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Field assessment of the risk of feral cat baits to non-target species in eastern Australia

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Data Accessibility Statement

All data are available within the manuscript or in the supplementary files.

ABSTRACT

Feral cats pose a significant threat to wildlife, agriculture and human health

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through predation, disease transmission and competition with native animals. Controlling feral cats and their impacts, however, is challenging. New and emerging 1080-based feral cat baits have shown promising results in western and central Australia, however the safety of these new baits for non-target species in eastern Australia, where many native animals are more sensitive to 1080 than their western conspecifics, has not been assessed. We investigated the uptake by non-target animals of 499 toxic Eradicat® baits across five different eastern Australian environs, and the uptake of non-toxic Eradicat® and Hisstory® baits at an additional two sites. Using field-based observations of species eating or removing baits, we determined that 13 non-target species (eight mammals, four birds, one reptile) were at high risk of individual mortality, with individuals of 11 of those 13 species (four birds, seven mammals) observed consuming enough toxic Eradicat® in a single visit to ingest a lethal dose of 1080. Feral cats (the target species) consumed only 3.1% of monitored baits, which was only 52% of the 31 baits they encountered. We recommend undertaking targeted population monitoring of species identified at high risk of individual mortality, to determine whether Eradicat® baits present a population-level risk to these species. Our findings suggest that the small-sized Eradicat® baits present a greater risk to non-target species in eastern Australia than the larger traditional 1080-based meat baits used for the control of wild dogs and foxes. Our study highlights the importance of performing risk assessments for different bait types, even when the same toxin is used, and of performing site-specific non-target risk assessments of new baits such as Eradicat® to assist developing guidelines for their safe and effective use in different environs.

Keywords

Eradicat®, Hisstory®, LD_{50}, 1080, *Felis catus*

INTRODUCTION

Reducing the impacts of feral cats (*Felis catus*) is a key objective for conservation managers, livestock producers and human health agencies globally. Feral cats inflict significant negative impacts on wildlife, livestock and human health (Dubey 2010; Medina et al. 2011) through predation (Fancourt 2015; Judge et al. 2012; McGregor et al. 2015), disease transmission (Burns et al. 2003; Szabo et al. 2004; Work et al. 2000) and competition with native animals (Medina et al. 2014). These impacts appear to be more pronounced in Australia, where endemic wildlife did not evolve in the presence of eutherian predators such as cats (Salo et al. 2007). Accordingly, the introduction, spread and establishment of feral domestic cats following European settlement in the late 1700s is thought to have contributed to the extinction and decline in range and abundance of dozens of native mammal species (Woinarski et al. 2015), with southern Australia reporting some of the highest levels of cat-borne diseases globally (Fancourt and Jackson 2014).

An estimated 2-6 million feral cats occupy over 99% of Australia's 7.7 million km^2 land area, including many islands (Legge et al. 2017), making the control of feral cats and their impacts a landscape-scale challenge. However, safe and efficacious control options to reduce feral cat population size and impacts are currently limited. Trapping, shooting and exclusion fencing can be effective at local scales, but these approaches can be labour intensive, costly and have limited application to control across larger areas (Bengsen 2015; Short et al. 1997). Apex or large predators such as the dingo have been proposed as a way to control feral cats at the landscape scale (Dickman et al. 2009), however fine-scale spatiotemporal analyses show that cats can coexist with dingoes, without apparent suppression of cat activity, abundance or fitness (Fancourt et al. 2019). Traditional poisoned meat baiting using the toxin 1080 (sodium fluoroacetate) can be effective at controlling populations of introduced canid species such as wild dogs (*Canis familiaris*) and foxes (*Vulpes vulpes*) across the landscape, but is typically less effective at controlling feral cats (e.g. Burrows et al. 2003; Fancourt et al. 2021). Trials testing the uptake and efficacy of two new 1080 feral cat baits, Eradicat® and Hisstory® (Algar et al. 2015), have reported some promising results in western and central Australia, however results within and across sites are highly variable (Bengsen 2015). While Eradicat® is currently only registered for use in Western Australia, and Hisstory® is not yet registered, the safety and efficacy of these two new cat baits have not been assessed in eastern Australian environs.

A key consideration when using poison baits to control introduced predators, including feral cats, is the potential risk of mortality to non-target animals. Australia is unique in that many native wildlife evolved in the presence of fluoroacetate-bearing plants (Twigg and King 1991). This evolutionary exposure has given many native species a much higher tolerance to fluoroacetate-containing compounds such as sodium fluoroacetate (compound 1080, hereafter "1080") than introduced species such as wild dogs, foxes and feral cats (McIlroy 1981b). Accordingly, the use of baits containing low doses of 1080 can provide a cost-effective way to control introduced predators over large areas, while minimising the risk to non-target native species. But the tolerance of native animals to 1080 varies significantly among species and regions. Many plants of the genera *Gastrolobium* and *Oxylobium* in south-western Australia contain high concentrations of fluoroacetate, yet those occurring in northern Australia, in addition to *Acacia georginae*, produce lower concentrations (Twigg and King 1991), and fluoroacetate-bearing plants are mostly absent from eastern Australia. This regional variation in fluoroacetate exposure has led to marked regional variation in 1080 sensitivity amongst conspecifics. For example, *Antechinus flavipes* from southern Australia are >3 times more sensitive to 1080 than their western Australian conspecifics (King et al. 1989), and marsupial herbivores in eastern

Australia are >100 times more sensitive than conspecifics in western Australia (McIlroy 1986). Accordingly, while 1080-based feral cat baits such as Eradicat® are considered safe for many non-target species in western Australia, the risk to non-target species in eastern Australia is potentially much greater.

The use of 1080 canid baits is considered safe for many non-target native species in eastern Australia (e.g. Körtner 2007), however the smaller bait size, higher application rates and increased palatability of 1080 feral cat baits (such as Eradicat® and Hisstory®) present a different risk profile for non-target species. For example, fox and wild dog baiting programs in eastern Australia typically use large bait sizes (~125-250 g), thereby reducing the chance that small non-target mammals and birds could handle, move or eat an entire bait (Gentle et al. 2014). Furthermore, the high 1080 tolerance of many native animals requires they find and eat multiple baits to ingest enough 1080 to be lethal. The lower application rates of canid baits (typically 10-20 baits km^{-2}) reduces the likelihood that individual animals will encounter multiple baits, but should this occur, many species are too small to consume enough meat in a single meal to receive a lethal dose of 1080. Accordingly, the size, presentation and application rates of typical 1080 canid baits contribute to their safety for most non-target species in eastern Australia. By comparison, while Eradicat® and Hisstory® baits contain less 1080 (4.5 mg $bait^{-1}$) than wild dog baits (6-10 mg $bait^{-1}$), their substantially smaller size (~15 g) and much higher application rates (up to 50 baits km^{-2}) increase the likelihood that individual animals will encounter and consume multiple baits, and potentially a lethal dose of 1080. For example, a 3.25 kg wedge-tailed eagle (*Aquila audax*) needs to consume 30.85 mg of 1080 to receive a lethal dose of 9.49 mg kg^{-1} (McIlroy 1984). To achieve this, an eagle would need to eat 0.4 kg of 125g wild dog baits containing 10 mg 1080 (~3.1 baits) or ~1.3 kg of 250g wild dog baits containing 6 mg 1080 (~5.2 baits) but consume only ~0.1 kg of Eradicat®

baits (~7 baits) to receive a lethal dose. Accordingly, thorough non-target risk assessment is required before seeking to use and/or register Eradicat® baits to control feral cats in eastern Australian environs.

