How to snap your cat: optimum lures and their placement for attracting mammalian predators in arid Australia

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Abstract

Context. Automatically activated cameras (camera traps) and automated poison-delivery devices are increasingly being used to monitor and manage predators such as felids and canids. Maximising visitation rates to sentry positions enhances the efficacy of feral-predator management, especially for feral cats, which are typically less attracted to food-based lures than canids.

Aims. The influence of camera-trap placement and lures were investigated to determine optimal monitoring and control strategies for feral cats and other predators in two regions of semi-arid South Australia.

Methods. We compared autumn and winter capture rates, activity patterns and behaviours of cats, foxes and dingoes at different landscape elements and with different lures in three independent 6 km × 3 km grids of 18 camera-trap sites.

Key results. Neither visual, olfactory or audio lures increased recorded visitation rates by any predators, although an audio and a scent-based lure both elicited behavioural responses in predators. Cameras set on roads yielded an eight times greater capture rate for dingoes than did off-road cameras. Roads and resource points also yielded highest captures of cats and foxes. All predators were less nocturnal in winter than in autumn and fox detections at the Immarna site peaked in months when dingo and cat activity were lowest.

Conclusions. Monitoring and management programs for cats and other predators in arid Australia should focus on roads and resource points where predator activity is highest. Olfactory and auditory lures can elicit behavioural responses that render cats more susceptible to passive monitoring and control techniques. Dingo activity appeared to be inversely related to fox but not cat activity during our monitoring period.

Implications. Optimised management of feral cats in the Australian arid zone would benefit from site- and season-specific lure trials.

Additional keywords: auditory, camera traps, *Canis lupus dingo*, *Felis catus*, grooming traps, olfactory, *Vulpes vulpes*.

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Introduction

Optimal monitoring and management of predators is important to protect both livestock (Mitchell and Kelly 1992; Southwell *et al.* 2013; Fleming *et al.* 2014 and wildlife (Kinnear *et al.* 1998; Judge *et al.* 2012). Poison baiting is the most widespread tool for broadscale predator control in Australasia and other regions (e.g. Thomson and Algar 2000; Dexter and Murray 2009; Moseby and Hill 2011). However, more targeted or efficient predator-control techniques are required, particularly for feral cats (*Felis catus*), when bait uptake is low (e.g. Risbey *et al.* 1997; Algar *et al.* 2007; Moseby and Hill 2011; Moseby *et al.* 2011) or when risks to non-target species from indiscriminate poison baiting are excessive. Live trapping of predators and automated poisoning stations provide important tools for localised predator control (Petel

et al. 2004; Robinson and Copton 2014). Recent developments have also suggested that feral cats may be controlled using automated grooming traps that apply a lethal dose of toxin to their fur, which is ingested involuntarily while grooming (Read 2010; Read *et al.* 2014). Each of these targeted control methods are enhanced through increased predator visitation rates at bait or trap sites.

A wide range of dietary, olfactory, auditory or visual stimuli are used to lure predators and increase the efficacy of traps, bait stations and poison-delivery mechanisms (Turkowski *et al.* 1983; Moseby *et al.* 2004). Lures for baits, M-44 poison ejectors or cage traps need to elicit, or not compromise, a feeding or biting response (Mitchell and Kelly 1992, Clapperton *et al.* 1994). However, a wider range of lures can be used to increase

predator visitation rates to monitoring or management stations such as sandpads (Bullard *et al*. 1983; Edwards *et al*. 1997), camera traps (Bengsen *et al*. 2011) or grooming traps.

In addition to selection of optimal lures, other factors can affect the precision of predator-monitoring programs. Predator activity is typically focussed at resource points or pathways through the environment (Mahon *et al*. 1998; Edwards *et al*. 2001; Moseby *et al*. 2009); hence, the location of sentries or control devices is important for representative monitoring or optimised management of predators. Furthermore, the height and positioning of cameras can also affect the sensitivity of predator-monitoring programs (Swann *et al*. 2004; Meek *et al*. 2012).

In the present study, we investigated the efficacy of different lures and camera-trap placement for detecting and attracting feral cats, foxes (*Vulpes vulpes*) and dingoes (*Canis lupus dingo*) at two semi-arid Australian sites using a grid and Latin square study design. This study differs from most previous lure-efficacy trials by targeting lures for cats, which are typically less inclined to scavenge or be attracted to food-based lures than are canids, and also by using visitation rates rather than consumption of baits as the key response variable. We also investigated predator activity patterns, albeit over a short time scale, to determine whether interactions among cats, foxes and dingoes may influence

visitation rates in different seasons. Results are used to suggest optimum lures and placements of cameras or control stations for detecting or intercepting predators.

Materials and methods

Study localities

This study was conducted at two mallee sand-dune localities in the semi-arid zone of South Australia (Fig. 1), both inhabited by the nationally threatened sandhill dunnart (*Sminthopsis psammophila*) and malleefowl (*Leipoa ocellata*), which were the impetus for predator monitoring and management programs. Secret Rocks (SR) is a privately owned nature reserve in north-eastern Eyre Peninsula on the southern margin of the pastoral zone. Positioned south of the Dog Fence where dingoes are excluded, foxes and cats were the dominant terrestrial predators and western grey kangaroos (*Macropus fuliginosus*) were in high abundance. Wheat paddocks bordered the study region to the west and south; hence, house mice (*Mus domesticus*) were periodically abundant in favourable seasons. By contrast, the second study locality at Immarna lies north of the Dog fence, near the north-western margin of the Yellabinna Regional Reserve in the far west of South Australia. Both dingoes and
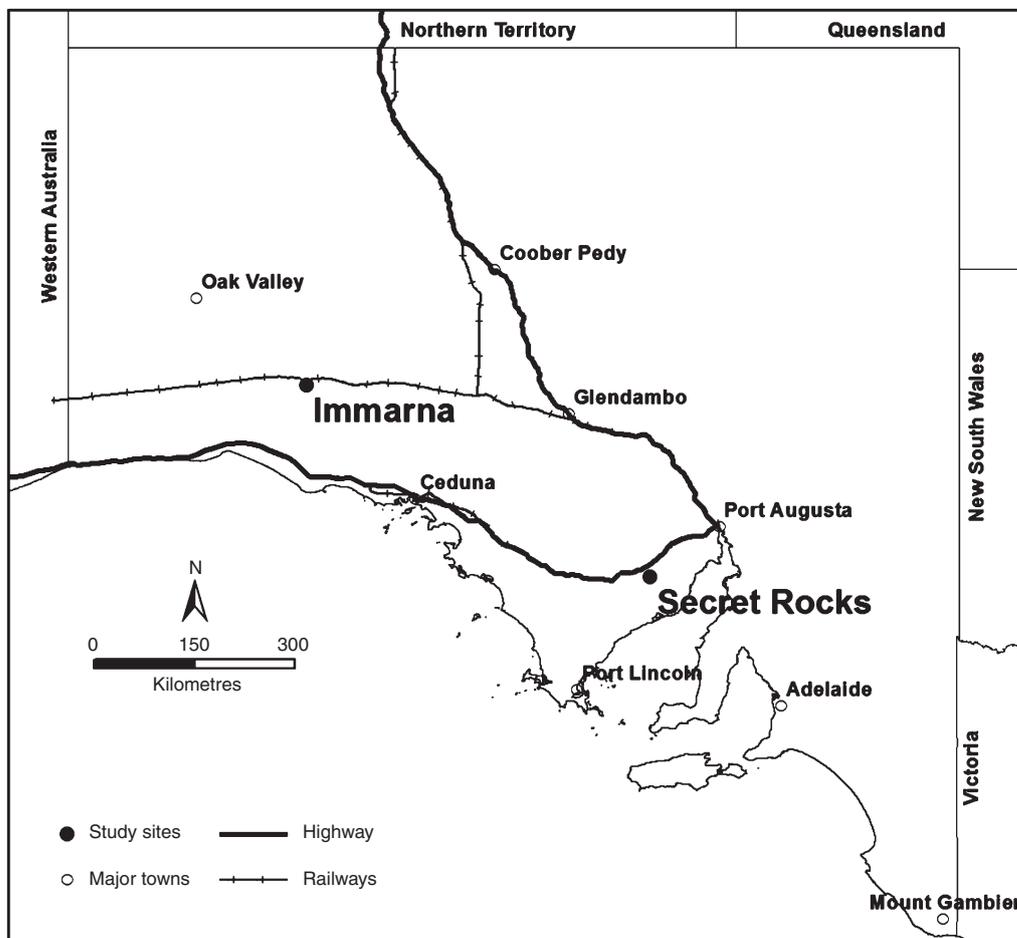

