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The value of camera traps in monitoring a feral-cat and fox reduction program

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Abstract

Context. We examined the effectiveness of camera traps to monitor the success of a feral-cat (*Felis catus*) and fox (*Vulpes vulpes*) reduction program near Ravensthorpe, Western Australia.

Aims. To determine whether camera traps are an effective tool to measure a reduction in the abundance of *F. catus* and *V. vulpes* at a local scale.

Methods. In all, 201 Foxoff® baits (i.e. 1080) were laid along the edge of unsealed tracks for each of three periods (i.e. opened 13–15 May 2017, Period 1 closed 29–31 May 2017, Period 2 closed 12–13 June 2017, Period 3 closed 25–26 June 2017), and 98 bait sites were monitored by camera traps during each period. In addition, 150 baited cage traps were deployed to catch *F. catus* for the same three periods. *Vulpes vulpes* and *F. catus* were also shot in the adjacent paddocks before traps were opened and during the laying of traps and bait replacement. We used the first 13 days of camera-trapping data for each period to examine whether there was a significant reduction in *V. vulpes* and *F. catus*.

Key results. Camera traps recorded a significant reduction in *V. vulpes* images, but knock-down with Foxoff® baits was not as effective as in other programs, and there was no change in the measured abundance of *F. catus*. Numerous baits were taken and not recorded by camera traps. Multiple *V. vulpes* moved past or investigated, but did not take baits and a *V. vulpes* was recorded regurgitating a bait.

Conclusions. Camera traps were not effective for recording bait-take events. *Vulpes vulpes* knock-down was low and slow compared with other studies, did not reflect the number of baits taken and Foxoff® baits appeared unpalatable or unattractive to many *V. vulpes*.

Implications. Camera traps did not record a high proportion of bait-take, appeared to be insensitive to small changes in fox and cat abundance and Foxoff® baits were less effective in reducing the abundance of *V. vulpes* than in other studies.

Additional keywords: bait-take, *Dasyurus geoffroii*, *Felis catus*, feral pest, Foxoff®, *Vulpes vulpes*.

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Introduction

Felis catus and *V. vulpes* have had a severe negative impact on Australian fauna since their introduction (Abbott *et al.* 2014). Doherty *et al.* (2016), in their global meta-analysis of invasive mammal impacts, indicated that *F. catus* and *V. vulpes* ranked first and sixth respectively, in their impacts on native fauna. In an Australian context, McLeod (2004) argued that *V. vulpes* was Australia's most destructive introduced predator, costing the national economy an estimated AU$227.5 m annually, followed by feral *F. catus* at AU$146 m. Woinarski *et al.* (2014, 2017, 2018) indicated that feral *F. catus* is a serious vertebrate pest in Australia, and has had a severe negative impact on native fauna (also see Doherty *et al.* 2017). *Vulpes vulpes* has also been implicated in the loss of most of the critical-range mammals in Australia (Department of the Environment Water Heritage and the Arts 2008; Dickman 2015; Woinarski *et al.* 2015; Doherty *et al.* 2017).

The most commonly used method for *V. vulpes* control is lethal baiting (Saunders *et al.* 2010). Populations of mammals such as *Bettongia penicillata*, *Trichosurus vulpecula*, *Dasyurus geoffroii* and *Petrogale lateralis* have shown increases following intensive 1080 baiting programs for *V. vulpes* (Kinnear *et al.* 1988; Burrows and Christensen 2002; Kinnear *et al.* 2010). For *F. catus*, lethal control is either by baiting, shooting or trapping. In Western Australia, broad landscape-scale baiting programs for *F. catus* and *V. vulpes* have been undertaken with mixed success (Algar *et al.* 2011; Dundas *et al.* 2014; Marlow *et al.* 2015). Two primary problems with broad-scale aerial-baiting programs are uncontrolled uptake of baits by non-target species and unpredictable ambient weather conditions before and during the distribution of the bait. For example, Dundas *et al.* (2014) reported that 99% of the 1080 baits laid to control *V. vulpes* in the northern jarrah forests of Western Australia and monitored by camera traps were taken by non-target species; and a field trial to compare the efficacy of *Eradicat*® and *Curiosity*® baits in the Cape Arid National Park and Nuytsland Nature Reserve resulted in poor uptake because of reduced bait attractiveness or palatability and inappropriate weather (Algar *et al.* 2011).

Annual vertebrate-fauna monitoring programs for conservation significant species near Ravensthorpe, Western Australia, have indicated a decline in *Leipoa ocellata*, *Pseudomys shortridgei*, *P. occidentalis* and *Isoodon fusciventer* since surveys commenced in 1999 and images from camera traps indicated that *F. catus* and *V. vulpes* are widespread in the bushland in the study area (Terrestrial Ecosystems 2015, 2017). It was suggested by Terrestrial Ecosystems (2013, 2014, 2015, 2017) that *F. catus* and *V. vulpes* are likely to have had a significant impact on these species, because other studies have implicated these two predators in these species decline (Benshemesh 2007; Smith *et al.* 2007; Morris *et al.* 2008; Woinarski *et al.* 2014; Burbidge and Woinarski 2016).

Despite camera traps having similar manufacturer-listed specifications, they can vary in sensitivity (Meek *et al.* 2014; Urlus *et al.* 2015). For example, a comparison of Reconyx HC550, Reconyx PC850 and high-sensitivity author-modified PC850 (i.e. their peak signal frequency was adjusted to 10.2 Hz and maximum gain was set to 78 dB, which reduces the temperature-differential trigger threshold) in monitoring bait take showed the modified high-sensitivity camera traps to be far superior to the other two models (i.e. recorded bait-take of the high-sensitivity PC850 was 75%, HC550 recorded bait-take at 20% and PC850 recorded bait-take at 33.3%; Heiniger and Gillespie 2018). A failure to consider camera-trap performance can, therefore, lead to inaccurate conclusions. However, Bengsen *et al.* (2011) reported camera traps used to identify individual *F. catus*, and in conjunction with the capture–mark–capture methods, they were useful for monitoring changes in the density of *F. catus* populations, and Austin (2014) reported a similar finding for northern quolls. Robley *et al.* (2015) reported on two methods for assessing *V. vulpes* occupancy in the Grampians National Park in Victoria and concluded that it was possible to use camera traps for unbiased monitoring; however, they also acknowledged that the detection rate for different types of camera traps varied and all camera traps can fail to detect a substantial proportion of the total known triggering events and visits by animals (also see Driessen *et al.* 2017).

