A bait efficacy trial for the management of feral cats (*Felis catus*) in karri forest areas after timber harvesting activities

A Report for the Forest Products Commission, Manjimup

Two individual feral cats within the baited area, one carrying a mardo (*Antechinus flavipes*) and one taking an Eradicat® bait

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Abstract

Reducing the impacts of introduced predators in areas that are recovering from timber harvesting activities is a key objective for the conservation of wildlife in the karri forests of southwest Western Australia. Feral cats in particular are currently an unmanaged threat in these landscapes. We investigated the efficacy of baiting with the cat bait Eradicat ® as a control tool to temporarily reduce feral cat (*Felis catus*) activity while vegetation within harvested areas was re-establishing. In particular we were interested in whether Eradicat® baits would be taken by feral cats in karri forest areas that had been disturbed by harvesting operations; whether baiting could be used to reduce feral cat activity; and whether Eradicat ® baits pose a risk to non-target species in the karri forest. We assessed bait uptake patterns and relative activity levels for feral cats, foxes, potential prey (critical weight range mammals and small birds) and other native species. We used remote cameras to collect data at 30 baited sites and 30 unbaited sites for 12 months prior to and 12 months following commencement of a 2-weekly baiting program. We also identified factors likely to influence bait uptake and activity levels, and simultaneously measured these to inform predictive models. Feral cats encountered only 12% of the 810 monitored baits. Of those encountered only three were taken and all were taken by young individuals within the first two bait deployment periods. Non-target species took 95% of eaten baits and a 93% of these were taken within the first six days following bait deployment. Most baits were taken by bush rats (*Rattus fuscipes*), quenda (*Isoodon fusciventer*), mardo (*Antechinus flavipes*) and brushtail possum (*Trichosurus vulpecula*). While bait uptake for feral cats was low, a 54% reduction in feral cat activity was achieved following commencement of baiting and decreases were most pronounced after the sixth baiting session. Fox activity also decreased by 75% in the baited area. There were no reductions in feral cat and fox activity in the control area. Small mammal and bird activity levels consistently increased in the treatment area due to the presence of a novel food source. There was no significant change in activity for these groups in the control area. While the reduction in activity for the introduced predators is unlikely to be a direct result of the baiting program, secondary poisoning may be a factor. We discuss the implications of these findings for feral cat control and fauna conservation in disturbed forested landscapes of southwest WA.

Introduction

Since their introduction to Australia, the feral cat (*Felis catus*) and red fox (Vulpes vulpes) have been implicated in the extinction of more than 20 species and are believed to have contributed to catastrophic declines across northern and southern parts of Australia (Johnson, 2006, McKenzie *et al*. 2007, Woinarski *et al.* 2011, Fisher *et al.* 2013, Woinarski *et al.* 2014, 2015, Davies *et al.* 2017, Wayne *et al.* 2017). These introduced predators are considered a significant threat to a diverse range of species, due to their direct predatory effects as well as indirect effects of competition, disease transmission and induced predator avoidance behaviours (e.g., Morris *et al.* 2000, Friend 2003, Courtenay and Friend 2004, Gilfillan *et al.* 2010, Dunlop and Morris 2012, Medina *et al.* 2011, Judge *et al.* 2012, Pearson 2012, Doherty et al 2014, Fancourt and Jackson 2014, Medina *et al.* 2014, Read *et al.* 2015).

Reducing the impacts of introduced predators has become a priority for conservation managers worldwide (Woinarski *et al.* 2011, Blancher 2013, Loss *et al.* 2013, Nogales *et al.* 2013, Fancourt *et al.* 2016) and substantial efforts have been invested in the research and development of management approaches aimed at mitigating their impact. Examples include predator-free fencing (Frank et al 2014, Hayward *et al.* 2014, Legge *et al.* 2018), translocation of threatened species to predator free islands (Abbott 2000, Dunlop *et al.* 2015, Morris *et al.* 2017, Burbidge *et al.* 2018), and lethal control options (e.g. Burrows *et al.* 2003, Rodríguez *et al.* 2006, de Tores and Berry 2007, Hetherington *et al.* 2007, Algar *et al.* 2011, Algar *et al.* 2013, Johnston *et al.* 2013, Read *et al.* 2015, Doherty and Ritchie 2017, Hunter *et al.* 2018, Algar *et al.* 2019).

Baiting programs are currently undertaken on a broad scale in Western Australia for the control of foxes, using Probaits® containing 3.0mg of the toxicant sodium monofluroacetate (1080) (Marlow 2000, Thomson and Algar 2000, Thomson *et al*. 2000, Morris *et al*. 2005, Marlow *et al*. 2015a). At some sites however, fauna recovery has not been sustained, possibly as a result of the mesopredator release of feral cats (Marlow *et al.* 2008, Marlow *et al.* 2015b, Wayne *et al*. 2015, Allen *et al.* 2016, Molsher *et al.* 2017). Feral cats are vulnerable to poisoning by 1080, but do not readily take fox baits (Burrows *et al.* 2003; Algar and Burrows 2004, Algar and Richards 2010). A targeted bait Eradicat® containing 4.5 mg of 1080 was designed to be more appealing to cats and is currently in an experimental phase (Algar *et al.* 2002, Algar and Burrows 2004, Algar *et al.* 2007, Algar and Brazell 2008, Algar *et al.* 2011, Comer *et al.* 2018, Fancourt *et al.* 2019).

Feral cats are less likely than foxes to consume baits, especially when live prey are available (Risbey *et al.* 1997, Algar *et al.* 2007, Moseby *et al.* 2011, Christensen *et al.* 2013, Read *et al.* 2015). The use of Eradicat ® to reduce the impact of feral cats has been demonstrated to be effective only in situations when feral cats are under food stress and live prey are limited, such as during dry periods in winter in arid and rangeland landscapes of northern and central Western Australia, when young, predator-vulnerable prey are not present, and when reptile activity is low (Algar and Angus 2000, Algar 2006, Algar *et al.* 2007, Algar *et al.* 2010, Christensen *et al.* 2013, Comer *et al.* 2018, Algar *et al.* 2019, Palmer *et al.* 2021). Additional complications arise due to the limitation of baiting programs to environments or seasons where bait removal or effects on non-target species can be mediated (McGregor *et al.* 2014, Buckmaster *et al.* 2014, McGregor *et al.* 2015).

The Eradicat® bait has also more recently been trialled in in southern parts of Western Australia, with outcomes from these areas less effective due to availability of live prey throughout the year, higher levels of bait interference from non-target species, and higher levels of moisture affecting bait palatability and toxicity (Dundas *et al.* 2014, Comer *et al.* 2018, Wayne *et al.* in press). The potential for successful baiting of feral cats in these landscapes may therefore be limited to periods following disturbances such as fire and timber harvesting that initially result in an increase in prey vulnerability for predation, followed by temporary periods of lower prey availability.

Recent research provides evidence that introduced predators are attracted to and hunt more effectively in recently disturbed habitats, due to reduced habitat complexity, reduced vegetation cover and modified habitat connectivity, which increase prey vulnerability (Legge *et al.* 2011, McGregor *et al.* 2014, Lawes *et al.* 2015, Leahy *et al.* 2015, 2016, McGregor *et al.* 2016, Hradsky et al 2017). However, processes that reduce habitat complexity, cover and connectivity are also likely to lead to a reduction in prey activity, either due to predation impacts or as a result of fauna retreating into core refuge areas. Less predictable variation in the spatial and seasonal availability of prey in these environments may result in a period where feral cats are temporarily food limited and more likely to switch prey. Prey switching has been shown to increase the likelihood of cats eating novel food sources and carrion (e.g., Catling 1988, Algar *et al.* 2007, Christensen *et al.* 2013, McGregor *et al.* 2020). This concept is of interest to land managers in the area who are seeking effective feral cat control techniques for the protection of threatened fauna.

This project aimed to undertake a feral cat baiting trial in the southern karri forest of Western Australia, using the Eradicat ® Bait. The objectives of the trial were to determine if: 1) there was a period of reduced prey availability in areas of karri forest that had been disturbed by harvesting operations 2) Eradicat ® baits would be taken by feral cats in these karri forest areas 3) baiting could reduce feral cat activity for a short period of time, to confer protection to fauna while vegetation within harvested areas was re-establishing; and 4) to identify whether Eradicat ® baits pose a risk to non-target native species in the karri forest.

This project was designed to complement and build upon a cat baiting trial being implemented by the Department of Biodiversity Conservation and Attractions in the nearby southern jarrah forest (Wayne *et al.* 2016, Wayne *et al.* in press).

Methods

Study area

This study was undertaken across two forested areas covering a total area of 5655 ha within karri (*Eucalyptus diversicolor*) forest near Pemberton in Western Australia (Figure 1). The two forested study areas occur within the Karri Forest Management Unit (CCWA 2013, Figure 1) and in the Warren Bioregion, one of 89 large geographically distinct Australian bioregions classified by the Interim Biogeographic Regionalisation for Australia (DSEWPAC 2013). The climate within the bioregion is moderate Mediterranean with cool, wet winters and warm dry summers. The relatively high rainfall and low evapotranspiration of the bioregion makes it unique in Western Australia (Hopper *et al.* 1992, Hearn *et al.* 2002). The vegetation within the study areas is characterised by tall, wet karri forests and consists of a mix of mature forest, regrowth forest, and seasonally inundated riparian systems. Approximately 38% of the forests in the region are vested as State forests and timber reserves, and approximately 0.6% of these forests are planned to be harvested and regenerated annually (CCWA 2013). Western Australia's national parks, conservation parks, nature reserves, State forests and timber reserves are vested in the Conservation Commission of Western Australia and managed by the Department of Biodiversity Conservation and Attractions. The Forest Products Commission is responsible for the harvesting and regeneration of native forest and plantations within State forests and timber reserves (CCWA 2013). The Forest Products Commission commits resources to the management of threatening processes prior to and following harvesting operations, including the management of introduced predators such as the fox. Standard post-harvest fox control includes monthly hand-baiting of harvested areas with probait ® for three years following harvesting. This is in addition to aerial fox baiting programs that occur on a landscape scale every three months in this area.