Fig. 1. Location of Secret Rocks and Immarna study sites in South Australia.

camels (*Camelus dromedarius*) were present at Immarna and western grey kangaroos and emus (*Dromaius novaehollandiae*) were considerably less abundant than at Secret Rocks.

Study design

Pilot studies at both Secret Rocks (Moseby and Read 2014) and Immarna (J. Read, unpubl. data) indicated greater detectability of cats with camera traps compared with using track plots, which have been used in many other studies of fox, cat and dingo populations in arid Australia (Allen *et al*. 1996, 2013; Read and Eldridge 2010). Cameras also facilitated recording of individuals, temporal dynamics, changes in population abundance and behaviour of target species (e.g. Bengsen *et al*. 2011; Meek *et al*. 2012) that were not possible from track plots.

Grids of 18 cameras (6 × 3) were established in a range of landscape elements. Two camera grids (Grid A and Grid B) were established at Secret Rocks, ~5 km apart, but only a single camera grid was established at Immarna. Lures and unlured controls were rotated through these camera-trap sites on a 14–28-day rotation, using a Latin square design to ensure that all sites received each lure type over the duration of the study. The detection rates of mammalian predators were compared between lure types and landscape elements, to determine whether detectability of predators could be optimised.

Camera-trap placement

Reported mean home-range size of cats in arid Australia ranges from 7 to 32 km^2, although home ranges of male cats in arid Australia can exceed 100 km^2 and some cats have been recorded moving up to 34 km at times of nutritional stress (Edwards *et al*. 2001; Moseby *et al*. 2009). Few studies have measured cat home range in semi-arid mallee, with one study finding considerably smaller home-range sizes of between 1.7 and 6.2 km^2 for female and male cats, respectively (Jones and Coman 1982). Given that the present study was primarily established to investigate optimised detection of feral cats, camera-trap grids were designed so that individual cats could potentially be photographed by at least five cameras, on the basis of an inferred average home-range size of 4 km^2 so that we could assess home-range size and overlap. We recognise that the scale of our grids is smaller than optimal for foxes and dingoes that typically range more widely.

At each of the three grids, 18 Reconyx HC600 cameras with IR flash were installed in three rows of six camera-trap sites, each row and trap site being ~1 km apart. One row of camera traps was located on a single lane track in each grid, where predator activity is typically concentrated (Allen *et al*. 1996; Mahon *et al*. 1998;

Read and Eldridge 2010). The other cameras were placed in two rows 1–1.2 km either side of the track, near localities determined *a priori* by using aerial photography. Sites were selected in the field within 200 m of the designated grid location, at sites considered to maximise the chance of detecting predators. No attempt was made to standardise representation of landscape elements, rather, given the low predator densities expected, we aimed to maximise cat detection at each camera site. Resource points, such as rabbit (*Oryctolagus cuniculus*) warrens, malleefowl mounds or waterpoints, were selected if present, followed by dune crests, where cat and fox activity is typically highest (Mahon *et al*. 1998; Moseby *et al*. 2009; Read and Eldridge 2010) or, as a last resort, kangaroo pads that provide a path through the vegetation. Each camera trap was assigned to one of the following landscape elements: road, fence and road, inactive malleefowl mound, rabbit warren, waterhole, dune crest or kangaroo pad (Table 1). Camera traps were typically placed at ~22° to the direction of roads or kangaroo pads to maximise the likelihood that animals moving along these thoroughfares would be detected by the camera traps (Meek *et al*. 2012; Ballard *et al*. 2014). Camera traps were placed ~20–30 cm above the ground level, which approximates the shoulder height of cats, which is recommended for camera traps (Swann *et al*. 2004), and aimed at a focal point ~3 m in front. Vegetation within the focal range was removed to reduce false triggering. Cameras were set with high sensitivity to take three 1080-pixel images at 1-s interval and with no quiet period after activation.

To avoid the confounding effect of multiple images of single animals moving into and out of camera range, discrete detection events for all animals were separated by 2 h, except where a distinctly different animal was identified. The time of each detection event was recorded to compare activity patterns between species and localities. A photo library was compiled for all cats and dingoes detected from each grid, in an attempt to track the geographic range over which individuals were detected. Individual foxes were difficult to distinguish.

Lures

A range of olfactory, auditory and visual lures were trialled and compared with unlured stations that were rotated through the camera sites. Food-based lures that have proved useful in other feral-cat studies (e.g. Bengsen *et al*. 2011) were not used because cats are unlikely to investigate or consume food lures (baits) when they are not food stressed (Risbey *et al*. 1997; Algar *et al*. 2007; Moseby *et al*. 2011; Christensen and McDonald 2013). Furthermore, food-based lures were believed to become significantly less attractive through time in the semi-arid

Table 1.   Number of camera sites (*n*) in each landscape element at the three study grids and the total number of cats, foxes and dingoes recorded in each of these landscapes in each grid

For example, nine cameras were installed along roads on Secret Rocks Grid A and these cameras recorded eight cats, 36 foxes and no dingoes (note that dingoes were not present at Secret Rocks)

Grid	Road	Fenced road	MF mound	Rabbit warren	Dune crest	Kangaroo pad	Waterhole
Secret Rocks A	(9) 8,36,0	(2) 1,8,0	(2) 3,9,0	(0)	(2) 0,5,0	(2) 0,5,0	(1) 14,43,0
Secret Rocks B	(8) 38,142,0	(1) 4,37,0	(3) 1,23,0	(0)	(1) 5,8,0	(5) 8,42,0	(0)
Immarna	(4) 7,26,49	(0)	(1) 1, 14, 0	(4) 20,17,13	(8) 15,29,4	(0)	(0)

environment, or even consumed by mammalian, bird, reptile or invertebrate scavengers, during the 2–4-week periods between revisiting camera traps.