The risk of non-target mortality from 1080 feral cat baiting programs can be influenced by a range of variables. Desktop risk assessments can consider important theoretical risk criteria such as the species-specific sensitivity to 1080, body size, diet and feeding behaviour (e.g. Buckmaster et al. 2014) to estimate the risk of mortality. However, the theoretical risk of mortality may not equate to the actual risk under field conditions. Other factors, including the relative palatability of bait to each species, availability of bait and alternative foods, the amount of bait and toxin ingested by each individual, and variation in individual susceptibility to the toxin may all influence the probability of mortality (McIlroy 1984). For example, while lab-derived sensitivities suggest spotted-tailed quolls (*Dasyurus maculatus*) are at theoretical risk of mortality from 1080-based wild dog baits (McIlroy 1981b), field assessments have found quolls consume 1080 wild dog baits and survive, with some quolls surviving after eating multiple baits and consuming in excess of the theoretical lethal dose of 1080 (Körtner 2007). Alternatively, species considered to be at theoretical risk of mortality might not encounter enough baits in the landscape, or might not consume the baits they do encounter. Accordingly, while desktop-based assessments provide an important first step in identifying the potential risk of feral cat baits to non-target species, field-based risk assessments are also required to observe behavioural responses to baits in the landscape, and evaluate any additional risks or mitigating factors. No field trials have been performed to assess the risk of Eradicat® or Hisstory® baits to non-target species in eastern Australian environs. A recent study used non-toxic bait uptake trials to assess the risk of Eradicat® baits to non-target species on Kangaroo Island in southern Australia (Hohnen et al. 2020). However, while non-toxic baits are commonly used for preliminary risk assessments where species of conservation significance may be sensitive to toxic baits, there are often differences in the uptake and palatability of toxic and non-toxic bait (Gentle 2005). Studies have demonstrated that 1080 reduces the palatability of meat (Calver et al. 1989; Morgan 1982; Sinclair and Bird 1984), with species such as northern quolls consuming many more non-toxic Eradicat® baits than the toxic equivalents (Palmer et al. 2017). Accordingly, trials using non-toxic baits, such as those used by Hohnen et al. (2020), will likely overestimate the consumption of toxic baits, and the risk of toxic Eradicat® baits to non-target species.

We performed a series of field-based bait uptake trials to assess the potential risk of Eradicat® and Hisstory® feral cat baits to a range of non-target species in several different eastern Australian environs. We assessed a range of risk criteria including: 1) how quickly baits were taken; 2) which species removed or consumed baits; 3) bait encounter rates for each species; 4) the proportion of bait encounters for each species that resulted in bait removal or consumption; 5) whether baits were eaten or taken out of the camera's field of view (fate unknown); 6) the species-specific sensitivity to 1080; 7) the number of baits required to consume a lethal dose of 1080; and 8) the amount of meat/bait matrix required to be consumed as a percentage of the species' body weight. We identified 'at risk' species that require further population-level monitoring to determine whether baiting leads to significant population-level impacts for each species (Glen et al. 2007). The implications of our findings are discussed in the context of using 1080 baits to manage feral cats and balancing the benefits and risks of feral cat control to non-target species.

MATERIALS AND METHODS

Study sites

We performed bait uptake trials at seven sites across Queensland, Australia

(Figure 1; Table 1). All sites were located within national parks and were selected to cover a range of different environs (arid, semi-arid, temperate, rainforest, subtropical and northern tropical savannas), thereby maximising the number of non-target species being assessed. As the Eradicat® bait product label prohibited the use of baits in areas where northern quoll (*Dasyurus hallucatus*) or their habitat may be present, all study sites except Taunton National Park (TNP) were located outside of these areas (Figure 1). However, as extensive long-term trapping and camera monitoring programs by the Queensland Parks & Wildlife Service (QPWS) had found no evidence of northern quolls at TNP in recent decades, the Australian Pesticides and Veterinary Medicines Authority (APVMA) granted approval to use this site (APVMA research permit PER81817). Detailed site information including location, bioregion, vegetation communities, bait type, number of baits and deployment patterns, monitoring dates and cameras used is provided in Table 1.

Baits

Two new 1080-based feral cat baits, Eradicat® and Hisstory®, were used in the current study. Both bait types are chipolata-sized sausage-style baits comprising 70% kangaroo meat mince, 20% chicken fat and 10% digest and flavour enhancers that are attractive to feral cats (Algar et al. 2007). Baits are ~20g wet-weight, dried to 15g, blanched then frozen (Algar and Burrows 2004). Both baits contain 4.5mg of 1080, but differ in their presentation of the toxicant. In Eradicat®, the 1080 is centrally injected directly into the bait medium, meaning that animals consuming the medium are also likely to consume the toxicant. Hisstory® baits encapsulate the 1080 within a polymer hard shell delivery vehicle (HSDV; Johnston et al. 2011) implanted into the bait matrix. The HSDV is designed to reduce the risk of non-target mortality, with most native Australian species predicted to reject the HSDV when masticating their food (Buckmaster et al. 2014; Hetherington et al. 2007; Marks et al. 2006). Because cats tend to 'shear' their food into large pieces that are swallowed whole, the entire acid-soluble HSDV is designed to be consumed by cats intact, dissolving in the cat's stomach to release the toxin once ingested.

Prior to deployment, frozen baits were defrosted in direct sunlight and allowed to 'sweat' until the oils and lipid-soluble digest material exuded from the bait's surface. Baits were lightly sprayed with a permethrin-based residual insecticide (Coopex®, Bayer Cropscience Pty Ltd, Hawthorn East, Australia) at a concentration of 12.5 g L^{-1}, as per the recommended bait preparation protocol. Previous trials in Western Australia have demonstrated that the use of Coopex® can greatly enhance bait uptake by feral cats by deterring meat ants and reducing bait degradation (Algar et al. 2007).

Eradicat® baits can be aerially deployed or surface laid at up to 50 baits km^{-2}. In Western Australia, baits are typically dropped in batches of 50 baits that scatter over an area ~200 x 40 m when aerially deployed, with 1 km spacing between batches along flight transects (Algar et al. 2015). However, due to potentially higher risks to non-target species in eastern Australia, we determined that a more conservative risk-based deployment pattern would drop a batch of 5 baits every 200 m along parallel flight transects, with 500 m spacing between transects. This deployment pattern would reduce the risk of an animal encountering and eating multiple toxic baits, while still giving the recommended maximum application rate of 50 baits km^{-2}. Similarly, ground baiting in Western Australia places a single Eradicat® bait every 100 m along tracks (Algar et al. 2015). However, to reduce the risk of non-target animals encountering (and eating) multiple toxic baits, we increased the spacing between toxic baits to 200 m. Where possible, we deployed baits during the dry season (late autumn - early spring) when temperatures, rainfall and activity of non-target species were at an annual low.

Bait uptake trials

Toxic bait trials. We monitored species interactions with 499 toxic Eradicat® baits across five sites (MRNP, GNP, CFNP, TNP, CNP; Figure 1; Table 1). Baits were applied to simulate one of the two management deployment patterns; 1) aerial baiting along straight-line flight transects, or 2) surface-laid ground baiting along vehicle track-based transects. For aerial baiting deployment, a test drop of baits thrown from a helicopter (flight speed 50 knots, flight altitude 150 ft AGL) revealed that a batch of five baits thrown together would scatter across a ~40 m^2 ground area (~8 m x 5 m). Accordingly, to simulate aerial baiting deployment, we surface laid 25 baits along 800 m straight-line transects across the landscape, with clusters of five baits spread over 40 m^2, and 200 m spacing between bait clusters. For track-based ground deployment, we surface laid 25 baits along 5 km vehicle track transects, with a single bait placed up to 10 m away from the track, and 200 m spacing between baits. For both deployment patterns, transects comprised 25 baits per transect, with 3-5 transects per site located in different areas to ensure different habitat types and different non-target communities were sampled across each site (n=75-125 baits per site; Table 1). Each bait was monitored with a dedicated camera for 14 nights or until the bait was taken, whichever occurred first. Cameras used passive infrared sensors to detect a heat-in-motion differential between an animal and the background temperature, and an infrared flash for night-time illumination. Cameras were programmed to either record photos (CFNP, TNP) or 10 second videos (MRNP, GNP, CNP). The make and model of cameras used at each site are listed in Table 1. Baits were also visually inspected at regular intervals throughout the 14 nights to assess bait condition and to determine the date of bait take (in case of camera failure to detect bait removal).

Non-toxic bait trials. Non-toxic baits were used at two sites (ADNP, MNP) due to the known presence of carnivorous or omnivorous threatened species that might be susceptible to toxic baits: the kowari (*Dasyuroides byrnei*) and greater bilby (*Macrotis lagotis*) at ADNP, and Julia Creek dunnart (*Sminthopsis douglasi*) at MNP.

Non-toxic Hisstory® baits were used at ADNP, with the HSDV containing a non-toxic biomarker, rhodamine B, in place of the 1080 toxin. One hundred baits were surface laid and monitored with fifty cameras (Table 1) spaced at 100 m intervals across two 2.5 km transects. One transect was located in core kowari habitat and the other was located in core bilby habitat. The 25 cameras on the kowari transect each monitored an individual bait, while each of the 25 cameras on the bilby transect monitored a group of three baits placed together in the camera's centre of the field of view. For each motion trigger, cameras were programmed to take 10 photos in rapid succession with no delay. Due to the remote location and regional flooding events preventing subsequent access to the site, cameras ran continuously until they could be retrieved around 10 weeks later.

