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Uptake of 'Eradicat' feral cat baits by non-target species on Kangaroo Island

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Abstract

Context. Predation by feral cats (*Felis catus*) threatens a range of vertebrate species across Australia, and cat-free islands increasingly act as safe havens for biodiversity. A feral cat eradication program has begun on Kangaroo Island (4405 km^2) in South Australia, and poison baiting is likely to be one of the main methods used.

Aims. Here, we trial a non-toxic version of a cat bait, 'Eradicat', on western Kangaroo Island, to examine its potential impact on non-target species.

Methods. Non-toxic baits containing the biomarker Rhodamine B were deployed across four sites in early August and late November in 2018, with bait take and consumption assessed both by remote cameras and by the presence of Rhodamine B in mammalian whisker samples taken post-baiting.

Key results. Cats encountered baits on very few occasions and took a bait on only one occasion in August (<1% of 576 baits deployed). Non-target species accounted for over 99% of identifiable bait takes. In both seasons, >60% of all baits laid was taken by either the common brushtail possum (*Trichosurus vulpecula*), bush rat (*Rattus fuscipes*) or Australian raven (*Corvus coronoides*). In November, Rosenberg's goanna (*Varanus rosenbergi*) and southern brown bandicoot (south-eastern subspecies; *Isoodon obesulus obesulus*), listed nationally as Endangered, also took baits (3% and 1% respectively). The Kangaroo Island dunnart (*Sminthopsis fuliginosus aitkeni*), listed nationally as endangered, approached a bait on only one occasion, but did not consume it. Evidence of bait consumption was visible in the whiskers of captured common brushtail possums (100% of post-baiting captured individuals in August, 80% in November), bush rats (59% in August and 50% in November), house mice (*Mus musculus*) (45% in November) and western pygmy-possums (*Cercartetus concinnus*) (33% in November).

Conclusions. Although feral cat baiting has the potential to significantly benefit wildlife on Kangaroo Island, impacts on non-target species (particularly the bush rat and common brushtail possum) may be high.

Implications. Alternative cat baits, such as those containing a toxin to which native species have a higher tolerance or that are less readily consumed by native wildlife, will be more appropriate.

Additional keywords: cat control, eradication, management, 1080, threatened species.

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Introduction

Introduced vertebrate predators are one of the top threats to Australian wildlife (Evans *et al.* 2011). Since European colonisation of Australia, the feral cat (*Felis catus*) and European red fox (*Vulpes vulpes*) have contributed to the extinction of at least 22 of the 30+ mammal species that have disappeared from Australia (Woinarski *et al.* 2014). Some Australian mammals now persist only in areas without introduced predators, such as offshore islands or within fenced predator-free enclosures (Dickman 1996; Legge *et al.* 2018).

Kangaroo Island is one of Australia's largest offshore islands (4405 km^2) and is considered a stronghold for some vertebrate species that are now rare or threatened on the adjacent mainland. These include Rosenberg's goanna (*Varanus rosenbergi*), pygmy copperhead (*Austrelaps labialis*), bush stone-curlew (*Burhinus grallarius*), glossy black-cockatoo (*Calyptorhynchus lathami*) and southern brown bandicoot (*Isoodon obesulus obesulus*) (Pepper 1996; Gates and Paton 2005; Rismiller *et al.* 2010). However, surveys conducted over the past 15 years indicate that some of the island's fauna are now rare, such as the Kangaroo Island dunnart (*Sminthopsis fuliginosus aitkeni*) and heath mouse (*Pseudomys shortridgei*), or locally extinct, such as the spotted-tailed quoll (*Dasyurus maculatus*) (Kemper *et al.* 2010; Gates 2011; Haouchar *et al.* 2014). The island is free of the red fox and European rabbit (*Oryctolagus cuniculus*), but does have high densities of feral cats (Bengsen *et al.* 2011), which are likely to be a key threat to the persistence of several the island's animal species, especially mammals.

Both for economic and environmental reasons, Kangaroo Island is one of five offshore Australian islands for which eradication of feral cats is proposed within the next decade (Australian Federal Government 2015). Poison baiting of feral cats is one of the main methods likely to be used in this process, because baits can be dropped aerially, allowing cats to be controlled in locations inaccessible by road (Algar and Burrows 2004). Cat baiting trials have occurred across Australia, with their success varying with factors such as bait palatability and the abundance of food resources in the landscape at the time of baiting (Algar and Burrows 2004; Algar *et al.* 2007; Moseby *et al.* 2009; Buckmaster 2012). Recent studies have suggested that if cat baiting can be conducted effectively, strong positive benefits are immediately experienced by resident wildlife populations (Robinson *et al.* 2015; Macdonald *et al.* 2017). 'Eradicat®' is the only feral cat bait that can currently be purchased in Australia, under strict conditions managed by the Western Australian Department of Biodiversity, Conservation and Attractions. Each sausage-shaped bait consists of 15 g of kangaroo meat and chicken fat and contains 4.5 mg of sodium fluoroacetate, a poison widely known as '1080'.