The two forest study areas comprised a treatment (impact) and a control, and were selected on the basis of: 1) minimum size of 2500 ha; 2) minimum 10 km separation to increase the likelihood of site independence; 3) no issues with seasonal access; 4) similarity in relation to dominant forest types, planned harvesting regimes and existing fox baiting programs; 5) no planned burning within the sites, other than that associated with normal timber harvesting activities; and 6) harvesting operations planned between 2018 and 2021.

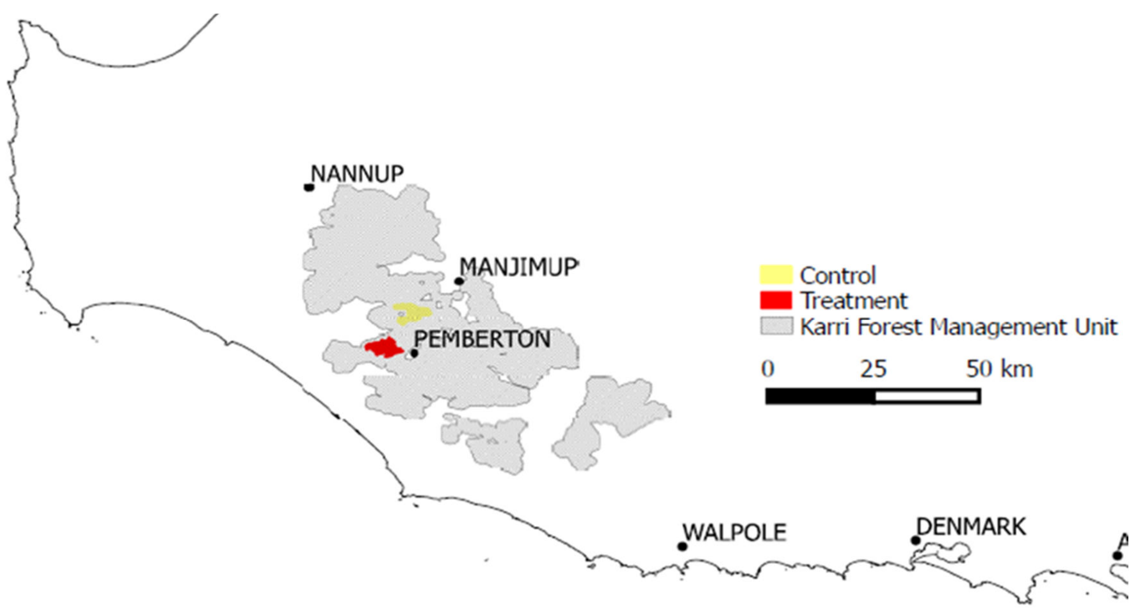


Figure 1: Location of the treatment and control areas within the Karri Forest Management Unit

Survey design

Cameras were deployed between January 2019 and February 2021 at sixty camera stations, with a minimum distance of 1 km separating cameras. The 1 km spacing was based on research undertaken by Dillon and Kelly (2007), which showed that increasing camera spacing above 1 km underestimated feline activity. A combination of Moultrie (model 999i Zero Glow, Moultrie Feeders, Birmingham, AL) and Scoutguard (model SG560P Low Glow, Scoutguard, Australia) were used. The 60 cameras were split evenly between the control and the treatment areas and were set following protocols in Wayne *et al.* 2016, to ensure consistency between the two studies. Cameras were deployed on or near overgrown vehicle tracks due to recent studies that have determined that on-track detectability is higher for introduced predators (Read and Eldridge 2010, Hradsky *et al.* 2017, Dawson *et al.* 2018, Geyle *et al.* 2020; Wysong *et al.* 2020).

To capture temporal patterns in activity potentially related to baiting, we split detections of feral cats, foxes and potential prey species into 54 discrete survey sessions, each consisting of a continuous period over 14 nights. Of the 54 survey sessions, 27 occurred prior to commencement of baiting and 27 occurred following commencement of baiting. For post-baiting surveys, bait deployment occurred within the treatment sites on the first day of each survey session. Potential prey included small birds and critical weight range mammals, specifically the bush rat (*Rattus fuscipes*), brush-tailed phascogale (*Phascogale tapoatafa wambenger*), mardo (*Antechinus flavipes*), quokka (*Setonix brachyurus*), quenda (*Isoodon fusciventer*) and brushtail possum (*Trichosurus vulpecul*a).

The survey design within the treatment and control areas was identical, except that a toxic Eradicat ® bait was applied at all camera stations within the treatment area every two weeks following commencement of the baiting period in mid-January 2020 (summer 2020). Baits were sweated for 24 hours prior to deployment, deployed by hand after 4pm to reduce interference from diurnal carrion-eating birds, such as Corvids and Kookaburras, and positioned 1.5 m from each camera in the centre of the camera's field of view. Sites were checked for deteriorating baits at each subsequent baiting event and old baits were deep buried onsite at least 0.5 metre below natural ground level as per safety requirements for 1080 (DoH 2018). Throughout the duration of the project, only four baits were disposed of in this manner. All remaining baits were consumed or removed by animals. Control sites were also visited every two weeks to replicate the level of disturbance from visitation. Camera maintenance and image download activities for both areas were undertaken during the fortnightly visits.

Detections were considered independent if there was a minimum interval of 30 minutes between photographs of the same species, or if there was an obvious difference between species or individuals in any images captured within the 30 minute period (Ridout and Linkie 2009, 2011, Sollmann *et al.* 2013, Meek *et al.* 2014, Burton *et al.* 2015, Meek *et al.* 2016). For each independent detection event, the date, time, species present, the number of individuals, and any distinguishing features of feral cats (e.g. juvenile, distinctive markings, coloration) were recorded.

For each camera site, images were also carefully observed to identify bait interaction behaviours and the species responsible. Bait interaction behaviours were categorised as: eaten or removed, fragments eaten, sniffed, or no bait interaction. The species involved in each interaction was recorded.

A number of factors were considered likely to influence RAI and bait uptake, such as the distance to the closest active harvesting operation (machines still onsite), distance to areas that had been harvested within the previous 12 months, distance to areas that had been harvested within the previous three years, distance to the forest edge (cleared paddocks), distance to the closest riparian system, temperature on the night of bait deployment, rainfall patterns prior to and following bait deployment, the season and likely associated availability of food resources, relative activity levels of potential prey and other introduced predators, the level of bait interference by other species, the time since bait deployment and the influence of this on bait deterioration and bait interference, and the time since commencement of baiting and the influence of this on bait interaction behaviours, e.g. as a result of availability of a novel food source. These data contributed to potential predictor variables during modelling (Table 1). Both the control and treatment sites were also being baited with Probait® for the control of foxes. This baiting occurs quarterly by aircraft at a landscape scale, and monthly by hand in areas that have been harvested within the previous three years. The aerial baiting program was not considered an uncontrolled variable, given the systematic and routine deployment of baits across both the treatment and control areas. The monthly hand-baiting programs however did vary slightly between the treatment and control areas due to the association of the program with areas that had been recently harvested. Whether a site was hand-baited with Probait® during each survey session was therefore also included as a variable in the models (Table 1).

Table 1: Predictor variables used in modelling.

ID	Description	Response Variable
Sea	Categorisation of survey periods into Summer, Autumn, Winter and Spring.	RAI, BU
SS	Identification of the 54 survey sessions.	RAI, BU
C_T	Categorisation of sites into control or treatment areas.	RAI
Pre-Post	Categorisation of survey sessions as pre or post baiting with Eradicat® baits	RAI
Bait	Categorisation of survey sessions as baited or unbaited with Eradicat® baits.	RAI
R(Cat)	Relative abundance index for feral cat (#independent detection events within 14 day survey period)	RAI, BU
R(Fox)	Relative abundance index for fox (#independent detection events within 14 day survey period)	RAI, BU
R(Prey)	Relative abundance index for combined small birds and critical weight range mammals (#independent detection events within 14 day survey period)	RAI, BU
BU(IP)	Bait uptake by introduced predators, feral cat and fox combined due to a single bait uptake event by a feral cat. Bait uptake is defined as consumption on camera of an entire bait or part of a bait.	BU
BU(NT)	Bait uptake by non-target species. Bait uptake is defined as consumption on camera of an entire bait or part of a bait.	BU
BDT	Bait deployment time. Number of nights since deployment of the most recently deployed bait, expressed as a proportion of the 14 day period between bait deployment events.	BU
BCT	Bait commencement time. Number of nights since commencement of baiting, expressed as a proportion of the 378 nights of survey between first and final bait deployment survey periods.	BU
DA	Distance to the closest active harvesting operation. Number of kilometres (km) to the closest area where machines are onsite and timber harvesting is currently occurring.	RAI, BU
D12	Distance to areas that had been harvested within the previous 12 months (km).	RAI, BU
D3Y	Distance to areas that had been harvested within the previous three year (km).	RAI, BU
DFE	Distance to the closest area with cleared paddocks (km).	RAI, BU
DR	Distance to the closest riparian system, defined as creek, swamp or river, for which an informal reserve buffer is protected from harvesting (km).	RAI, BU
FB	Categorisation of survey sessions as baited or unbaited with Probait® baits.	RAI, BU
MT	Minimum temperature during the 24 hours following deployment of the most recently deployed bait measured in degrees Celsius (BOM Weather Station 009592, Pemberton WA).	BU
RP	Total rainfall recorded during the 7 days prior to deployment of the most recently deployed bait (BOM Weather Station 009592, Pemberton WA)	BU
RA	Total rainfall recorded during the 7 days following deployment of the most recently deployed bait (BOM Weather Station 009592, Pemberton WA)	BU

Analysis

The number of independent events per survey session (14 camera-nights) were calculated as a relative abundance index (RAI) (O'Brien *et al.*, 2003, Zhao et al 2020) for feral cat, fox and potential prey species. Linear mixed-effects models were used to assess variability in the RAI values in relation to the BACI (Before-After, Control-Impact) design with inferences made on the interaction term in the analysis. Bait uptake (bait partially or completely eaten on camera) rates for feral cats, foxes and non-target species were related to potential predictor variables using logistic regression models. Data were transformed to achieve homoscedasticity and normality of residuals. Prior to modelling, the procedure of Hosmer and Lemeshow (2000) was used with a stricter cut-off of P > 0.10 to reduce variables to an acceptable level. During modelling, variables were removed from the global model in each model set if they had a probability > 0.2 (Hosmer and Lemeshow 1989). All analyses were completed using the Stata software package (StataCorp LLC 2021).

