Assessing factors that influence the use of Curiosity® feral cat baits in Victoria

A Biodiversity Response Planning project

A. Robley, L. Cockman, S. Donald, M. Hoskins, A. Shiells and L. Stringer

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Acknowledgement

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it. We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

We are committed to genuinely partner, and meaningfully engage, with Victoria's Traditional Owners and Aboriginal communities to support the protection of Country, the maintenance of spiritual and cultural practices and their broader aspirations in the 21st century and beyond.

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A Biodiversity Response Planning project

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Context:

The Victorian Government declared feral cats an established pest on Parks Victoria estate and DELWP managed forested lands in 2018. As feral cats rarely exhume buried food, poison baits must be surface laid and can be deployed from the air or the ground. This increases the potential for exposing non-target species to encountering and consuming the bait. There is only limited information available about the rate at which baits are removed by non-target animals and the environmental factors that impact the bait's attractiveness and palatability to feral cats, two factors that reduce the efficacy of control programs.

Aims:

We aimed to (i) assess the fate of Curiosity® feral cat baits that were laid in three of five study sites (ii) to assess environmental factors that may influence its palatability and attractiveness to feral cats at those three study sites and (iii) to continue exploring ways to make cage trapping more efficient at two of the five sites.

Methods:

We assessed bait survival and non-target bait-take rate of surface-laid non-toxic Curiosity feral cat baits at Big Desert State Forest (BDSF), Hattah–Kulkyne (HKNP), and Wilsons Promontory National Park (WPNP). At HNKP and WPNP, we assessed environmental conditions that might influence the degradation of the Curiosity bait by placing non-toxic baits containing the dye Rhodamine B (RhB) in individual small wire cages to prevent take by animals, leaving the baits exposed to the elements. At all three sites we placed non-toxic baits in front cameras and monitored survival (encounter and consumption) over two 14-day periods.

We used survival analysis to investigate both the probability that surface-laid baits would survive when at risk of being taken and exposed to the elements, and when caged-baits were exposed to the elements.

For study areas where they were adequate data, feral cat density was estimated using photographic captures and recaptures of individual cats that could be readily identified from camera images, as well as the number of detections per camera of individuals that could not be identified.

The Barwon South West (BSW) and WPNP Biodiversity Response Planning projects implemented cage trapping to assess a range of lures and visual attractants.

Results:

Caged-bait trials. At HKNP, caged-bait survival was best predicted by the daily maximum temperature 48 hours prior to inspection, and was negatively associated with temperatures over 25ºC. At WPNP, caged-bait survival was negatively impacted when rainfall in the previous 48 hours' rainfall, lagged by 24 hours was above 19 mm. Overall, 65% of baits ($n = 31$) at WPNP had signs of RhB dye in the bait matrix; at HKNP, two baits were observed to have small amounts of leaching.

Surface-laid baits. The median survival time of surface-laid Curiosity baits varied from 5 (WPNP) to 17 days (BDSF). At BDSF, feral cats were recorded consuming two baits and encountering, but not consuming, three baits. At HKNP or WPNP, no bait take by feral cats was observed, although cats encountered bait at HKNP at six sites. Non-target bait interference accounted for most bait takes, with ravens (*Corvus* sp.) and foxes (*Vulpes vulpes*) removing the most baits.

Feral cat density. At BDSF feral cat density was estimated at 0.24 cats/km^2 (95% CI 0.102–0.356), with a corresponding abundance of 56 cats (95% CI 24–84). No estimate was possible at HKNP due to low detection rates. At WPNP, feral cat density was estimated at 0.64 cats/km^2 (95% CI 0.40–0.96), with an estimated abundance across the Yanakie Isthmus of 54 cats (95% CI 30–80).

Cage trapping. BSW cage trapping resulted in the capture of four feral cats. No preferences of lure types were observed. At WPNP, cage trapping resulted in two cats being caught.

Conclusions and recommendations:

The attractiveness and palatability of Curiosity feral cat baits and their availability were influenced by both weather conditions and interference by non-target species. At our wettest site, rainfall over 19 mm rendered baits unattractive, while at more arid sites, temperatures of more than 25ºC over several days desiccated the baits. On average, bait survival was significantly shorter (median 3–9 days) at WPNP (rain affected) than at HKNP (median survival 12 days). Thus, the timing of baiting operations in relation to either rainfall or temperature events will be critical to bait survival.

At our sites, non-target species removed up to 50% of baits. Given the estimated densities of cats (0.24–0.64 cats/km^2) and the recommended density of bait deployment (50 baits/km^2, as per the label conditions), this rate of removal is still likely to leave enough baits in the environment for feral cats to encounter.

Based on the findings of our study, and our knowledge of feral cat control programs from around Australia, we make the following recommendations for implementing feral cat control in Victoria:

1. As baits can be interfered with shortly after ground-based deployment, and can be quickly rendered unattractive and unpalatable, baits should be deployed from the air at the recommended density of 50 baits/km^2. This will ensure a high probability of encounter by cats shortly after deployment.
2. To help reduce interference from birds, the effectiveness of adding colour (blue or green) to Curiosity as a deterrent to corvids and other bird species should be investigated.
3. To reduce the rain impacts on bait, investigate approaches to prevent moisture entering baits while allowing volatile chemical attractants to be emitted, or applied to the outer surface of baits.
4. To increase the chances of baits remaining viable, baiting should occur when rainfall is forecast to be below 20 mm on any one day over the period when baits are to be laid, and when temperatures are forecast to be less than 25ºC and stable over the period of control (while observing label conditions regarding the presence of goanna species).
5. When unfavourable environmental conditions occur while baits are in situ, a second baiting run should be applied as soon as possible, so that enough baits are available to feral cats in a short space of time to maximise the likelihood of a population knockdown.
6. Investigation into the environmental factors that impact on Curiosity needs to be undertaken at various sites and times to confirm the ranges of environmental conditions that affect baits as presented in this report.

1 Introduction

In April 2017, the Victorian Government released Biodiversity 2037 (*Protecting Victoria's Environment – Biodiversity 2037*; DELWP 2017) to stop the decline of the state's native plants and animals, and to improve the natural environment so it is healthy, valued and actively cared for. Biodiversity 2037 contains 20-year management output targets across public and private land. These management output targets include the control of pest predators [e.g. foxes (*Vulpes vulpes*) and feral cats (*Felis catus*)] in priority locations across 1.5 million hectares. Funding for the implementation of management actions is through the Biodiversity Response Planning (BRP) process.

Five BRP feral cat projects (funded for 3 years) are implementing management actions involving a range of control tools. Three of these projects (Barwon South West, Mallee and Wilsons Promontory) covered a total of 25 000 ha in 2018–2019 to 2020–2021, through an investment of $1.65 million dollars. The Year 1 outcomes for these projects have been completed and were reported in Robley et al. (2019). The current report presents the results of Year 2 for these three projects.

Over the past few decades, robust evidence has emerged that demonstrates the significant impact that feral cats have on native wildlife through direct predation (Nogales et al. 2004; Marlow et al. 2015; Jones et al. 2016). It has been shown that feral cats preferentially select small mammals as prey (Kutt 2012), and that some individual feral cats can be disproportionately responsible for predation on populations of native species (Moseby et al. 2015). Predation by feral cats has been identified as the main contributing factor in the failure of several reintroduction programs (Moseby et al. 2011; Moseby et al. 2015; Hardman et al. 2016). Feral cats have also been demonstrated to be the main predator of medium-sized mammals, at locations in which there has been sustained control of foxes (Marlow et al. 2015). In Victoria, there are 43 species listed under the *Flora and Fauna Guarantee Act 1988* (FFG Act) or the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) as threatened by feral cat predation.

In Victoria, feral cats have become established in almost every terrestrial habitat type, although limited direct evidence is available of the specifics of feral cat habitat use or of their density. Density estimates range from 0.24/km^2 in the Mallee in spring (Robley et al. 2017) to 0.98/km^2 in wet forests of the Otway Ranges (M. Rees, University of Melbourne, 2018 unpublished data).

Feral cats are obligate carnivores and can obtain their water requirements almost entirely from their food (Duffy and Capece 2011). As a result, feral cats prefer eating live prey such as rabbits (*Oryctolagus cuniculus*), small mammals and lizards (MacDonald et al. 1984; Holden and Mutze 2002) over the consumption of carrion, including baits deployed during control programs. In addition, feral cats tend only to consume baits when hungry, regardless of palatability (Algar et al. 2007). In arid environments, studies have shown that the likelihood of feral cats consuming baits is related to the ratio of prey (small mammals) to feral cat abundance (Algar et al. 2007; Christensen et al. 2013; Read et al. 2015).

The Victorian Government declared feral cats an established pest on public land in 2018. That declaration allows for a more practical application of currently available tools (confinement traps, shooting) and provides for the use of emerging tools (baits, grooming traps) when they become available. On Parks Victoria estate and DELWP managed forested lands (where the declaration applies), land managers are now able to humanely destroy cats identified as feral and caught in cage traps. In addition, DELWP can undertake spotlight shooting without the need for demonstrating that all reasonable attempts have been made first to capture feral cats.