The purpose of the present study was to examine the efficacy of camera traps, and, specifically, we asked the following two questions:

- are they an effective tool in measuring a reduction in *F. catus* and *V. vulpes* numbers; and
- are they useful in detecting bait take by target and non-target species (e.g. *Dasyurus geoffroii*)?

Materials and methods

Study site

The study area is 32 km east of Ravensthorpe in Western Australia where there had been a reduction in *L. ocellata*, *P. shortridgei*, *P. occidentalis* and *I. fusciventer*. The baiting program was on land south and north of the South Coast Highway (Fig. 1). Woodman Environmental (2015) recorded the following three broad vegetation types in the study area: (1) mallee shrubland or woodland dominated by *Eucalyptus* sp. over shrubland on sandplain; (2) mallee woodlands dominated by *Eucalyptus* sp. over mixed shrubland on clay soils; and (3) tall–mid-shrublands dominated by *Allocasuarina campestris* and/or *Calothamnus quadrifidus* over low mixed shrublands and sedges on granite-derived soils. The bushland is surrounded by agricultural land that is mostly used for cereal cropping.

Trapping and shooting

In total, 150 large wire cage traps (320 mm × 250 mm × 820 mm), each baited with a tin of sardines, were deployed along the edge of infrequently used tracks in the bushland to target *F. catus* (Fig. 1). All traps were checked and cleared daily within 4 h of sunrise. All caught *F. catus* individuals were humanely euthanased and the lateral view photographed. Given the size of feral cat and fox home ranges (White *et al.* 2006; Carter *et al.* 2012; Bengsen *et al.* 2016; Newsome *et al.* 2017), it is likely that most of the feral cats and foxes to the west and north-west of the mining area and south of the barrier fence (i.e. ~6000 ha; Fig. 1) would have been exposed to lethal baits and trap sites.

Felis catus and *V. vulpes* were shot in the adjacent agricultural paddocks during the deployment of the first and second round of baiting (Fig. 2). A record was maintained of all *V. vulpes* and *F. catus* individuals shot and all *F. catus* individuals trapped.

Vulpes vulpes and *F. catus* individuals shot and trapped during the deployment of Foxoff® baits and camera traps between 11 and 15 May 2017 (i.e. before Period 1 commenced) were not considered in the analysis of changes in the relative abundance of *V. vulpes* and *F. catus*, because this activity occurred before the commencement of monitoring the abundance of *F. catus* and *V. vulpes*.

Vulpes vulpes *and* F. catus *reduction program*

Dexter and Meek (1998) used Foxoff® baits to reduce a *V. vulpes* population at Beecroft Peninsula, New South Wales. In the Dexter and Meek (1998) program, a pre-feeding of non-lethal Foxoff® baits was followed by the deployment of lethal Foxoff® baits, which were buried 100 mm below the surface. This program resulted in killing most of the known *V. vulpes* individuals on the first day. On the basis of that study, Foxoff® was considered to be an effective lethal bait for the purposes of reducing *V. vulpes* numbers. Pre-feeding was not used in our study because it is not typically used by practitioners in fox-reduction programs when laying baits.

Foxoff® baits were acquired from Animal Control Technologies (Australia) Pty Ltd, Victoria, and used in the baiting program for *V. vulpes*. The baiting period of May–June was selected because of the distributor's recommendation and it was a period when *Varanus rosenbergi* was inactive, because individuals of this species were likely to dig up and take numerous baits (see Kreplins *et al.* 2018). All 201 baits for each survey period were buried ~100 mm below the surface, as recommended by the distributor and as done by Robley *et al.* (2011), using a small pick to open a V shape in the substrate, inserting the bait and closing the substrate to leave the least possible disturbance. *Vulpes vulpes* baits were laid along the edge of