Akaike's Information Criterion with a small sample size correction (AICc) was used for model selection and models with delta AICc values ≤ 2 were considered to have strong support (Burnham and Anderson 2002). In addition, changes in the log-likelihood ratio and cumulative AICc weights were used to evaluate strength of evidence for each model. Pearson Chi-Square goodness-of-fit tests were used to assess the fit of models to the data.

Mark-resight abundance estimates were not possible due to an inability to reliably identify individuals from photographs. Use of detection histories and occupancy models were considered and discarded due to the demonstrated low power of these models to detect small changes (<20%) within a BACI design, particularly given the minor treatment impacts expected and the relatively small sample size in this study (Popescu *et al.* 2012).

Results

Relative activity index (RAI)

A total of 9813 independent capture events were recorded during 45,360 trap nights between January 2019 and February 2021 (98,560 images). Of these independent events, 1362 were of feral cats, 2517 foxes, 2271 critical weight range mammals and 1734 small birds (Figure 2). There were an additional 1905 independent capture events for native species that were not considered vulnerable to feral cat predation, such as the western grey kangaroo and emu, as well as 24 capture events for other feral animals such as the feral pig. Feral cats in this study were most active during winter. Foxes were most active in autumn (Figure 2).

Linear mixed effects models identified that season, survey session, the RAI of other species, the distance to the closest riparian system, and proximity to areas that had been harvested within the previous 12 months were variables with the most influence on the RAI for feral cats, foxes and potential prey species (Table 2). Hand-baiting of sites with Probait ® also influenced the RAI of foxes but not that of feral cats or potential prey. The remaining variables did not contribute significantly to the strength of the models in each model set.

Overall, native mammals were most active in autumn and native birds were most active in spring, although species-level differences were observed. Feral cat activity and fox activity at the treatment sites increased during the first autumn following commencement of baiting and then decreased significantly thereafter (Figure 2). The most notable deviations from the control sites occurred between survey period 33 and 54 for both species, i.e. after 6 baiting sessions (Figure 2). For both feral cats and foxes, there was an overall significant difference in RAI between pre and post baiting periods in the treatment sites (cat m_1 16.48 m_2 7.59 t=3.62, p=0.00 and fox m_1 30.96 m_2 8.41 t=6.92 p=0.00, Table 3). This equates to a 54% reduction in activity for feral cats and a 73% reduction in activity for foxes. There was no significant difference in RAI between pre and post baiting periods in the control sites for these species (t=-0.18, p=0.86 and t=0.14, p= 0.89, Table 3).

The activity levels of potential prey at the treatment sites increased immediately following commencement of baiting and this increase was sustained throughout the 12 month baiting period (Figure 2). There was an overall significant difference in RAI between pre and post baiting periods in the treatment sites for potential prey species (m_1 21.78 m_2 72.75 t= -11.02, p=0.00, Table 3). There was no significant difference in RAI between pre and post baiting periods in the control sites for potential prey species (m_1 25.70 m_2 28.04 t=-0.46, p=0.65, Table 3).

For feral cats, foxes and potential prey species, RAI decreased with increasing distance from riparian systems, with >95% of detections occurring within 0.5 km of a riparian system (Figure 3). This pattern was consistent between the treatment and control areas and is unsurprising given the disturbance from harvesting within both areas. Riparian systems offer refugia and are usually close to recently harvested areas which offer feeding opportunities.

The proximity of sites to areas that had been harvested within the previous 12 months also significantly influenced the RAI of foxes and potential prey species in both the treatment and control areas (Table 2, Figure 3). RAI was highest for these groups at sites that were within 2 km of recently harvested areas in both the control and treatment areas. In addition, the RAI for foxes was lower in areas that were being baited with Probait ® in both the control and treatment areas.

Table 2: Results of linear mixed effects models investigating the relationship between site level variables and the RAI for feral cat, fox and potential prey species. Models ranked in order of relative strength.

Variable	Model	F	AICc	ΔAICc	w	k
R(Cat)	Bait Sea SS R(Fox) R(Prey) DR*	78.39	7706.59	0.00	0.71	6
	Bait Sea SS R(Fox) R(Prey) DFE	90.51	7709.58	2.99	0.16	6
	Global Model	50.25	7710.52	3.93	0.10	11
	Sea SS R(Fox) R(Prey) DFE	107.40	7712.94	6.35	0.03	5
	Bait Sea SS R(Fox)	130.84	7722.79	16.20	0.00	4
R(Fox)	Bait SS R(Cat) R(Prey) DR D12 FB*	77.45	11486.85	0.00	0.81	7
	Bait Sea SS R(Cat) R(Prey) DFE DR DA D12 FB	69.76	11491.19	4.34	0.09	10
	Global Model	63.59	11491.50	4.65	0.08	11
	Bait SS R(Cat) R(Prey) DFE DR DA FB	86.15	11494.46	7.61	0.02	8
	Bait SS R(Cat) R(Prey)	148.30	11567.45	80.60	0.00	4
R(Prey)	Bait Sea R(Cat) R(Fox) DR D12*	70.72	12847.21	0.00	0.43	6
	Bait Sea R(Cat) R(Fox) DFE DR DA D12 D3Y	63.03	12847.78	0.57	0.32	9
	Bait Sea R(Cat) R(Fox) DA D12	93.25	12848.79	1.58	0.20	6
	Global Model	51.56	12851.57	4.36	0.05	11
	Bait R(Cat) R(Fox)	175.47	12871.63	24.42	0.00	3

*Strongest model. Only the global model (all variables) and the 4 highest ranked models are shown for each model set. Variables modelled: Bait, Sea, SS, R(Cat), R(Fox), R(Prey), DFE, DR, DA, D12, D3Y, FB. See Table 1 for explanation of model variables. F values, Akaike's Information Criterion corrected for small sample size (AICc), Akaike weights (w) and number of model parameters (k) are presented.

Table 3: Post-hoc means comparison tests of RAI for feral cat, fox and potential prey species. Mean (Standard Error), t-test and p-values are presented for pre vs post baiting within the control and treatment areas.

	Control				Treatment			
	Pre	Post	T	p	pre	post	t	p
Feral Cat	12.67 (1.50)	13.00 (1.04)	-0.18	0.86	16.48 (2.14)	7.59 (1.19)	3.62	0.00
Summer	7.37 (3.23)	7.50 (1.84)	-0.03	0.97	6.13 (1.48)	5.25 (0.65)	0.31	0.76
Autumn	15.17 (2.98)	15.66 (1.31)	-0.15	0.88	18.37 (1.22)	22.51 (1.78)	-1.79	0.10
Winter	15.71 (2.51)	14.13 (1.32)	0.20	0.84	29.62 (3.47)	10.25 (1.25)	5.25	0.00
Spring	13.67 (2.09)	15.17 (1.81)	-0.54	0.60	14.76 (0.92)	2.87 (0.61)	10.74	0.00
Fox	27.07 (3.14)	26.44 (2.56)	0.14	0.89	30.96 (2.88)	8.41 (1.51)	6.922	0.00
Summer	13.34 (4.89)	12.85 (2.76)	0.07	0.94	18.04 (4.07)	3.38 (1.98)	3.23	0.01
Autumn	46.13 (5.35)	42.50 (4.11)	0.52	0.62	48.36 (3.29)	19.25 (1.57)	7.99	0.00
Winter	28.00 (3.12)	26.86 (2.32)	0.29	0.77	34.75 (3.68)	8.38 (1.27)	6.78	0.00
Spring	25.02 (4.57)	27.83 (3.63)	-0.48	0.63	25.36 (1.95)	2.62 (0.49)	11.28	0.00
Potential Prey	25.70 (3.89)	28.04 (3.27)	-0.46	0.65	21.78 (2.22)	72.75 (4.05)	-11.02	0.00
Summer	11.54 (3.62)	13.12 (2.26)	-0.38	0.71	17.12 (3.43)	62.63 (8.43)	-14.99	0.00
Autumn	50.03 (10.89)	51.33 (7.56)	-0.10	0.92	31.12 (4.71)	79.05 (5.47)	-6.63	0.00
Winter	17.71 (2.73)	23.28 (2.44)	-1.52	0.15	14.62 (2.23)	64.25 (6.87)	-6.86	0.00
Spring	29.67 (3.31)	31.33 (1.23)	-0.47	0.65	21.37 (1.83)	86.62 (3.43)	-16.79	0.00