The declaration also enables the use of poison baits to control feral cats. The Curiosity® bait has been developed to enable the broad-scale management of feral cat populations in south-east Australia. Curiosity baits are composed of a small meat-based sausage containing a small hard plastic pellet encapsulating the toxin. As feral cats rarely exhume buried food, poison baits must be surface laid. The APVMA label sets out the conditions for use for Curiosity. For ground baiting, baits must be placed at intervals of a minimum of 100 m and not exceed 50 baits/km^2. For aerial baiting, baits are to be dispersed at a maximum rate of lay of 50 baits/km^2. Baiting lines can be spaced at 500 m or 1 km intervals.

Aerial or ground deployment increases the potential for exposing non-target species to encountering and consuming the bait, and thus increases the potential for affecting non-target populations while reducing the efficacy of the control program.

The Curiosity bait encapsulates para-amino-propiophenone (PAPP) in an acid-soluble polymer that forms a robust pellet, known as a Hard-Shell Delivery Vehicle (HSDV: Johnston et al. 2020). Several studies have indicated that the inclusion of the HSDV is effective at reducing the likelihood of non-target species ingesting the pellet (Marks et al. 2006; Hetherington et al. 2007; Forster 2009, Johnston et al. 2020). Buckmaster et al. (2014) undertook an assessment of the potential for exposure to the encapsulated toxicant for all Australian reptile, bird and mammal species and recommended further studies to assess the hazard that the baits present to non-target species.

However, we currently have few examples of the appropriate use of Curiosity (timing, number of repeated applications, spatial scale, level of population reduction achieved) in south-east temperate and wet forests. In addition, there is only limited information available about the rate at which baits are removed by non-target animals and the environmental factors that impact on the bait's attractiveness and palatability to feral cats. In one study, Johnston (2012) observed that the effectiveness of a control operation was likely impacted by rain making the baits unpalatable.

To maximise the ability of the BRP feral cat control projects to build management capability, we investigated the efficacy of feral cat control with the following objectives:

- to quantify the 'fate' of surface-laid Curiosity feral cat bait under field conditions
- to assess the environmental factors that impact the attractiveness and palatability of Curiosity
- assess feral cat density at study sites
- to use this information, and information from Year 1, to model plausible management scenarios
- to provide recommendations to improve the management of feral cats in Victoria.

This information is critical for future planning and management efforts and will feed directly into management decision systems, such as Strategic Management Prospects.

2 Methods

2.1 BRP feral cat control projects

The BRP investment in feral cat projects covers five projects across seven sites. This project aims to utilise the implementation of three BRP projects, one in the Mallee [which has two sites: Hattah–Kulkyne National Park (HKNP) and Big Desert State Forest (BDSF)], one on the Isthmus at Wilsons Promontory National Park (WPNP) and one in Barwon South West (BSW) [which has two sites: Cobboboonee National Park (CNP) and Mount Clay State Forest (MCSF)] (Table 1).

The Mallee sites are semi-arid, with hot, dry summers and mild winters. Vegetation at the study sites was predominately Riverine Grassy Forest and Intermittent Swampy Woodland. The Isthmus experiences cold summers and cold, wet winters. Vegetation is a mixture of Heathland and Mixed Dry Forest Woodland. The Barwon South West sites have cool summers and wet winters. Dominate vegetation is Low Land Forest and Heathy Woodland.

Table 1. The BRP project locations and sites used in this study to assess the effectiveness of management options for reducing feral cat populations.

Location	Sites	2019/20 activities	Area (ha)
BRP047—Controlling feral cats in the Mallee for improved management outcomes	Hattah–Kulkyne National Park	Curiosity bait trials	5700
	Big Desert State Forest	Curiosity bait trials	5400
BRP083—Developing control options for feral cats at Wilsons Promontory to improve management capability	Wilsons Promontory National Park	Curiosity bait trials and cage trapping	4500
BRP024—Glenelg Ark: the next phase	Cobboboonee National Park	Cage trapping	3200
	Mount Clay State Forest	Cage trapping	3200

All sites contained native species known to be threatened by feral cat predation and were either determined by an existing management program for the control of introduced pests, or were areas identified as benefiting from control via Strategic Management Prospects analysis.

2.2 Assessing the condition of (caged) Curiosity feral cat bait under field conditions

At HKNP and WPNP we placed 40–45 non-toxic Curiosity feral cat baits, each containing a HSDV with 5.5 mg Rhodamine B (RhB) dye in the pellet (manufactured by Scientec Research Pty Ltd, Melbourne, Victoria), in individual small wire cages (12 cm x 3 cm x 8 cm). These were spaced at ~25–50-m intervals and pegged to the ground, but otherwise open to the elements (Figure 1). Before being laid, Curiosity baits were thawed and placed in direct sunlight for at least one hour. This process, termed 'sweating', causes the oils and lipid-soluble digest to exude from the surface of the bait. All Curiosity baits were sprayed during the sweating process with an ant-deterrent compound (Coopex®, the main active constituent being permethrin). This process is aimed at preventing bait degradation by ant attack (the physical presence of ants on and around the bait medium may deter bait acceptance by feral cats).

The condition of each baits was visually assessed every day for 14 days at both sites, noting the amount of degradation to the bait matrix that had occurred, the presence of insects (ants, etc.). A subset of three baits (selected a random) were inspected every second day at each location to determine whether the bright pink RhB dye was visible, indicating the pellet had leaked and baits were further scored as either 0 (no leak) or 1 (leaked). On the 14th day, all remaining pellets were inspected for signs of RhB leaking into the bait matrix and scored accordingly. At each site, we recorded the 24-hour rainfall (mm), and minimum and maximum daytime temperatures (°C) for the week preceding the trial period as well as during the trial period.

Figure 1. Small wire cages used to exclude animals from accessing non-toxic Curiosity feral cat bait.

We used survival analysis to determine the fate of Curiosity feral cat baits. This approach is concerned with the survival of the subject of interest. In this case, we were interested in how long baits remain available to feral cats once deployed, and what environmental and other factors might influence that time. First, we specified a survival distribution by comparing the applicability of' six standard distributions (exponential, generalized-gamma, Gompertz, log-logistic, log-normal, Weibull). The distribution that provided the best fit according to Kaplan–Meier estimates as well as Akaike Information Criterion (AIC, Burnham and Anderson 2002) values were used in further analysis. We then assessed a range of plausible alternative models that included explanatory variables against the null model. We used both the Log-likelihood and the AIC to provide an estimate of the relative quality of the statistical models for a given dataset and as a means for selecting the most likely fitting models (Burnham and Anderson 2002). Survival analyses were run using the function 'flexsurvreg' in RStudio (RStudioTeam 2020) using the package 'flexsurv' (Jackson 2016).

The time to mortality for each bait was defined as the number of days between when the bait was laid and when the bait was observed to be unpalatable/unattractive to feral cats. Baits were scored as either unattractive or unpalatable based on the visual assessment of the bait. On a few occasions, small mammals were able to remove baits; these baits were known to be live up to the day before the bait was removed, but their fate remained unknown.

2.3 Assessing the fate of surface-laid Curiosity feral cat bait

We assessed the availability and fate of baits by placing a bait on the ground in front of heat-in-motion digital cameras (Reconyx, LLP Wisconsin, USA) and inspecting the resulting images to determine what species had taken the bait and when at HKNP, BDSF and WPNP.

We deployed 123 cameras at HKNP, 85 cameras at BDSF and 50 at WPNP. Cameras were set at each location for ~56 days, and each camera was set ~30 cm above the ground, facing south and programmed to take five images per trigger, with no delay between triggers. Cameras were 'settled' into the environment for 14 days before a non-toxic version of the Curiosity bait containing a HSDV with 5.5 mg Rhodamine B (RhB) dye in the pellet was placed on the ground 1.5 m in front of each camera. After 14 days, any remaining baits were removed. Following a second 14-day 'quiet' period, a second round of non-toxic bait was placed in front of the cameras for a minimum of 14 days, after which the trial concluded.

No other lures were used to attract animals into the bait sites, and baits were not tethered. Baits were sweated and sprayed (as described above) before deployment.

Bait fate was recorded as being either '1' or '0'. A record of 1 was assigned when a bait was encountered and consumed, i.e. the bait was observed to be consumed by a feral cat, fox, wild dog, raven (*Corvus* sp.) or other bird species, small mammal, rodent or reptile, and was thus subsequently unavailable to feral cats. These were baits that were taken from the field of view by species observed to have consumed baits previously. When we were unable to determine the fate of a bait, i.e. the camera failed to trigger when the bait was removed, this may have been due to a small mammal's body temperature being too close to the ambient temperature to trigger the camera's sensor. On such occasions, if baits were known to be live up until the time they disappeared from the field of view, their fate was recorded as unknown. A record of 0 was assigned when the fate of a bait was unknown (it was taken out of view, and the camera failed to detect removal) or if it was still available at the end of the trial.

Previous experience and anecdotal evidence indicated that Ravens can quickly learn to find and take baits within hours by observing operators when baits are being laid. This has the effect of artificially biasing the possible fate of baits. To remove this potential source of bias, we removed bait take by Ravens on the day baits were laid.

We used survival analysis as described above to estimate the survival times of surface-laid non-toxic Curiosity feral cat baits exposed to the environment. The time to mortality for each bait was defined as the number of days between when a bait was laid and when the bait was observed to be removed by a feral cat or other species. When it was not possible to determine the fate of a bait, these were right-censored, i.e. the 'mortality event' was not observed during the trials.