Although 1080 baiting may benefit native wildlife populations by decreasing the rate of predation by feral cats, there is also potential for the baiting to have direct negative impacts on wildlife if they consume the baits, because many native species are readily killed if they ingest the poison. Sodium fluoroacetate (1080) occurs naturally in some Australian plant genera, particularly *Gastrolobium* (Twigg *et al.* 2003), and native mammals tend to have higher tolerance of 1080 in areas where *Gastrolobium* spp. are common, such as south-western Australia (Twigg and King 1991; Twigg *et al.* 2003). Tolerance can vary even within a species; for example, bush rats (*Rattus fuscipes*) from south-western Australia have a much higher 1080 tolerance (LD50 of 30.1 mg kg^{-1}) than do individuals from South Australia (LD50 of <1.8 mg kg^{-1}; Twigg *et al.* 2003). The term 'LD50' is often used in toxicology to describe the amount of a substance an animal needs to consume for it to be lethal 50% of the time.

The southern brown bandicoot and Kangaroo Island dunnart are two nationally listed threatened taxa found on Kangaroo Island that would be likely to benefit significantly from cat control; however, neither is likely to have a high tolerance of 1080. Whereas no studies have directly examined the 1080 tolerance of Kangaroo Island dunnarts, a congeneric species of similar size, the fat-tailed dunnart (*Sminthopsis crassicaudata*), has a low tolerance (LD50 = 2.06 mg kg^{-1}; Calver *et al.* 1989) and needs to consume only 0.09 g (0.6%) of a 15 g Eradicat bait to reach LD50 (Sinclair and Bird 1984). The southern brown bandicoot has a slightly higher tolerance of 1080 (LD50 = 7 mg kg^{-1}; Twigg *et al.* 1990) and would need to consume 21 g of Eradicat bait (1.2 baits) to reach LD50. The bush rat and common brushtail possum from south-eastern Australia also have a reasonably low tolerance of 1080 and would reach their LD50 with consumption of 0.4 and 5.8 g (respectively) of an Eradicat bait (LD50 = 1.8 and 0.9 mg kg^{-1} respectively; Twigg and King 1991; Twigg *et al.* 2003). If significant proportions of the local populations of these species consumed Eradicat baits, post-baiting population declines would be likely. On Christmas Island, bait-suspension devices successfully decreased bait consumption by non-target species such as land crabs (*Cardisoma carnifex*), hermit crabs (*Coenobita perlata*), black rats (*Rattus rattus*) and feral chickens (*Gallus domesticus*) (Algar and Brazell 2008); however, such devices are unlikely to be effective on Kangaroo Island because of the abundance (and proclivity for taking bait) of common brush-tailed possums, which are likely to be able to reach anything accessible to a cat.

Eradicating cats on islands can support long-term native wildlife conservation (Campbell *et al.* 2011; Robinson *et al.* 2015); however, before eradication occurs, it is important that the methods used are effectively evaluated. A low tolerance of 1080 is only a problem if non-target animals eat the baits; however, no field based studies have successfully examined the propensity of these species in South Australia to do so. A desktop analysis of potential bait uptake by Australian mammals by Buckmaster *et al.* (2014) estimated that both southern brown bandicoots and Kangaroo Island dunnarts could potentially eat Eradicat baits; however, this is yet to be confirmed in the field. One small-scale trial of Eradicat was run on eastern Kangaroo Island, but at sites with no known records of the southern brown bandicoot or Kangaroo Island dunnart, and bait consumption was examined only using camera traps and with no use of non-toxic biomarker to examine bait ingestion (P. Hodgens 2017, unpubl. data). A second non-toxic trial of a cat bait called 'Curiosity®' was run on eastern Kangaroo Island, but was unsuccessful because bait uptake was determined by animal tracks that could not be identified on over 50% of occasions (Denny 2009). Therefore, the broadscale impacts and feasibility of Eradicat baiting on Kangaroo Island remain unknown.

To examine the non-target impacts of Eradicat baiting, we ran an uptake trial of non-toxic baits on western Kangaroo Island, at sites with recent records of the Kangaroo Island dunnart and southern brown bandicoot. We aimed to determine (1) what proportion of non-toxic Eradicat baits is taken by feral cats compared with non-target species, (2) what proportion of non-target species populations will consume non-toxic Eradicat baits, and (3) how uptake by non-target species varies between

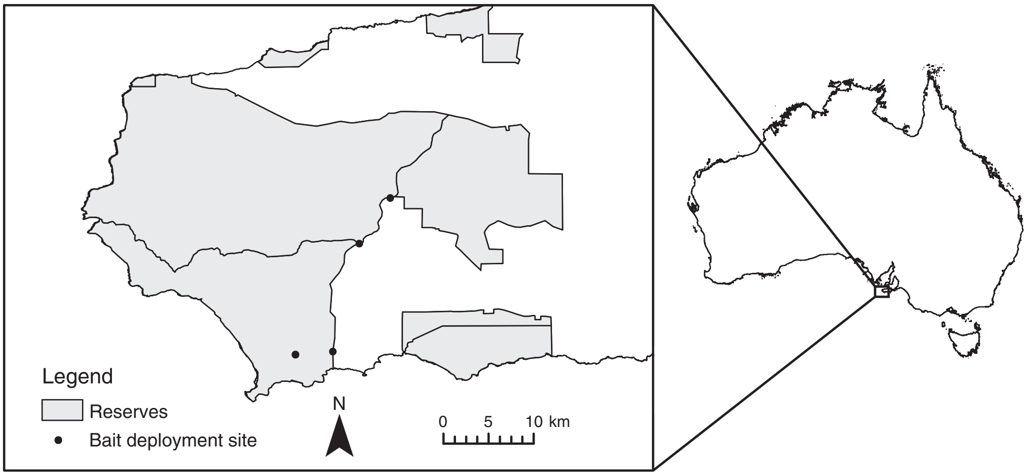

Fig. 1. Locations of four sites where non-toxic 'Eradicat' baits were deployed, on western Kangaroo Island.

sites that are baited once (representative of aerial baiting), or multiple times (representative of long-term intensive baiting). The results of the present study should indicate the extent to which both cats and non-target species will be affected by Eradicat baiting on Kangaroo Island, and, hence, whether this method has utility for cat eradication there.