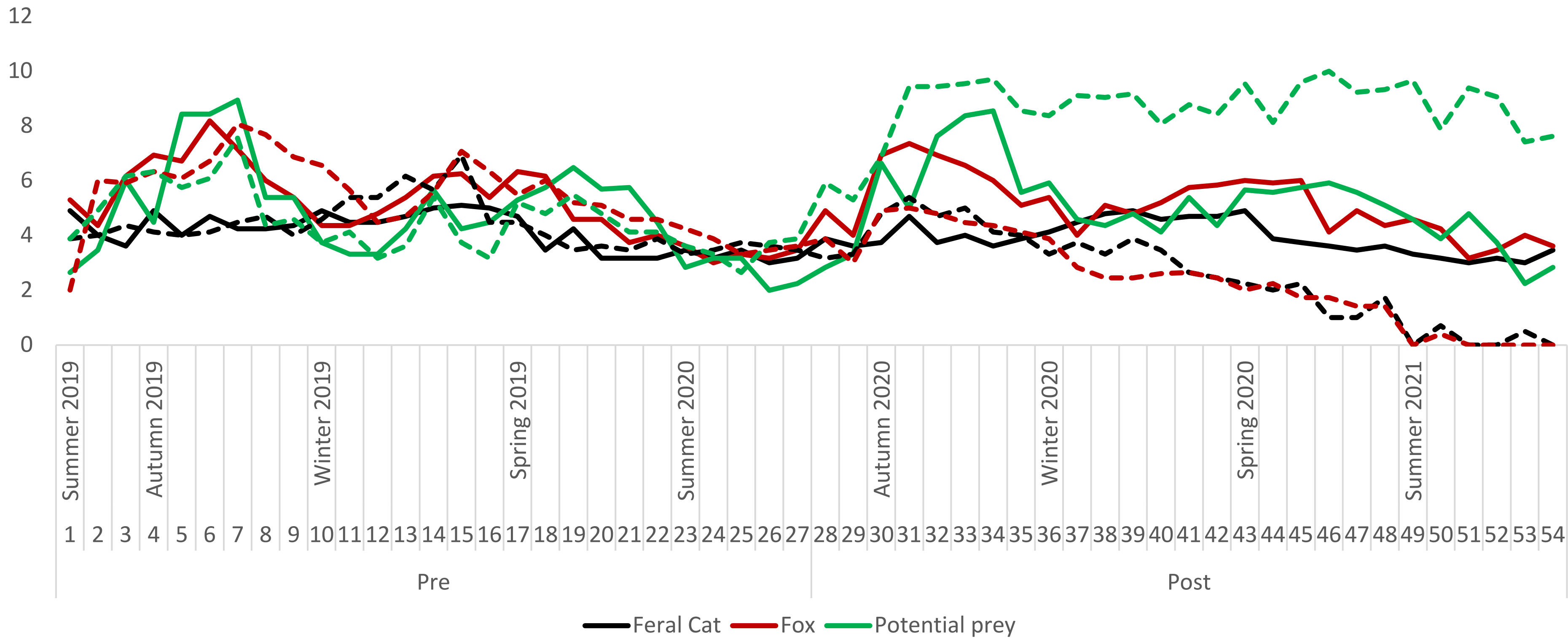
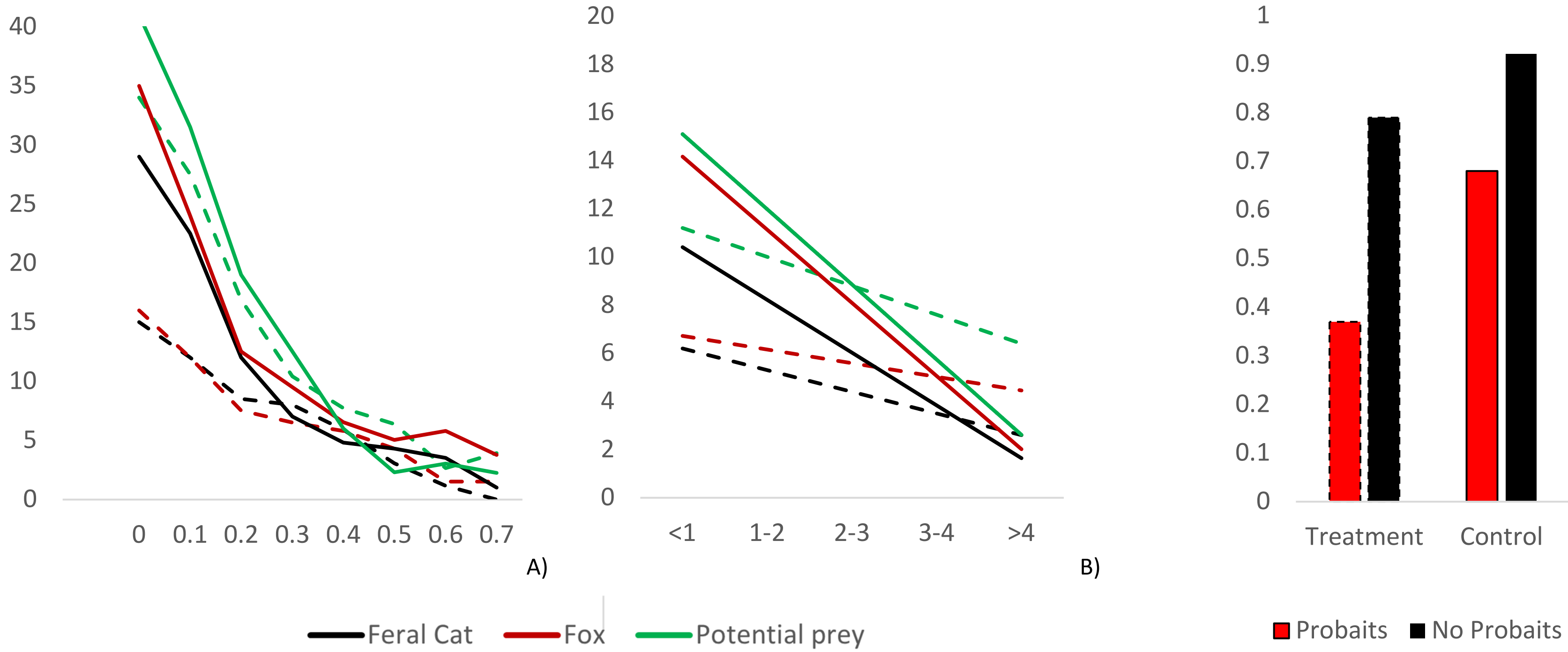


Figure 2: Variability in the total RAI for feral cats, foxes and potential prey species (critical weight range mammals and small birds) in relation to the BACI (Before-After, Control-Impact) design. Solid lines represent the control area and dashed lines represent the treatment area. Data have been SQRT transformed.



	Treatment		Control	
	F	p	F	p
Feral Cat	5.05	0.03	8.43	0.00
Fox	4.37	0.04	6.80	0.01
Potential Prey	6.64	0.01	6.85	0.01

Treatment		Control	
F	p	F	p
4.73	0.00	4.29	0.00
3.01	0.04	5.21	0.00
6.97	0.00	9.18	0.00

Treatment		Control	
F	p	F	p
2.24	0.15	0.68	0.42
3.67	0.06	3.43	0.05
0.29	0.59	0.07	0.79

Figure 3: Average RAI for feral cats, foxes and potential prey species (critical weight range mammals and small birds) in relation to A) the proximity of sites to the closest riparian system (km), B) the proximity of sites to harvesting that has occurred within the previous 12 months (km) and C) whether sites had been hand-baited with Probait ®. Solid lines represent the control area and dashed lines represent the treatment area.

Introduced predator interactions with baits

Feral cats were detected at 97 of the 810 deployed baits (12%). Of these detections, one included an individual taking an entire bait, and two included individuals feeding on bait fragments that had already been exposed to significant bush rat activity (Table 4, Figure 4). These three individuals were not detected at the bait sites again. Feral cats were observed sniffing at the bait or surrounds in 13 of these detections and for the remaining 81 detections (83%), individuals walked through the site with no interest in the bait or bait site (Table 4). Where cats were observed interacting with baits, the mean bait age was 5.2 days (range 2-7 days) and in all instances there had been small mammal activity observed on and around the bait in the days prior. All bait uptake events occurred during the first two bait deployment periods in February 2020. All subsequent interactions between feral cats and baits occurred during autumn and early winter.

Cat removing entire bait — Cats eating bait fragments following significant bush rat activity

Figure 4: Detections of bait uptake events by feral cats.

Foxes were detected at 109 of the 810 deployed baits (13%) and individuals removed an entire bait or bait fragments in 16 of these detections (Table 4, Figures 5, 8). Foxes were observed sniffing at the bait or surrounds during an additional 22 of these detections and for the remaining 71 detections (65%), individuals walked through the site with no interest in the bait or surrounds (Table 4). Where foxes were observed interacting with baits, the mean bait age was 8.7 days (range 1-13 days) and in 29 instances (80%) there had been small mammal activity observed on and around the bait in the days prior. Bait uptake by foxes occurred in late summer through to early winter, during survey sessions 28-36 (bait deployments 1-9) (Figure 10). Only 3 uptake events occurred after this period.

Figure 5: Examples of detections of bait uptake events by foxes.

While there was a relatively low uptake of baits by feral cats and foxes in the treatment area, there were 16 independent capture events of feral cats and 12 of foxes where individuals were carrying prey species such as bush rats, mardos, quenda and quokka (Figure 6). In the control area 11 predation events by feral cats and 7 by foxes were detected. Predation events captured by the cameras are likely to represent a very small proportion of those occurring and these may have contributed to opportunities for secondary poisoning.

Black feral cat carrying a mardo and then a bush rat 2 days apart

Grey tabby with a bush rat

Fox carrying a quokka

Fox carrying a rabbit

Figure 6: Examples of predation events at treatment sites.

Given the low number of bait uptake events for feral cats and foxes, models attempting to explain bait uptake were developed using combined data for these two introduced predators. The strongest model to explain bait uptake by introduced predators identified survey session, bait uptake by non-target species, time since bait deployment, time since commencement of baiting and distance to the closest riparian system as important factors influencing bait uptake (Tables 5, 6).