2.4 Feral cat density assessment

Detections of individual feral cats at multiple camera sites potentially produce spatially correlated detections. Spatially correlated detections are essential for obtaining unbiased estimates of population density when a population is totally unmarked (Ramsey et al. 2015). We used detections of feral cats collected from the cameras established for the assessment of bait fate, as described above. The cameras were spaced at ~300–500-m intervals to ensure that individual feral cats could potentially be detected at multiple camera trap locations.

Images of feral cats were inspected, and if distinctive natural markings could be used to identify the individual (Figure 2), a unique I.D. and corresponding detection history was recorded for that individual. For individuals that could not be identified, the number of detections of unmarked individuals per camera was recorded.

Figure 2. Features used to identify individual feral cats. These included (i) number and position of bands on the tail, (ii) number, shape and position of bands on the forelegs and the hind legs, and (iii) pattern of stripes and bands on the body. (iv) Other unique identifiers included shape of ears and colouring, e.g. white or tabby patterns.

Feral cat density was estimated by spatially explicit mark–recapture (SMR) models that utilise both marked and unmarked individuals for analyses (Royle et al. 2013; Forsyth et al. 2019). SMR models assume that the marked individuals are a random sample from the population and that marking occurs throughout the defined state-space (defined below). For the cat data, it was assumed that cats with distinctive marks were no more likely to be detected than cats without such markings and that cats with distinctive markings could be detected on any of the cameras throughout the defined state-space. Both assumptions appeared to be reasonably well supported by the camera data collected. In addition, it was also assumed that all marked individuals were correctly identified and that no marked individuals were lost or emigrated from the area during the study.

The data consisted of an array of J sampling devices having locations at $X = (x_{j1}, x_{j2})$, ($j = 1, 2, \ldots J$) and set for K occasions ($k = 1, 2, \ldots K$) (here $J = 55$ and $K = 21$). The observations at each device, denoted h_{jk}, take binary values, indicating detection of at least one individual by device j at occasion k. Hence, $h_1 = (01001)$ indicates detections on occasions 2 and 5 by device number 1. The resulting data are a $J \times K$ matrix of detections h.

The encounter histories for the SMR algorithm consist of two parts. The first part consists of the encounter histories h_{ij} for each marked individual i ($i = 1 \ldots m$), detected by camera j on occasion k; the second part relates to the unmarked individuals, for which the full detection histories of each individual by the devices are latent (unknown) and must be estimated. We used the SMR model detailed in Forsyth et al. (2019) to estimate the latent detection histories for the latter group, and thus the population density of the cats, as well as the structural parameters related to detection probability and home range utilisation.

The SMR model was fitted using Markov chain Monte Carlo (MCMC) sampling in Nimble (de Valpine et al. 2017). We defined the state-space by buffering the locations of the outermost cameras by 2 km in each direction, to give a total area A of 83 km^2. We drew 20,000 samples from the MCMC algorithm from each of three chains, using diffuse initial values and discarding the first 10,000, leaving 10,000 samples from each chain to form the posterior distribution of the parameters. Convergence was assessed using the Brooks–Gelman–Rubin convergence statistic $\hat{R}$.

2.5 Cage trapping

Feral cat wire cage trapping (40 cm × 40 cm × 70 cm; Wiretainers Pty Ltd, Melbourne) was undertaken at BSW and WPNP to improve the capabilities and working knowledge of cat-trapping methods of the staff involved in these projects.

The BSW project implemented cage trapping over two sessions at both MCSF and CNP, first in late winter/early spring 2019 and then in late autumn/early winter 2020. Eighty cage traps were set for 11–13 nights over 3 weeks and checked daily. Before cage trapping commenced at the BSW sites, a grid of ~100 Reconyx heat-in-motion–activated digital cameras were set at each of MCSF and CNP to help determine where to place cage traps. Cameras were spaced at ~500–1000-m intervals along roads and tracks, covering the same general area as the cage traps. Cameras were lured with a mix of visual (e.g., CD's) and olfactory scents (e.g., tinned tuna). Camera traps were set in June–August 2019 and March–mid-April 2020 and generally operated for ~42 nights. At CNP, an additional 20 cameras were placed in and around a 450-ha fire area in March–mid-April 2020. This area was burnt in December 2019.

At WPNP, 62 cage traps were set for 3358 cage trap nights between September and November 2019. At WPNP, a mix of fish oil on a visual lure, tuna (in a small can), fried chicken, and ad-hoc bird wings and feathers were used. Visual lures were a combination of small tea strainers and coloured fishing lures (without hooks) (Figure 3).

Figure 3. Range of visual lures used at Wilsons Promontory National Park in feral cat cage trapping.

At each location, traps were spaced at an average of 1-km intervals along accessible roads, and vehicle and walking tracks, covering an area of approximately 40 km^2. Traps were covered with hessian and placed in shaded and sheltered positions to provide protection for captured animals from the elements (Figure 4).

Figure 4. Cage trap *in situ* at one of the two Biodiversity Response Planning project locations at which cage trapping was undertaken in Year 2.

Details of feral cats captured (sex, weight, body and reproductive condition) and lure type were recorded.

Feral cats were euthanised at the point of capture by project staff. If in the unlikely circumstance a domestic cat was captured, it was to be transported to either the local council pound or a veterinarian clinic, where it would be managed according to local government regulations.

3 Results

3.1 Survival of (caged) Curiosity feral cat bait

At HKNP, we modelled caged-bait survival against time (null model), and

- the previous 24-hour daily maximum temperature,
- the previous 48-hour daily maximum temperature,
- the previous 24-hour temperature lagged by 24 hours, and
- the previous 48-hour daily maximum temperature lagged by 24 hours.

As total rainfall at HKNP during the trial was only 3.1 mm it was not included as a covariate in the models.

Daily maximum temperature lagged by 48 hours was the best fit for the bait survival data (AIC 43.6 vs Null model AIC 117) (Appendix 1). Bait survival declined over a period of consecutively warmer days, with the temperature rising from 15°C over 5 days from day 9 (survival probability = 0.99) to 23°C on day 14 (survival probability = 0.00) (Figure 5).

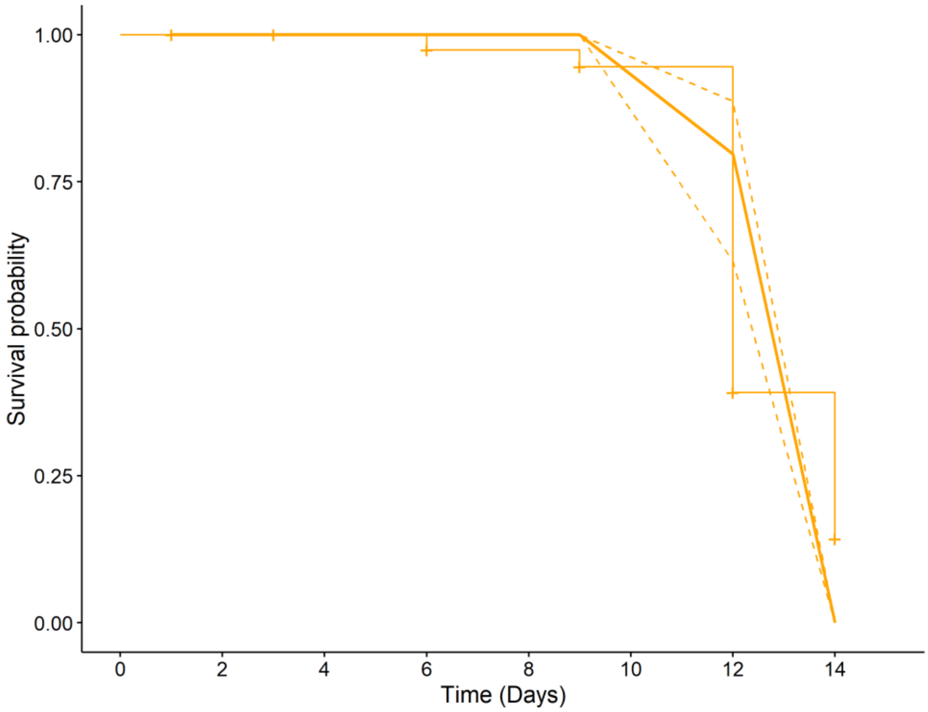

Figure 5. Survival time of caged Curiosity baits at Hattah–Kulkyne National Park.
Dark orange line = predicted survival curve, dashed orange lines = 95% confidence limits (CLs). Light orange line = Kaplan–Meier survival curve, + = right-censored data points.

At WPNP, we modelled bait survival over time (null model) and

- the previous 24-hour rainfall (9 am – 9 am),
- the previous 48-hour rainfall,
- the previous 24-hour rainfall lagged by 24 hours, and
- the previous 48-hours rainfall lagged by 24 hours.

Caged-bait survival was best predicted by the previous 48 hours rainfall total lagged by 24 hours (AIC 80.8 vs Null model 136.1, Appendix 1) (Figure 6). Bait survival decreased significantly when the previous 48 hours rainfall lagged by 24 hours was above 19 mm. The probability of a bait surviving on day 11 was 0.95 (lagged rainfall 2.4 mm), on day 12 it had decreased to 0.60 (lagged rainfall 19.2 mm) and by day 13 survival probability was 0.006 (lagged rainfall 44.4 mm). By day 14, all remaining baits were assessed as being unattractive and unpalatable.