Two olfactory lures were trialled. 'Catastrophe A' lure manufactured by Outfoxed Pest Control (Ivanhoe, Victoria, Australia) consisted of a blend of phenyl acetate in oil. The second olfactory lure, valerian oil, has been used as a lure for fox and cat trapping (Schlexer 2008; Hanke and Dickman 2013; D. Peacock and P. Meek, pers. comm. 2013). Both of these lures were volatile and, hence, were placed in a glass jar (100 mL) and mixed with moistened 'Rainsaver' water-storing crystals. Approximately 30 drops of valerian oil or one teaspoon of Catastrophe A lure were blended with enough water to saturate 10 g of crystals, which was sufficient to retain detectable odour when the lures were replaced within 14–28 days. The lure jars were mostly buried with their apertures shaded to reduce evaporation. Containment of the olfactory lure medium within glass jars also minimised odour remaining at a camera site after the lures were moved.

The battery operated feline-attracting phonic (FAP) manufactured by Westcare Electronics, (Bassendean, WA, Australia), which emits a near continuous automated sound of a meowing cat, was the only auditory lure trialled. FAPs have proven useful in attracting cats or foxes in other studies (Moseby *et al.* 2004) and were placed low in bushes to assist sound broadcast without risk of the units being observed by the predators or flooded by surface-water flows.

Visual lures trialled included three different flashing LED lights and 70-mm-diameter flattened aluminium pie-dish ('shiny' lure) attached to a high branch by fishing line and swivel. The 'flashing light' was a 4LED Asklen TL-32C LED bicycle rear tail-light set on 'Flashing 2' setting that randomly but continuously flashed one of four red LEDs, providing a minimum of 360 h of battery power. 'White' light was a single white-flashing LED and 'Red' was a single red-flashing LED light. All lures were loosely tied by cable-ties or fishing line to high branches and were visible from some directions for over 100 m, especially when blowing in the breeze.

Lures trialled at Secret Rocks Grid A were white light, red light, valerian and FAP, whereas Catastrophe A, valerian and shiny were trialled at Secret Rocks Grid B. Lures were trialled continuously from 5 February until 28 August 2013. Each lure was rotated through all 18 camera-trap sites in each grid in a Latin square arrangement, so that at any one time, four replicates of each lure were trialled along with at least four controls, and so that lure type was not confounded with landscape element. Rotation time varied between 2 and 4 weeks and lures were refreshed with new odour or batteries before redeployment. All lures were considered to be functioning at the completion of their 2–4-week session. On the rare occasion that battery lights had failed, or when camera footage showed that lures had been removed, the site was categorised as a control treatment until lures were replaced.

At Immarna, four lures (valerian oil, Catastrophe A, FAP and flashing light) were rotated around all 18 camera sites in a Latin square arrangement. All lures were refreshed and rotated after periods of 3–4 weeks. Over the study period from 6 April to 18 September 2013, each lure was placed at each camera site, with a minimum of 360 total trap-nights for each lure. Seasonal influences on activity patterns were explored by comparing the

time of records between autumn (February to May) and winter (June to August).

The efficacy of different lures was assessed by two criteria. First, the number of detections of each predator at each lure was compared to detection rate at control cameras without lures. Second, any behavioural interaction that predators had with the lures, such as sniffing, pouncing or marking on the lure, were recorded and compared.

One potentially confounding factor recognised was the marking of camera sites by urine spraying or defecating that may have affected subsequent detection rate after lures were changed. Determining whether predators were attracted by, or responding to, lures or previous scent marking, was also challenging. When animals clearly re-marked adjacent to a scat or spray site recorded earlier and not immediately at a lure, this activity was assigned to 'marking' rather than the lure treatment. We minimised the confounding nature of predator visitations initiated by scent markings or previous experience, before the initiation of the experiment by rotating all lures and unlured controls through each camera site.

Analyses

Observation rates

For each of the three subject species, we used a suite of nested mixed-effects models to estimate the influence of site, lure type and landscape element on the expected number of animal observations. The response variable for each species was the number of independent animal observations (separation between observations > 2 h) for each combination of camera-trap site and lure type, standardised by the number of days that each combination was active. These standardised observation rates were log-transformed for normality. Models ranged from a global model with additive fixed effects for site, lure and landscape element to a null model. Camera-trap site (nested within study site) was specified as a random effect in all models. Identity variance structures allowed separate variances for each level of landscape element in the cat and fox models, and each lure type for the dingo models. Models were fitted by maximising the log-likelihood, rather than restricted log-likelihood, for consistency with information-theoretic model selection, using the lme4 package (Bates *et al.* 2012) in the R statistical environment (R Development Core Team 2012).

The relative support for each model in each species set was assessed using Akaike weights, based on second-order Akaike information criterion (AICc). Parameter estimates were averaged across all models, with Akaike weights summing to ≥0.95 in each species set (Burnham and Anderson 2000).

Interactions with lures

We used logistic regression to estimate the probabilities of cats, foxes and dingoes interacting differently with each lure. Interactions were classified as 'none' if the photographed animal neither looked at or approached the lure, 'sniff lure' if the animal approached and apparently showed interest in the lure, and 'mouthed lure' if the animal obviously interacted with the lure by, for example, biting or jumping at it. For each species, the type of response (none, sniff lure or mouthed lure) was specified as the dependent variable and the lure type as the independent variable.

Results are presented as probability ratios, i.e. the ratio of the probability that an animal does not interact with a lure to the probability that it mouths or sniffs the lure. We used z-tests to test whether differences between each lure type and the control lure were greater than zero, at the $\alpha = 0.05$ level.

For cats, we considered only binary responses of no apparent response and a physical interaction with the lure (i.e. sniffing or mouthing the lure). The specific type of response to each lure could not be separated further because of high zero counts. Similarly, all three types of light treatment (red, white and flashing) were collapsed into a single level for foxes and cats because of small sample sizes. Red- or white-light treatments were not used at the Immarna site, and were, therefore, not available to dingoes.

Several studies have indicated that some feral cats and other animals appear to respond to the presence, triggering or IR flash of camera traps (e.g. Bengsen *et al.* 2011; Meek *et al.* 2012). We used multinomial logistic regression to estimate the differences in the frequency of responses to cameras (none, flee, stare at camera, approach camera) among species.