Materials and methods

Study area

The non-toxic Eradicat-bait uptake trial was conducted at four sites within the Flinders Chase National Park and Ravine des Casoars Wilderness Protected Area on western Kangaroo Island (Fig. 1). This part of the island receives 600–800 mm of rain annually, mostly between May and September (Bureau of Meteorology 2019). Sites had an overstorey of Kangaroo Island mallee-ash (*Eucalyptus remota*), brown stringybark (*E. baxteri*) and coastal white mallee (*E. diversifolia*). All sites were baited and, subsequently, trapped in both winter–spring (August 2018) and spring–summer (November), to examine how bait uptake varies with temperature and rainfall. Previous trapping at these sites in 2017 and 2018 had identified that the Kangaroo Island dunnart (listed nationally as Endangered) was present at all sites, and the southern brown bandicoot (listed nationally as Endangered) was known from two of the sites (Hohnen *et al.* 2019). Other terrestrial vertebrates native to Kangaroo Island (and likely to take baits), such as the bush rat, western pygmy-possum (*Cercartetus concinnus*), little pygmy-possum (*C. lepidus*), common brushtail possum, tammar wallaby (*Notamacropus eugenii*), western grey kangaroo (*Macropus fuliginosus*) and Rosenberg's goanna, were present at all sites.

Non-toxic baiting

Each non-toxic Eradicat bait (15 g when dried, 20 g when wet) contained 20 mg of Rhodamine B, a non-toxic substance used to trace bait uptake by mammals (Fisher *et al.* 1999; Fairbridge *et al.* 2003). The baits contained 70% kangaroo meat, 20% chicken fat, 10% digest and flavour enhancers (patent no. AU13682/01; Algar and Burrows 2004). Prior to deployment, baits were 'sweated' by defrosting in the sun so that oils formed on the surface of the sausages to make them smell more strongly. All sausages were dusted with Coopex (Bayer, Leverkusen, Germany) insecticide to prevent attack by ants and other insects. This insecticide has previously been reported to not reduce bait acceptability to feral cats (Algar and Burrows 2004). At each site, there was a 3×4 grid of 12 baits spaced equidistant on a 100 m grid, which (including a buffered area of 100 m around the grid) resulted in 0.2 km^{-2} area (0.4 km $\times$ 0.5 km). The resulting baiting density of 60 baits km^{-2} (12 baits 0.2 km^{-2}) was based on densities used in successful bait trials set in similar eucalypt woodland habitat on French Island (Johnston *et al.* 2011). Previous baiting programs have successfully achieved cat population declines by using a wide range of bait densities from 10–25 baits km^{-2} in open desert habitat (Burrows *et al.* 2003; Moseby and Hill 2011) to 100 baits km^{-2} in coastal Western Australia (Algar and Burrows 2004). The manufacturers suggest densities of 10 baits km^{-2} for ground baiting and from 25–50 baits km^{-2} for aerial bait deployments (Algar and Burrows 2004; Algar *et al.* 2013).

At each bait location, a motion-activated Reconyx® Rapidfire PC 800 or HC 600 camera trap (Holmen, WI, USA; used to identify species visiting and removing bait) was attached to a stake positioned 0.5 m off the ground. The camera was angled downward at 45°, to face a bait positioned on the ground 0.5 m away, in the centre of a flat area where the vegetation had been removed. Cameras were programmed to take three images per trigger, one second apart, with no minimum time delay between triggers. Camera traps were revisited on six occasions over the 2-week baiting period. On each revisit, the presence/absence of a bait at a given station was recorded and all missing or old baits were replaced, resulting in a total of 72 baits being deployed at each site in each trapping period. Rebaiting was conducted for two reasons, first, to test for differences in bait uptake between the first round of baiting (representing of aerial baiting at a density of 60 baits km^{-2}) and all six rounds (representing intensive baiting), and, second, to maximise the chances of a Kangaroo Island dunnart encountering a bait as this species occurs at very few sites and very low densities (Hohnen *et al.* 2019). It should be noted that, in some areas, baiting densities differ from those