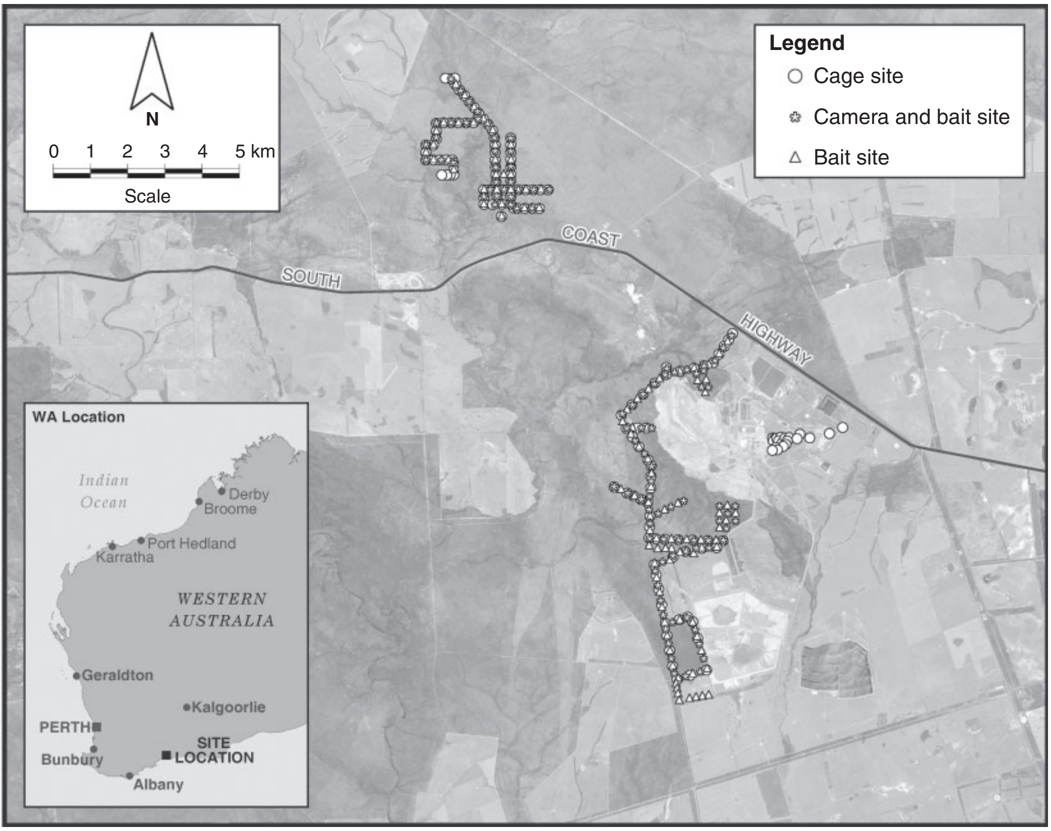

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Fig. 1. Location of camera traps and baiting sites.

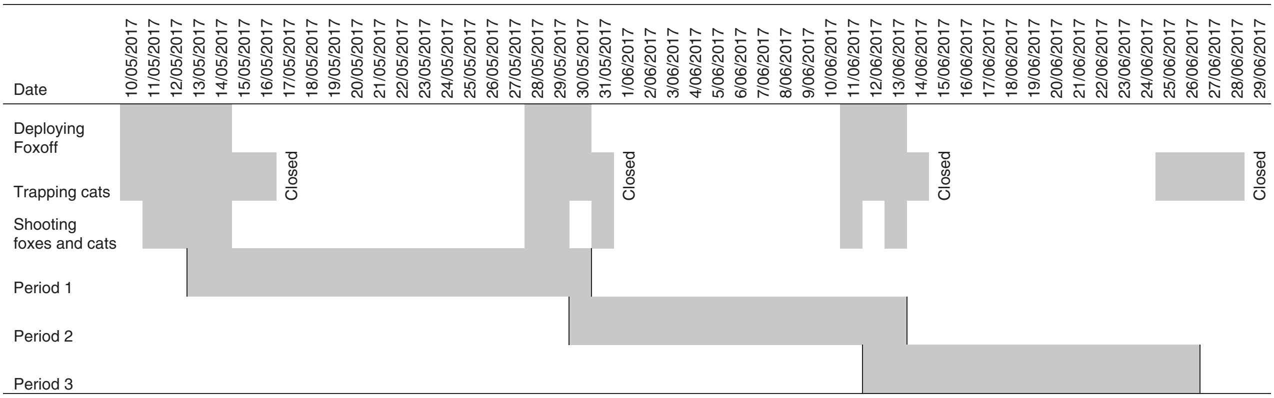

Fig. 2. Timeline of shooting, trapping, baiting and survey periods.

infrequently used tracks in the bushland (Fig. 1), as Towerton *et al.* (2011) and Carter *et al.* (2019) indicated that there was likely to be a greater level of *V. vulpes* activity on tracks than in the adjacent bushland (Read and Eldridge 2010; Dawson *et al.* 2018). Each bait had a stick from nearby placed upright ~30 cm from the bait, so the bait location could be easily identified in camera-trap images.

The timing of the baiting and monitoring program, including the three 13-day survey periods, are shown in Fig. 2. Earthworks occurred along one of the tracks containing camera traps and baits, and this action resulted in some baits being removed. These baits were replaced at the beginning of the next baiting period. Where a bait could have been removed by machinery during a baiting period, then bait removal was recorded as ‘unsure whether it was taken by a fox’, and was not considered as part of the analysis.

When lethal baits were replenished at the end of each period, a record was maintained of whether there was evidence to indicate that (1) the previously laid bait had been taken, (2) the bait was not taken (substrate unaltered and bait was present in the ground) or (3) we were unsure whether it was taken (i.e. removed by machinery).

Camera traps

We used 100 camera traps that were mounted on a star picket ~40 cm high, with the lens being perpendicular to the ground, ~3–4 m from the buried Foxoff® bait and at right angles to the typical direction of fox movement along the track, so that the bait was centred on the camera detection zone, which is in accordance with Meek *et al.* (2014). Approximately every second Foxoff® bait on the ground had a camera trap (Fig. 1). Two camera traps were removed on 3rd June 2017, to accommodate the adjacent tenement holder's request, and data from these two camera traps have been deleted from the analyses. All camera traps were Reconyx HyperFire HC600 (Reconyx, Inc., Holmen, Wisconsin, USA) with a 16-GB micro-storage card. Eneloop or Fujitsu AA rechargeable NiMH batteries were used to ensure that the maximum number of images were recorded. Camera settings were as follows: motion sensor was set 'on', sensitivity was set at 'high', there were five photographs per trigger, the wait interval per five photographs was 1 s, there was no quiet period, image resolution was set at 1080p and night mode was set on 'balanced'. Reconyx HC600 maximum distance for detection is 30 m during the day and 18 m at night, and it has a detection zone and a detection angle of 40° (Reconyx Inc. 2013).

We considered that ambient conditions were suitable for camera traps to detect differences between a mammal's surface body temperature and the ambient temperature (i.e. study period minimum temperature (mean ± s.e.) was 6.9°C ± 0.3, mean maximum was 17.6°C ± 0.5 and mean daily rainfall was 1.4 mm ± 0.5).

We had planned to record which of the euthanased *F. catus* individuals were recorded on camera traps on the basis of the variations in pelt patterns (Bengsen *et al.* 2011; Hohnen *et al.* 2013). Where it was feasible, images of all *F. catus* individuals were identified on the basis of images of *F. catus* that had been shot or euthanased after being trapped.