Bait uptake by introduced predators was more likely to occur where there was a lower level of bait uptake by non-target species (m_1 0.47, m_2 0.18, t=2.45, p=0.04, Table 6). Baits were taken by introduced species more frequently in the first eight days following bait deployment (Figure 7), and between survey periods 28-33, which equates to bait deployment events 1-6 (Figure 8). The number of bait interactions after the 6th bait deployment decreased dramatically, as did the RAI for both feral cats and foxes (Figures 2, 8). The most significant season for bait uptake by introduced predators was autumn, which equates to bait deployment events 3-8 (Figure 8). Baits were also more likely to be taken within 300 m of a riparian system.

Table 4: Bait interactions categorized for 810 bait deployment events based on activity observed on camera during the 14 days/ nights following bait deployment. The proportion (%) and frequency of detection events are presented for each category. Data are pooled across sites and survey periods. Percentages are rounded to the closest integer.

Category of Bait Interaction	%	Freq	Comments
Eaten or removed by feral cat or fox	1	5	1 feral cat (subadult black), 4 foxes
Fragments eaten by feral cat or fox	2	14	2 feral cats (both subadult tabby), appeared to be eating fragments of bait from the ground
Sniffed by feral cat or fox	4	35	
Eaten or removed by non-target	4	36	Australian magpie, brushtail possum, bush rat, grey currawong, laughing kookaburra, mardo
Fragments eaten by non-target	37	302	Australian magpie, brushtail possum, brush-tailed phascogale, bush rat, grey currawong, laughing kookaburra, mardo, quenda, quokka, western grey kangaroo
Sniffed by non-target but not eaten	23	183	Brushtail possum, bush rat, grey currawong, laughing kookaburra, mardo, quenda, quokka, western grey kangaroo
Introduced predator present but no bait interactions visible on camera	19	154	
No bait interactions visible	10	83	Evidence of insect activity onsite

Table 5: Results of models to explain bait uptake by introduced predators (feral cat and fox) and non-target species.

Variable	Model	ll (model)	AICc	ΔAICc	w	k
BU(IP)	SS R(Fox) BU(NT) BCT BDT DR*	-33.01	80.01	0	0.75	6
	SS R(Fox) BU(NT) BCT BDT	-35.82	83.65	3.64	0.12	5
	SS MT RP RA R(Cat) R(Fox) R(Prey) BU(NT) BDT BCT DFE DR DA D3Y	-26.83	83.67	3.66	0.12	14
	Global Model	-26.79	89.59	9.58	0.01	17
	SS BCT BU(NT) BDT	-43.22	96.45	16.44	0.00	4
BU(NT)	R(Prey) BU(IP) BDT DR*	-268.18	550.38	0	0.83	4
	MT RP RA Sea R(Fox) R(Prey) BU(IP) BDT DFE DR DA D3Y	-264.09	554.18	3.8	0.12	12
	MT Sea R(Prey) BU(IP) BDT	-272.55	557.11	6.73	0.03	5
	Sea R(Prey) BU(IP) BDT D3Y	-273.15	558.32	7.94	0.02	5
	Global model	-263.54	563.09	12.71	0.00	17

*Strongest model. Only the global model (all variables) and the 4 highest ranked models are shown for each model set. Variables modelled: Sea, SS, MT, RP, RA, R(Cat), R(Fox), R(Prey), BU(NT), BDT, BCT, DFE, DR, DA, D12, D3Y, FB. See Table 1 for explanation of model variables. Log-likelihood (model), Akaike's Information Criterion corrected for small sample size (AICc), Akaike weights (w) and number of model parameters (k) are presented.

Table 6: Post-hoc means comparison tests of bait uptake for introduced predators and non-target species. Mean (Standard Error), t-test and p-values are presented for no bait uptake vs bait uptake within the treatment sites. N=810 bait deployment events.

	Bait uptake by introduced predators				Bait uptake by non-target species			
	No Uptake	Bait taken	t	P	No Uptake	Bait taken	t	p
MT	9.55 (0.14)	11.18 (1.08)	-1.72	0.09	10.08 (0.20)	9.47 (0.16)	1.70	0.08
RP	7.96 (0.57)	11.03 (4.94)	-0.77	0.44	7.31 (0.75)	8.84 (0.88)	-1.33	0.18
RA	5.60 (0.42)	4.45 (1.98)	0.40	0.69	5.30 (0.56)	5.89 (0.60)	-0.71	0.48
Sea	2.56 (0.04)	2.11 (0.08)	1.49	0.13	2.56 (0.06)	2.53 (0.05)	0.26	0.79
R(Cat)	0.27 (0.02)	0.35 (0.15)	-0.49	0.62	0.25 (0.02)	0.31 (0.03)	-1.19	0.23
R(Fox)	0.27 (0.02)	1.71 (0.35)	-8.72	0.00*	0.32 (0.03)	0.27 (0.03)	0.95	0.34
R(Prey)	2.44 (0.09)	1.71 (0.48)	1.25	0.21	1.81 (0.10)	3.12 (0.13)	-8.09	0.00*
BU(Other)	0.47 (0.02)	0.18 (0.09)	2.45	0.01*	0.32 (0.01)	0.02 (0.01)	2.44	0.01*
BDT	0.66 (0.01)	0.33 (0.05)	3.35	0.00*	0.94 (0.01)	0.33 (0.02)	31.06	0.00*
BCT	0.51 (0.01)	0.24 (0.05)	3.82	0.00*	0.52 (0.01)	0.48 (0.01)	1.71	0.08
DFE	0.98 (0.02)	0.65 (0.12)	2.56	0.01*	0.98 (0.03)	0.96 (0.02)	0.66	0.51
DR	0.29 (0.01)	0.18 (0.02)	2.65	0.01*	0.41 (0.01)	0.26 (0.01)	3.86	0.00*
DA	1.66 (0.04)	1.88 (0.36)	-0.73	0.47	1.69 (0.06)	1.63 (0.05)	0.78	0.43
D12	1.86 (0.05)	1.99 (0.18)	-3.39	0.69	1.93 (0.06)	1.83 (0.07)	1.04	0.29
D3Y	1.06 (0.03)	1.43 (0.29)	-1.84	0.06	1.06 (0.04)	1.08 (0.05)	--0.40	0.68
FB	0.38 (0.02)	0.29 (0.11)	0.75	0.45	0.37 (0.02)	0.38 (0.02)	-0.13	0.89

*p-value significant at alpha <0.05

Table 7: Percentage and frequency of bait uptake events (entire and partial baits) attributed to feral cat, fox, and non-target species. LD_{50} for 1080 (monofluoroacetate) is presented for Western Australia where these values are available (Twigg *et al.* 2003, APVMA 2008). Where a range is presented, the LD_{50} is variable based on the proportion of naturally occurring *Gastrolobium* in the local area. Percentages are rounded to the closest integer.

Common Name	Scientific Name	Family	Percentage of baits taken	Frequency of baits taken	LD_{50} mg/kg
Bush rat	*Rattus fuscipes*	Muridae	55	201	20-45
Quenda	*Isoodon fusciventer*	Peramelidae	9	32	18.8
Mardo	*Antechinus flavipes*	Dasyuridae	8	29	11.8
Brushtail possum	*Trichosurus vulpecula*	Phalangeridae	6.5	23	118
Laughing kookaburra	*Dacelo novaeguineae*	Alcedinidae	5	17	>6**
Fox	***Vulpes vulpes***	**Canidae**	**4.5**	**16**	**0.14**
Grey currawong	*Strepera versicolor*	Artamidae	4	13	10.9-15.7 *
Western grey kangaroo	*Macropus fuliginosus*	Macropodidae	4	14	47
Feral cat	***Felis catus***	**Felidae**	**1**	**3**	**0.4**
Australian magpie	*Gymnorhina tibicen*	Artamidae	1	4	7.6-12.9**
Brush-tailed phascogale	*Phascogale tapoatafa wambenger*	Dasyuridae	1	4	7.3
Quokka	*Setonix brachyrurus*	Macropodidae	1	1	37.6

* LD_{50} is provided for pied currawong in eastern Australia. LD_{50} values in WA are likely to be much higher.

** LD_{50} value is for NSW. The LD_{50} values in WA are likely to be much higher.

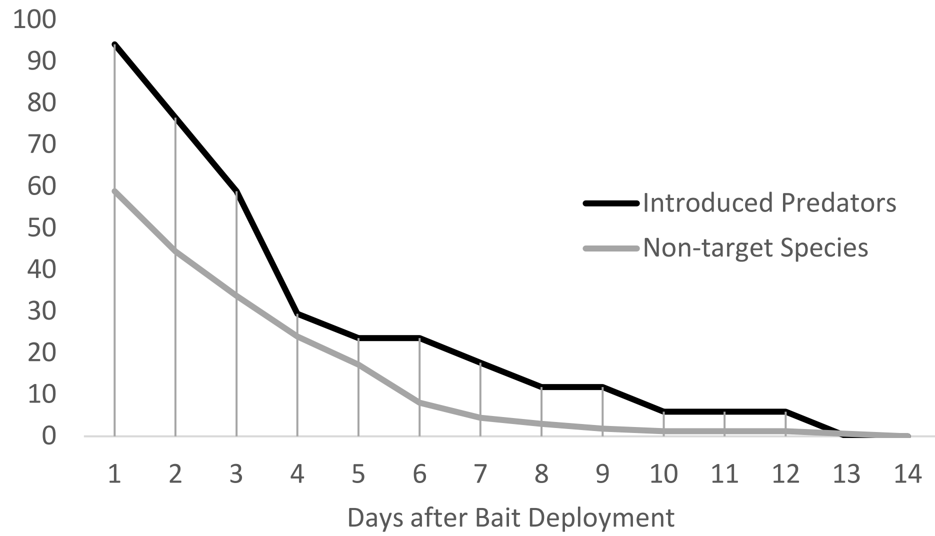


Figure 7: Cumulative bait removal curve, presenting the percentage of baits remaining over the 14 day survey period following removal of baits by introduced predators and non-target species. Frequency data pooled across all bait deployment periods.