At MNP, 40 individual non-toxic Eradicat® baits were surface laid along the edge of vehicle tracks, with ~350-1000 m spacing between baits. An additional 10 baits were each placed in patches of preferred habitat of the Julia Creek dunnart (Mitchell grass, *Astrebla* spp.) up to 50 m away from vehicle tracks. Each of the 50 baits was monitored with a dedicated camera programmed to take five photos in rapid succession for each motion trigger. Due to the remote location of the site, cameras ran continuously until they were retrieved seven weeks later.

Risk assessment – toxic bait trials

Rate of bait take. At each of the five sites where toxic Eradicat® baits were monitored (MRNP, GNP, CFNP, TNP, CNP), we reviewed the photos and videos from the bait monitoring cameras to determine when each bait was eaten or removed (taken out of the camera field of view), and calculated the rate of bait take in each environ. Baits were monitored for 14 nights or until the bait was eaten or removed, whichever occurred first.

Bait take by species. For each bait eaten, partially eaten, or removed out of the camera's field of view, we identified the animal responsible to the species level (or genus if the species could not be confidently identified). To facilitate species-level risk assessments, we also classified each species according to origin (native or introduced) and conservation status under the *Environment Protection and Biodiversity Conservation Act 1999*.

Bait encounter rates by species. For each species, we recorded the number of times a bait (or partial bait) was encountered, and how many encounters resulted in the bait (or partial bait) being eaten or removed. We then classified each species into one of three initial risk categories: 'potentially at risk' if the species ate or removed a bait (or partial bait), 'low risk' if the species encountered $\geq$ 10 baits but did not eat or remove any baits, or 'data deficient' if the species did not eat or remove any baits but there were too few encounters (<10) to confidently assess risk. Bait interactions were monitored for 14 nights or until the bait was eaten or removed, whichever occurred first.

Species risk assessment. Species initially classified as 'potentially at risk' were investigated further to determine: 1) what proportion of bait encounters resulted in bait consumption or removal; 2) whether baits were eaten (high risk) or taken out of the camera's field of view (risk unknown); 3) the species sensitivity to 1080 (species-specific laboratory-derived LD_{50}, the lethal dose required to kill 50% of a large population) from the literature; 4) the proportion of a bait, or number of baits required for an individual to consume a lethal dose of 1080; and 5) the amount of bait required to consume a lethal dose of 1080 (assuming that the 1080 is evenly distributed throughout the bait matrix), as a percentage of the species' body weight. Where species could not be identified below genera (antechinus: *Antechinus* spp. and dunnarts: *Sminthopsis* spp.), the LD_{50} of species known to occur at these sites (where available) were used for the risk assessment. Where the species LD_{50} was derived using animals sourced from different regions, we used the LD_{50} derived from eastern Australian-sourced animals wherever possible. These criteria were then used to assess the risk of mortality from toxic Eradicat® baits, using the decision tree in Supplementary Table S1.

Risk assessment – non-toxic bait trials

For several native species, 1080 can reduce the palatability of baits (Calver et al. 1989; Morgan 1982; Sinclair and Bird 1984). Accordingly, our risk assessment for the non-toxic bait trials at ADNP and MNP was limited to observing whether threatened species interacted with baits, and whether these species found the non-toxic bait matrix palatable. While we cannot make any robust assessment about the potential palatability or risk of toxic baits to these species, we reported all detected species interactions to help inform further risk assessments prior to undertaking toxic bait trials where these species might occur.

RESULTS

Toxic bait trials

Rate of bait take. Marked differences were observed in the number and rate of toxic Eradicat® baits taken across environs, with baits in cooler, more humid environments removed much more swiftly than baits in semi-arid and arid areas (Figure 2). Across all five sites, 57.6% of the 499 monitored baits were taken in the 14 nights following deployment, however this varied among sites, ranging from 84.8% in rainforest (MRNP) down to only 25.6% in arid environs (CNP) (Table 2).

Bait take by species. Toxic Eradicat® baits were eaten and/or removed by 24 different species (13 mammals, 3 reptiles, 8 birds) across the five sites, as detailed in

Table 2. Of the 57.6% baits taken, only 3.1% were eaten by feral cats. The remaining 54.5% were eaten or removed by native non-target species (41.1%), introduced non-target species (1.2%) and ants (0.2%), with 12.0% of bait takes not detected on cameras. Most baits were taken by birds (23.4%), followed by non-target mammals (13.9%) and reptiles (5.0%) (Table 2).

Some bait-taking species were detected across multiple sites, however the main non-target species differed among sites. Corvids (*Corvus* spp.) took the most baits overall (11.8% across four sites) and removed the greatest number of baits at two of the drier sites (TNP: 31.7%, CNP 17.6%). In rainforest (MRNP), mammals took 39.5% of baits, with most baits taken by fawn-footed melomys (*Melomys cervinipes*; 21.0%), northern brown bandicoots (*Isoodon macrourus*; 7.0%) and antechinus (*Antechinus* spp.; 6.0%). Birds took 24.0% of the baits in rainforest, with most baits removed by green catbirds (*Ailuroedus crassirostris*; 10.0%) and Australian magpies (*Cracticus tibicen*; 6.0%). As ambient temperatures increased towards the end of the trial, a further 5.8% of baits were eaten by lace monitors (*Varanus varius*). In mesic forests (GNP), birds took 39.3% of monitored baits, with most baits taken by pied currawongs (*Strepera graculina* 13.1%), corvids (11.1%) and laughing kookaburras (*Dacelo novaegineae* 10.1%). Mammals took a further 21.7% of baits at this site, with common brush-tailed possums (*Trichosurus vulpecula*; 11.8%) and antechinus (5.6%) the main bait-taking mammals. At CFNP, reptiles took 19.0% of baits, with most baits eaten by sand monitors (*Varanus gouldii*; 17.0%), however a large proportion (31.3%) of the total 55.3% bait takes were not detected on cameras. See Table 2 for a list of bait-taking species at each site.

Bait encounter rates by species. Across the five sites, toxic Eradicat® baits were encountered 3713 times by 116 species, including feral cats. The 115 non-target species encountering baits included 34 mammal, 10 reptile and 71 bird species. See

Supplementary Table S2 for details of bait encounters and removals by species for each site.

Feral cats encountered baits (or partial baits) 31 times, but only 16 encounters (52%) resulted in the bait being eaten. For non-target mammals, while 34 species encountered baits, only 12 species (35%) ate or removed some or all of the baits they encountered (Supplementary Table S2(a)). Only 6% of the 1567 bait encounters by non-target mammals resulted in the bait being eaten or removed, however this conversion rate varied between sites (Supplementary Table S2(a)). Bait take occurred for 17-22% of non-target mammal encounters at GNP and MRNP respectively, however rates were lower at drier sites (CFNP, TNP, CNP) where only 0-3% of mammal encounters led to bait take. Once baits were encountered, the mammal species most likely to consume baits included introduced black rats (*Rattus rattus*) and red foxes (both 100%), introduced wild dogs (50%), northern brown bandicoots (45%), fawn-footed melomys (43%), antechinus (36%), long-nosed potoroos (*Potorous tridactylus*; 20%), long-nosed bandicoots (*Perameles nasuta*; 17%) and common brush-tailed possums (16%).

Reptiles were the taxa most likely to consume encountered baits, with 25 of 53 (47%) bait encounters resulting in bait consumption (Supplementary Table S2(b)). Only three of the 10 species encountering baits ate some or all of the baits they encountered, including sand monitors (77%), black-headed monitors (*Varanus tristis*; 67%) and lace monitors (55%).

Birds accounted for the highest number of bait encounters (2062), but like mammals, only 6% of encounters led to bait take (Supplementary Table S2(c)). Of the 71 species encountering baits, only 12 species (11%) ate or removed baits. Bird species most likely to remove or eat encountered baits included green catbirds (83%), laughing kookaburras (53%), corvids (47%), pied currawongs (44%) and Australian brush-turkeys (*Alectura lathami*; 36%) (Supplementary Table S2(c)).

A total of 11 mammal and 23 bird species were classified as ‘low risk’ (Table 3) based on high bait encounter rates with no baits taken (Supplementary Tables S2(a,c)). Due to the low number of bait encounters, a further 11 mammals, 7 reptiles and 40 bird species encountering baits (Supplementary Table S2) were classified as ‘data deficient’ (Table 3). The 24 species (13 mammals, 3 reptiles, 8 birds) observed removing or eating baits (Table 2), including feral cats, were classified as ‘potentially at risk’ (Table 3), and more detailed risk assessments were subsequently performed for each species in Table 4.