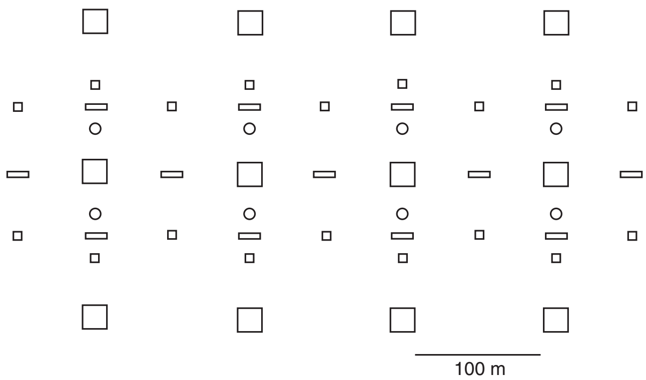

Fig. 2. Aerial view of the non-toxic baiting trial site design. Large squares indicate camera trap stations, small squares indicate Elliott traps, rectangles indicate cage traps and circles indicate pitfall traps.

trialled in the present study. For example, in Western Australia, when 50 baits are aerially deployed, they are distributed over an area of 200 × 40 m within each 1 km^2 cell. To evaluate how uptake by non-target species varied among sites baited once (representative of aerial baiting) or multiple times (representative of long-term intensive baiting), we ran a chi-square test of independence in R (R Development Core Team 2018).

Trapping

Two weeks after the baiting period, all sites were trapped for six nights. We set eight pitfall traps, 12 cage traps and 24 Elliott traps in a grid formation across each trial site. The pitfall traplines consisted of two pitfall traps (buckets 70 cm deep, 28 cm in diameter) located ~5 m from the distal ends of a 30 m drift fence line (Fig. 2). This fence consisted of impermeable black plastic, 60 cm high, held up by metal stakes, forming a solid barrier that guided animals moving through the site towards the pitfall traps. Pits were left open and checked at dawn and dusk. Cage and Elliott traps were opened only in the evening and checked and closed at dawn, and were baited with a mixture of peanut butter and oats.

All captured animals, including mammals, reptiles and amphibians, were identified to species. Captured mammals were placed into calico bags, weighed and their sex was determined. To identify recaptures of individuals, a tuft of hair was removed from the rump. To determine the extent of Rhodamine B ingestion (as an indication of bait consumption) by the captured mammals, eight mystacial vibrissae (whiskers) were plucked from each individual with forceps. The whisker was gripped close to the skin so that the entire whisker was removed from the follicle. If bait was ingested, Rhodamine B would be detectable in the whiskers within 4 days of consumption (Fisher 1999). While ingestion of bait can be detected, this method does not determine how much bait was consumed. Following processing, animals were released at the point of capture. The whiskers were stored in sealed envelopes for later mounting and examination under a fluorescence microscope to check for traces of Rhodamine B.

Whisker analysis

Whiskers were analysed following the protocol outlined in Fisher (1998). Whiskers from each sample were washed in 70% ethanol and then dried and mounted onto a slide with Fluoroshield mounting fluid (Sigma, St Louis, MT, USA), and sealed with clear nailpolish. The samples were viewed under a Zeiss Axiosop 2 fluorescence microscope (Zeiss, Oberkochen, Germany), using a green filter (Filter 21) so that light emission from the Rhodamine B could be seen. We noted the banding characteristics on each whisker, including both the number and position. The number of banded whiskers per sample was also recorded.

Tolerance of 1080

We assessed the likely 1080-tolerance (LD50) of wildlife on western Kangaroo Island through a literature review. Where possible, we used studies that sourced animals from places that did not have plants that naturally contain 1080 (such as *Gastrolobium* spp.; Eason *et al.* 1992), therefore, using animals that were similar in their 1080 exposure to those on Kangaroo Island. This is because, across Australia, the 1080-tolerance of a species can differ, depending on whether or not it has evolved in an area where 1080 naturally occurs in local plants (Twigg *et al.* 2003). We calculated the amount of an Eradicat bait an individual could consume for all non-target species that took baits during the trial, using the literature to find estimates of both the LD50 and average weight of adult individuals in the non-target species. Calculations for the amount of 1080, the weight of bait, and the total amount of a bait an animal needs to consume to reach LD50 are provided in the supplementary material (Table S1, available as Supplementary material to this paper). Note that animals may also show significant but non-lethal responses to bait uptake, so our assessment of LD50 does not encompass all possible detrimental impacts of bait consumption. The species with the lowest tolerance to 1080 were the house mouse and bush rat, followed by the tammar wallaby, feral cat, common brushtail possum, southern brown bandicoot and western grey kangaroo (full details in Table 1).

Results

Baiting

In each baiting period (early August and late November), 12 baits were deployed across each of the four sites on six baiting occasions (288 per season, and 576 in total). When the bait stations were checked 2–3 days after deployment, almost 100% of baits (287/288) had been removed in August, and 89% of baits (257/288) had been removed in November. In August, cameras recorded vertebrate animals removing the baits on 71% (204/287) of the occasions when a bait was taken, but missed photographing the bait-taking animal on 29% of occasions. Of the 71% of identifiable bait takes, the majority involved the bush rat, common brushtail possum, Australian raven (*Corvus coronoides*), with a few by the house mouse (*Mus musculus*; Tables 2, 3). In the November baiting episode, cameras recorded vertebrates removing baits on 80% (207/257) of occasions when a bait was taken, but failed to photograph the species that took baits on 20% of occasions. Of the 80% of bait takes that the cameras recorded, most involved the common brushtail possum, bush rat, Australian raven and a low percentage taken by Rosenberg's goanna, the southern brown bandicoot and the house mouse. Some species, including the tammar wallaby,