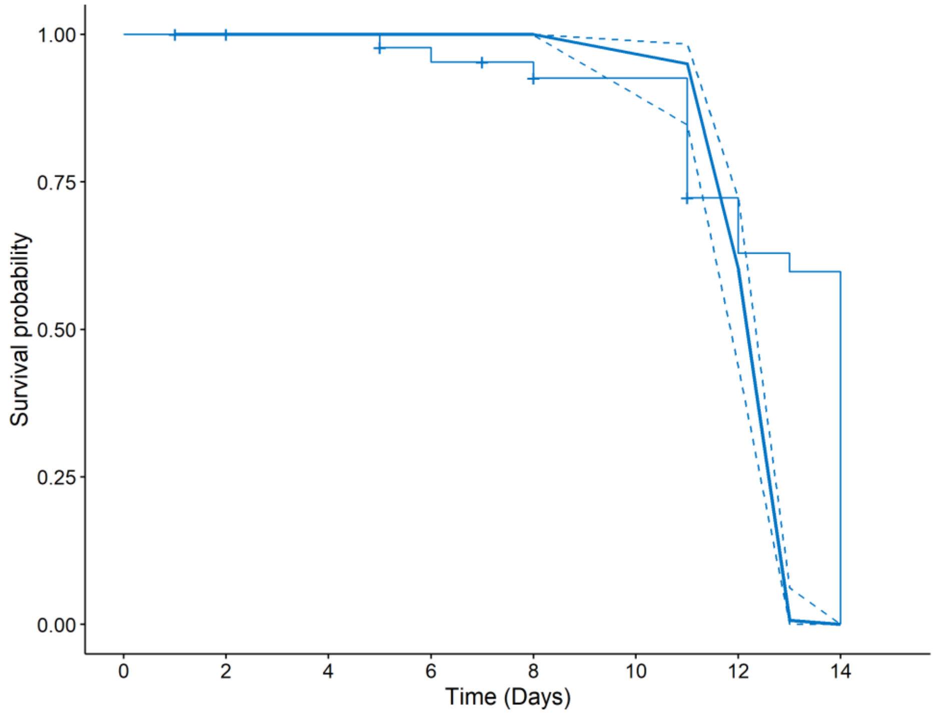

Figure 6. Survival time of caged Curiosity baits at Wilsons Promontory National Park.
Light blue line = Kaplan–Meier survival curve, + = right-censored data points, dark blue line = predicted survival curve with the previous 24 hours rainfall lagged by 24 hours, dashed blue lines = 95% C.L.s.

3.1.1 Pellet condition

The percentage of inspected pellets that were recorded as leaching RhB dye at WPNP was associated with rainfall, with the proportion of leaching increasing from just over 0.2 to 1.0 from day 12 onwards (Figure 7).

By day 5 at WPNP, all baits had changed colour to a dull grey, and the structure of the bait changed to become very soft, although no leaching was observed in these baits. The first leaching was observed on day 7 (22% of inspected baits), and the previous 24 hours had experienced 7.0 mm of rain. In total, 65% of baits (*n* = 31) at WPNP had signs of RhB dye in the bait matrix (Figure 7), and at HKNP only two baits were observed to have small amounts of leaching of RhB into the bait; rainfall total for the trial period was 3.1 mm.

Figure 7. Curiosity feral cat baits at day 14 of the Wilsons Promontory National Park trial, showing signs of RhB leaking into the bait matrix.

At both locations, mammals were able to dig under some cages and remove the bait, despite cages being pegged down. At HKNP, foxes were identified as digging under eight cages, and on five occasions, traces of RhB dye were observed nearby. On one occasion a discarded pellet was found (Figure 8a and b).

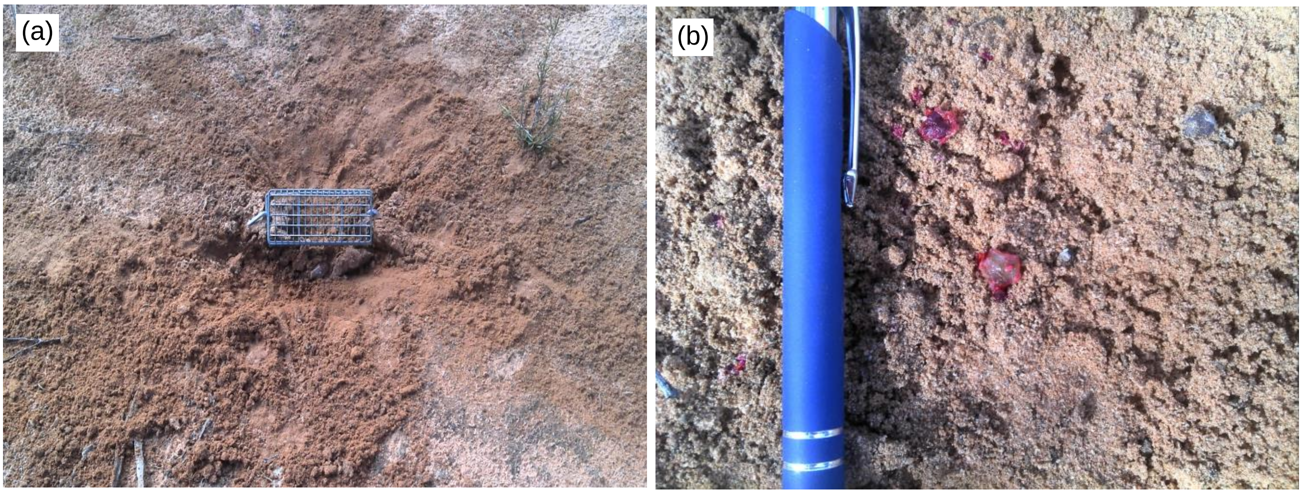

Figure 8 (a) Sign of fox excavation of Curiosity feral cat bait, and (b) RhB dye and Curiosity bait pellet on ground after bait had been dug up from under a cage at Hattah–Kulkyne National Park.

At least one fox was recorded chewing baits rather than swallowing the bait whole (Figure 9).

Figure 9. Fox at Hattah–Kulkyne National Park recorded during the bait fate trials 'chewing' a Curiosity feral cat bait.

At WPNP, small mammals were identified as consuming small portions of bait during the cage trials over several days, most probably *Antechinus* species, which were small enough to access the bait through gaps in the wire cage. On five occasions, baits had the pellet exposed and were found on the ground. These baits were not included in the assessment of leaching.

3.2 Survival of surface-laid Curiosity baits

We modelled the survival of surface-laid bait over time and against the two trial rounds as a result of bait-take by cats and non-target species. At both BDSF and HKNP, the start time for each bait deployment was staggered, so we used a staggered enter model. At WPNP, all baits were deployed on the same day in both rounds. At both BDSF and HKNP, we removed data points for which ravens took baits on the same day as they were laid. This was to remove the bias in the bait survival rate due to behaviour learned by the ravens observing baits being deployed.

Surface-laid bait survival was best predicted by including Round (i.e. the round the bait was laid) and using a Weibull distribution at BDSF (AIC 334.4 vs Null 345.5), by Round and a Gompertz distribution at HKNP (AIC 525.0 vs Null 536.1) and by the null model with a log-normal distribution at WPNP (AIC 451.1 vs Null) (Appendix 2).

At BDSF, the bootstrapped median survival time of surface-laid Curiosity baits placed in front of digital cameras was 17 days (Figure 10a), with the estimated probability of survival at day 14 in round 1 being 0.74 (95% CI 0.58–0.82) and in round 2 being 0.25 (95% CI 0.12–0.40).

At HKNP, the bootstrapped median survival time of surface-laid bait was 13 days (Figure 10b), with the estimated probability of survival at day 14 in round 1 being 0.64 (95% CI 0.54–0.74) and in round 2 being 0.27 (95% CI 0.15–0.45).

At WPNP, the bootstrapped median survival time of surface-laid bait was 5 days (Figure 10c). There was no significant difference in the probability of survival between rounds at WPNP, and the estimated mean probability of survival at day 14 was 0.16 (95% CI 0.08–0.26).