Species risk assessment. Of the 23 non-target species detected eating or removing baits, nine mammals, one reptile and four bird species were assessed as being at high risk of individual mortality from toxic Eradicat® baits, and two reptiles were assessed as low risk (Table 4). A risk assessment could not be performed for the remaining species, either because an LD_{50} had not been determined for the species, or because the species was only detected removing the bait away from the camera, with no observations of whether the animal ultimately ate any or all of the bait (Table 4). As not all species consume the baits they remove (e.g. Körtner et al. 2003), bait removal could not be used as a proxy for bait consumption. See Table 4 for the detailed risk assessment for each species.

As mammals tend to be more sensitive to 1080 than birds and reptiles (McIlroy 1986), most non-target mammal species (9/12) only needed to eat less than half an Eradicat® bait (<7.5 g meat) to ingest a lethal dose of 1080, while two other mammals required less than a single bait (<15.0 g meat). Several mammals were detected eating more than the required amount of Eradicat® to ingest a lethal dose, adding further weight to our risk assessment. Native mammals considered at high risk of individual mortality included fawn-footed melomys, common brush-tailed possums, northern brown bandicoots, long-nosed bandicoots, short-eared brush-tailed possums (*Trichosurus caninus*) and the vulnerable long-nosed potoroo (Table 4). Introduced mammals with a high individual risk of mortality, in addition to feral cats, included the red fox and wild dog. Australian ravens (*Corvus coronoides*), pied currawongs and Australian magpies all required less than a single Eradicat® bait to ingest a lethal dose (Table 4). Individuals of all three species were observed eating at least a full Eradicat® bait, confirming a high individual risk of mortality for these bird species. While two reptile species (sand monitors and lace monitors) ate most baits they encountered, they each required 7-23 Eradicat® baits to ingest a lethal dose, placing these species at low risk of individual mortality. Two black-headed monitors were each observed eating a single bait on different transects, however based on our bait deployment patterns, this species was considered likely to encounter and consume the required 1.39 baits for a lethal dose, and hence was assessed as being at high risk of mortality.

Non-toxic bait trials

Non-toxic Hisstory® bait trial (ADNP): Corvids removed 41% of the non-toxic Hisstory® baits, with black kites (*Milvus migrans*), Spencer's monitors (*Varanus spenceri*), nankeen kestrels (*Falco cenchroides*) and a kowari taking a further 11% of baits. Forty bait removals were not detected by the Reconyx cameras, and eight baits were not taken. Detailed species interactions are listed in Supplementary Table S3. No threatened species were observed eating baits. Kowaris encountered baits 181 times, chewing at the corner of 11 baits (but not eating them), and urinating on baits 30 times. Only one bait was removed by a kowari, although it is unknown whether it was eaten away from the camera, and hence we were unable to assess if they would eat or reject the HSDV. Bilbies encountered baits 30 times but showed little interest in baits, with only 5 bilbies sniffing a bait, and none attempting to eat or remove any baits.

Non-toxic Eradicat® bait trial (MNP): Rain in the week following bait deployment resulted in the rapid degradation of many baits, mostly by meat ants that consumed the bait contents once the Coopex®-covered bait skin had been breached. Twenty-five species were detected encountering baits, including 13 feral cats, however corvids and yellow-spotted monitors (*Varanus panoptes*) were the only species detected removing baits (4% each), with 42 bait takes either missed by the Reconyx cameras or eaten by ants. No Julia Creek dunnarts were detected, and hence no assessment could be made about the likelihood of bait consumption. Species interactions with non-toxic Eradicat® baits at MNP are listed in Supplementary Table S4.

DISCUSSION

Our findings suggest that Eradicat® feral cat baits present a high risk of individual mortality for several native and introduced non-target species in eastern Australia. Using field-based observations of species interacting with baits in the landscape, we determined that 13 non-target species (six native mammals, two introduced mammals, four birds, one reptile) were at high risk of individual mortality, with individuals of 11 of these 13 species (seven mammals, four birds) observed consuming enough toxic bait to ingest a lethal dose of 1080 (Table 4). We also identified a further 12 taxa that are potentially at risk and 58 observed taxa (11 mammals, 7 reptiles, 40 birds) that were data deficient (Table 3). We recommend that targeted population monitoring of these high risk species be performed as part of future Eradicat® baiting trials, to determine whether the high risk of individual mortality signals a population-level risk for each of these non-target species (Glen et al. 2007).

Our observations and subsequent risk analyses identified several species at high risk of individual mortality (Table 4), however, the ultimate fate of these individuals could not be ascertained from bait uptake cameras. Although we observed many individuals eating enough Eradicat® bait to consume a theoretical lethal dose, several factors would influence their subsequent mortality. First, the amount of 1080 ingested will depend on the distribution of the toxin in the bait matrix. The 1080 in Eradicat® baits is nominally centrally injected, potentially concentrating the 1080 into the centre of the bait. Some species such as the long-nosed potoroo were observed eating only a small portion at the end of the bait, which may contain little (if any) 1080, although the bait injection site was variable (authors personal observation, this study). Given most bait-consuming species were observed eating the entire bait, the distribution of the 1080 within the bait would be largely inconsequential. Second, the age of the bait when eaten is also an important factor, as 1080 rapidly degrades in meat baits (Fleming and Parker 1991), meaning that susceptible non-target species would need to eat more Eradicat® baits on day 14 to receive the same lethal dose available on day one. However, as most baits were removed in the first few days (Figure 2) when 1080 loss is minimal, our risk assessment remains representative (and appropriately conservative). Third, LD_{50} values are commonly derived through captive, laboratory-based trials, and a variety of methodological, environmental or individual-based factors (e.g. route of administration, ambient temperature, diet, body condition and size, stress and metabolic demands) may influence the susceptibility of an individual to 1080 (McIlroy 1981a; Oliver and King 1983). The common use of oral and intraperitoneal dosing to administer 1080 in laboratory trials can yield a lower LD_{50} (higher sensitivity) than would apply to animals consuming 1080-based meat baits (Sinclair and Bird 1984) due to some 1080 binding to the meat (Livanos and Milham 1984) and potentially passing through the animal undigested (Sinclair and Bird 1984). While we have adopted a conservative approach in our risk assessment by using the mean adult body weight of the smaller sex (Table 4), as the

LD_{50} is presented as a lethal dose kg^{-1} of body weight, juvenile individuals would require even less 1080 and would be at higher risk of mortality due to their smaller body size, while in sexually dimorphic species, the larger sex would require more 1080 and be at lower risk of mortality. Accordingly, the LD_{50} value used for risk assessments is only a guide to expected mortality and may overestimate or underestimate the risk of mortality for some individuals.

While we have identified non-target species at high risk of individual mortality, this does not necessarily equate to a population-level risk or impact. For a population to be at risk, a significant proportion of individuals in the population need to encounter and consume enough baits to each ingest a lethal dose. In the current study, we aimed to reduce the likelihood of individuals encountering multiple baits by dispersing baits across the landscape (see ***Baits*** section in Materials and Methods), rather than adopt the Western Australian protocol of clumping baits in batches of 50 (Algar et al. 2015). However, nearly all non-target species observed eating or removing baits in the current study required less than a single Eradicat® bait to ingest a lethal dose of 1080 (Table 4). Furthermore, most of these species were likely to eat or remove the baits they encountered, with 11 non-target species eating or removing >40% of encountered baits, and 8 of those species eating or removing ≥50% of the baits they encountered (Table 4). Using our deployment strategy adopted in the current study, an animal would never be more than 270 m away from a bait. The Western Australian deployment strategy, where bait batches are spaced 1 km apart, would result in a large proportion of the landscape remaining free of baits, with some animals needing to travel up to 700 m to encounter the nearest bait. This may reduce the number of individuals that will encounter baits, particularly for species with small activity ranges. However, any attempt to increase spacing between baits will not only reduce the likelihood of non-target species encountering baits, but also reduce the likelihood of feral cats encountering baits, potentially reducing the efficacy of feral cat baiting programs. The optimal distribution strategy might ultimately be a hybrid of the two approaches discussed here, with more baits deployed per transect, but transects spaced further apart. We recommend future studies compare the population-level target and non-target impacts of different deployment strategies, to determine which strategy poses the lowest non-target risk in eastern Australian environs, and importantly, whether each deployment pattern achieves adequate control efficacy of feral cats.

