuring, evaluating and improving the effectiveness of invasive predator control programs: Feral cat baiting as a case study. Journal of Environmental Management **280**:111691.

Forsyth DM, Woodford L, Moloney PD, Hampton JO, Woolnough AP, Tucker M. 2014. How does a carnivore guild utilise a substantial but unpredictable anthropogenic food source? Scavenging on hunter-shot ungulate carcasses by wild dogs/dingoes, red foxes and feral cats in south-eastern australia revealed by camera traps. PloS one **9**:e97937.

Gentle MN. 2005. Factors affecting the efficiency of fox (vulpes vulpes) baiting practices on the central tablelands of new south wales. Thesis.

Gentle MN, Saunders GR, Dickman CR. 2007. Poisoning for production: How effective is fox baiting in south-eastern australia? Mammal Review **37**:177–190.

Geyle HM, Stevens M, Duffy R, Greenwood L, Nimmo DG, Sandow D, Thomas B, White J, Ritchie EG. 2020. Evaluation of camera placement for detection of free-ranging carnivores; implications for assessing population changes. Ecological Solutions and Evidence **1**:e12018.

Glen A, Gentle MN, Dickman C. 2007. Non-target impacts of poison baiting for predator control in australia. Mammal Review **37**:191–205.

Greentree C, Saunders G, Mcleod L, Hone J. 2000. Lamb predation and fox control in south-eastern australia. Journal of Applied Ecology **37**:935–943.

Haddaway NR, Grainger MJ, Gray CT. 2022. Citationchaser: A tool for transparent and efficient forward and backward citation chasing in systematic searching. Research Synthesis Methods **13**:533–545.

Hayward MW, Boitani L, Burrows ND, Funston PJ, Karanth KU, MacKenzie DI, Pollock KH, Yarnell RW. 2015. Ecologists need robust survey designs, sampling and analytical methods. Journal of Applied Ecology **52**:286–290.

Hayward MW, Marlow N. 2014. Will dingoes really conserve wildlife and can our methods tell? Journal of Applied Ecology **51**:835–838.

Hone J. 1999. On rate of increase (r): Patterns of variation in australian mammals and the implications for wildlife management. Journal of Applied Ecology **36**:709–718.

Hone J, Drake VA, Krebs CJ. 2017. The effort–outcomes relationship in applied ecology: Evaluation and implications. BioScience **67**:845–852.

Hone J, Duncan RP, Forsyth DM. 2010. Estimates of maximum annual population growth rates (rm) of mammals and their application in wildlife management. Journal of Applied Ecology **47**:507–514.

Johnson CN, Crowther MS, Dickman CR, Letnic MI, Newsome TM, Nimmo DG, Ritchie EG, Wallach AD. 2014. Experiments in no-impact control of dingoes: Comment on allen et al. 2013. Frontiers in zoology **11**:1–3.

Johnston M, Algar D, O'Donoghue M, Morris J, Buckmaster T, Quinn J. 2020. Efficacy and welfare assessment of an encapsulated para-aminopropiophenone (PAPP) formulation as a bait-delivered toxicant for feral cats (felis catus). Wildlife Research **47**:686–697.

Kitchener A, Van Valkenburgh B, Yamaguchi N. 210AD. Felid form and function. In biology and conservation of wild felids. Oxford University Press, Oxford, UK.

Lyons MB, Mills CH, Gordon CE, Letnic M. 2018. Linking trophic cascades to changes in desert dune geomorphology using high-resolution drone data. Journal of the Royal Society Interface **15**:20180327.

McIlroy J, Cooper R, Gifford E, Green B, Newgrain K. 1986. The effect on wild dogs, canis f. Familiaris, of 1080-poisoning campaigns in kosciusko national park, n.s.w. Wildlife Research **13**:535–544.

Mills CH, Wijas B, Gordon CE, Lyons M, Feit A, Wilkinson A, Letnic M. 2021. Two alternate states: Shrub, bird and mammal assemblages differ on either side of the dingo barrier fence. Australian Zoologist **41**:534–549.

Molsher RL. 1999. The ecology of feral cats, felis catus, in open forest in new south wales: Interactions with food resources and foxes. Thesis.

Nakagawa S, Ivimey-Cook ER, Grainger MJ, O'Dea RE, Burke S, Drobniak SM, Gould E, Macartney EL, Martinig AR, Morrison K. 2023. Method reporting with initials for transparency (MeRIT) promotes more granularity and accountability for author contributions. Nature Communications **14**:1788.