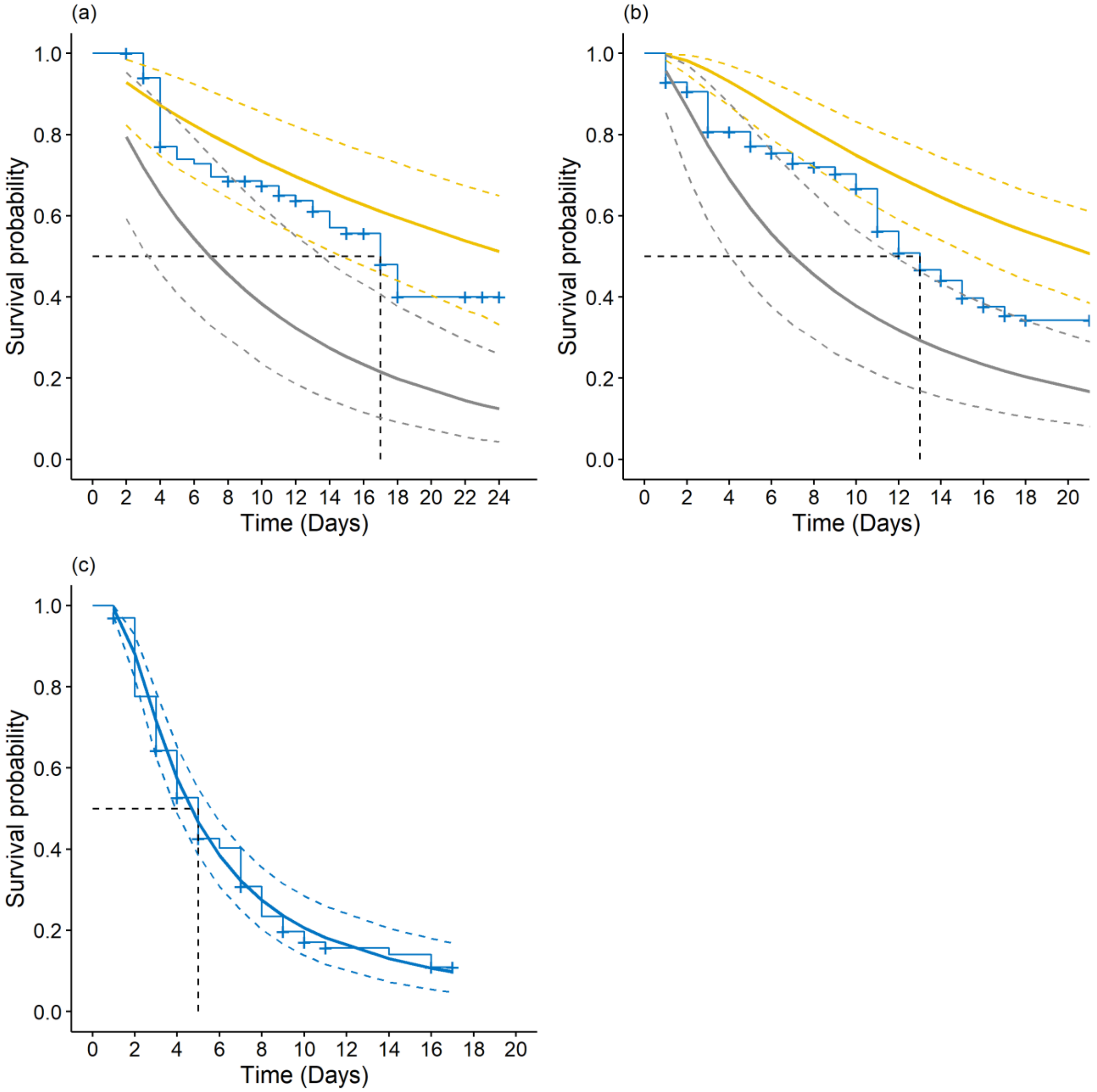

Figure 10. Survival curves for surface-laid Curiosity bait at (a) Big Desert State Forest, (b) Hattah–Kulkyne National Park and (c) Wilsons Promontory National Park.
Blue lines = Kaplan–Meier survival estimates. Yellow lines = smoothed round 1 predicted survival curves (dashed lines 95% C.L.s), grey lines = smoothed round 2 predicted survival curves (dashed lines 95% C.L.s). Horizontal and vertical dashed lines indicate median survival times.

At BDSF, feral cats were recorded consuming two baits in Round 1, 8 days and 9 days after they were laid, and encountering but not consuming baits on three occasions, 2, 3 and 5 days after they were laid (Table 2). The largest decrease in available baits in Round 1 occurred on day four (20%), but from day four onwards, few baits were interfered with or removed by non-target species with 70% of bait still available. Round 2 bait take was higher, by day four 47% of baits had been removed. The cumulative effect was that the overall number of baits declined each day (Figure 11) with a greater rate of decline in Round 2.

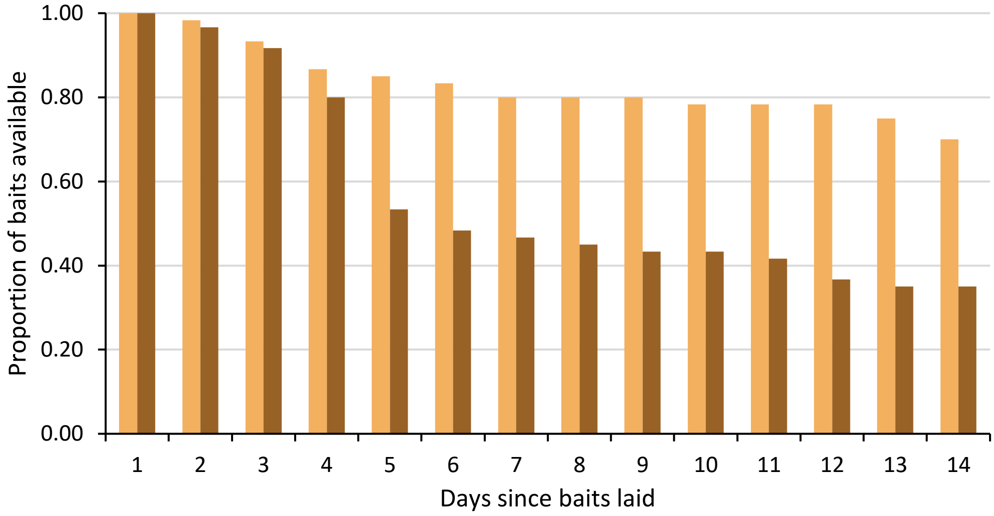

Figure 11. The mean proportion of baits removed by non-target species, and the mean proportion of baits available to feral cats each day at Big Desert State Forest.
Round 1 – orange, Round 2 – brown.

At HKNP, no feral cat was observed to take a bait, even though the baits were presumably attractive, palatable and available. The largest decrease in available baits occurred in the first 2 days (21%) in Round 1, but from day 3 onwards, few baits were interfered with or removed by non-target species. In Round 2, 40% of baits were removed by day 2, after which there was a steady decline. The cumulative effect was that the overall number of baits declined each day (Figure 12) with a greater rate of decline in Round 2.

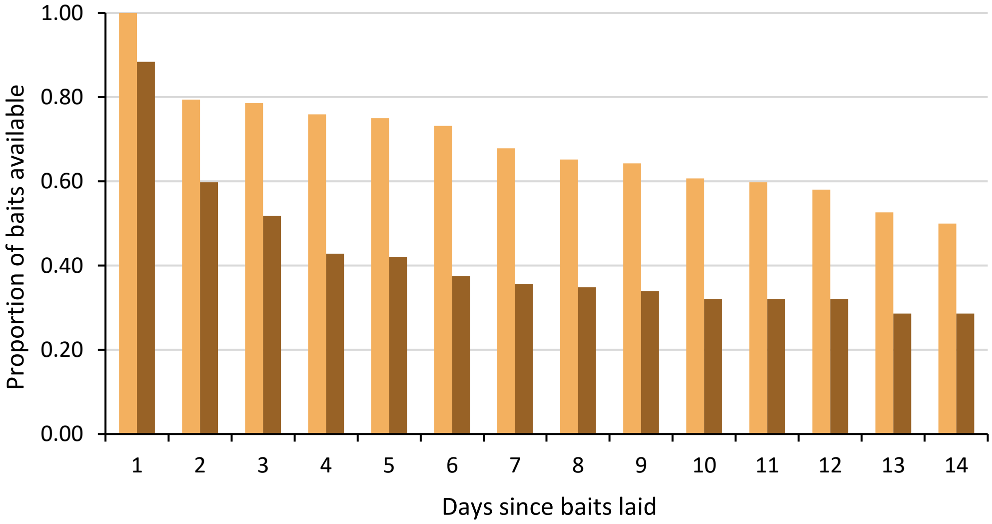

Figure 12. The number of baits available to feral cats each day at Hattah–Kulkyne National Park.
Round 1 – orange, Round 2 – brown.

At WPNP, no feral cat was recorded encountering or consuming a bait. Feral cats were observed at 12 camera sites, 2 in R1 and 7 in R2, and 3 detections were outside the period of bait deployment. The largest decreases in available baits occurred in the first 2 days (just over 20% in both rounds; Figure 13). In Round

1, the proportion of available baits remained constant at around 60%, while in Round 2 bait availability steadily declined to under 20% of baits being available by day 14 (Figure 13).

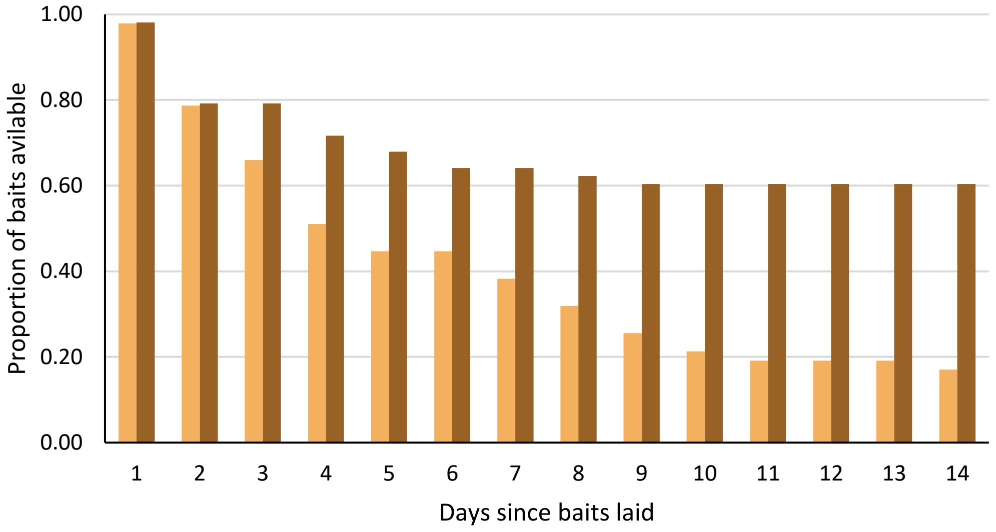

Figure 13. The mean proportion of baits removed by non-target species and the mean proportion of baits available to feral cats each day at Wilsons Promontory National Park.
Round 1 – orange, Round 2 – brown.