The use of baits encapsulating the toxin within an HSDV implanted into the bait matrix, such as Hisstory® and Curiosity® (Algar et al. 2015), might reduce the risk to non-target species in eastern Australia. Both baits are based on the Eradicat® bait matrix, but the toxin is encapsulated within a polymer HSDV (Johnston et al. 2011) implanted into the bait matrix. Hisstory® and Curiosity® differ only in the toxin contained in the HSDV; Hisstory® baits contain 4.5 mg of 1080 (same as Eradicat®), while Curiosity® baits contain 78 mg of the toxin para-aminopropiophenone (PAPP). PAPP is considered safe for some non-target species, however compared to 1080, safety data are not currently available for many native species (McLeod and Saunders 2013), and so the non-target risk remains unknown. Small doses of PAPP are lethal for several non-target species, with goannas (*Varanus* spp) being highly susceptible to mortality from PAPP (Frappell 2007, cited in McLeod and Saunders 2013), restricting the use of PAPP to areas where or times when goannas are not active (Jessop et al. 2013). Desktop analyses by Buckmaster et al. (2014) suggest that 47 native species are likely to ingest implanted HSDVs, and a further 343 native species are possibly able to consume HSDVs. While field trials assessing the non-target consumption of HSDVs in baits are limited, findings from the small number of non-target species tested are mixed (de Tores et al. 2011; Heiniger et al. 2018). As most of the high risk non-target species identified in the current study are still considered by Buckmaster et al. (2014) as likely to consume the HSDV, the benefit of encapsulating the toxin for these species is unlikely to reduce the risk of mortality for these species. However, desktop risk assessments might not reflect the real risk in the landscape. Field trials are required to determine whether non-target species in eastern Australia consume or reject the HSDV when encountering baits in the landscape, and whether these encapsulated baits are a viable option for reducing the risk of feral cat baits to non-target species in eastern Australian environs.

While our bait uptake cameras provide a more realistic risk assessment under field conditions than desktop-based assessments, care should be taken in relying solely on bait uptake cameras to assess the risk to non-target species. At some sites, cameras missed many detections of species taking baits, and so our risk assessment may underestimate the true risk to some non-target species. Most of the missed bait-takes were on Reconyx cameras (78% of misses) which miss significantly more detections than more sensitive camera models (Fancourt et al. 2018). Additionally, many of the missed bait-takes occurred during autumn and late spring when reptiles were more active. Cameras that use passive infrared sensors to detect animals are notoriously unreliable for detecting reptiles, particularly when the thermal contrast between the reptile and the background is small (Welbourne 2014). Accordingly, our risk assessment for reptiles might be understated. Conversely, we found that some corvids at TNP followed us as we deployed baits in front of monitoring cameras in the early morning, with many corvids detected removing baits on camera soon after deployment. To address any potential bias in the bait-take data in subsequent bait uptake trials, baits were deployed later in the day when corvids were less active. Similarly, at sites devoid of structural features and tall vegetation (such as the clay pans at CNP and gibber plains at ADNP), corvids might have been particularly attracted to the posts used for mounting bait uptake cameras, drawing them in to a bait that they otherwise might not have detected in the landscape. Accordingly, the rate of bait removal by corvids at these sites (and the associated risk assessment) might be higher than would otherwise be expected from the aerial deployment of baits during operational baiting programs.

When considering the use of Eradicat® baits in eastern Australia, like any predator baiting program, the risk of direct non-target mortality from bait consumption should be weighed against any potential benefits that might result from suppressing predator populations (Glen et al. 2007). While bait removal by non-target animals can pose a high risk of direct mortality, it also reduces the number of baits available for the target species, potentially reducing the efficacy of baiting programs and any potential benefits to native animals (Dundas et al. 2014; Woodford et al. 2012). In the current study, feral cats ate only 3.1% of the 499 monitored toxic Eradicat® baits, while 54.5% of baits were taken by non-target species. Cat population density could potentially influence bait encounter rates by cats, however it is unlikely that this would explain the observed low bait encounter rates by cats. For example, only one feral cat was detected encountering a bait at TNP, and no baits were consumed by cats (Supplementary Table S2(a)). The population density at TNP was estimated at 0.43 cats km^{-2}, around 59% higher than the national average density of 0.27 cats km^{-2} (Fancourt et al. 2019; Legge et al. 2017), suggesting that cat density was not so low as to limit the potential for access to baits by more than a very low number of cats. Similarly, feral cat home ranges at TNP averaged 33 km^2 (MCP100) and covered up to 140 km^2 (Wilson et al. 2017), with home ranges of multiple cats overlapping. Therefore, it is likely that our bait uptake transects were sufficient to cross multiple cat home ranges. While several baits were still available to cats, they only consumed 52% of the 31 baits they did encounter, suggesting that bait attractiveness and palatability were often sub-optimal for cats at the time of encounter. However, consumption rates varied between sites, ranging from 0% (0/7) of baits encountered by cats being eaten at CFNP, through to 100% (7/7) of encountered baits being eaten by cats at GNP (Supplementary Table S2(a)). Accordingly, any risk-benefit analyses of proposed Eradicat® baiting programs should be site-specific, as the suite of species present, rate of bait removal by target and non-target species, and bait palatability will differ across different environments and seasonal conditions, ultimately influencing the risks and benefits at each site.

Our findings suggest that 1080-based Eradicat® baits pose a higher risk to many non-target species in eastern Australia than other 1080-based predator baits. While 1080-based canid baits are considered safe for most non-target species in eastern Australia, Eradicat®'s smaller bait size makes it more easily moved and consumed by many small- and medium-sized non-target species that would have difficulty moving a typical 125-250 g canid bait. The smaller bait size also equates to a greater concentration of 1080 (0.30 mg g^{-1}) than canid baits (0.024-0.08 mg g^{-1}), meaning less meat needs to be consumed to ingest a lethal dose. For example, Eradicat® baits contain 0.3 mg of 1080 per gram of meat (4.5 mg 1080 per 15 g meat bait) which is 3.8-6.3 times more than traditional wild dog meat baits currently used in Queensland (6-10 mg 1080 per 125 g bait) and 12.5 times more than traditional fox meat baits (3 mg 1080 per 125 g meat bait) and NSW wild dog meat baits (6 mg 1080 per 250 g meat bait). Our findings highlight the importance of assessing the risk of different bait types, even those that use the same toxin, as bait size, palatability, attractiveness, deployment patterns and application rates can all influence risk to target and non-target species.

Control tools must be acceptably target-specific, including avoiding deleterious impacts to populations and any broader ecological consequences that may result from non-target species mortalities (Gentle et al. 2014). We have identified several non-target species from Eradicat® baiting programs where more detailed studies are required to determine whether individual-level risk of mortality translates into population-level impacts in eastern Australian environs. Different suites of non-target species are exposed, and therefore at risk, in different environs, supporting the need for site-specific risk assessments prior to using Eradicat®. Future research should also investigate the rate of Eradicat® degradation in different environments, to further inform risk assessments and assist in developing appropriate guidelines for the safe and effective deployment of bait in eastern Australia.

Figure captions

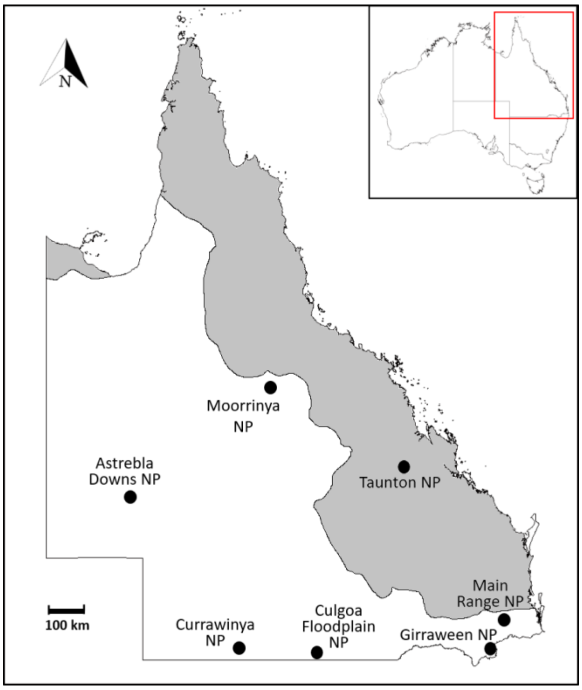

Figure 1. Map showing location of seven national park (NP) study sites used for assessing the risk of feral cat baits to non-target species in Queensland, Australia. Shading indicates approximate area where the northern quoll (*Dasyurus hallucatus*) or its habitat may occur, as per the Department of Environment Species Profile and Threats Database at http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=331. Inset shows location of Queensland within Australia.