All camera-trap images were inspected in Windows Photo Viewer as jpeg files and grouped according to the baiting period (i.e. Periods 1, 2 and 3). Separate capture events were defined as any group of photographs of an animal of the same species (i.e. *V. vulpes*, *F. catus* or *D. geoffroii*) separated by at least 30 min or where they were clearly a different individual (e.g. white *F. catus* and black *F. catus*). Thirty minutes was selected because both *V. vulpes* and *F. catus* have been observed on multiple occasions moving through the landscape, and 30 min was deemed more than sufficient for an individual to have moved out of the vicinity of a camera trap. For each image of a *F. catus*, *V. vulpes* or *D. geoffroii*, the activity of the animal in the proximity of the bait was recorded in one of the following categories: (1) moved past the bait without showing any interest in the bait; (2) investigated the bait but did not take the bait; and (3) took the bait. Where there was some ambiguity about whether the animal took the bait, a judgement was made on the basis of the animal's posture at the bait, whether its mouth was open near a bait and whether it moved off quickly afterwards. *Vulpes vulpes* individuals could not be identified, and only a few of the *F. catus* individuals could be reliability identified in camera-trap images, so we were unable to identify occasions when a particular *V. vulpes* or *F. catus* was recorded (i.e. double counting). We have assumed that the potential multiple records of individual animals remained constant across surveyed habitats and for the duration of the study.

Data analysis

There were 13–16 days between baiting periods. To standardise the analyses, only camera-trap images recorded in the first 13 days after the baits were laid or replenished were used. All images of *F. catus*, *V. vulpes* and *D. geoffroii* were recorded, and, in addition, camera-trap images of *Corvus coronoides*, *Strepera versicolor* and *D. geoffroii* were inspected to determine whether they had taken a bait.

Because it was not possible to obtain a valid estimate of absolute population abundance or density for *F. catus* and *V. vulpes*, and the differences in abundance between surveys were more important than were absolute abundances, a relative abundance index was used to describe changes in the populations over time. We used two generalised linear mixed-effects models (GLMMs) to estimate the expected number of *V. vulpes* and *F. catus* observations per day for three survey periods (following Bengsen *et al.* 2011; Bengsen 2014). For each species, survey period was specified as a fixed effect, whereas camera-trap station and day (nested in the survey period) were specified as random effects. We used Poisson error distributions because these closely approximated the distributions of the *V. vulpes* and *F. catus* count data, and log-link functions ensured that confidence intervals were positive. Mixed-effects models such as these produce an index that is a function of detection probability and population abundance or density. Such indices have been justly criticised for confounding detectability and abundance when they have been used inappropriately. However, the GLMM-based indices we used are well suited for assessing the effects of significant population-management actions over short time intervals, when the change in density in between surveys is expected to be much larger than are any changes in detectability (Bengsen *et al.* 2011; Bengsen 2014).

It is known that sound and light emitted by camera traps can be detected by some animals (Meek *et al.* 2016). It was assumed, for this investigation, that *V. vulpes* and *F. catus* did not respond with consistent aversion or attraction to camera traps in a way that would introduce bias (Read *et al.* 2015; Meek *et al.* 2016). To test whether the presence of camera traps influenced bait uptake, we used a 2 × 2 contingency table with heterogeneity chi-square test.

Results

Euthanased F. catus *and shot* V. vulpes

During the three survey periods, eight *F. catus* individuals were caught and euthanased, and six *V. vulpes* individuals were shot in the paddocks that surrounded the bushland in which the baits were deployed. *Felis catus* and *V. vulpes* individuals trapped and shot between 10 and 17 May 2017 (before the first monitoring period) would have reduced the local population, but this reduction would not be evident in the camera images, because these animals where euthanased before the monitoring program commenced.

Table 1. Number of images of *Felis catus* and *Vulpes vulpes*, and whether baits were taken during Baiting periods 1, 2 and 3

Parameter	Pre-baiting period 1	Baiting period 1	Pre-baiting period 2	Baiting period 2	Pre-baiting period 3	Baiting period 3
Opened		13 May 2017		30 May 2017		11 June 2017
Closed		31 May 2017		13 June 2017		26 June 2017
Number of *F. catus* euthanased	14		7		1	
Number of *V. vulpes* euthanased	6		5		1	
Number of baits not taken		63		56		72
Number of baits taken		33		35		24
Number of baits where it was unsure whether taken or not		2		7		2
Number camera traps that recorded at least one *V. vulpes* in the baiting period		34		17		11
Number of *V. vulpes* recorded on all camera traps		47		26		14
Number of *V. vulpes* recorded moving past the bait, without showing any interest in the bait on all camera traps		33		14		4
Number of *V. vulpes* that investigated the bait, but did not take the bait, recorded on all camera traps		13		12		9
Number of *V. vulpes* that either walked past or investigated the bait and there was a bait remaining at the end of the baiting period		34		11		5
Number of *V. vulpes* recorded taking a bait on a camera trap		1		0		1
Number camera traps that recorded at least one *F. catus* in the baiting period		24		28		24
Number of *F. catus* recorded on all camera traps		41		41		35
Number of camera traps that recorded at least one *D. geoffroii* in the baiting period		4		3		4
Number of *D. geoffroii*, recorded on all camera traps		4		6		8
Number of *D. geoffroii* that were recorded moving past the bait, without showing any interest in the bait, on all camera traps		3		2		3
Number of *D. geoffroii* that were recorded investigating the bait, but did not take the bait, all camera traps		1		4		5
Number of *D. geoffroii* that were recorded taking a bait on all camera traps		0		0		0

Bait take

On the basis of visual evidence at the bait-burial site (i.e. bait had been dug out or the bait had been removed when the replacement bait was being installed), 191 baits were not taken, 92 baits were taken, and we were unsure of the status of 11 baits (Table 1). A much higher number of Foxoff® baits was taken (33, 35 and 24) than was the corresponding reduction in the number of *V. vulpes* individuals recorded by the camera traps (47, 26, 14, acknowledging that many foxes would have been recorded on multiple occasions and at different camera traps, so the camera-trap recordings inflate the number of foxes actually present; Table 1). The number of *F. catus* individuals euthanased (i.e. 7 at the end of Period 1, and 1 at the end of Period 2) over the three periods did not correspond to the number of cats recorded by camera traps over the same three periods (e.g. 41, 41 and 35), particularly when it is acknowledged that individual cats would have been recorded on multiple occasions and multiple camera traps.