Results

At Secret Rocks, a total of 82 feral cat detections was recorded from 23 of the 36 sites, at an average capture rate of 0.022 cats per trap-night over the 4450 trap-nights from February to August 2013 (Table 1). In total, 359 fox detections were made from 35 of the Secret Rocks camera sites at an average capture rate of 0.095 foxes per trap-night (Table 1). In addition, hundreds of emus and western grey kangaroos, 24 malleefowls, 264 goats (*Capra hircus*), 10 rabbits, six euros (*Macropus robustus*), two red kangaroos (*Macropus rufus*) and one fallow deer (*Dama dama*), plus a wide range of reptiles and other birds were recorded on the camera traps. Feral cat pelage typically comprised weakly striped or spotted tabbies, lacking clearly distinguishing markings, which largely prohibited capture–mark–recapture analysis (cf. Bengsen *et al.* 2011). However, one distinctively marked cat with a white neck was recorded on eight occasions from four camera traps, a cat with a white foot was recorded once from two cameras and another marbled tabby was recorded on one occasion. Three ginger cats were photographed; however, we could not determine whether these were the same individual.

One of the original 18 cameras at Immarna was excluded from analyses because of malfunction and rapid battery depletion through vegetation triggering during several sessions. In total, 43 cat records were made from 14 of the remaining 17 cameras (0.015 cats per trap-night), 86 fox records were made from all 17 cameras (0.03 foxes per trap-night) and 54 dingo records were made from nine cameras (0.19 dogs per trap-night) in a total of 2788 camera trap-nights from April to September 2013 (Table 1). A minimum of six different cats and three different dingoes were recognised within the 18-km^2 Immarna camera-trap grid. A distinctively marked marbled tabby was detected at four camera-trap sites from three adjacent rows, but all other distinctive cats were recorded only at individual sites. One dingo was detected 36 times from eight sites, and two other dingoes were each detected from four sites on a total of four or five occasions. The most abundant large herbivores detected at Immarna were camels (92 records) and rabbits (70 records)

and only 14 western grey kangaroo images and no emus were recorded.

Observation rates (landscape elements)

Capture rates of cats and foxes were both 12 times greater at the one camera site located at a waterhole than at any other site, and feral cats were photographed stalking or pouncing on common bronzewing pigeons (*Phaps chalcoptera*) around dusk on six occasions at this waterhole. However, this site was excluded from further analysis because of lack of spatial replication and the consequent confounding of landscape element with camera site.

The null model for cats was best supported by the data, although model-averaged parameter estimates showed a tendency for greater observation rates at sites on rabbit warrens and roads (Fig. 2). Contrasts in the landscape element model also indicated that cats were more frequently recorded at rabbit warrens than at dune sites ($t_{46} = -2.07$, $P = 0.04$), malleefowl mounds ($t_{46} = -2.27$, $P = 0.03$) or animal pads ($t_{46} = -2.22$, $P = 0.03$), and more frequently recorded on roads than at malleefowl mounds ($t_{46} = -2.12$, $P = 0.04$). Dingoes were 8.2 times more likely to be observed at camera stations on roads at the Immarna grid than off roads (Fig. 2). Support for the landscape element of the dingo model, showing a selection for roads over other landscape elements, was strengthened by collapsing the five off-road elements into one, for parsimony (Table 2). Fox captures were not strongly influenced by landscape element, with the model including only site as a fixed effect being the best supported model in the set (Table 2).

Observation rates (lures)

There was no support for any model that included an effect for lure type for any species (Table 2). Although not significantly different from controls or other lures, capture rates of feral cats at Secret Rocks were higher using the 'shiny' rattling aluminium lure (Fig. 3) and, at Immarna, they were higher using Catastrophe A and FAP lures (Fig. 4). Although not visited significantly more often than controls, the Catastrophe A lure was the most successful for foxes at Secret Rocks (Fig. 3), whereas detection rates of foxes at Immarna were higher at the valerian-oil and flashing-light lures (Fig. 4). The incidence of marking, as an alternative 'lure', was too low for statistical analyses and, hence, has been excluded from figures; no marking was evident from cats or dingoes, and 12 marking events were recorded across five lure types for foxes.

Interactions with lures

Interaction with a lure typically involved the predator directly and deliberately sniffing, moving or stalking the lure. Feral cats interacted with the FAP lure on four occasions at Immarna, with one of these events involving a cat repeatedly jumping at and eventually knocking down a FAP lure placed in a tree fork above the camera. Other cats were photographed in a crouched stalking pose adjacent to FAP devices hidden under *Triodia* clumps at Immarna, yet surprisingly, no cats were obviously attracted to FAP lures at Secret Rocks. Of the 50 observations of cats at control sites, only one cat was recorded sniffing or mouthing, i.e. the probability of a cat showing no behavioural response (0.98) was 49 times greater than the probability of it
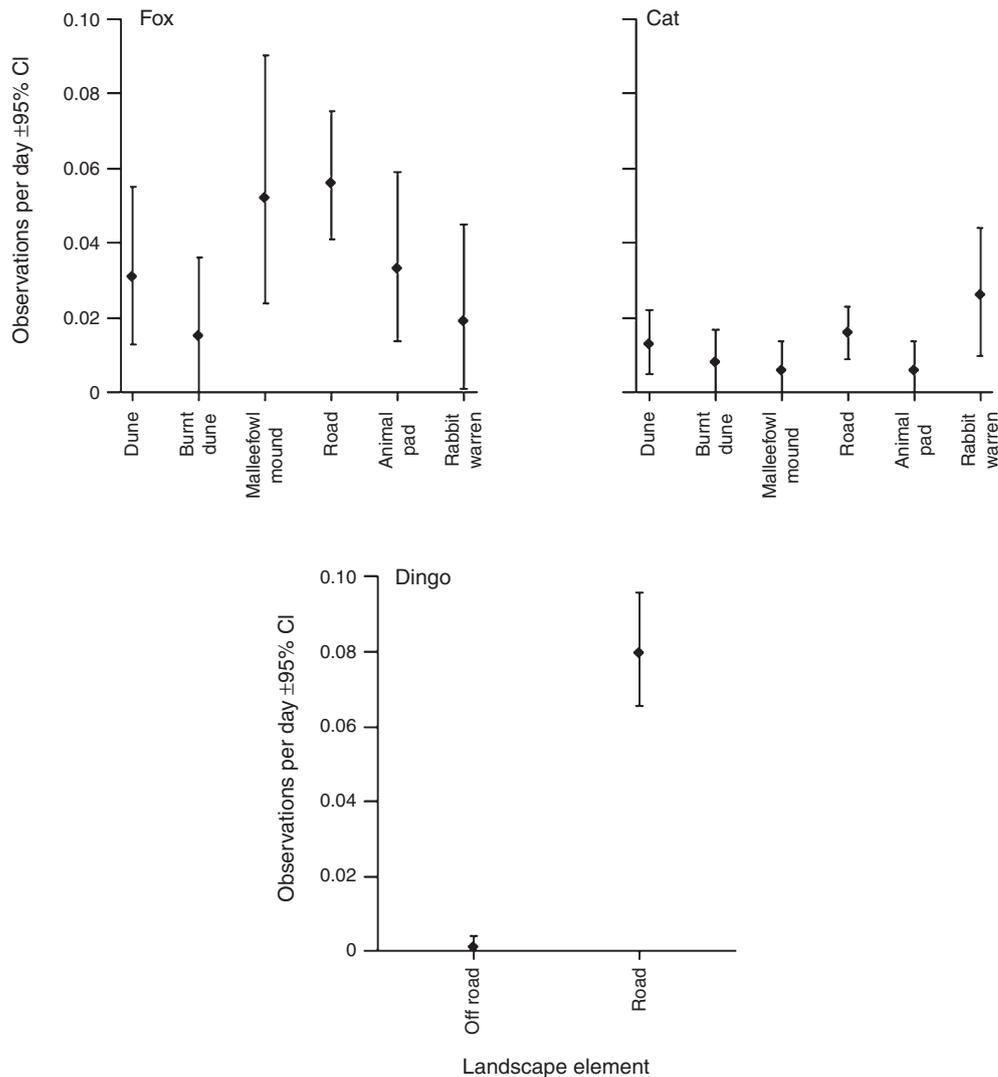
Fig. 2. Expected number of cat, dingo and fox observations per day at camera-trap stations in different types of landscape element (the single waterhole site with very high detections has been removed).