Table 1. The number of 15 g Eradicat baits that a species must consume before reaching its LD50
The origin of animals used in the study, relative to the distribution of plants that naturally contain 1080, is included (adapted from Twigg and King 1991). OKR, outside know range; PE, potential exposure; IKR, inside known range

Common name	Scientific name	Location	Average adult bodyweight (kg)	LD50 ($mg\,kg^{-1}$)	Amount of 1080 for LD50	Weight of bait for LD50 (g)	Number of baits for LD50	Reference
Australian raven	*Corvus coronoides*	PE	0.6	5.1	3.0	9.9	0.7	McIlroy (1982)
Common brushtail possum	*Trichosurus vulpecula*	OKR	2.6	0.9	2.2	7.5	0.5	McIlroy (1984)
Bush rat	*Rattus fuscipes*	OKR	0.1	1.8	0.1	0.5	<0.1	Twigg *et al.* (2003)
Cat	*Felis catus*	PE	4.2	0.3	1.7	5.6	0.4	Eason *et al.* (1992)
House mouse	*Mus musculus*	PE	0.0	8.3	0.1	0.4	<0.1	Twigg and King (1991)
Rosenberg's goanna	*Varanus rosenbergi*	OKR	0.7	40	28	93	6.2	Twigg and King (1991)
Southern brown bandicoot	*Isoodon obesulus*	OKR	0.8	7.0	5.6	19	1.2	Twigg and King (1991)
Tammar wallaby	*Notamacropus eugenii*	OKR	6.0	0.2	0.9	3.0	0.2	Oliver *et al.* (1979)
Western grey kangaroo	*Macropus fuliginosus*	OKR	30	20	600	2000	133	Oliver *et al.* (1979)

western grey kangaroo and Kangaroo Island dunnart, triggered the cameras when a bait was present, but were not recorded taking the bait (Table 2). In August, feral cats were photographed encountering a bait on only two occasions and were recorded consuming the bait once. In November, feral cats were recorded encountering baits on four occasions but were not recorded consuming any.

Species that took baits most frequently on encounter (across both seasons) were the Australian raven (100% or 77/77), Rosenberg's goanna (100% or 7/7), bush rat (94% or 159/169), common brushtail possum (90% or 154/171) and house mouse (77% or 10/13). Species with a low uptake of rates included the southern brown bandicoot (25% or 3/12) and feral cat (17% or 1/6; Table 2). Although the tammar wallaby, western grey kangaroo and short-beaked echidna encountered baits reasonably frequently (61, 13 and 12 encounters respectively), none took baits on these occasions.

When considering the first round (i.e. the 2–3 days after the initial deployment) of baiting only, 48 baits were deployed across four sites in both August and November. After 2–3 days, 98% (47/48) of baits had been taken in August, and 60% (29/48) in November. In August, cameras detected the species that took the baits on 29 of the 47 occasions a bait was taken (62%), and, of those, most were taken by the bush rat, common brushtail possum and Australian raven (Table 3). In November, cameras detected the species that took the bait on 93% of occasions, and, again, the majority were taken by the common brushtail possum, Australian raven and bush rat, but with 10% being taken by Rosenberg's goanna. For all seasons, the bush rat, common brushtail possum and Australian raven took baits on >80% of instances they encountered them (Table 2). When considering the November and August data together, the frequency of bait uptake by different species did not vary between the first round of baiting and all six rounds (χ^2 (5) = 6.8, P = 0.23). Similarly, there was no difference between the first round and all six rounds in November (χ^2 (5) = 8.4, P = 0.13); however, in August, there was a significant (χ^2 (3) = 13.4, P = 0.003) difference, potentially driven by the higher proportion of bait takes by the bush rat in the first round.

Whisker analysis

Whisker samples were collected principally from the common brushtail possum, bush rat and house mouse, as well as the southern brown bandicoot, little pygmy-possum and western pygmy-possum. All 18 brushtail possums (100%) caught in August exhibited banding in their whiskers, being indicative of having eaten a bait. In November, 83% of brushtail possums caught (10 total) exhibited evidence of having eaten a bait (Table 4). At least half of the bush rat population exhibited evidence of bait consumption in both August (59%) and November (50%). For the house mouse, 59% of captured individuals (5 total) showed evidence of bait consumption in August, but none showed evidence of bait consumption in November. Although captures of other species were too few to make robust conclusions, no captured little pygmy-possum or southern brown bandicoot showed evidence of having consumed a bait. In contrast, evidence of bait consumption was detected in whiskers of two western pygmy-possums (33%) caught in November. It is important to note that although bait

Table 2. November and August bait uptake by wildlife species on western Kangaroo Island, including data from the first round of baiting, and all six rounds of baiting

The number of times the animals triggered the cameras when a bait was present, and the times they took the baits, are shown