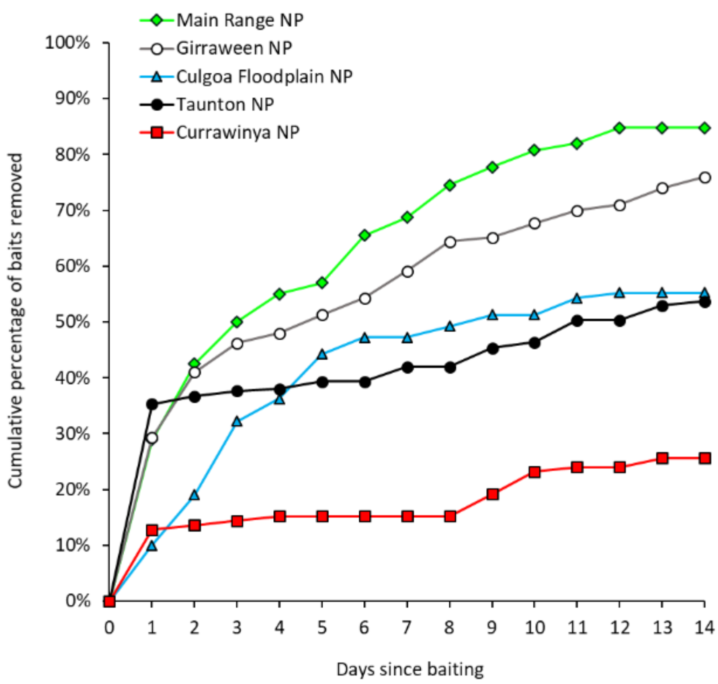

Figure 2. Cumulative percentage of monitored toxic Eradicat® baits removed across five sites during the 14 days following bait deployment. Number of monitored baits at each site are provided in Table 1.

Table captions

Table 1. Information for study sites used in the current study to assess the risk of Eradicat® and Hisstory® baits to non-target species in eastern Australian environs, including location, vegetation descriptions, trial dates, bait types, deployment patterns and monitoring cameras used at each site.

Study site	Location	Bait type	Toxic/Non-toxic	No. of baits	Bait monitoring dates	Camera make and model	Video/Photo	Deployment pattern	Bioregion	Environ	Dominant vegetation communities
Main Range National Park (MRNP)	-27.98° 152.36°	Eradicat	Toxic	100	21 Sept - 5 Oct 2018	100 Swift 3C (std lens)	Video	Aerial (50) + ground (50)	Southeast Queensland. Forms part of the Gondwana Rainforests of Australia World Heritage	Rainforest	Rainforest, open eucalypt forest

									Area		
Girraween National Park (GNP)	-28.85 151.98	Eradicat	Toxic	99	31 Aug - 14 Sept 2018	99 Swift 3C (std lens)	Video	Aerial (50) + ground (49)	New England Tablelands	Temperate	Tall open forest, woodland, sedgeland, heathland and shrubland
Culgoa Floodplain National Park (CFNP)	-28.94° 147.02°	Eradicat	Toxic	100	23 Oct - 6 Nov 2017	50 Ltl Acorn Ltl-5310A, 50 Reconyx HC600	Photo	Aerial (50) + ground (50)	Mulga Lands	Semi-arid	Coolabah (*Eucalyptus coolabah*) woodlands on alluvial floodplains, interspersed with black box (*E. largiflorens*) and poplar box (*E. populnea*) woodlands mixed with brigalow (*A. harpophylla*), gidgee (*A. cambagei*) and mulga communities
Taunton National Park (TNP)	-23.53° 149.22°	Eradicat	Toxic	75	26 July - 9 Aug 2017	50 Ltl Acorn Ltl-5310A, 25 Reconyx HC600	Photo	Aerial	Northern Brigalow Belt	Semi-arid, Subtropical	Brigalow and acacia dominated communities interspersed with poplar box dominated woodlands

Currawinya National Park (CNP)	-28.65° 144.39°	Eradicat	Toxic	125	23 July - 6 Aug 2018	65 Ltl Acorn Ltl-5310A, 60 Swift 3C (wide angle lens)	Video	Aerial	Mulga Lands	Arid	Mulga (*Acacia aneura*), interspersed with open eucalypt forests and woodlands on floodplains, and samphire dominated ephemeral lakes, saltpans and claypans
Astrebla Downs National Park (ADNP)	-24.21° 140.57°	Hisstory	Non-toxic	100	21 May - 3 Aug 2016	50 Reconyx HC600	Photo	Custom. See *Bait uptake trials - non-toxic baits*	Mitchell Grass Downs and Channel Country	Arid	Deep cracking clay soils with flat to undulating erosional plains dominated by barley Mitchell grass (*Astrebla pectinate*). *E. coolabah* and *E. camaldulensis* open woodlands line the minor drainage lines and billabongs that dissect the area
Moorrinya National Park (MNP)	-21.41° 144.98°	Eradicat	Non-toxic	50	21 Mar - 9 May 2018	50 Reconyx HC600	Photo	Custom. See *Bait uptake trials - non-toxic baits*	Desert Uplands	Northern tropical savanna	Eucalypt and acacia woodlands interspersed with grassland plains dominated by spinifex,

blue grass (*Dichanthium setosum*) and Mitchell grass

Table 2. Fate of 499 toxic Eradicat® baits at five study sites in eastern Australia, indicating bait removal by species. Origin - native (N) or introduced (I) to Australia; EPBC status - listed as vulnerable (V) under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*; Study sites - Main Range National Park (MRNP), Girraween National Park (GNP), Culgoa Floodplain National Park (CFNP), Taunton National Park (TNP), Currawinya National Park (CNP), as described in Table 1 and Figure 1.

Common name	Scientific name	Origin	EPBC	Number of baits taken						% of monitored baits					
		N/I	status	MRNP	GNP	CFNP	TNP	CNP	Total	MRNP	GNP	CFNP	TNP	CNP	Total
Feral cat	***Felis catus***	***I***		***3.5***	***7.0***	***-***	***-***	***5.0***	***15.5***	***3.5***	***7.1***	***-***	***-***	***4.0***	***3.1***
MAMMALS															
Fawn-footed melomys	*Melomys cervinipes*	N		21.0	-	-	-	-	**21.0**	21.0	-	-	-	-	**4.2**
Common brush-tailed possum	*Trichosurus vulpecula*	N		1.0	11.7	-	5.8	-	**18.5**	1.0	11.8	-	7.7	-	**3.7**
Antechinus	*Antechinus stuartii, A.flavipes, A.subtropicus*	N		6.0	5.5	-	-	-	**11.5**	6.0	5.6	-	-	-	**2.3**
Northern brown bandicoot	*Isoodon macrourus*	N		7.0	-	-	-	-	**7.0**	7.0	-	-	-	-	**1.4**
Red fox	*Vulpes vulpes*	I		1.0	2.3	-	-	-	**3.3**	1.0	2.3	-	-	-	**0.7**
Dunnart	*Sminthopsis macroura, S.crassicaudata, S.murina*	N		-	-	-	1.0	1.0	**2.0**	-	-	-	1.3	0.8	**0.4**
Long-nosed bandicoot	*Perameles nasuta*	N		1.7	-	-	-	-	**1.7**	1.7	-	-	-	-	**0.3**
Short-eared brush-tailed	*Trichosurus caninus*	N		1.5	-	-	-	-	**1.5**	1.5	-	-	-	-	**0.3**