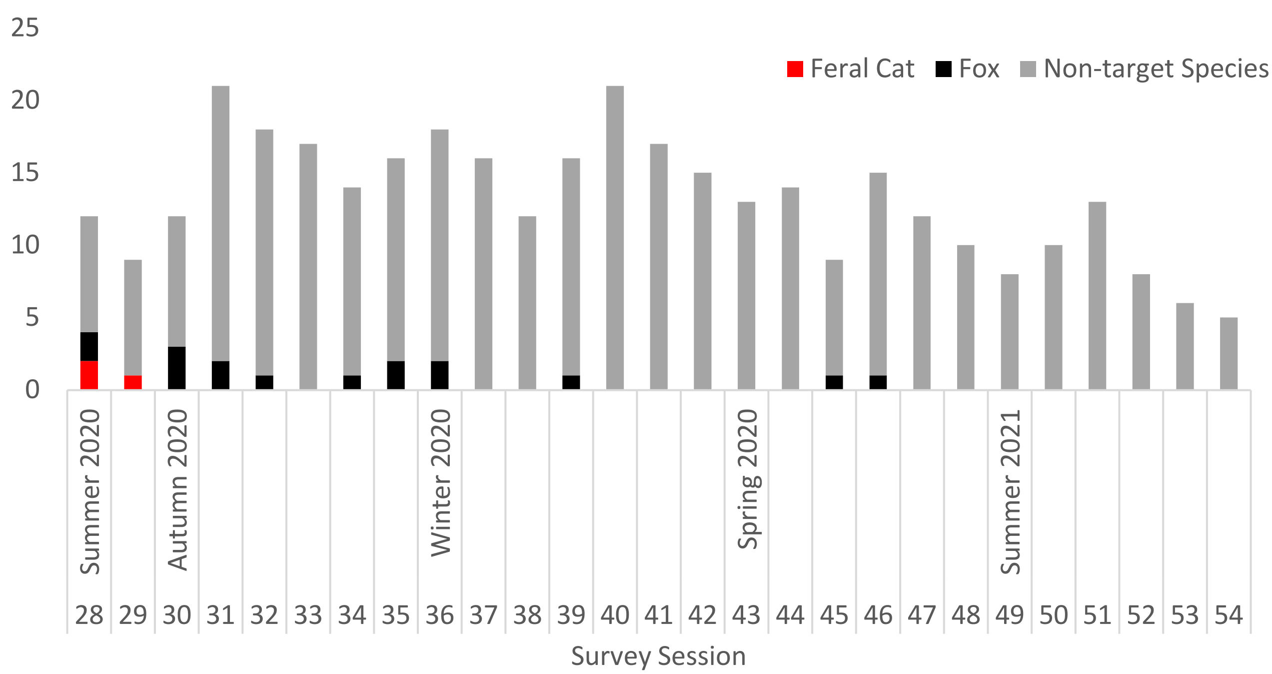


Figure 8: Baits taken by feral cat, fox and non-target species in relation to survey session. Survey session 28-54 equate to bait deployment event 1-27. For introduced predators, n=19 baits; for non-target species n=357 baits.

Non-target species interactions with baits

Of the 357 baits that were consumed either entirely or partially, 338 (95%) were taken by native species (Tables 4, 7). The Australian magpie (*Gymnorhina tibicen*), brushtail possum, bush rat, grey currawong (*Strepera versicolor*), laughing kookaburra (*Dacelo novaeguineae*) and mardo were observed removing entire baits on 36 occasions (Tables 4, 7, Figure 9). On an additional 302 occasions, the Australian magpie, brushtail possum, brush-tailed phascogale, bush rat, grey currawong, laughing kookaburra, mardo, quenda, quokka, and western grey kangaroo (*Macropus fuliginosus*) were observed consuming bait fragments onsite and in an additional 183 instances, these species were onsite with a bait present and showed some interest in the bait by sniffing the bait and surrounding area (Table 4).

Where non-target species were observed interacting with baits, mean bait age was 2.9 days (range 1-14 days) and individuals of some species were detected returning to the same site regularly, particularly bush rats. Of non-target species that were observed consuming baits, those within Dasyuridae (mardo and brush-tailed phascogale) and Peramelidae (quenda) have the lowest tolerance to 1080 (Twigg *et al.* 2003, APVMA 2008, Table 7). In addition, bush rats are of potential concern due to the range in LD_{50} for this species and their small body size. The RAI for each of these species was investigated to determine whether there were any declining trends suggestive of poisoning. The RAI for bush rats and mardos increased significantly following commencement of baiting and remained consistently high through to the end of the baiting trial in comparison to pre-baiting activity levels (Figure 10). The RAIs for brush-tailed phascogale and quenda also increased slightly following commencement of baiting and remained higher than pre-baiting activity levels through to the end of the trial, with no observable decline. For both of these species, detections showed seasonal patterns (Figure 10). It is important to note that as activity indices, these data may not present a true indication of individual losses. In many instances increases in activity are likely to be attributable to a small number of individuals that have modified their behaviour based on the availability of a novel food source.