Camera traps

The number of *V. vulpes* individuals recorded by camera traps progressively declined over the three survey periods (i.e. 47, 26, 14), as did the number of *V. vulpes* individuals that investigated the baits (i.e. 13, 12, 9; Table 1). On one, and possibly two, occasions, a *V. vulpes* took the bait (scored as investigating the bait) and immediately regurgitated the bait (Figs 3, 4).

There were numerous occasions, although with the number of occasions showing a progressive decline, over the three survey periods where a *V. vulpes* individual either walked past (i.e. 33, 14, 4) or investigated (i.e. 13, 12, 9) a bait but did not take it, and there was an increase in the number of baits remaining at the end of the third survey period (i.e. 63, 56, 72). We noticed that some of the *V. vulpes* individuals appeared to stare at the camera, suggesting that they had detected its presence.

The number of images of *F. catus* recorded by camera traps was similar for the three survey periods (e.g. 41, 41 and 35; Table 1). On all occasions, an *F. catus* individual walked past the bait and did not investigate or take the bait. Some *F. catus* individuals that had very distinctive body markings or colour patterns (e.g. black body with white feet, tabby with one or more white feet) were identifiable on the camera images; however, the majority of the *F. catus* individuals recorded were difficult to identify because they were tabby with either mackerel stripping or with blotches arranged in rows on their flanks or a combination of these two, or the image was blurred because of movement. We noticed that some of the *F. catus* individuals appeared to stare at the camera, suggesting that they had detected its presence.

The GLMM indicated there was no detectable decrease in the actual number of *F. catus* observations per camera trap per day between Periods 1 and 2 ($z = 0.267$, $n = 2548$, one-sided $P > 0.05$) or between Periods 1 and 3 ($z = 0.135$, $n = 2548$,

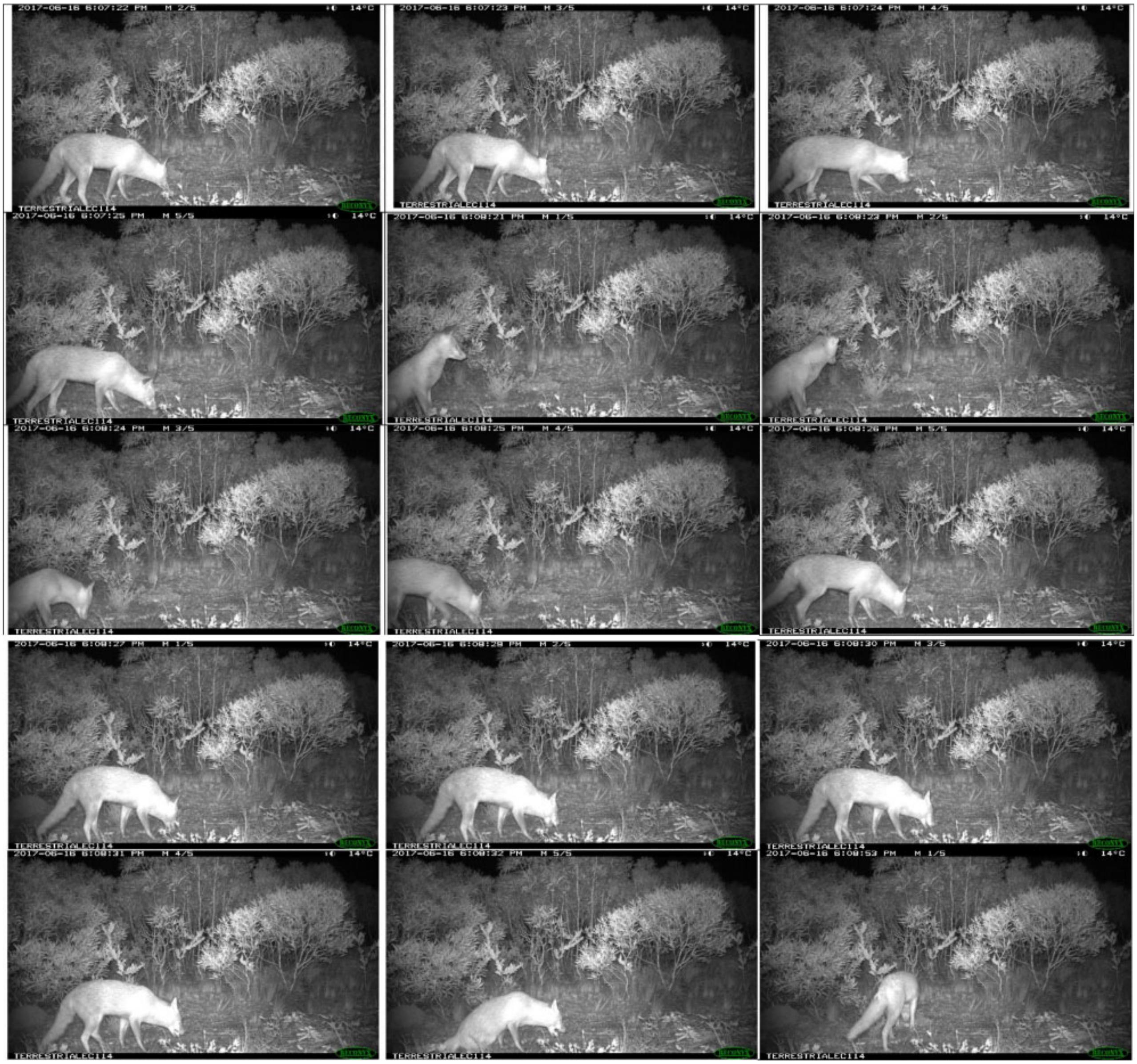

Fig. 3. A *Vulpes vulpes* individual takes the bait in the centre image in the top row, drops the bait in the left image on the second row, takes the bait again in the left image on the fourth row and it then appears to regurgitate the bait in the centre image on the fifth row.