being recorded sniffing or mouthing (0.02). Only the FAP and Catastrophe A lures provided statistically detectable reductions in this ratio, which represent improvements in the response rate. Cats observed at FAP lures were equally likely (0.5) to interact (mouth or sniff) with the lure as to not interact with it, representing a 98% decrease in the likelihood of a cat showing no behavioural response to the lure, relative to control sites ($z = 3.16$, $n = 8$, $P = 0.002$). The probability of a cat observed at a Catastrophe A lure showing no behavioural response (0.84) was only 5.25 times the probability of it mouthing or sniffing the lure (0.16); so, although cats were still more likely to show no response to a Catastrophe A lure than to mouth or sniff it, the relative likelihood of a cat showing no behavioural response at a Catastrophe A lure was 89% lower than at control sites ($z = 1.96$, $n = 25$, $P = 0.05$, Fig. 5).

Of the 176 observations of foxes at control sites, 6% were recorded sniffing, whereas 94% showed no apparent behavioural response, i.e. the probability of a fox showing no behavioural

response was 15.7 times greater than the probability of it being recorded sniffing. No foxes were recorded mouthing. The two olfactory lures both reduced the relative risk of a fox showing no response to a lure compared to sniffing the lure, but not the relative risk of a fox showing no response to a lure compared to mouthing it. The probability of a fox showing no behavioural response to a Catastrophe A lure (0.65) was only 2.4 times the probability of it sniffing the lure (0.27), representing an 85% decrease in the likelihood of a fox showing no response relative to control sites ($z = 4.51$, $n = 61$, $P < 0.001$). The probability of a fox showing no behavioural response at a valerian lure (0.70) was only 3.18 times the probability of it sniffing the lure (0.22), representing a 78% decrease in the likelihood of the lure being ignored, relative to controls ($z = 3.79$, $n = 62$, $P < 0.001$, Fig. 5).

Only one of the 16 dingoes observed at control sites was observed sniffing, and no dingoes were observed mouthing at any site. The probability of a dingo showing no behavioural response at control sites (0.94) was, therefore, 15.7 times greater than the

Table 2. Selection criteria for a set of models describing visitation to camera-trap stations in relation to site (S), landscape element (LE) and lure type (L) available at the stations

An additional model, comprising a single variable in which all levels of the landscape-element variable have been collapsed into a binary on- or off-road variable, is included for dingoes. K, number of parameters; AICc, second-order Akaike information criterion; Δ_i, difference in AIC between Model i and the most supported model; ω, Akaike weight: relative likelihood of the model, given the data

| Fixed effect	K	AICc	Log-likelihood	Δ_i	ω_i	Cumulative ω
Foxes						
S	10	599.97	−289.59	0.00	0.81	0.81
LE	13	604.13	−288.40	4.16	0.10	0.91
Null	8	604.41	−293.95	4.45	0.09	1.00
L	15	614.24	−291.24	14.27	0.00	1.00
S + LE + L	22	617.12	−284.66	17.15	0.00	1.00
Cats						
Null	8	287.11	−135.30	0.00	0.60	0.60
LE	13	288.36	−130.52	1.24	0.32	0.92
S	10	291.30	−135.26	4.19	0.07	1.00
L	15	299.11	−133.68	12.00	0.00	1.00
S + LE + L	20	300.75	−128.81	13.64	0.00	1.00
Dingoes						
Road	9	94.84	−37.22	0.00	0.97	0.97
LE	12	102.04	−36.85	7.20	0.03	1.00
LE + L	15	109.17	−36.10	14.32	0.00	1.00
Null	8	126.30	−54.20	31.45	0.00	1.00
L	12	135.36	−53.51	40.52	0.00	1.00
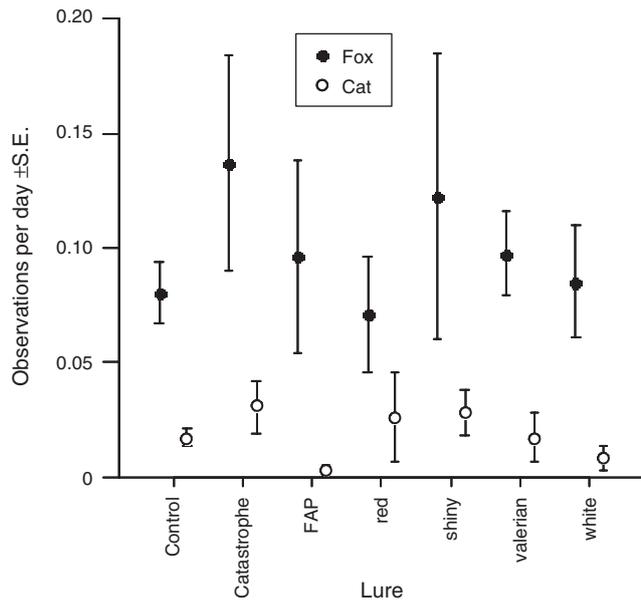
Fig. 3. Mean (+1 s.e.) detection rate of cats and foxes for different lures from both Secret Rocks grids (4180 trap-nights; note that waterhole site was excluded).