3.2.1 Non-target bait interference

At BDSF, foxes (*n* = 6) and a wild dog (*Canis familiaris*, *n* = 1) were also observed consuming bait. At HKNP, foxes encountered 28 baits (18%) over the two rounds, being observed to consume baits on 20 of these occasions. At WPNP, foxes were recorded encountering 6 baits and consuming 2 of these.

Other species recorded removing baits from the field of view at BDSF and HKNP were small rodents (e.g. Mitchell's Hopping Mouse [*Notomys mitchellii, n* = 1]), Grey Shrike-thrush (*Colluricincla harmonica*, *n* = 7), Pied Butcherbird (*Cracticus nigrogularis*, *n* = 1) and a European Rabbit (*n* = 1). A Grey Shrike-thrush took 1 bait, and Stumpy-tailed Lizards (*Tiliqua rugosa*) took 2 baits (Table 2).

The reason for the differences in survival rates between rounds at both BDSF and HKNP is associated with the rate at which baits were taken by ravens. At BDSF, ravens took 31% of all baits laid across the two rounds, and these were assumed to be unavailable to feral cats. At HKNP, ravens took 78 of all observable baits (50%) over both rounds, and these were also assumed to be unavailable to feral cats. In Round 1, 18% of baits had been taken by the third day after being laid, while in Round 2, 56% of baits were taken by the third day. These were all taken by ravens.

At WPNP, ravens took 38 (35%) of all baits laid across both rounds, and these were assumed to be unavailable to feral cats. Baits that were absent from the field of view accounted for 14% of taken baits. Foxes were recorded taking 2 baits. Species recorded either consuming or removing baits from the field of view were Antechinus (*n* = 4), Bush Rat (*Rattus fuscipes*, *n* = 1), Dunnart (*Sminthopsis* sp., *n* = 1), Common Brush-tailed Possum (*Trichosurus vulpecula*, *n* = 1), Emu (*Dromaius novaehollandiae, n* = 1) and Australian Magpie (*Cracticus tibicen*, *n* = 4) (Table 2).

Table 2. Species observed to have consumed, encountered and/or removed baits at each study site.

Location	Species	Encountered only	Removed from view	Encountered and consumed	*Risk of consuming pellet
Big Desert SF	Feral cat	3	–	2	Possible
	Ravens	-	39	1	Possible
	Fox	0	–	6	Possible
	Wild Dog	–	–	1	Possible
	Mitchell's Hopping Mouse	–	1	–	Unlikely
	Grey-shrike Thrush	–	7	–	Unlikely
	Pied Butcher Bird	–	1	–	Possible
	Rabbit	–	1	–	Unlikely
Hattah–Kulkyne NP	Feral cat	6	–	–	-
	Ravens		72		-
	Fox	8	–	20	-
	Grey-shrike Thrush	–	1	–	-
	Stumpy-tailed lizard	–	1	–	Possible
Wilsons Promontory NP	Feral Cat	1	0	-	-
	Fox	4	–	2	-
	Raven	38	38		-
	Antechinus species	4	4	-	Unlikely
	Brush-tailed Possum	1	1	-	Possible
	Emu	1	1	-	Possible
	Australian Magpie	4	4	-	Possible

NP = National Park; SF = State Forest.

3.3 Feral cat density estimates

Big Desert State Forest

A total of 9 individual cats were identified, with 4 unidentified cats also being detected 12 times within 96 days. Feral cats were recorded at 12% of sites (n = 10) from 6579 camera trap nights; in comparison, foxes were detected at 42% of sites. Cats moved up to 3 km between camera locations, with the mean maximum distance moved between locations being 2.6 km.

The estimated abundance ($\hat{N}$) of cats within the state-space (236 km^2) was 56.2, with a corresponding density estimate of 0.24 cats/km^2. The precision of the estimates was satisfactory, with a 95% CI for cat density of 0.102–0.356 (Table 3). The coefficient of variation (CV) was 0.28 (28%). The estimated spatial scale parameter (σ) was 1.86 km, which corresponds to a 95% circular home range size of 65.2 km^2. However, this estimate was imprecise as a consequence of the limited number of individual recaptures. The daily probability of detection when a camera coincided with the centre of a cat home range was 0.0007, which was extremely low (Table 3).

Table 3. Parameter estimates of feral cat population size ($\hat{N}$), density and the detection functions (g_0, σ) from the secr model applied to detections in camera traps from Big Desert State Forest.

Parameter	Mean	SD	2.5%	97.5%
$\hat{N}$	56.2	15.6	24	84
Density (feral cats/km^2)	0.24	0.066	0.102	0.356
g_0	0.0007	0.0004	0.0001	0.0016
σ (km)	1.86	0.67	0.84	3.11

Hattah–Kulkyne National Park

A total of 6 individual feral cats were detected at 6 different cameras on 6 occasions (7408 camera trap nights) of the study. Determination of density requires that at least some individuals are recaptured at multiple locations. Camera spacing and duration of deployment were considered adequate to produce this data; however, insufficient individuals were detected to enable density estimation of feral cats at this site.

Wilsons Promontory National Park

Feral cats were detected 18 times on 21 occasions. A total of 10 feral cats could be identified through natural markings, with detections of unmarked cats occurring at 12 locations (Figure 14). Unfortunately, only a single known individual was detected at more than one camera. Hence, estimates of the home range utilisation parameter should be interpreted with some caution. This also has implications for the estimation of density, which has correspondingly low precision.

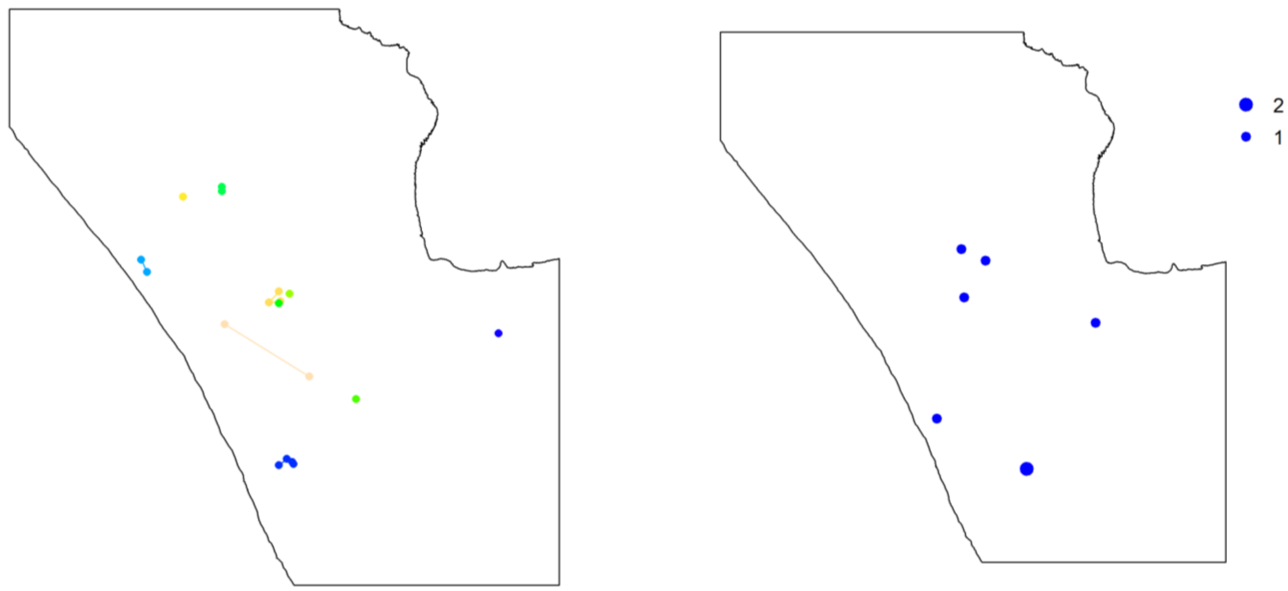

Figure 14. Detections of 10 'marked' cats (left plot) and unmarked cats (right plot) at WPNP. Size of dots = number of detections.

The estimated abundance ($\hat{N}$) of cats within the state-space (84 km^2) was 54, with a corresponding density estimate of 0.64 cats/km^2. The precision of the estimates, however, was low, with a 95% CI for cat density of 0.40–0.96 (Table 4). The CV was 0.25. The estimated spatial scale parameter (σ) was 0.43 km, which corresponds to a 95% circular home range size of 3.5 km^2. However, this estimate was unstable, which was a consequence of only a single cat being detected on more than one camera. The daily probability of detection when a camera coincided with the centre of a cat home range was 0.038, which was also low (Table 4).

Table 4. Parameter estimates of feral cat population size($\hat{N}$), density and the detection functions (g_0, σ) from the spatial mark–resight model applied to cat detections by camera traps at Wilsons Promontory National Park.