Fig. 4. A *Vulpes vulpes* showing what has been interpreted as bait-regurgitation behaviour.

one-sided $P > 0.05$; Fig. 5). There was also no detectable decrease in *V. vulpes* activity between the first and second surveys ($z = -0.815$, $n = 2548$, one-sided $P > 0.05$); however, there was a decrease in *V. vulpes* activity over the course of the study, and the number of expected *V. vulpes* observations per camera station per day in Period 3 was lower than that in Period 1 ($z = -2.316$, $n = 2548$, one-sided $P < 0.05$; Fig. 6).

There was no difference in bait uptake with and without a camera trap being present for any period or overall (before commencement of trapping, $\chi^2 = 0.50$, d.f. = 1, $P > 0.05$;

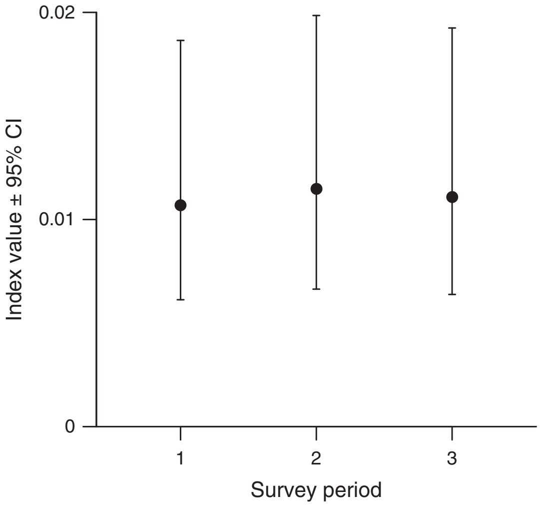

Fig. 5. Relative-abundance indices of *Felis catus* calculated from three 13-day camera-trap surveys coinciding with three *Vulpes vulpes* baiting and *F. catus* trapping operations. Index and confidence intervals (CI) have been back-transformed from Poisson distributions.

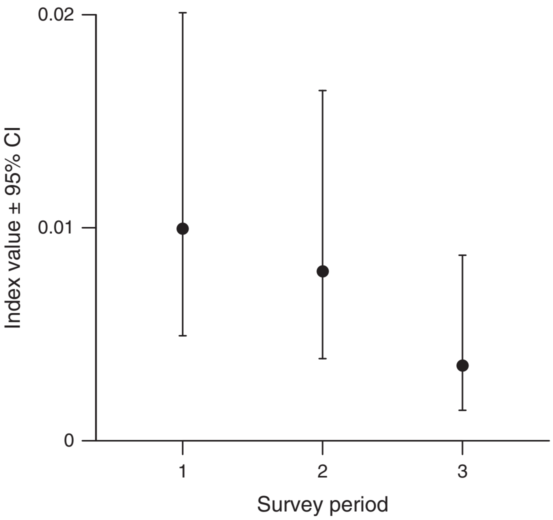

Fig. 6. Relative-abundance indices of *Vulpes vulpes* calculated from three 13-day camera-trap survey periods coinciding with three *V. vulpes* baiting and *Felis catus* trapping operations. Index and confidence intervals (CI) have been back-transformed from Poisson distributions.

Period 1, $\chi^2 = 0.17$, d.f. = 1, $P > 0.05$; Period 2, $\chi^2 = 0.76$, d.f. = 1, $P > 0.05$; heterogeneity test, $\chi^2 = 1.00$, d.f. = 2, $P > 0.05$).

Other species

In the first baiting period, *D. geoffroii* was recorded on 4 of the 98 camera traps and there were four separate recordings of a *D. geoffroii* (three times a *D. geoffroii* walked or ran past the bait; and, on one occasion, it investigated the bait but did not take the bait; Table 1). During the second baiting period, *D. geoffroii* was recorded on three camera traps and there were six separate recordings of a *D. geoffroii* (two observations when *D. geoffroii* walked or ran past the bait; and four occasions when the *D. geoffroii* investigated the bait but did not take the bait). *Dasyurus geoffroii* was recorded on four camera traps during the third baiting period and there were eight separate recordings of a *D. geoffroii* (three occasions when the *D. geoffroii* walked or ran past the bait; and, on five occasions, the *D. geoffroii* investigated the bait but did not take the bait). We found two independent scats (~5 km apart) of a trapped *D. geoffroii* that contained red marker pellets, indicating that it had eaten a Foxoff® bait. *Dasyurus geoffroii* moved very quickly in the vicinity of a camera trap and it was very difficult to positively record that a *D. geoffroii* had taken the bait, if it had done so. This rapid movement also made it difficult to identify some *D. geoffroii* individuals on the basis of the location of spots on the body.

Occasionally, a *C. coronoides* or a *S. versicolor* was recorded on the ground, near where the bait was buried, but there were no images of a bait being taken by one of these birds or these birds digging in the vicinity of the baits.

Discussion

The number of camera-trap images of *V. vulpes* decreased over the three survey periods (Fig. 6); however, although 68 baits were taken from monitoring sites and presumably a similar number were taken from non-monitored sites in Survey periods 1 and 2, there was no significant reduction in fox abundance between Survey periods 1 and 2. Many Foxoff® baits were ignored by *V. vulpes*, and many baits were taken, but the species that removed most of these baits went unrecorded by camera traps, which concurs with the findings of Moseby and Read (2014) who reported that camera traps recorded only 13 of 37 instances of Eradicat baits being taken. Despite the number of *F. catus* trapped and shot (i.e. 8 during the monitoring period and 14 pre-monitoring), there was no significant decline in the number of *F. catus* recorded over the three survey periods (Fig. 5).