Common name	Scientific name	Total triggers	Bait taken	% uptake	Total triggers	Bait taken	% uptake
First round of baiting							
Australian raven	*Corvus coronoides*	3	3	100	8	8	100
Feral cat	*Felis catus*	0	0	0	2	0	0
Southern brown bandicoot	*Isoodon obesulus*	2	0	0	1	0	0
Tammar wallaby	*Notamacropus eugenii*	15	0	0	6	0	0
Western grey kangaroo	*Macropus fuliginosus*	1	0	0	1	0	0
Bush rat	*Rattus fuscipes*	27	22	81	6	5	83
Short-beaked echidna	*Tachyglossus aculeatus*	1	0	0	0	0	0
Common brushtail possum	*Trichosurus vulpecula*	9	4	44	15	11	73
Rosenberg's goanna	*Varanus rosenbergi*	0	0	0	3	3	100
Total		58	29	50	42	28	67
All six rounds of baiting							
Shy heathwren	*Calamanthus cauta*	0	0	0	3	0	0
Grey shrikethrush	*Colluricincla harmonica*	0	0	0	1	0	0
Australian raven	*Corvus coronoides*	32	32	100	45	45	100
Feral cat	*Felis catus*	2	1	50	4	0	0
Southern brown bandicoot	*Isoodon obesulus*	5	0	0	7	3	43
Tammar wallaby	*Notamacropus eugenii*	32	0	0	29	0	0
Western grey kangaroo	*Macropus fuliginosus*	4	0	0	9	0	0
House mouse	*Mus musculus*	7	7	100	6	3	50
Bush rat	*Rattus fuscipes*	113	108	96	56	51	91
Kangaroo Island dunnart	*Sminthopsis fuliginosus aitkeni*	0	0	0	1	0	0
Short-beaked echidna	*Tachyglossus aculeatus*	3	0	0	9	0	0
Common brushtail possum	*Trichosurus vulpecula*	63	56	89	108	98	91
Rosenberg's goanna	*Varanus rosenbergi*	0	0	0	7	7	100
Total		261	204	78	285	207	73

Table 3. The percentage of baits taken by all species that approached the bait stations in August and November for both the first round of baiting and all six rounds of baiting

		First round		All rounds	
Common name	Scientific name	Winter	Summer	Winter	Summer
Shy heathwren	*Calamanthus cauta*	–	–	–	–
Grey shrikethrush	*Colluricincla harmonica*	–	–	–	–
Australian raven	*Corvus coronoides*	6	28	11	18
Feral cat	*Felis catus*	–	–	–	–
Southern brown bandicoot	*Isoodon obesulus*	0	0	0	1
Tammar wallaby	*Macropus eugenii*	–	–	–	–
Western grey kangaroo	*Macropus fuliginosus*	–	–	–	–
House mouse	*Mus musculus*	0	0	2	1
Bush rat	*Rattus fuscipes*	47	17	38	20
Kangaroo Island dunnart	*Sminthopsis fulginosus aitkeni*	–	–	–	–
Short-beaked echidna	*Tachyglossus aculeatus*	–	–	–	–
Common brushtail possum	*Trichosurus vulpecula*	9	38	20	38
Rosenberg's goanna	*Varanus rosenbergi*	0	10	0	3
Unknown	*Unknown*	38	7	29	19

consumption can be detected, the amount of bait consumed by these individual animals cannot.

Discussion

Our results have indicated that baiting of feral cats on western Kangaroo Island by using Eradicat baits could have a large negative impact on non-target native species. Non-target species accounted for over 99% of identifiable bait takes, with only one bait taken by a feral cat. In both August and November, the common brushtail possum, bush rat and Australian raven, all being locally abundant, accounted for over 60% of all bait takes, and all three of these species have a reasonably low tolerance of 1080, needing to consume less than a single bait for it to be lethal in most cases. However, Rosenberg's goanna (listed as

Table 4. The number of individuals with whisker samples where Rhodamine B banding was, or was not, visible, split between the two trial periods (August and November) pooled across all study four sites

Common name	Species	August			November		
		Number of individuals without bands	Number of individuals with bands	Proportion of individuals with bands (%)	Number of individuals without bands	Number of individuals with bands	Proportion of individuals with bands (%)
Western pygmy-possum	*Cercartetus concinnus*	–	–	–	4	2	33
Little pygmy-possum	*Cercartetus lepidus*	1	–	0	2	–	0
Southern brown bandicoot	*Isoodon obesulus*	–	–	–	1	–	0
House mouse	*Mus musculus*	6	5	45	5	–	0
Bush rat	*Rattus fuscipes*	34	48	59	19	19	50
Common brushtail possum	*Trichosurus vulpecula*	–	18	100	2	10	83

vulnerable in South Australia) was not reported at bait stations in August and took baits only in November, suggesting that impacts of baiting on this species could be minimised by baiting in August when the species is inactive. Impacts on the Kangaroo Island dunnart and southern brown bandicoot were difficult to determine because of the low number of detections. Feral cats remain a significant threat to native fauna on the island, and feral cat baiting is still the most cost-effective method of controlling cats in wilderness areas (Algar and Burrows 2004). However, it appears that broadscale Eradicat baiting could have large negative impacts on common native fauna, and the investigation or other baits or avenues of cat control may be required.