probability of it sniffing at the site (0.06). The Catastrophe-A and FAP lures both reduced this ratio significantly. The probability of a dingo being recorded sniffing at a Catastrophe-A lure (0.83) was 4.9 times greater than the probability of it showing no behavioural response, representing a 99% decrease in the
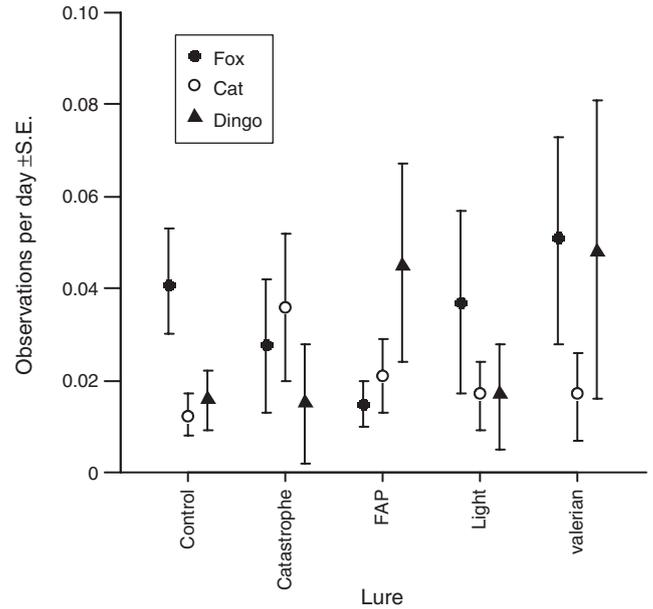

Fig. 4. Mean (+1 s.e.) capture rate of cats, foxes and dingoes at different lures at Immarna.

likelihood of the lure being ignored relative to control sites ($z = 2.87$, $n = 6$, $P = 0.004$). The probability of a dingo being recorded sniffing at a FAP lure (0.56) was 1.27 times greater than the probability of it showing no behavioural response (0.44), representing a 95% decrease in the likelihood of the lure being ignored ($z = 2.38$, $n = 9$, $P = 0.02$, Fig. 5).

Wedge-tailed eagle (*Aquila audax*), spotted nightjar (*Eurostopodus argus*), barn owl (*Tyto alba*), crested bellbird (*Oreoica gutturalis*) and grey shrike thrush (*Colluricincla harmonica*) all approached FAP lures, but no other non-targets interacted with any other lures.

A total of 16% of cats at Secret Rocks and 19% at Immarna either looked at or approached the camera but none appeared to flee from cameras ($n = 122$ observations). The probability of responding to the camera by staring at it rather than showing no apparent response was 2.52 times greater for cats than foxes ($z = 2.30$, $n = 557$, $P = 0.02$), and the probability of approaching the camera over showing no response was 4.46 times greater for cats than foxes ($z = 2.83$, $n = 557$, $P = 0.005$, Fig. 6). Foxes exhibited all four behavioural responses to cameras, namely, none, fleeing, staring and approaching ($n = 435$ observations), but 92.4% showed no apparent response. No dingoes showed any behavioural response to cameras ($n = 49$ observations). Wedge-tailed eagles hopped around for extended periods and stared at cameras on three occasions.

Predator activity patterns

Both cats and foxes were mostly crepuscular and nocturnal, especially in the warmer autumn months with peak detections between 2000 hours and 0400 hours, although diurnal activity increased in winter (Figs 7, 8). Dingoes were active by day and night at Immarna, with detections peaking within a few hours after both sunrise and sunset (Fig. 7). Detection rates of foxes at Immarna generally increased throughout the study period at
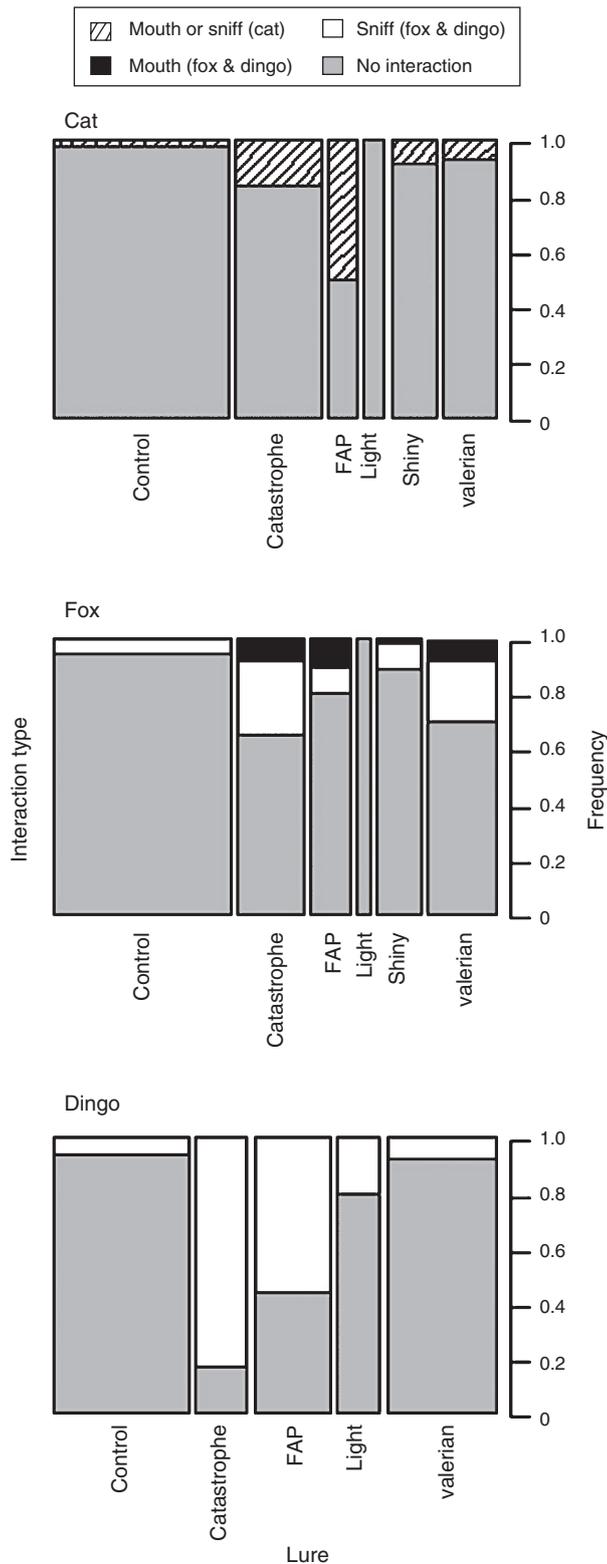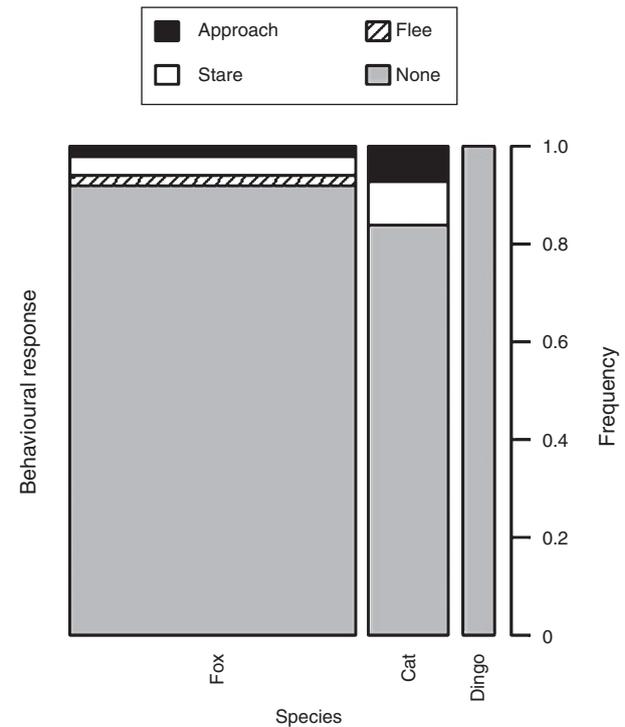
Fig. 6. Frequencies at which foxes, feral cats and dingoes showed four different behavioural responses to remote cameras (grey = no response, hatched = flee, white = stare, black = approach). Bar widths indicate the relative sample size for each species.