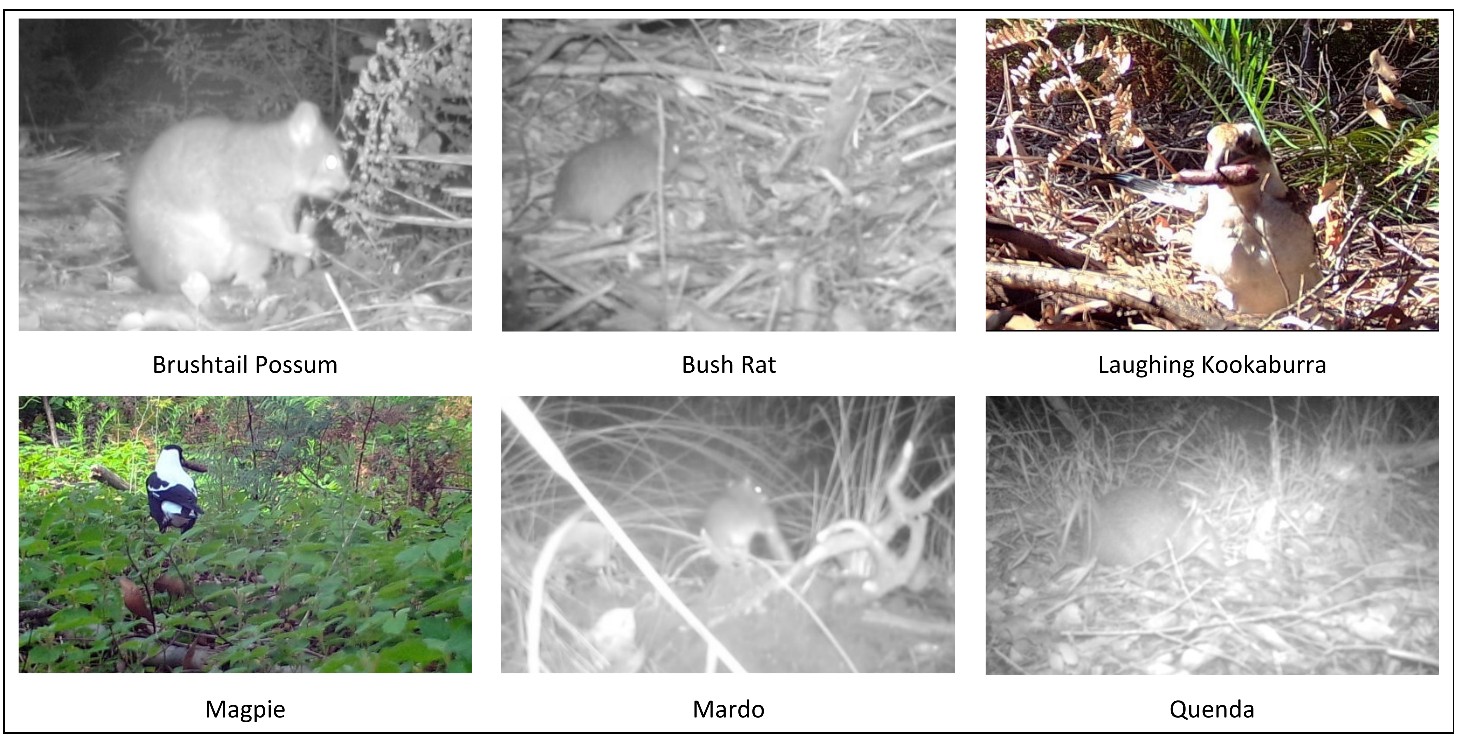


Figure 9: Examples of detections of bait uptake events by non-target species

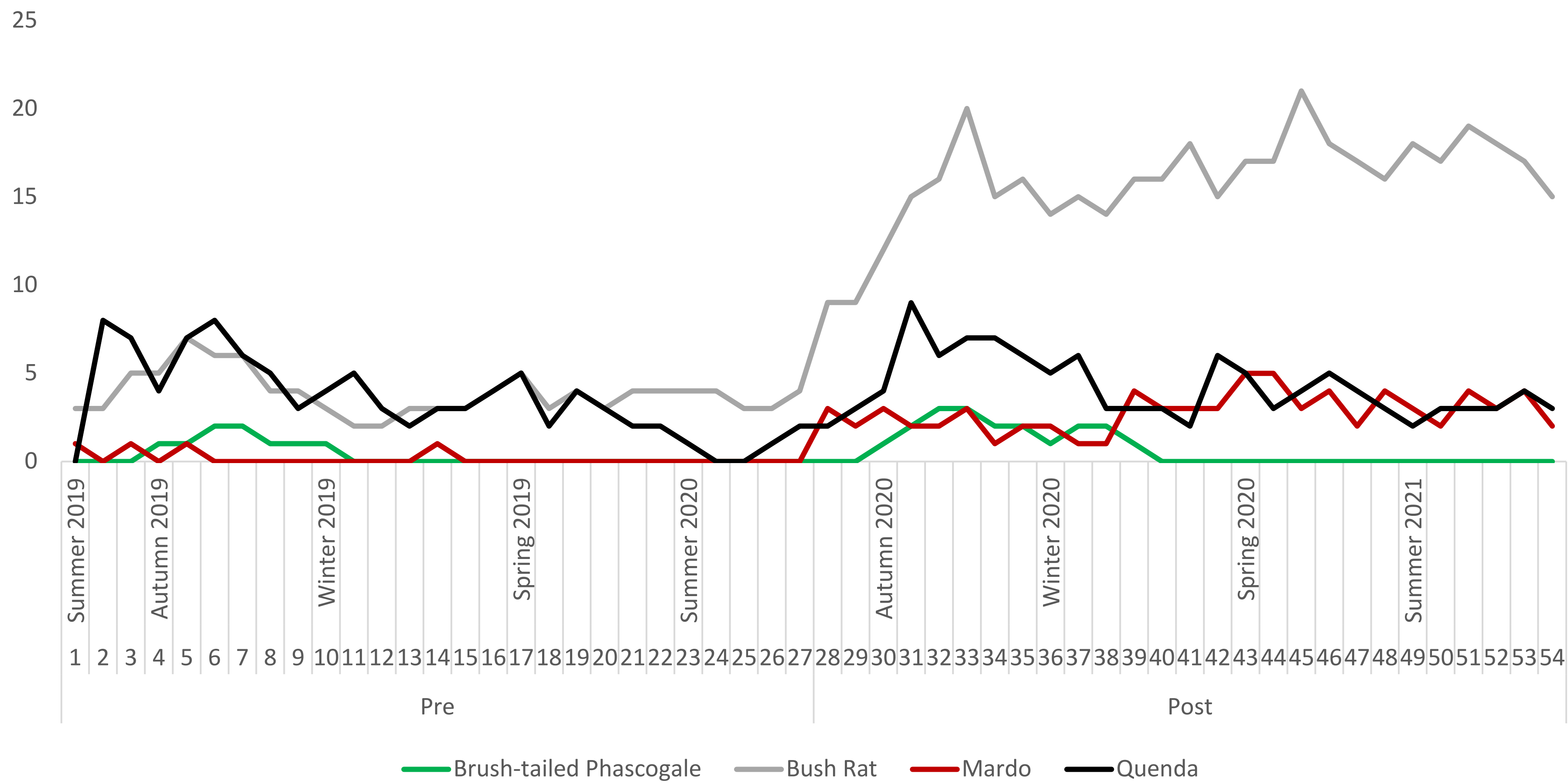


Figure 10: Variability in the total RAI in relation to baiting, for species potentially at risk of non-target poisoning including brush-tailed phascogale (*Phascogale tapoatafa wambenger*), bush rat (*Rattus fuscipes*), mardo (*Antechinus flavipes*) and quenda (*Isoodon fusciventer*).

For non-target species, the strongest model to explain bait uptake identified the RAI of potential prey species, bait uptake by introduced predators, time since bait deployment and distance to the closest riparian system as the most important factors influencing bait uptake (Tables 5, 6).

A high RAI of potential prey species increased the likelihood of bait removal by non-target species (m_1 1.81, $mean_2$ 3.12, t=-8.09, p=0.001, Table 6). Non-target species were comprised significantly of potential prey species, which makes the influence of this factor unsurprising. Non-target species were less likely to take a bait where bait uptake by introduced predators had occurred (m_1 0.32, m_2 0.02, t=2.44, p=0.000, Table 6). Again, this is unsurprising given introduced predators were more likely to take the entire remaining bait. Baits were more likely to be taken by non-target species within the first three days following bait deployment (mean 2.9 days) (Figure 7) and within 300 m of a riparian system.

Bush Rats in particular increased rapidly in areas where baits were being deployed and modified their temporal behaviour to coincide with bait deployment. This species was frequently onsite within hours of bait deployment and highest levels of activity were detected within the first few days following bait deployment. Multiple native species were regularly detected eating fragments of the same bait, with bush rats onsite first and spending significant amounts of time at the bait site (6-86 images, mean 17.9 images). Quenda and mardo visited bait sites 4-13 days after bait deployment and remained onsite for briefer periods than the bush rats (1-39 images, mean 8.1 and 7.3 images respectively). In some sites, by the 4th bait session, bush rats were onsite nightly or every second night during the inter-baiting period. Interestingly, the RAI of introduced predators was not significant in the models for non-target bait uptake, which suggests that the presence of predators was not affecting the behaviour of native species.

Discussion

Did feral cats take the bait?

While feral cats encountered 12% of the 810 baits deployed, only three of these baits were consumed. There was a higher number of baits taken by foxes (17), as would be expected for a species with a diet that routinely includes carrion (Catling 1988, Jackson *et al.* 2007, Saunders and McLeod 2007, O'Connor *et al.* 2020). While feral cats will scavenge on carrion, live prey are likely to be more attractive, particularly at times and places where they are abundant (Bradshaw 2006, Bonnaud *et al*. 2007, Fisher *et al.* 2015). Where cat baiting trials have been successful, bait uptake has been limited to seasonal periods of scarcity of live prey (Algar and Angus 2000, Algar 2006, Algar *et al.* 2007, Algar *et al.* 2010, Christensen *et al.* 2013, Comer *et al.* 2018, Algar *et al.* 2019, Palmer *et al.* 2021).

This study attempted to identify a seasonal period of scarcity of live prey in relation to harvesting activities. It was hoped that there would be a period where prey species were less available as they retreated to core refuges in response to harvesting activities, and that cats attracted to the areas of disturbance would therefore temporarily be more attracted to the Eradicat® bait. Potential prey species, however, were available consistently throughout the two year survey period with peaks in activity in autumn and spring. In fact, the availability of live prey significantly increased in areas where active baiting was occurring, due to the attraction of small mammals to the bait (Figures 2, 9).

The low bait uptake by feral cats may also have been influenced by the home range size of feral cats in the study area and proximity of bait sites to tracks. The home range of feral cats in the southern forests of Western Australia is unknown, however measured home ranges of feral cats across Australia are highly variable, ranging from 50 hectares up to 15,553 hectares (Jones and Coman 1982, Edwards *et al.* 2001, Molsher *et al.* 2005, Moseby *et al.* 2009, Doherty *et al.* 2014, Bengsen *et al.* 2015, Comer *et al.* 2018). While feral cats in some areas preferentially use tracks (e.g. Read and Eldridge 2010, Hradsky *et al.* 2017, Dawson *et al.* 2018, Geyle *et al.* 2020; Wysong *et al.* 2020), in general, tracks represent a small proportion of their home range, and as a result individuals may access tracks for a relatively small proportion of their daily activity (Algar *et al.* 2007, Doherty and Algar 2015, Fisher *et al.* 2015). For individuals that spend significant periods in off-track habitat, it is less likely that they will encounter baits laid near or on tracks, and those that do are unlikely to encounter them within the first three days when baits are still palatable and available.

The three baits taken by feral cats in this study occurred within the first two bait deployment events in February 2020 and all events involved subadult individuals. This may reflect a response of naïve individuals to a novel event in their habitat. These cats were not detected at the bait sites again despite two of them having consumed only fragments of the bait. Given their relatively small size (approximately 2-2.5 kg), <1 mg of toxin would have been needed for a lethal dose (22% of the bait) and this is a possible explanation for their subsequent lack of detection. An alternative explanation is non-detection due to behavioural avoidance of the bait sites following an unpleasant sub-lethal dose of the toxin.

To cause a decline in the overall population of feral cats, at least 57% of individuals need to be removed (Hone *et al.* 2010). Anecdotally, at the beginning of this study there were 12 individual cats known to be alive in the treatment area, based on unique features, markings and coloration (Bain 2019). At the end of the study, there were three of these still being detected. This count is likely to underestimate the relative abundance of individuals, given similar looking individuals were counted as a single individual, and that non-detection of individuals, immigration into and emigration out of the site have not been accounted for. In addition, the population is likely to extend well beyond the study area and the size of this broader population is unknown. However, superficially there appears to have been a 75% reduction in the number of individuals known to be alive within the study area during the 12 month baiting period, with minimal reinvasion during this period. Given three of the twelve individuals took a bait, this reduction in the number of individuals is unlikely to be directly attributable to the baiting program.

Did baiting reduce feral cat activity?

Despite the low bait uptake, the RAI for feral cats started to decrease significantly in the treatment sites after six baiting sessions and there was no corresponding decrease in the unbaited control sites. There was a 54% reduction in feral cat activity for the post-baiting period, in comparison with the pre-baiting period. This suggests that baiting activities contributed to a reduction in the activity of this species, possibly as a result of secondary poisoning through consumption of prey species that are relatively tolerant to the Eradicat® bait, such as bush rats. There are many studies documenting secondary poisoning of feral cats, especially after rabbit or rodent baiting programs (Gillies and Pierce 1999, Heyward and Norbury 1999, Alterio 2000, Nogales *et al.* 2004, Read *et al.* 2015). The 3.42 mg of 1080 required to kill an average sized bush rat is more than enough toxin to kill a 3 kg feral cat, even after some of it has been metabolised in the bush rat or degraded in the environment. A 73% decrease in RAI also occurred for foxes for the post-baiting period, in comparison with the pre-baiting period.