possum															
Wild dog/dingo	*Canis familiaris*	I		-	1.0	-	-	-	**1.0**	-	1.0	-	-	-	**0.2**
Black rat	*Rattus rattus*	I		-	1.0	-	-	-	**1.0**	-	1.0	-	-	-	**0.2**
European rabbit	*Oryctolagus cuniculus*	I		-	-	-	0.5	-	**0.5**	-	-	-	0.7	-	**0.1**
Long-nosed potoroo	*Potorous tridactylus*	N	V	0.3	-	-	-	-	**0.3**	0.3	-	-	-	-	**0.1**
Total Mammals				**39.5**	**21.5**	**-**	**7.3**	**1.0**	**69.3**	**39.5**	**21.7**	**-**	**9.7**	**0.8**	**13.9**
REPTILES															
Sand monitor	*Varanus gouldii*	N		-	-	17.0	-	-	**17.0**	-	-	17.0	-	-	**3.4**
Lace monitor	*V. varius*	N		5.8	-	-	-	-	**5.8**	5.8	-	-	-	-	**1.2**
Black-headed monitor	*V. tristis*	N		-	-	2.0	-	-	**2.0**	-	-	2.0	-	-	**0.4**
Total Reptiles				**5.8**	**-**	**19.0**	**-**	**-**	**24.8**	**5.8**	**-**	**19.0**	**-**	**-**	**5.0**
BIRDS															
Corvids	*Corvus coronoides, C.bennetti, C.orru*	N		-	11.0	2.0	23.8	22.0	**58.8**	-	11.1	2.0	31.7	17.6	**11.8**
Pied currawong	*Strepera graculina*	N		3.0	13.0	-	-	-	**16.0**	3.0	13.1	-	-	-	**3.2**
Australian magpie	*Cracticus tibicen*	N		6.0	3.0	2.0	-	-	**11.0**	6.0	3.0	2.0	-	-	**2.2**
Green catbird	*Ailuroedus crassirostris*	N		10.0	-	-	-	-	**10.0**	10.0	-	-	-	-	**2.0**
Laughing kookaburra	*Dacelo novaegineae*	N		-	10.0	-	-	-	**10.0**	-	10.1	-	-	-	**2.0**
Grey shrike-thrush	*Colluricincla harmonica*	N		3.0	1.0	-	-	3.0	**7.0**	3.0	1.0	-	-	2.4	**1.4**
Australian brush-turkey	*Alectura lathami*	N		2.0	1.0	-	-	-	**3.0**	2.0	1.0	-	-	-	**0.6**
Apostlebird	*Struthidea cinera*	N		-	-	1.0	-	-	**1.0**	-	-	1.0	-	-	**0.2**
Total Birds				**24.0**	**39.0**	**5.0**	**23.8**	**25.0**	**116.8**	**24.0**	**39.3**	**5.0**	**31.7**	**20.0**	**23.4**
Ants				-	0.7	-	0.7	-	**1.4**	-	0.8	-	1.0	-	**0.2**
Missed				12.0	7.0	31.3	8.5	1.0	**59.8**	12.0	7.1	31.3	11.3	0.8	**12.0**
Total baits removed				**84.8**	**75.2**	**55.3**	**40.3**	**32.0**	**287.6**	**84.8**	**76.0**	**55.3**	**53.7**	**25.6**	**57.6**
Not taken				15.2	23.8	44.7	34.7	93.0	**211.4**	15.2	24.0	44.7	46.3	74.4	**42.4**
Total baits monitored				**100.0**	**99.0**	**100.0**	**75.0**	**125.0**	**499.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Table 3. Summary of preliminary risk assessment for native and introduced species encountering toxic Eradicat® baits during bait uptake trials in eastern Australian environs. Risk categories: Potentially at risk (species ate or removed partial, whole or multiple baits), Low risk (species encountered ≥10 baits but did not remove or eat any baits), Data deficient (species did not remove or eat any baits, but insufficient encounters (<10) to assess risk). Species names listed as common name (scientific name). * indicates introduced species.

Potentially at risk	Low risk	Data deficient
MAMMALS	Black-striped wallaby (*Macropus dorsalis*)	Common wallaroo (*Osphranter robustus*)
Antechinus (*Antechinus* spp.)	Bridled nailtail wallaby (*Onychogalea frenata*)	Common wombat (*Vombatus ursinus*)
Black rat (*Rattus rattus*)*	Eastern grey kangaroo (*Macropus giganteus*)	Cow (*Bos indicus, B. taurus*)*
Common brush-tailed possum (*Trichosurus vulpecula*)	Echidna (*Tachyglossus aculeatus*)	Feathertail glider (*Acrobates pygmaeus*)
Dunnart (*Sminthopsis* spp.)	Feral goat (*Capra hircus*)*	House mouse (*Mus musculus*)*
European rabbit (*Oryctolagus cuniculus*)*	Feral pig (*Sus scrofa*)*	Koala (*Phascolarctos cinereus*)
Fawn-footed melomys (*Melomys cervinipes*)	Red kangaroo (*Osphranter rufus*)	Microbat
Feral cat (*Felis catus*)*	Red-necked pademelon (*Thylogale thetis*)	Rodent (*Pseudomys oralis?*)
Long-nosed bandicoot (*Perameles nasuta*)	Red-necked wallaby (*Macropus rufogriseus*)	Small mammal
Long-nosed potoroo (*Potorous tridactylus*)	Rufous bettong (*Aepyprymnus rufescens*)	Swamp rat (*Rattus lutreolus*)
Northern brown bandicoot (*Isoodon macrourus*)	Swamp wallaby (*Wallabia bicolor*)	Western grey kangaroo (*Macropus fuliginosus*)
Red fox (*Vulpes vulpes*)*	Albert's lyrebird (*Menura alberti*)	Burns's dragon (*Amphibolurus burnsii*)
Short-eared brush-tailed possum (*Trichosurus caninus*)	Australian logrunner (*Orthonyx temminckii*)	Eastern bearded dragon (*Pogona barbata*)
Wild dog/dingo (*Canis familiaris*)*	Black-faced woodswallow (*Artamus cinereus*)	Gecko
REPTILES	Bourke's parrot (*Neopsephotus bourkii*)	Red-bellied black snake (*Pseudechis porphyriacus*)
Black-headed monitor (*Varanus tristis*)	Brown treecreeper (*Climacteris picumnus*)	Skink
Lace monitor (*Varanus varius*)	Crested bellbird (*Oreoica gutturalis*)	Shingle-back lizard (*Tiliqua rugosa*)
Sand monitor (*Varanus gouldii*)	Crested pigeon (*Ocyphaps lophotes*)	Yellow-faced whip snake (*Demansia psammophis*)
BIRDS	Eastern whipbird (*Psophodes olivaceus*)	Australasian pipit (*Anthus novaeseelandiae*)
Apostlebird (*Struthidea cinerea*)	Eastern yellow robin (*Eopsaltria australis*)	Australian owlet-nightjar (*Aegotheles cristatus*)
Australian brush-turkey (*Alectura lathami*)	Emu (*Dromaius novaehollandiae*)	Australian ringneck (*Barnardius zonarius*)
Australian magpie (*Cracticus tibicen*)	Fairy-wrens (*Malurus* spp. – see # below)	Bar-shouldered dove (*Geopelia humeralis*)
Corvid (*Corvus* spp.)	Jacky winter (*Microeca fascinans*)	Blue bonnet (*Northiella haematogaster*)
Green catbird (*Ailuroedus crassirostris*)	Red-capped robin (*Petroica goodenovii*)	Brown quail (*Coturnix ypsilophora*)
Grey shrike-thrush (*Colluricincla harmonica*)	Rufous fantail (*Rhipidura rufifrons*)	Brown thornbill (*Acanthiza pusilla*)
Laughing kookaburra (*Dacelo novaegineae*)	Superb lyrebird (*Menura novaehollandiae*)	Common bronzewing (*Phaps chalcoptera*)
Pied currawong (*Strepera graculina*)	Thrush (*Zoothera* spp.)	Crimson chat (*Epthianura tricolor*)
	White-browed scrubwren (*Sericornis frontalis*)	Crimson rosella (*Platycercus elegans*)
	White-throated treecreeper (*Cormobates leucophaeus*)	Double-barred finch (*Taeniopygia bichenovii*)
	White-winged chough (*Corcorax melanorhamphos*)	Eastern spinebill (*Acanthorhynchus tenuirostris*)
	Willie wagtail (*Rhipidura leucophrys*)	Galah (*Eolophus roseicapilla*)
	Wonga pigeon (*Leucosarcia picata*)	Golden whistler (*Pachycephala pectoralis*)
	Yellow-throated scrubwren (*Sericornis citreogularis*)	Grey butcherbird (*Craticus torquatus*)
	Zebra finch (*Taeniopygia guttata*)	Grey fantail (*Rhipidura albiscapa*)
	# Fairy-wrens occurring at study sites:	Grey-crowned babbler (*Pomatostomus temporalis*)
	Red-backed fairy-wren (*Malurus melanocephalus*)	
	Splendid fairy-wren (*Malurus splendens*)	
	Superb fairy-wren (*Malurus cyaneus*)	
	Variegated fairy-wren (*Malurus lamberti*)	
	White-winged fairy-wren (*Malurus*	

	leucopterus)	Hooded robin (*Melanodryas cucullata*) Horsfield's bushlark (*Mirafra javanica*) Little friarbird (*Philemon citreogularis*) Magpie-lark (*Grallina cyanoleuca*) Masked woodswallow (*Artamus personatus*) Mulga parrot (*Psephotus varius*) Noisy miner (*Manorina melanocephala*) Noisy pitta (*Pitta versicolor*) Painted button-quail (*Turnix varius*) Pied butcherbird (*Cracticus nigrogularis*) Red wattlebird (*Anthochaera carunculata*) Red-browed finch (*Neochmia temporalis*) Red-browed treecreeper (*Climacteris erythrops*) Rufous songlark (*Cincloramphus mathewsi*) Satin bowerbird (*Ptilonorhynchus violaceus*) Speckled warbler (*Chthonicola sagittata*) Spotted bowerbird (*Ptilonorhynchus maculatus*) Spotted pardalote (*Pardalotus punctatus*) Spotted quail-thrush (*Cinclosoma punctatum*) Tawny frogmouth (*Podargus strigoides*) White-browed treecreeper (*Climacteris affinis*) White-naped honeyeater (*Melithreptus lunatus*) Yellow-faced honeyeater (*Lichenostomus chrysops*)

Table 4. Detailed risk assessment of Eradicat® baits for native and introduced species in eastern Australian environs.