Both the common brushtail possum and bush rat took over 50% of the all baits laid in both November and August, and both species took the baits on over 80% of occasions that they encountered them. Over 50% of bush rats, and 80% of possums captured at the sites in both November and August showed evidence that they had consumed baits. Both species have low tolerance of 1080, with the possum needing to consume only half of a 15-g Eradicat bait to reach its LD50, and the bush rat just 1% of a 15-g bait. Few studies have previously documented impacts of feral cat baiting on these common species. In a study by Fenner *et al.* (2009), bush-rat populations were not affected by baiting for foxes, but the raw meat baits used in that study had a lower concentration of 1080 (0.024 mg g^{-1} bait, compared with 0.3 mg g^{-1} Eradicat bait), and were deployed at a lower density (40 baits km^{-2}) than in the current study (60 baits km^{-2}), aerial feral cat baiting operations in Western Australia (Algar *et al.* 2013), and the Northern Territory (Macdonald *et al.* 2017). The common brushtail possum has been recorded taking raw meat (fox) baits (Martin *et al.* 2002; Mallick *et al.* 2016), grain (Gillies and Pierce 1999; Veltman and Pinder 2001) and carrot baits (Murphy *et al.* 1999; Spurr and Drew 1999), but no studies have examined the uptake of feral cat baits (which differ from the above in their form and composition). The results from our study suggested that baiting could have a large negative impact on both the bush rat and common brushtail possum.

The Australian raven could also be negatively affected by Eradicat baiting (taking 11% and 17% of baits in both August and November respectively) because baits were taken on 100% of occasions that they were encountered. This species also has an LD50 low enough that a single bait could be lethal (McIlroy 1984; Powlesland *et al.* 1999). In a separate Eradicat trial on eastern Kangaroo Island, uptake by corvids varied with season, but was sometimes as high as 40% (P. Hodgens, pers. comm.). In central Western Australia, corvids also took over 40% of Eradicat baits (Doherty and Algar 2015) and, in South Australia 11% (Moseby and Hill 2011). Corvids are highly visual predators, and in systems were they are a serious nest predator, predation rates are highest at the most obvious nests (Ekanayake *et al.* 2015). High rate of bait uptake by corvids in our study may have been influenced by us hand-baiting, with corvids watching our behaviour. Aerial baiting would not provide such visual cues to corvids, so their rate of take may be lower in such situations.

In contrast to the aforementioned species, continuous baiting may have a low impact on Rosenberg's goanna (listed in South Australia as *Vulnerable*). In the present trial, Rosenberg's goanna was very likely to take the baits in November when the ambient temperature was warmer and they were active (seven bait takes from seven encounters). Previous bait trials across Australia have recorded high bait uptake by varanids both in captivity (de Tores *et al.* 2011) and in the wild (Doherty and Algar 2015). However, this species has a reasonable tolerance of 1080 and needs to consume more than six baits to reach its LD50. Also, this species is inactive during the colder months; there were no sightings on the cameras in August, and, therefore, baiting impacts could be mitigated by restricting baiting to this time of year. A similar pattern was noticed for the southern brown bandicoot, with bait uptake for this species occurring only in November (three bait takes from 12 encounters); however, this encounter rate was too low for robust conclusions to be made. In previous trials, a mixture of wild and captive bandicoots were found to consume on average 8.5 g of a 20 g bait, and, on some occasions, consume the whole bait (Hetherington *et al.* 2007), suggesting that, in some circumstances, they will eat a sufficient amount of bait to approach their LD50 threshold.

The Kangaroo Island dunnart has largely disappeared from eastern Kangaroo Island, and is rarely encountered in the west (Hohnen *et al.* 2019). It is likely to benefit significantly from control of Kangaroo Island's feral cat population; however, the impact of feral cat baiting on this species is uncertain. There is evidence that other species of dunnart have a low tolerance of 1080, particularly those from areas outside the distribution of *Gastrolobium* spp., including *Sminthopsis crassicaudata* (LD50 2.06 mg kg^{-1}, or 1% of an Eradicat bait) and *S. macroura* (LD50 = 1 mg kg^{-1}, or 7% of an Eradicat bait; Calver *et al.*

1989). However, Sinclair and Bird (1984) suggested that *S. crassicaudata* may be able to detect the presence of 1080, because captive individuals conditioned to eating meat significantly decreased their intake (and, in some instances, vomited) when consuming meat dosed with 2.83 mg kg^{-1} of 1080. Field-based studies elsewhere, including in the Gibson Desert and the MacDonnell Ranges in central Australia, found no evidence of Eradicat bait consumption or a post-baiting population decline of *Sminthopsis* species (Angus *et al.* 2002; Macdonald *et al.* 2017). In the current study, unfortunately only one Kangaroo Island dunnart approached a camera when a bait was available, and although it did not eat the bait, little can be inferred from a single such encounter. Furthermore, population-scale impacts of bait consumption need to be contextualised with reference to the relative population size of different species. Although our study reported few instances of Kangaroo Island dunnarts and southern brown bandicoots encountering and consuming baits relative to the numbers of common brushtail possums and bush rats doing so, it may be that a higher proportion of the total population of bandicoots took bait than was the case for brushtail possums and bush rats. However, the total population sizes of these species in the study area are not known.