Disparity between evidence of baits being taken and camera images indicating baits being taken

There were far more baits taken than were recorded being taken by camera traps (33 vs 1 in Period 1; 35 vs 0 in Period 2; 24 vs 2 in Period 3; i.e. 3.3% recorded being taken). It is known that camera traps often fail to detect all animals that come into their detection range (Dixon *et al.* 2009; Hughson *et al.* 2010; Robley *et al.* 2010; Moseby and Read 2014; Ballard *et al.* 2015; Urlus *et al.* 2015; Stokeld *et al.* 2015; Driessen *et al.* 2017; Heiniger and Gillespie 2018). Driessen *et al.* (2017), Hughson *et al.* (2010) and Urlus *et al.* (2015) compared the performance of camera traps from different manufactures and indicated that all of their camera traps failed to detect a substantial proportion of the total known triggers and visits by animals. Heiniger and Gillespie (2018) used three camera-trap models from the same manufacturer (e.g. Reconyx) with similar specifications and recorded differences in performance. Ballard *et al.* (2015) laid 51 1080-poison meat baits on the surface and each was monitored using the same camera traps as what we used. All 51 baits were removed by Day 8, 14 by *V. vulpes*, 19 by corvids and the remaining 18 removal events were unrecorded. They indicated that the Reconyx HC600 camera traps failed to record as many records of fauna as did sand plots, and did not detect bandicoots and possums at all, despite their presence being recorded in the sand plots. Therefore, camera traps from different and the same manufacturer have differing performances, and it would appear that all camera traps fail to detect mammal fauna in the detection zone, and, for some, this can be a high proportion of possible recordings.

Temperatures at night were low; so, we presumed that there would be a detectable difference between the background surface temperature and the surface temperature of *V. vulpes* and *F. catus*, and, therefore, presence of either of these species in the detection zone should have been adequate to trigger the camera traps. Our camera-trapping data did not record multiple bait-taking events and, therefore, we will have underestimated the number of *V. vulpes* individuals that visited our baits and had taken a bait. Although camera traps are now widely used in monitoring the success of feral-animal reduction programs and are used to provide estimates of occupancy and whether management programs are effective (Towerton *et al.* 2011; Bengsen *et al.* 2014; Ballard *et al.* 2015; Stokeld *et al.* 2015; Heiniger and Gillespie 2018), it must be appreciated that not all bait removal events and occasions when *V. vulpes* and probably *F. catus* move into the detection zone are being recorded.

We noticed that some *V. vulpes* and *F. catus* individuals stared at the camera, indicating that they had detected its presence. Some individuals retreated from the camera and a few *V. vulpes* individuals moved away quickly; however, as Meek *et al.* (2016) reported, the response or pattern of behaviour was not consistent and Read *et al.* (2015) reported that *F. catus*, but not *Canis familiaris*, and rarely *V. vulpes*, responded to the camera traps. *Vulpes vulpes* is particularly wary, and the intrusiveness of the camera trap may be causing animals to shy away from the bait; however, we found no difference in bait uptake between the baits monitored with a camera trap and those not monitored.

Attractiveness of Foxoff®

Vulpes vulpes individuals investigated or walked past Foxoff® baits on 57.5% of occasions, which would suggest that the bait was unattractive to many *V. vulpes* individuals or that they had developed a neophobic response to baits or bait stations (Thompson and Fleming 1994; Allsop *et al.* 2017). In contrast, Dexter and Meek (1998) and Robley *et al.* (2011) reported Foxoff® baits being very successful in reducing a local population of *V. vulpes*, both with almost an immediate high-percentage knock-down, indicating that bait attractiveness was not a problem in those studies; so, the unattractiveness of the bait appears to be a local issue.

Thompson and Fleming (1994), Hunt *et al.* (2007) and Saunders and McLeod (2007) all reported a form of bait avoidance, unpalatableness or bait aversion that could be a problem when baiting to reduce *V. vulpes* numbers. Bait aversion is likely to have developed if *V. vulpes* individuals had ingested a sublethal dose of 1080, regurgitated their intestinal contents and rapidly learnt not to take a bait. Figure 3 appears to show a *V. vulpes* individual regurgitating a bait, and Fig. 4 is less convincing, but the body posture would suggest that the *V. vulpes* individual may also have regurgitated a bait. We could find no other reports of baits being regurgitated by *V. vulpes*. The attractiveness of Foxoff® baits at our study site appears much less palatable than for other investigations (Dexter and Meek 1998; Robley *et al.* 2010). If it is the taste that is unpalatable, then this may be based on prior experience, and, if this is the case, then the local *V. vulpes* population may have developed an aversion to Foxoff® baits or they are being picked up and cached and not being eaten when they are lethal. This aversion or unattractiveness of the bait may have come about by baits being taken early in the baiting program and cached by *V. vulpes*, and eaten when the 1080 dose was no longer lethal. If this was the case, then the number of baits taken in the second and third survey periods would have been low, which was not the case (i.e. bait-take was 33, 35, 24 respectively, for the three successive periods), although there was a decrease in the third survey period. Another possible explanation is that surface baits laid in the surrounding area by others before this investigation had resulted in sublethal doses being ingested and this had contributed to bait aversion in the local *V. vulpes* population (Allsop *et al.* 2017; Kreplins *et al.* 2018) and perhaps vixens had taught their offspring not to take baits (Slabbert and Rasa 1997; Hepper and Wells 2006).