Parameter	Mean	Median	SE	2.5%	97.5%
$\hat{N}$	53.7	53	13.5	30	80
Density (feral cats/km^2)	0.64	0.63	0.16	0.40	0.96
g_0	0.038	0.036	0.016	0.011	0.069
σ (km)	0.43	0.42	0.087	0.29	0.59

3.4 Feral cat cage trapping

BSW cage trapping resulted in the capture of two feral cats (a 4.2 kg male and a 3.7 kg female) at MCSF and a single female feral cat (3.0 kg) at CNP. In mid-May 2020, in the planned burn fire scar in CNP, two female cats weighing 2.2 and 2.6 kg were captured. No preferences of lure types were observed.

At WPNP, cage trapping resulted in two female cats (2.25 and 3.75 kg) being caught in October 2019. Non-target species caught included blue-tongue lizards, which were all released unharmed at the point of capture.

No preferences of lure types were observed at either site.

4 Discussion

We set out to quantify factors that influence the survival (attractiveness/palatability and field life) of Curiosity feral cat bait. At our sites, we found that rainfall, temperature and non-target interference can influence the availability of Curiosity baits to feral cats. Based on our results, there would appear to be a 'Goldilocks zone' when temperatures are below ~25°C for several days following a deployment with little increase over time, and when rainfall in the previous 48 hours is less than ~20 mm. Curiosity is likely to be most effective in environments that have mild winter temperatures and only moderate rainfall. Sites in wetter zones may face a smaller environmental window and reduced bait life in the field.

Non-target interference with bait is when baits are removed by non-target species, making the bait unavailable to feral cats. In this study, most bait interference was by corvids soon after baits were laid, particularly at WPNP. It was likely the activity of the operators when laying bait attracted corvids to the bait location. It is also likely that, once a bait was found, a search image was imprinted, allowing corvids to find other baits. Corvids are known to be intelligent and quick learners (Izawa and Watanabe 2012). On one occasion, a corvid was recorded arriving at a bait site holding a bait in its beak, indicating it had learnt to find multiple baits. As a proportion of available baits on any given day, non-target interference ranged between 0 and 36%.

A limited number of studies have investigated the LD_{50} (the dose of a toxin that could kill 50% of the individuals that consumed the poison) of Curiosity to a range of non-target species (Savarie et al. 1983; Marks et al. 2006; Easton et al. 2014). There have also been some studies on individual species consumption and rejection of the HSDV pellet (Algar 2006; Heiniger et al. 2018; Johnston et al. 2019) and a desk-top risk assessment completed for a wide range of Australian native species (Buckmaster et al. 2014). Of the nine native species observed either encountering, removing or consuming a Curiosity cat bait in our trials, five have the possibility of consuming the pellet. Of these, all would need to consume multiple baits (3 - 5) within a short period to receive a lethal dose. Foxes and a single wild dog were also observed consuming a bait. Each of these species is susceptible to PAPP poisoning, but would also need to consume multiple baits within a relatively short period of time to receive a lethal dose.

During aerial baiting operations, it is unlikely that corvids would be able to key in on the activity of baits being laid; hence, the likelihood of them discovering the baits would be substantially less. If the ground-based application of bait is the only option, then it may be possible to add a blue or green colour to the bait, making it harder for birds to see. Colour has been applied to other bait products to discourage bait-take by birds (Hartley et al. 2000). Laying baits under shrubs or other vegetation as a method of hiding baits from non-target species may decrease the bait encounter rate and affect bait stability. However, placing baits under shrubs or vegetation may provide a microclimate that favours spoiling of the bait through mould growth (higher humidity and lower evapotranspiration). It also predisposes baits to greater opportunity for consumption by other non-target species, especially rodents and small mammals. If ground baiting is being undertaken along vehicle tracks, then baits should be placed between the wheel pads, where a cat has the best chance of encountering the bait while moving along the track. However, if ground-based baiting is to be undertaken, then the bait density that can be achieved needs careful consideration. To overcome the reduction in available baits a high bait density is needed. Current label conditions specify a baiting rate of 50 baits/km^2; at that rate, non-target interference alone is unlikely to have a significant impact on efficacy.

Fox bait take was highest at WPNP (18% over two rounds). To be lethal to foxes, a fox would need to consume approximately 2-3 Curiosity baits within a short time (~less than 30 minutes). However, foxes might affect efficacy in areas with high fox density by taking baits. In these areas, undertaking a ground-based fox-baiting operation prior to implementing aerial bating targeting feral cats should be considered. This would increase the probability that feral cats could encounter a bait, by reducing competition for baits. A reduction in fox density may also result in wider movement by feral cats increasing the chance of encountering a bait. It has been shown that where foxes were removed, feral cats foraged more in open habitats (Molsher et al. 2017) and tended to increase in number (Hunter et al. 2018).

In arid environments, studies have shown that the likelihood of feral cats consuming baits is related to the ratio of prey (small mammals) to feral cat abundance (Algar et al. 2007; Christensen et al. 2013; Read et al. 2015). These authors were able to predict the success or failure of feral cat control operations based on the relationship between pre-baiting feral cat abundance and the abundance of small mammals. In arid and semi-arid environments, small mammal abundance is known to fluctuate in response to environmental triggers, such as rainfall (Dickman et al. 1999). In wetter environments, such as in south-eastern Australia, the relationship between feral cat prey abundance and the likelihood of feral cats taking bait is unknown. The underlying productivity of forest systems in southern Victoria may be relatively more reliable than that of more semi-arid north-west Victoria. Hence, feral cats may not experience the same degree of food stress in southern Victoria as is present in more arid habitats, which may reduce the propensity of cats to take baits.

The most likely prey of feral cats at HKNP are rabbits, reptiles and waterbirds, as the small mammal fauna is depauperate. By early winter, most of this prey base would be at its lowest density. However, in the southern sites, the range of prey that feral cats could potentially access (small rodents, small and medium-sized mammals, ground- and low-nesting birds, and reptiles) are likely to provide a relatively stable food source. For example, at CNP cameras detected 10 mammal and 10 bird species that feral cats would be able to prey on, whereas at HKNP cameras detected 3 mammal, 1 reptile and 4 bird species likely to be subject to predation by feral cats. While these are not abundance estimates, they do provide some insight into the relative differences in potential prey species between our cooler/wetter and warmer/dryer sites. We require more detailed information (on the temporal availability of prey and on what feral cats are preying upon) to be able to make better decisions about when to implement feral cat control, whether by trapping or baiting.

Density estimates based on the mark–resight data collected from the camera surveys had high levels of uncertainty, despite this method having been used in several studies around Australia in recent years (McGregor et al. 2015; Ramsey et al. 2015; Forsyth et al. 2019). As the name suggests, the method requires the resighting of known individuals at different times and places during the survey period. The probability of a feral cat encountering a camera trap is a primary assumption of the analytical approach and is related to the spatial arrangement (spacing and density) of camera traps relative to the feral cat home range size and movement rate. We used estimates from the literature as the basis for judging feral cat home range size (Jones and Coman 1982; Molsher et al. 2005; Buckmaster 2011; Johnston 2012; Bengsen et al. 2015; McGregor et al. 2015) and a previous density estimate undertaken at HKNP (Robley et al. 2017). The high levels of uncertainty in our density estimates were influenced by the low levels of detections and recaptures of individual feral cats. More information on feral cat home range and movement is required in order to be able to assess the effectiveness of control operations and plan the associated monitoring programs.

Cage trapping is a labour-intensive and therefore expensive method that is unsuitable for population-level control and should only be used as a supplement to more appropriate landscape-scale tools, e.g. baiting. Feral cats have high reinvasion potential (Lazenby et al. 2014), so shooting and trapping are unlikely to be useful broad-scale control tools in isolation. These two techniques are most useful for removing 'problem' individual feral cats preying on threatened species (see Moseby et al. 2015), in the later stages of eradication programs (see Algar et al. 2002), or as adjuncts to large-scale baiting operations. Conventional trapping typically presents ethical and logistical challenges; non-target species may be caught, and traps must be checked daily. Automated cat-specific grooming traps that spray a toxin onto passing individuals are currently in development and may help to circumvent some of these issues (Read et al. 2014).

Consideration needs to be given to the potentially adverse effects of low-level culling or harvesting of feral cats that often occurs with trapping-only programs. Lazenby et al. (2014) found that following low-level culling in two open sites in southern Tasmania, the relative abundance and activity of feral cats increased in the cull sites, even though the numbers of cats captured per unit effort during the culling period declined. They suggested this was due to immigration following the removal of dominant cats.

The APVMA label conditions prescribe a baiting rate of 50 baits/km^2 with baits laid either from the air or by ground baiting. This density of baits is designed to allow a feral cat to have a high chance of encountering a viable bait in a short period of time, overcoming the issues of non-target interference and the environmental impacts. Current label and state government permit conditions for Curiosity reflect the potential risk to goannas (*Varanus* spp.), suggesting that baiting when temperatures are at ≤16ºC may reduce the likelihood of goannas encountering baits. In southern parts of Victoria where goannas are known to occur, the time of year when this temperature requirement is most likely to be met coincides with winter, a time of increased and more consistent rainfall. In northern parts of the state, with lower rainfall averages, mild winter maximum daytime temperatures can frequently exceed 16ºC (BOM 2020), potentially when goannas can become active (Jessop et al. 2017). In both regions, there will be logistical challenges to implementing effective feral cat control.