the same time as detection rates of both dingoes and cats declined (Fig. 9).

Discussion

Landscape element

The physical location of a camera trap in the landscape influenced detection rates of cats, foxes and dingoes in our study. As expected, dingoes were recorded more than eight times as frequently on road-based camera traps than on those set off road, which supports evidence for their preferential use of roads recorded from many other studies (Allen *et al.* 1996; Mahon *et al.* 1998; Read and Eldridge 2010). Locating camera traps on roads also increased capture rates of cats in our study, like it did for Wang and Fisher (2012), but we were unable to replicate the greater detectability for foxes demonstrated by Towerton *et al.* (2011). Our data supported the positioning of camera traps on roads for standardised monitoring of dingoes, cats and foxes (Meek *et al.* 2012; Ballard *et al.* 2014) and the concentration of predator-control activities adjacent to roads. Cat and fox detections were highest at a waterpoint at one of our study grids where dingoes were not present. Unfortunately, no malleefowl mounds were active at the time of the study but cat-capture rates peaked at active rabbit warrens at Immarna. Where detection of cats or foxes at low densities is important, such as, for example, in predator-eradication or intensive-control scenarios, inclusion of camera traps on resource points such as waterpoints and rabbit warrens is likely to improve detection probabilities.
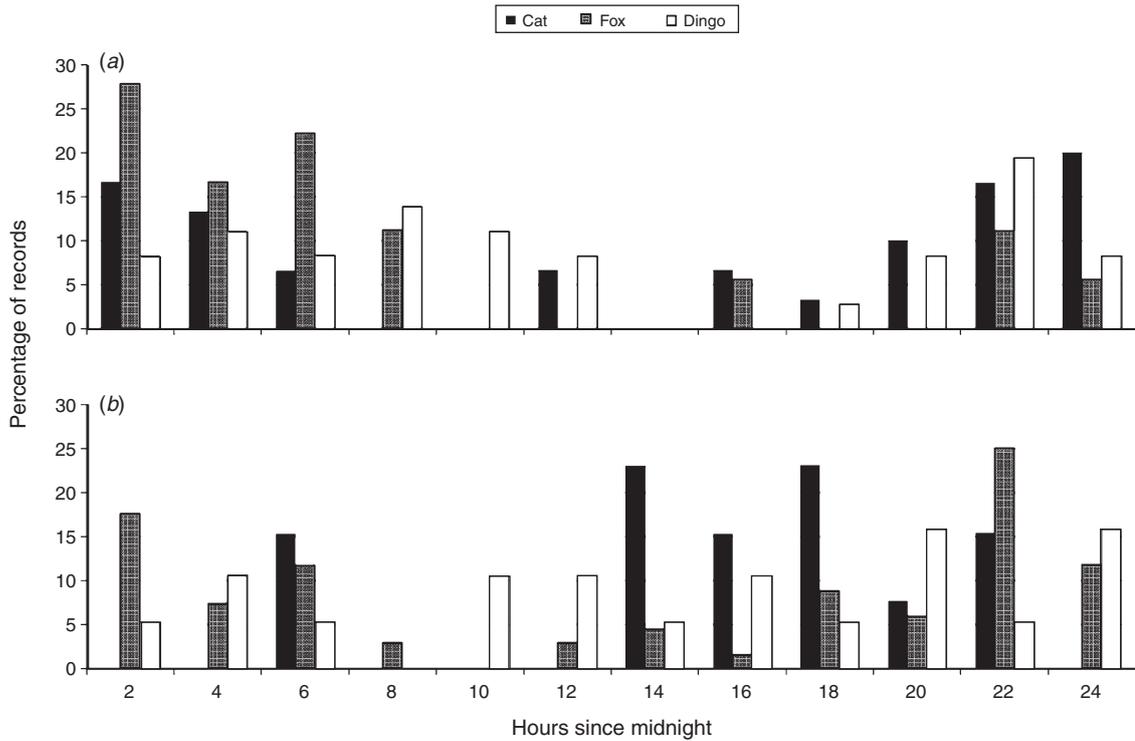
Fig. 5. Frequencies at which feral cats, foxes and dingoes interacted (hatched, black and white bars, respectively) or did not interact (grey bars) with different lure types. Bar widths indicate the relative sample size for each lure type.

Fig. 7. Time of day that cats, foxes and dingoes were detected on camera traps at Immarna in (*a*) autumn and (*b*) winter.
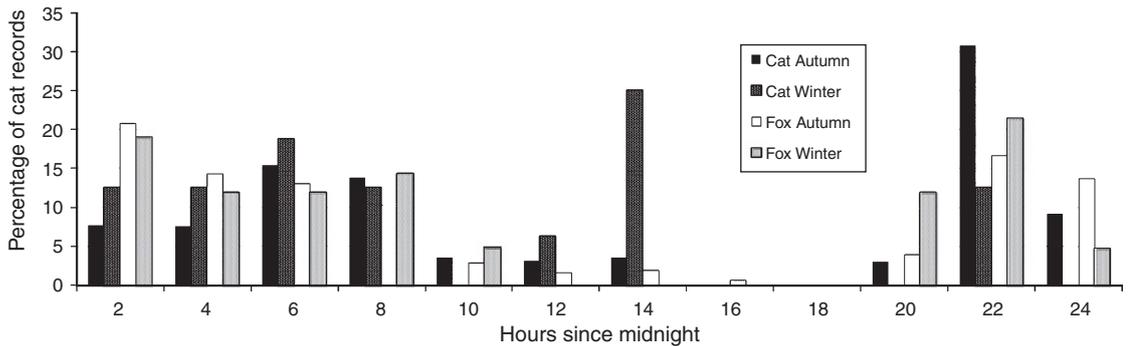

Fig. 8. Time of day that cats and foxes were recorded on camera traps at Secret Rocks in autumn and winter.