Declining number of Vulpes vulpes

Our data indicated an appreciable decline in the number of *V. vulpes* individuals over the three survey periods (i.e. ~68%); however, this decline, and rate of decline was lower than that reported by Robley *et al.* (2011) and Dexter and Meek (1998), and, more generally, by Saunders and McLeod (2007) in their review of *V. vulpes* baiting programs in Australia where they reported *V. vulpes* population reductions of 70–97% as a result of baiting programs. In addition to the 98 baits that were monitored, there were 101 baits deployed for the same three periods that were not monitored by a camera trap, and there was no difference in bait-take with or without a camera trap being present, so a similar number of baits was removed from these unmonitored bait stations. If the baits recorded as taken were eaten by *V. vulpes*, then there should have been an appreciable reduction in the number of *V. vulpes* individuals and this should have been detected in the difference in fox abundance between Survey periods 1 and 2; however, that was not the case. Although there was a significant reduction in the number of images of *V. vulpes* over the three baiting periods, *V. vulpes* was still present during the third baiting period. Alternative explanations are that baits were taken by non-target species (Moseby *et al.* 2011; Dundas *et al.* 2014), *V. vulpes* individuals in the study area took the baits and died and were almost immediately replaced by *V. vulpes* individuals from adjacent areas, or foxes cached a large number baits that did not, subsequently, deliver a lethal dose (Saunders *et al.* 1999; Thomson and Kok 2002; Gentle 2005). For example, Dundas *et al.* (2014) indicated that of 142 Probait® (salami-styled kangaroo-meat baits injected with 3.0 mg of 1080 poison) baits laid on the ground in the jarrah forest south-east of Perth and that were monitored by camera traps, 100 were taken, and only one was taken by a *V. vulpes* and the remaining baits were taken by non-target species. We recorded *C. coronoides* and *S. versicolor* on the ground near where baits were buried; although it is unlikely that they had dug up a bait, they may have taken baits that were dug up by other species. The only evidence we have of bait-take by non-target species is the red marker beads in scats in the bottom of cage traps that caught two different *D. geoffroii* individuals.

Rapid immigration to replace dead *V. vulpes* individuals could be a contributory explanation, although Thomson *et al.* (2000) reported an appreciable delay in immigration after a significant knock-down of foxes from a broad-scale aerial-baiting program in the Carnarvon area in August, with the invasion of mostly dispersing juvenile foxes occurring into the area in the subsequent March. Immigration of foxes from neighbouring areas could be influenced by the relative abundance of foxes in adjacent areas, the extent to which their home ranges overlapped and the extent to which foxes moved along the South Coast Highway to find carrion. If all or even a high proportion of the baits taken had a lethal consequence (i.e. ~92 monitored baits), then it is highly unlikely that immigrations from neighbouring areas could replenish the number of foxes in the baited area. Another explanation for the apparent higher number of baits taken than was the reduction in the numbers of *V. vulpes*, is that the baits were taken by *V. vulpes* and cached (Saunders *et al.* 1999; Thomson and Kok 2002). Foxoff® baits progressively lose their toxicity, particularly in damp conditions, so when *V. vulpes* individuals returned to the cached baits, they may no longer have contained a lethal dose of 1080. A third explanation is that some *V. vulpes* individuals were shot during the laying of the first lot of baits and, although these euthanased animals were not part of the feral pest-reduction numbers assessed in the present study, they reduced the number of foxes available for lethal baiting and, therefore, limited the potential recordable impact. This would mean that the decline in the number of *V. vulpes* during the study was less dramatic than would have been the actual case, because six *V. vulpes* individuals had been removed immediately before monitoring commenced, leaving a diminished population of *V. vulpes* in the study area. This may be a contributory explanation; however, given that 92 monitored lethal baits were taken and presumably an equal number of unmonitored baits were taken, and chuditch would have taken only a small number (on the basis of its abundance and spatial distribution), the diminished-population idea might account for a lesser change in fox numbers over the three period, but would not fully explain the results of *V. vulpes* recorded by camera traps during the three survey periods.

Number of F. catus *individuals*

There was no significant decline in the number of *F. catus* individuals recorded, despite the number of *F. catus* euthanased. Feral *F. catus* populations can be difficult to enumerate because these animals are usually solitary, nocturnal, elusive and occur in a low abundance, resulting in low detectability (Edwards *et al.* 2000); however, Robley *et al.* (2008) reported camera traps being better than cage traps, a DNA sampler and leg-hold traps in monitoring *F. catus* numbers. The following are the three possible explanations for this non-significant reduction in the local population of *F. catus* population: (1) the survey design was not significantly powerful enough to detect a change; (2) camera traps are not accurately recording *F. catus* individuals that entered the camera-trap detection zone; or (3) *F. catus* from adjacent areas increased its home range or moved into the vacant niche created when *F. catus* individuals were euthanased; or a combination of all three reasons. Lazenby *et al.* (2014) and Bengsen *et al.* (2011) reported that the relative abundance and activity of *F. catus* increased after a cull, and Lazenby *et al.* (2014) attributed this to an influx of new individuals from adjacent areas after dominant resident *F. catus* individuals were removed. Our data suggest that a higher proportion of the *F. catus* population must be removed (i.e. explanation a) before a reduction in their numbers is detectable using camera traps.

Conclusions

Many baits were taken (i.e. 92 monitored lethal baits and presumably an equal number of unmonitored baits); however, the majority of these events were not recorded by camera traps, indicating that camera traps were insensitive to recording this event. Bait take was also appreciably higher than the reduction in fox abundance, as evidenced by the non-significant reduction in fox abundance between Survey periods 1 and 2. The reduction in cat abundance (i.e. 8) was not detectable by camera traps. This indicates that small changes in *V. vulpes* and *F. catus* abundance are likely to be under-reported by camera traps, as has been indicated by other authors (e.g. Hughson *et al.* 2010; Urlus *et al.* 2015; Driessen *et al.* 2017; Heiniger and Gillespie 2018). This is of concern because camera traps are now widely used to detect changes in animal abundance (Dexter and Meek 1998; Robley *et al.* 2008; Bengsen *et al.* 2011). The knock-down of *V. vulpes* with Foxoff® baits was less and slower than reported for other similar projects (Dexter and Meek 1998; Robley *et al.* 2008), although it was ~68% over the three periods. Most feral-pest technicians deploying baits would bait once; therefore, less than 50% of the foxes are likely to have been killed using this baiting regime, and the numbers would soon return to pre-baiting levels, particularly if fecundity increases with a reduction in the population (Marlow *et al.* 2016). Many more baits were taken than the recorded reduction in fox abundance, suggesting that *V. vulpes* was caching baits or was ingesting sublethal doses of 1080 or that there was substantial immigration from neighbouring areas. Some *V. vulpes* individuals were also not attracted to or found Foxoff® baits unpalatable.

Conflicts of interest

G. Thompson and S. Thompson work for Terrestrial Ecosystems who were engaged by First Quantum Australia Nickel to implement a feral pest-reduction program and to establish the monitoring program.

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