Due to the low cost, efficiency and ability to cover areas that are inaccessible by road, aerial deployment of baits is likely to be the preferred method of bait deployment targeting feral cats. The logistics of aerial deployment can be challenging. Results of our study indicate the environmental window for laying baits will be small when considering the logistics of aerial baiting operations (locking in staff and aircraft to a specific time, once Curiosity is unfrozen the label conditions prescribe the use of the bait within one day). Ground based baiting has been implemented and shown to be of varying success (Doherty et al. 2015). The success of ground-based baiting will in part be tied to the ability to get a high enough density of baits into the landscape.

The Hisstory® bait for feral cats is currently being developed to complement the Curiosity bait for feral cats. Hisstory baits are like Curiosity baits in that they are composed of a small meat-based sausage containing a small hard plastic pellet encapsulating the toxin. In this case, the toxin is sodium fluoroacetate or 1080. While goannas are susceptible to the PAPP toxin, they are tolerant to a cat-sized dose of 1080 toxin. This means that Hisstory baits could be suitable for sites where goannas are typically active when rainfall totals are low.

While our results provide guidance to factors that are likely to influence the success of feral cat control in Victoria, knowledge gaps remain, limiting our ability to develop effective landscape-scale feral cat-control programs. Developing landscape-scale control of feral cats in Victoria will ideally be based on an increased understanding of:

- the optimal time, scale and frequency for undertaking baiting, particularly in southern Victoria, and when cats are most food stressed. This is likely to vary geographically because prey availability will fluctuate according to local conditions. This requires knowledge of seasonal changes in feral cat diet and of the relative abundances of prey species in the feral cat diet.
- feral cat home range and movement patterns, and bait uptake rates (including that by foxes and wild dogs). This requires locational data collected from GPS collars and simultaneous information on the fate of baits at known locations. This information can be incorporated into optimising control program designs.
- how to integrate feral cat control with herbivore, fox and wild dog control to optimise cost-effectiveness. This requires cost-benefit information for the various current approaches and knowledge of how these can be optimised through integrating control actions for multiple outcomes.
- the methods for detecting changes in feral cat numbers under Victorian conditions. There are currently several existing methods for detecting changes in feral cats. A comprehensive review and guide to the application, techniques and outcomes of each method would be beneficial to land managers.

4.1 Conclusion and recommendations

We have shown that rainfall and temperature need to be considered when implementing a cat control operation using Curiosity feral cat bait, that non-target interference can decrease the availability of bait for feral cats, and that in combination these have the potential to reduce the likely effectiveness of feral cat control. Cage trapping is an ineffective and costly tool and not appropriate for the reduction of feral cat populations at a landscape scale. Also, while we did not test underlying prey availability, this is likely to influence the success of cat control operations (Christensen et al. 2013). We have suggested actions that could help reduce these possible limitations and increase the likelihood of success. Density estimation is essential for being able to understand the effectiveness of any control action (Ramsey et al. 2015). While our estimates were uncertain, the general approach is sound and has been used successfully elsewhere (Ramsey et al. 2015). A better understanding of feral cat home range and movement will improve the outcomes for this method (Bengsen et al. 2011).

Based on the findings of our study, and our knowledge of feral control programs from around Australia, in addition to filling the identified knowledge gaps above, we make the following recommendations for implementing feral cat control in Victoria:

1. As baits can be interfered with shortly after ground-based deployment, and can be quickly rendered unattractive and unpalatable, baits should be deployed from the air at the recommended density of 50 baits/km2. This will ensure a high probability of encounter in a short period from deployment.
2. To help reduce interference from birds, the effectiveness of adding colour (blue or green) to Curiosity as a deterrent to corvids and other bird species should be investigated.
3. To reduce the rain impacts on bait palatability and attractiveness, investigate approaches to prevent moisture entering baits, while still allowing volatile chemical attractants to be emitted or sealing the bait and applying feral cat attractant to the outer layer of the bait.
4. To increase the chances of baits remaining viable, baiting should occur when rainfall is forecast to be below 20 mm on any one day over the period when baits are to be laid, and when temperatures are forecast to be less than 25ºC and stable over the period of control (while observing label conditions regarding the presence of goanna species).

5. When unfavourable environmental conditions occur while baits are in situ, a second baiting run should be undertaken as soon as possible, so that enough baits are available to feral cats in a short space of time to maximise the likelihood of a population knockdown.
6. Investigation into the environmental factors that impact on Curiosity needs to be undertaken at various sites and times to confirm the ranges of environmental conditions that affect baits as presented in this report.

Now that feral cats have been declared an established pest animal in Victoria, there is likely to be an increased investment by land managers in this control action. To ensure the maximum benefit from control actions it would be efficient to harness this effort in a coordinated manner to maximise learnings, and to establish operational infrastructure to enable acquisition of the required information in an adaptive learning framework.

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Appendix 1 Model output for Curiosity feral cat baits during cage bait trials

Hattah–Kulkyne National Park

The distribution that best fitted the data was the Gompertz distribution, and the model that best described the data incorporated the temperature lagged by 48 hours.

Table A1.1. Model parameter output, including temperature lagged, at Hattah–Kulkyne National Park

Parameters	Data mean	Estimate	L95%	U95%	SE	AIC	Log-likelihood
Shape	NA	3.92	2.49	5.36	7.31	43.6	-18.8
Rate	NA	1.09e-03	4.5e-06	2.6e-01	3.06e-03	–	–
Temperature lagged by 48 hours	19.9	-2.03	-2.76	-1.30	0.372	–	–

N = 45, Events: 26, Censored: 19, Total time at risk: 457, NA: not available, S.E.: standard error, AIC: Akaike

Table A1.2 Akaike Information Criterion for models of bait fate survival at Hattah-Kulkyne National Park

Model	df	AIC
the previous 48 hour daily maximum temperature	3	43.64
the previous 24 hour daily maximum temperature	3	72.72
the previous 24 hour temperature lagged by 24 hours	3	78.03
Null model	2	113.26
the previous 48 hour daily maximum temperature lagged by 24 hours	3	113.36

Wilsons Promontory National Park

The distribution that best fitted the data was the Gompertz distribution, and the model that best described the data incorporated the previous 48-hour rainfall total lagged by 24 hours.

Table A1.3. Model parameter output, including rainfall, at Wilsons Promontory National Park

Parameters	Data mean	Estimate	L95%	U95%	SE	AIC	Log-likelihood
Shape	NA	2.29	1.51	3.06	3.96	80.8	-37.41
Rate	NA	3.86e-11	1.15e-14	1.29e-07	1.6e-10	–	–
Previous 48 hours rain lagged by 24 hours	25.8	-0.13	-0.17	-0.084	–	–	–

N = 48, Events: 33, Censored: 15, Total time at risk: 499, NA: not available, S.E.: standard error, AIC: Akaike Information Criterion

Table A1.4 Akaike Information Criterion for models of bait fate survival at Wilsons Promontory National Park

Model	df	AIC
previous 48 hours rainfall lagged by 24 hours	3	80.8
previous 24 hour rainfall lagged by 24 hours	3	86.6
previous 48 hour rainfall	3	119.7
the previous 24 hour rainfall (9 am – 9 am)	3	126.5
Null Model	2	136.1

Appendix 2 Model output for survival of surface-laid baits

At both BDSF and HKNP, the start time for each bait deployment was staggered, so we used a staggered enter model. At WPNP, all baits were deployed on the same day in both rounds.

At both BDSF and HKNP, we removed data points associated with ravens taking baits on the day that they were laid. This was to remove the bias in the bait survival rate resulting from the behaviour learned by the ravens from observing baits being deployed, which is unlikely to occur in aerial baiting operations.

Big Desert State Forest

The distribution that best fitted the data was the Weibull distribution, and the model that best described the data included the Round in which the trial was undertaken.

Table A2.1. Model parameter output for bait survival at BDSF

Model	Parameters	Estimate	L95%	U95%	SE	AIC	Log-likelihood
Null	shape	0.768	0.415	1.421	0.241	345.5	–170.73
	scale	21.461	14.307	32.193	4.440	–	–
~Round	shape	NA	0.886	0.532	1.477	334.4	–164.19
	scale	NA	37.820	21.256	67.292	–	–
	Round – R2	0.394	-1.283	-2.175	-0.391	–	–

N = 94, Events: 42, Censored: 52, Total time at risk: 910, NA: not available, S.E.: standard error, AIC: Akaike Information Criterion

Hattah–Kulkyne National Park

The distribution that best fitted the data was the Gompertz distribution, and the model that best described the data the Round in which the trial was undertaken.

Table A2.2. Null model parameter output for bait survival at HKNP

Model	Parameters	Data Mean	Estimate	L95%	U95%	SE	AIC	Log-likelihood
Null	shape	-	-0.04	-0.07	-0.37e-3	0.018		
	rate	-	0.05	0.03	0.07	0.011		
~Round2		0.39	0.93	0.44	1.4	0.255	525.1	-259.52

N = 154, Events: 66, Censored: 88, Total time at risk: 1379, NA: not available, S.E.: standard error, AIC: Akaike Information Criterion

Wilsons Promontory National Park

The distribution that best fitted the data was the log-normal, and the model that best described the data was the null model.

Table A2.3. Null model parameter output for bait survival at WPNP

Parameters	Estimate	L95%	U95%	SE
Meanlog	1.6155	1.4515	1.7794	0.0837
Sdlog	0.8020	0.6838	0.9406	0.0652

N = 99, Events: 80, Censored: 19, Total time at risk: 572, Log-likelihood: –223.217, df = 2, SE: standard error, AIC: Akaike Information Criterion = 450.434

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