Optimal lures

We were unable to show any statistically detectable difference between the efficacy of any lures to attract cats, foxes or dingoes to camera traps because of the low numbers of predators detected. The confounding influences of predators being attracted to scent marking, or even memories of lures, from previous visits could not be discounted. Cats are primarily visually oriented hunters and are often thought to respond to visual lures. However, the failure of flashing aluminium plates or light-based lures to attract cats, foxes or dingoes into the detection zone of camera traps is consistent with previous studies that have reported no noticeable improvement in predator capture, detection or bait-take rates at sites augmented with visual lures (Turkowski *et al*. 1983; Edwards *et al*. 1997; Short *et al*. 1997; Molsher 2001).

Similarly, the lack of a significant increase in the visitation rate at olfactory lures in our study is consistent with the inefficiency of both valerian and catnip lures for attracting cats in other Australian arid-zone trials (Edwards *et al*. 1997; Hanke and Dickman 2013), although these studies reported greater cat-visitation rates at sites treated with cat anal-gland or urine preparations. Concentrations or delivery of our olfactory lures may not have been optimal, given that peak attractiveness of elicited response is sometimes achieved at intermediate concentrations of chemical lures (Turkowski *et al*. 1983) and that olfactory lures may dissipate quickly in hot dry conditions (Moseby *et al*. 2004). Furthermore, variation in the composition of volatiles of different valerian products (Bos *et al*. 1997) could account for the lower efficacy of valerian in our trials than others
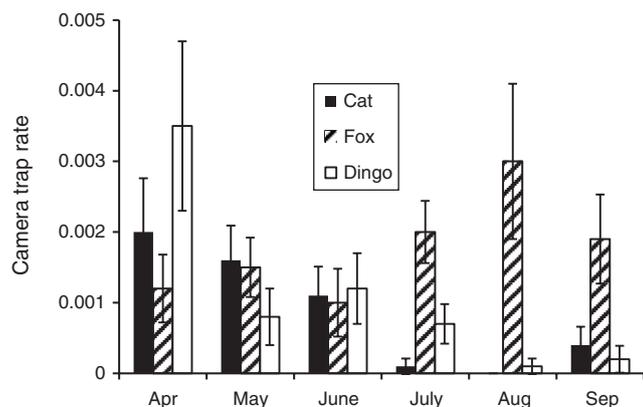
Fig. 9. Mean detection rate (+1 s.e.) of cats (*n* = 43), foxes (*n* = 86) and dingoes (*n* = 54) per trap-night at camera traps at Immarna from April to September 2013.

have experienced (MacDonald 1919). However, inefficiency of FAP lures to increase predator visitation at our sites was contrary to other studies that have demonstrated that electronic sound generators selectively attract cats (Moseby *et al*. 2004) and unpublished observations of FAPs increasing cat-visitation rates both on Kangaroo Island, South Australia (A. B. unpubl. data) and the Gulf Plain of Queensland (L. Brook, pers. comm.).

Lure efficacy is likely to vary among seasons and among individuals (Turkowski *et al*. 1983; Mitchell and Kelly 1992; Short *et al*. 2002). Further research into the optimum types and deployments of lures for different species, sites and seasons is therefore required, to develop improved management of predators, especially feral cats, which is a priority for Australian conservation (Denny and Dickman 2010; Christensen and McDonald 2013). Site-specific pilot trials to assess actual animal responses and detections over a range of seasons are, therefore, a worthy precursor to efforts to attract predators to focal points for monitoring or control.

The ineffectiveness of lures to increase cat visitation at camera sites may also be attributed to the short distance over which most lures are effective. Because of their larger daily movements and lesser ties to temporary focal points than for feral cats (Moseby *et al*. 2009), foxes should encounter sites within their range more quickly and frequently than cats. To attract cats, which may take several weeks to encounter fixed trap sites within their range, as efficiently as foxes, lures therefore need to operate over longer distances and for longer periods. Although louder audio lures are likely to be more effective in attracting predators from greater distances, our observations suggest that very loud persistent calls discourage cats and foxes from closely approaching audio lures (J. Read, pers. obs.). Therefore, optimum auditory lures might combine loud and relatively soft sounds with quiet periods that mimic the behaviour of luring sympatrics (e.g. cat yowling or kitten noises) or distressed prey.

Although lures did not increase the visitation rate of predators at camera traps in our study, they did differ in the behavioural responses they initiated. Both the FAP and Catastrophe A lures elicited significantly more responses than did controls or visual lures in cats and dingoes, whereas the two olfactory lures (valerian and Catastrophe A) elicited significantly more behavioural

responses in foxes than did other lures. This is important for predator-control devices such as traps or toxin-delivery devices that require animals to interact with lures or devices in a specific way or at very close range. Interestingly, cats, but not dingoes and rarely foxes, responded to the cameras themselves, confirming that the sounds or IR flash of the cameras could serve as a lure for cats (Bengsen *et al*. 2011; Meek *et al*. 2012). Our study suggested that auditory and olfactory lures can therefore be useful for monitoring or management programs where benefits are conferred by increasing the time and activity of cats at selected locations, e.g. capturing multiple images or hair for identification purposes or increasing susceptibility to grooming traps.

Predator-activity patterns

We confirmed that feral cats are predominantly nocturnal (Brook *et al*. 2012; Wang and Fisher 2012), although, like Mahon *et al*. (1998), we also occasionally recorded cats active throughout the day. Identification of key activity periods of different predators in different seasons can influence selection of optimal lures, particularly if visual lures that operate either by day or night are used to elicit responses in the predators. Furthermore, subordinate predators such as cats and foxes may respond differently to lures that mimic scent marking (Catastrophe A) or prey calls when apex-predator activity is relatively high or low.

The co-existence of cats and dingoes contradicts predator-hierarchy theories that suggest that unbaited dingo populations should suppress cat activity (Letnic *et al*. 2009). Co-habitation of the three predators may have been facilitated by differences in seasonal and temporal activity patterns (Brook *et al*. 2012), possibly driven by the apparent inability of dingoes to remain abundant, and perhaps dominate the predator hierarchy, throughout the study period at Immarna. Fox detections generally increased when dingo detections declined after June 2013, although this change in relative detectability could in part be explained by a temporal shift in the use of roads by either predator. Dingo activity may have been influenced by the lack of permanent water or variable access to camel carcasses in the remote Immarna locality. Although short-term changes in camera-trap detections of indistinguishable individuals do not provide unambiguous evidence of mesopredator release (Crooks and Soulé 1999), our findings support research from other localities that dingo activity is likely to have a greater influence on fox rather than cat activity (Moseby *et al*. 2012).

In conclusion, our study revealed the following key outcomes. Camera-trap capture rates were sensitive to detecting differences in spatial and temporal activity of cats, foxes and dingoes. Landscape elements, such as roads and resource points, were important in maximising predator detectability at our camera-trap grids in the South Australian arid zone. Although none of the lures we trialled resulted in significantly greater predator detectability than did unlured controls, olfactory and auditory lures can elicit behavioural responses that render cats more susceptible to active monitoring and control techniques.

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