Nogales M, Martín A, Tershy BR, Donlan CJ, Veitch D, Puerta N, Wood B, Alonso J. 2004. A review of feral cat eradication on islands. Conservation Biology **18**:310–319.

Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. 2016. Rayyan—a web and mobile app for systematic reviews. Systematic reviews **5**:1–10.

Palmas P, Gouyet R, Oedin M, Millon A, Cassan J-J, Kowi J, Bonnaud E, Vidal E. 2020. Rapid recolonisation of feral cats following intensive culling in a semi-isolated context. NeoBiota **63**:177–200.

Ratcliffe N, Bell M, Pelembe T, Boyle D, Benjamin R, White R, Godley B, Stevenson J, Sanders S. 2010. The eradication of feral cats from ascension island and its subsequent recolonization by seabirds. Oryx **44**:20–29.

Read J, Bengsen A, Meek P, Moseby K. 2015. How to snap your cat: Optimum lures and their placement for attracting mammalian predators in arid australia. Wildlife Research **42**:1–12.

Reddiex B, Forsyth DM, McDonald-Madden E, Einoder LD, Griffioen PA, Chick RR, Robley AJ. 2006. Control of pest mammals for biodiversity protection in australia. I. Patterns of control and monitoring. Wildlife Research **33**:691–709.

Rees MW, Wintle BA, Robley A, Pascoe JH, Pla ML, Birnbaum EK, Hradsky BA. 2023. Fox control and fire influence the occurrence of invasive predators and threatened native prey. Biological Invasions:1–19.

Robley A, Gormley A, Forsyth DM, Wilton AN, Stephens D. 2010. Movements and habitat selection by wild dogs in eastern victoria. Australian Mammalogy **32**:23–32.

Saunders G, Kay B, McLeod L. 1999. Caching of baits by foxes (vulpes vulpes) on agricultural lands. Wildlife Research **26**:335–340.

Sherley M. 2007. Is sodium fluoroacetate (1080) a humane poison? Animal Welfare **16**:449–458.

Spencer E, Newsome T. 2021. Dingoes dining with death. Australian Zoologist **41**:433–451.

Taggart PL, Taylor P, Patel KK, Noble DW. 2023a. Baiting in conservation and pest management: A systematic review of its global applications in a changing world. Biological Conservation **284**:110214.

Taggart PL, Taylor P, Patel KK, Noble DW. 2023b. Baiting in conservation and pest management: A systematic review of its global applications in a changing world. Biological Conservation **284**:110214.

Team RC. 2023. R: A language and environment for statistical computing. R foundation for statistical computing, vienna, austria. URL: Https://www.r-project.org/.

Thompson J, Fleming P. 1991. The cost of aerial baiting for wild dog management in north-eastern new south wales. The Rangeland Journal **13**:47–56.

Thomson P. 1986. The effectiveness of aerial baiting for the control of dingoes in north-western australia. Australian Wildlife Research **13**:165–176.

Viechtbauer W. 2010. Conducting meta-analyses in r with the metafor package. Journal of Statistical Software **36**:1–48.

Wallach AD, Bekoff M, Nelson MP, Ramp D. 2015. Promoting predators and compassionate conservation. Conservation Biology **29**:1481–1484.

West P, Saunders G. 2003. Pest animal survey 2002. An analysis of pest animal distribution and abundance across NSW and the ACT. NSW Agriculture.

Wickham H. 2016. ggplot2: Elegant graphics for data analysis. Springer-verlag new york. ISBN 978-3-319-24277, https://ggplot2.tidyverse.org.

Woinarski JCZ, Legge SM, Dickman CR. 2019. Cats in australia: Companion and killer. Chap 2: The natural history of cats. Page 344. CSIRO Publishing.

Wolf M, Weissing FJ. 2012. Animal personalities: Consequences for ecology and evolution. Trends in ecology & evolution **27**:452–461.

Wysong ML, Hradsky BA, Iacona GD, Valentine LE, Morris K, Ritchie EG. 2020a. Space use and habitat selection of an invasive mesopredator and sympatric, native apex predator. Movement Ecology **8**:1–14.

Wysong ML, Iacona GD, Valentine LE, Morris K, Ritchie EG. 2020b. On the right track: Placement of camera traps on roads improves detection of predators and shows non-target impacts of feral cat baiting. Wildlife Research **47**:557–569.