In our study, rates of bait encounter and uptake by feral cats were very low. Cats were recorded encountering baits on only two occasions in August and four occasions in November (of the total 576 baits laid). Of the six baits encountered, a cat took only one bait (in August). Uptake of baits by cats in previous studies appears very variable, with some being high (e.g. 89% and 75%; Johnston *et al.* 2011; Robinson *et al.* 2015) and some being low (e.g. 20% to >5%; Algar *et al.* 2011; Moseby and Hill 2011). The likelihood of a bait being encountered by a cat varies with the density of cats, the density of baits, and the level of competition with other species for the baits (Algar *et al.* 2007; Moseby and Hill 2011). The density of baits used in the present study (60 baits km^{-2}) was based on successful bait trials in similar eucalypt habitat on French Island in south-eastern Australia (Johnston *et al.* 2011). Given that the average home range of a cat on eastern Kangaroo Island is ~3.7 km^2 (P. Hodgens, unpubl. data), a cat at a given site would be likely to have had access to all 12 stations within its home range. Because the size of each of the four sites could fit within one individual cat's home range, potentially the trial sites were too small for many cats to have had access to them, so our results may reflect behavioural responses of very few individual cats. If the baits were deployed on a landscape scale, this would cease to be an issue. Previous baiting programs have successfully achieved cat population declines by using a wide range of bait densities from 10–25 baits km^{-2} in open desert habitat (Burrows *et al.* 2003; Moseby and Hill 2011) to 100 baits km^{-2} in coastal Western Australia (Algar and Burrows 2004). Potentially low bait encounter rates, as observed in our study, may also reflect a low density of cats. On western Kangaroo Island, there are 0.3–0.5 cats km^{-2}, which is a higher density than the average for mainland Australia (R. Hohnen, unpubl. data), but lower than on eastern Kangaroo Island where densities are 0.5–0.8 cats km^{-2} (P. Hodgens, unpubl. data). Higher bait encounter and uptake rates observed by a similar study on eastern Kangaroo Island might reflect higher densities of cats on that side of the island (P. Hodgens, unpubl. data). Also, we observed high competition for baits, with non-target species being involved in 99% of identifiable bait takes in August and November, decreasing bait availability for the target species.

Low bait uptake may also reflect a disinterest in scavenging. This has been observed in feral cats in other parts of Australia (Catling 1988; Short *et al.* 2002). However, on eastern Kangaroo Island, this does not seem to apply, because cats are readily caught in cage traps using chicken as bait (P. Hodgens, unpubl. data). This discrepancy may reflect the large number of roads and, therefore, roadkill on eastern Kangaroo Island, making cats in the east more accustomed to scavenging than those in the west (where there are few tracks and little traffic), and, therefore, also more likely to eat baits.

In the present trial, we compared bait uptake between an initial single round of baiting, and multiple rounds of baiting. This is because, potentially, uptake during the first round of baiting is more reflective of uptake during broadscale aerial baiting, where individuals have no previous experience with the baits. In contrast, after multiple rounds of baiting at a given site, animals might learn where the bait stations are and, if they survive the first round, target them. However, there were few differences in uptake when comparing the first round of baiting to the whole trial. In August, total uptake in the first round was very similar to that in the whole trial (98% compared with 99%), but in November, uptake during the first round was lower than that in the whole trial (60% compared with 98%). The results of the chi-square tests suggested that proportional uptake by the various non-target species did not differ between the first round and all rounds in November, or when considering both seasons together, but did vary in August, being potentially driven by higher uptake of bush rats during the first round. Despite this, in both the first round of baiting and in all rounds, the common brushtail possum, bush rat and Australian raven took over 60% of the baits. Overall, these results suggested that irrespective of how baits are deployed (once, or continually in a targeted manner), uptake by non-target species will be high.

Eradicat is the only feral cat bait currently available for commercial use in Australia; however, two others are in development: 'Curiosity®' and 'Hisstory®'. Both baits have a sausage-shaped meat exterior, similar to that of Eradicat, but use a hard-shelled delivery vehicle (HSDV), where poison is encapsulated in a hard, although digestible, pellet that sits in the centre of the sausage (Algar and Burrows 2004; Marks *et al.* 2006). The idea is that native Australian mammals generally chew their food such that they would be likely to eat around the hard capsule, whereas cats, which eat their prey without chewing, would swallow it whole, with the toxin being released when the HSDV dissolves in the cat's digestive tract (Marks *et al.* 2006). The baits use different toxins: 'Hisstory' uses 1080, 'Curiosity' uses para-aminopropiophenone, to which some Australian mammals have a higher tolerance (Fisher *et al.* 2008). Buckmaster *et al.* (2014) suggested that the use of a HSDV may help decrease potential impacts on the common brushtail possum, but potentially not the bush rat (that may be able to chew into them) or the Australian raven (which may be able to swallow baits whole).

Ultimately, the results of the present trial suggested that Eradicat may be an inappropriate choice of bait for broadscale feral cat control on western Kangaroo Island. Impacts on common species are of particular concern, with populations of the bush rat, common brushtail possum and Australian raven being likely to be severely negatively affected by the use of this bait. However, impacts on species such as Rosenberg's goanna may be avoided by baiting in August. Unfortunately, encounter rates by the threatened southern brown bandicoot and Kangaroo Island dunnart were too low to draw robust conclusions, except to confirm that bandicoots will consume baits in some circumstances. Other feral cat baits that are currently in development, such as 'Curiosity' or 'Hisstory', may have lower impacts on Kangaroo Island wildlife and could, therefore, be more appropriate to deploy at both local and landscape scales. Because uptake of baits by cats was low in the present study, we suggest that further investigation into the home-range size and movements of feral cats on western Kangaroo Island could inform and optimise the placement of alternative baits and increase cat encounter rates.

Conflicts of interest

The authors declare no conflicts of interest.

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