The reduction in RAI for feral cats and foxes occurred after the sixth baiting session and was sustained for the remaining 21 baiting periods (42 weeks) of the study. This significant and sustained decrease in the activity of introduced predators has implications for the protection of threatened species in areas that may be more vulnerable as a result of reduced understorey cover associated with harvesting activities.

Variables other than baiting with Eradicat ® that had an effect on the RAI for feral cats and foxes included proximity to riparian systems and recently harvested areas. The effect of these variables however was consistent between the control and the treatment area and is likely to be linked to the availability of refuge habitat for potential prey species within the unharvested riparian systems as well as the feeding opportunities associated with freshly disturbed vegetation, substrate and burning of harvest heaps in the adjoining areas disturbed by harvesting. The RAI for foxes was also influenced by hand-baiting programs targeting this species with Probait ®. Fox RAI was lower in areas that were being baited with Probait ®, however this was consistent within both the control and treatment areas. The additional reduction in fox RAI following commencement of Eradicat ® baiting was not reflected in the control area and is unlikely to be associated with the Probait ® baiting program.

While the reduction in RAI for feral cats and foxes following baiting is a promising outcome, the 12 month period of baiting was not sufficient to determine whether this level of reduction could be sustained for the three years usually allowed for understorey recovery in these forested areas. In addition, the reduction in RAI for feral cats and foxes following the sixth baiting session may have been a result of individuals leaving the area, drawn by other disturbances occurring at a landscape scale. For example, the treatment area was within 5 km of new harvesting activities that commenced in Big Brook Forest Block in 2020 and the control area was within 5 km of silvicultural burns undertaken in Court Forest Block in 2020. Given that the study occurred over a relatively small spatial and temporal scale, it is challenging to accurately interpret the results, and extrapolation to other areas may not be appropriate. Ideally the project should be repeated at additional sites to determine whether the patterns are consistent and to enable landscape disturbances outside of the study area to be proactively factored into the design.

Non-target implications

Of the baits taken, 95% were taken by native species and a large proportion of these baits were taken within 3 days, at least in part. Native species that took baits during the study included the Australian magpie, brushtail possum, brush-tailed phascogale, bush rat, grey currawong, laughing kookaburra, mardo, quenda, quokka, and western grey kangaroo (Table 7). Not only does this have implications for bait availability for feral cats, but it also has non-target implications.

Each of the 15 g baits contains 4.5 mg of 1080 and the toxin is eliminated from living animals within three days, with no persistence of residues in muscle, blood, fat, or the liver (DoH 2018). Of the non-target species, bush rats consumed the highest proportion of baits and were regularly detected at the same site nightly or every two nights foraging on bait fragments. This species has an LD_{50} of between 20 and 45 mg/kg and is expected to have a high tolerance to the baits (Twigg *et al.* 2003, APVMA 2008). For bush rats in Western Australia an LD_{50} of 45 is more likely and approximately 3.42 mg of 1080, or 76% of the toxin within an Eradicat ® bait, would be required to kill an average sized individual (76 g). It is unknown how much of each bait was consumed by bush rats, but many individuals spent considerable periods of time onsite eating fragments and in instances where this species was present, no bait portion remained onsite at the end of the 14 day period. It is highly likely that at least some individuals consumed lethal doses of the toxin, however there was no overall reduction in RAI for this species. In fact, activity levels post-baiting were significantly higher than pre-baiting levels throughout the 12 month baiting period, probably as a result of the novel food source provided by the baits (Figure 10).

The species of most concern include those within Dasyuridae (mardo and brush-tailed phascogale), due to their lower LD_{50} and small body size. The brush-tailed phascogale has the lowest LD_{50} at 7.3 mg/kg (Twigg *et al.* 2003, APVMA 2008). For an average sized individual (190 g), approximately 1.4 mg of 1080 would be required for a lethal dose, which is equivalent to roughly 31% of the toxin contained within an Eradicat® bait. During the four bait uptake events attributed to this species, only bait fragments were consumed within a very short period of time (mean 3.8 images), an average of 5 days after bait deployment and following a significant level of bush rat foraging. The palatability and toxicity of baits would be expected to decline over time as a result of bacterial decay, weather conditions, and insect and bush rat interference (Fisher *et al.* 2015, Bain 2020). A lethal dose during this period is unlikely, however this species remains of concern for future baiting programs in the area.

While the mardo has a higher LD50 of 11.8 mg/kg, the tiny size of this species makes it highly vulnerable to a lethal dose. Approximately 0.5 mg of 1080 would be required to kill an average sized individual (45 g), which is equivalent to just 10% of the toxin contained within a 15 g Eradicat ® bait. This species was detected consuming bait fragments on 26 occasions and carried off an entire bait on three occasions. This is not an indication that the bait was consumed, however the worst-case scenario is that this did occur, in which case, there is a high probability that these individuals consumed a lethal dose. The RAI patterns did not show any reduction in activity throughout the bait trial, in fact the post-baiting activity levels for this species remained significantly higher than pre-baiting levels throughout the 12 month baiting period (Figure 10).

For those species most at risk of poisoning from baiting programs, such as brush-tailed phascogale and mardo, it may be possible to identify opportunities to target baiting outside of their most active foraging periods. For example, in this study, brush-tailed phascogale were most active during late autumn- early winter.

While native predators, such as chuditch (*Dasyurus geoffroii*), were not detected in this study, these species are also known to occur in the karri forest, particularly in mixed forest types. As a result, it is critical that lethal measures aimed at the control of introduced species do not inadvertently affect populations of native predators, which are generally less tolerant to 1080 than native herbivores and omnivores.

Protection to fauna from baiting

Introduced predators are highly mobile and have good dispersal abilities, which means that they can quickly invade areas where previously resident individuals have been removed through lethal control (Lieury *et al.* 2015, Minnie *et al.* 2016, Palmas *et al.* 2020). In some instances, this has been shown to result in an increase in activity and pressure on threatened species as multiple subordinate individuals from surrounding areas compete for the vacated territory (e.g. Lazenby *et al.* 2014, Palmas *et al.* 2020). This was not observed during the 12 month baiting period in this study however, for this reason, the outcomes of the baiting program are unlikely to equate to long-term protection for fauna in the area or to any level of protection outside of the baited area.

The program has however contributed to significantly reduced activity levels for both feral cats and foxes in the area. While this result is likely to be short-term, it does have the capacity to meet one of the objectives of the study, which was to provide protection for fauna in areas disturbed by harvesting, during the period of understorey vegetation recovery. This is particularly the case if the baiting program and associated monitoring can be extended to include the full period of vegetation recovery. Monitoring during such baiting programs is critical to increase efficiency and efficacy e.g. by identifying when activity levels have reached acceptable thresholds and baiting can be ceased, enabling detection of reinvasion events that may require follow up baiting, and identifying non-target issues that need immediate mediation. This study may help to set acceptable thresholds for feral cat and fox activity in the karri forest.

Unfortunately, current approaches to monitoring of introduced predator activity levels may be cost prohibitive. In which case, a conservative commitment to three years of baiting seems an economical option.

Building natural resilience

Building natural resilience in fauna populations may be possible through means other than baiting, such as through maintaining and restoring habitat complexity and ecological refuges, provision of artificial refuges in areas that have been more intensely disturbed and where introduced predator activity is high and reducing access and habitat suitability for introduced predators.

Reductions in habitat complexity arising as a result of timber harvesting and regeneration burning can increase the impacts of predators by removing protective cover for prey species (Leahy *et al.* 2016). The maintenance of ecological refuges may increase the ability of native fauna to coexist with predators in these disturbed environments (Doherty *et al.* 2015). As a standard practice, occurrences of threatened species, important areas of habitat and key movement corridors are identified during fauna surveys that occur prior to commencement of harvesting in the karri forests of southwest Western Australia (Bain 2018, FPC 2020). Where threatened species are present, management strategies are implemented to reduce the risk to these species from harvesting and are likely to include exclusion of areas of occupied habitat or proactive consideration of opportunities for fauna refuge and movement. In addition, the informal reserve network established by the Forest Management Plan (CCWA 2013) requires protection of vegetation within riparian systems, fauna habitat zones and transport corridors at a landscape scale. This approach to harvesting affords a measure of protection to fauna through the protection of key areas of habitat within harvesting cells and the maintenance of areas of habitat complexity proximate to and through these cells. Where introduced predators have been identified during the pre-harvest surveys, additional baiting programs are also implemented, and these are currently effective at reducing predation pressure from foxes.

In some cases, where a high level of feral cat activity has been identified prior to harvesting, artificial refuges may be an additional strategy available for consideration, to temporally decrease predation pressure (e.g. Lettink *et al*. 2010, Smith *et al.* 2011). It is important to acknowledge that artificial refuges are unlikely to be required where the landscape level disturbances have been managed as described above. However, there are occasions where regeneration burns within the harvesting cell accidentally burn into riparian refuge areas, and in instances such as these alternative approaches to provision of refuge and protective cover may be needed. Such measures are likely to be deployed over relatively small areas and may be costly. Artificial refuges should be designed and assessed experimentally for individual species (Lettink *et al.* 2010).

Building natural resilience could also take the form of modifying habitat to increase the presence of naturally occurring sodium monofluoroacetate. The relative tolerance of many native species in Western Australia to 1080 (Twigg *et al.* 2003, APVMA 2008), may provide a management opportunity in the lethal control of feral cats, given their dietary preference for live prey. Deliberate poisoning using live and unaffected 'toxic Trojan prey' has previously been suggested as a feral cat control strategy in Australia that may be more appealing to the hunting instincts of cats (Read *et al.* 2015). This strategy could also be applied less directly to key areas where threatened species are susceptible to feral cat predation, by increasing the availability of naturally toxic plants such as *Gastrolobium* in the food chain. This is only an acceptable strategy in situations where negative risks to non-target species, such as rare *Dasyurids* have been mediated and where trophic relationships and ecosystem dynamics will not be undermined through modification of vegetation composition and structure.

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