Common name	Scientific name	Bait enc. # (n)	Encounters where bait taken (n)	(%)	Baits taken (n)	Bait eaten or removed E/R	LD_{50} (95% conf. limits) (mg/kg)	Mean body weight (kg) *	Amount of 1080 for LD_{50} (95% conf. limits) (mg)	No. of Eradicat® baits to consume LD_{50} (n)	Amt of meat to consume LD_{50}** (g)	Meat as % of body weight to consume LD_{50} (%)	Risk of individual mortality ***
Feral cat	***Felis catus***	**31**	**16**	**52**	**15.5**	**E**	**0.28 (0.07-0.49)** [1]	**3.75** [9]	**1.05 (0.26-1.84)**	**0.06-0.41**	**0.9-6.1**	**0.02-0.16**	**High (4)**
MAMMALS													
Fawn-footed melomys	*Melomys cervinipes*	54	23	43	21.0	E/R	2.65 (2.23-3.15)	0.08 [9]	0.20 (0.17-0.24	0.04-0.05	0.6-0.8	0.74-1.05	High (5)

							[2,a]		)				
Common brush-tailed possum	*Trichosurus vulpecula*	178	29	16	18.5	E	0.67 (0.58-0.79)[3]	2.50[9]	1.68 (1.45-1.98)	0.32-0.44	4.8-6.6	0.19-0.26	High (4)
Antechinus		42	15	36	11.5	R							? (1,2)
Brown antechinus	*Antechinus stuartii*						1.85 (1.43-2.40)[4]	0.020[9]	0.04 (0.03-0.05)	0.01	0.1-0.2	0.48-0.80	
Yellow-footed antechinus	*A. flavipes*						3.50[5]	0.034[9]	0.12	0.03	0.4	1.17	
Subtropical antechinus	*A. subtropicus*						na						
Northern brown bandicoot	*Isoodon macrourus*	20	9	45	7.0	E	3.5[5]	1.10[9]	3.85	0.86	12.8	1.17	High (4)
Red fox	*Vulpes vulpes*	4	4	100	3.3	E	0.13 (0.13-0.14)[6]	5.40[9]	0.70 (0.68-0.74)	0.15-0.17	2.3-2.5	0.04-0.05	High (4)
Dunnart		79	6	8	2.0	R							? (1,2)
Stripe-faced dunnart	*Sminthopsis macroura*						0.95 (0.57-1.60)[4]	0.020[9]	0.02 (0.01-0.03)	0.00-0.01	0.0-0.1	0.19-0.53	
Fat-tailed dunnart	*S. crassicaudata*						2.06 (1.58-2.69)[4]	0.015[9]	0.03 (0.02-0.04)	0.01	0.1	0.53-0.90	
Common dunnart	*S. murina*						na						
Long-nosed bandicoot	*Perameles nasuta*	23	4	17	1.7	E	7.70 (5.28-11.23)[4]	0.98[9]	7.55 (5.17-11.01)	1.15-2.45	17.2-36.7	1.76-3.74	High (6)
Short-eared brush-tailed possum	*Trichosurus caninus*	42	3	7	1.5	E	0.67 (0.58-0.79)[3,b]	3.50[9]	2.35 (2.03-2.77)	0.45-0.61	6.8-9.2	0.19-0.26	High (4)
Wild dog/dingo	*Canis familiaris*	2	1	50	1.0	E	0.11 (0.09-0.15)[4]	11.00[9]	1.21 (0.99-1.65)	0.22-0.37	3.3-5.5	0.03-0.05	High (4)
Black rat	*Rattus*	1	1	10	1.0	R	0.76	0.2	0.21	0.0	0.3-	0.12-	? (1)

	rattus			0			(0.37-1.04)[2]	8[9]	(0.10-0.29)	2-0.06	1.0	0.35	
European rabbit	*Oryctolagus cuniculus*	75	1	1	0.5	R	0.37 (0.34-0.40)[3]	1.57[9]	0.58 (0.53-0.63)	0.12-0.14	1.8-2.1	0.11-0.13	? (1)
Long-nosed potoroo	*Potorous tridactylus*	5	1	20	0.3	E	*c.* 0.15-0.20[3]	1.02[9]	0.15-0.20	0.03-0.05	0.5-0.7	0.05	High (5)
REPTILES													
Sand monitor	*Varanus gouldii*	22	17	77	17.0	E	43.60 (27.50-69.20)[7]	1.15[10]	50.14 (31.63-79.58)	7.03-17.68	105.4-265.3	9.17-23.07	Low (9)
Lace monitor	*V. varius*	11	6	55	5.8	E	27.5[7,c]	3.65[11]	100.29	22.29	334.3	9.17	Low (9)
Black-headed monitor	*V. tristis*	3	2	67	2.0	E	27.5[7,c]	0.23[12]	6.27	1.39	20.9	9.17	High (6)
BIRDS													
Corvids		131	61	47	58.8	E/R							
Australian raven	*Corvus coronoides*						*c.* 5.1[8]	0.60[13]	3.08	0.68	10.3	1.70	High (4)
Little crow	*C. bennetti*						13.37 (11.73-15.24)[8]	0.40[13]	5.34 (4.68-6.09)	1.04-1.35	15.6-20.3	3.91-5.08	High (4)
Torresian crow	*C. orru*						na						? (2)
Pied currawong	*Strepera graculina*	36	16	44	16.0	E/R	13.09 (10.90-15.72)[8]	0.28[13]	3.67 (3.05-4.40)	0.68-0.98	10.2-14.7	3.63-5.24	High (4)
Australian magpie	*Cracticus tibicen*	116	13	11	11.0	E/R	9.93 (7.59-12.92)[8]	0.25[13]	2.49 (1.90-3.24)	0.42-0.72	6.3-10.8	2.53-4.31	High (4)
Green catbird	*Ailuroedus crassirostris*	12	10	83	10.0	E/R	na						? (2)
Laughing kookaburra	*Dacelo novaegineae*	19	10	53	10.0	R	>6.00[8]	0.31[14]	1.84	0.41	6.1	2.00	? (1)
Grey shrike-thrush	*Colluricincla harmonica*	132	7	5	7.0	R	>12.00[8]	0.06[15]	0.75	0.17	2.5	4.00	? (1)

Australian brush-turkey	*Alectura lathami*	11	4	36	3.0	E	na	? (2)
Apostlebird	*Struthidea cinera*	80	1	1	1.0	R	na	? (1)

LD_{50} and body weight source references: 1 - Eason and Frampton (1991), 2 - McIlroy (1982b), 3 - McIlroy (1982a), 4 - McIlroy (1981b), 5 - Twigg and King (1991), 6 - McIlroy and King (1990), 7 - McIlroy et al. (1985), 8 - McIlroy (1984), 9 - Van Dyck and Strahan (2008), 10 - Green and King (1978), 11 - Guarino (2002), 12 - Thompson et al. (1999), 13 - Higgins et al. (2006), 14 - Higgins (1999), 15 - Higgins and Peter (2002), a - LD_{50} for grassland melomys (*M. burtoni*) used as indicative LD_{50}; b - LD_{50} for common brush-tailed possum (*T. vulpecula*) used as indicative LD_{50}; c - LD_{50} (lower 95% CL) for sand monitor (*V. gouldii*) used as conservative LD_{50}; na – LD_{50} not available.

bait encounters; * for sexually dimorphic species, mean body weight of the smaller sex was used to ensure risk assessments were conservative; ** amount of meat (g) to consume in order to ingest the LD_{50} of 1080, assuming the 4.5 mg 1080 is evenly distributed throughout the 15 g Eradicat® bait; ***risk of mortality determined using criteria in Supplementary File S1 (number in parenthesis indicates final step where risk was determined)

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