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Front cover photo: Feral Cat and Red Fox at monitoring stations (DSE).

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Summary

Predation by the Red Fox (*Vulpes vulpes*) threatens smaller native mammals, and ground-nesting birds, and may be partly responsible for several extinctions (e.g. Lunney 2001). Feral cats (*Felis catus*) kill a wide range of native wildlife (reviewed in Robley et al. 2004), and for this reason are thought to reduce the distribution and abundance of many native species, especially on islands.

The Grampians Ark project monitors the effectiveness of landscape-scale fox control for the protection of native wildlife and is a partnership program between Parks Victoria and the Department of Sustainability and Environment. The initiative plays a key role in the protection of Southern Brown Bandicoot (*Isoodon obesulus*), Long-nosed Potoroo (*Potorous tridactylus*), Heath Mouse (*Pseudomys shortridgei*) and Smokey Mouse (*Pseudomys fumeus*).

Fox-baiting programs have been implemented in the Grampians National Park since 1996. In 2007, the Victorian Government's Weed and Pests on Public Land initiative funded $1.2 million over four years (2007–2011) for the Grampians National Park to extend the baiting program as Grampians Ark joining the flagship statewide fox-baiting initiatives of Southern Ark and Glenelg Ark.

There are a number of indexes of abundance or activity that are currently used to measure changes in fox populations, and these are reviewed by Mitchell and Balogh (2007). Commonly used monitoring techniques (e.g., spotlighting, scat counts and sand-plot monitoring) are inaccurate for indexing changes in Feral Cat populations, or limited to islands (Mahon et al. 1998, Edwards et al. 2000, Saunders and McLeod 2007). However, all are non-linear indices that have had little or no validation to actual abundance.

Remote cameras are an efficient means of collecting presence/absence data. Camera trapping was found to be the most efficient method for monitoring fox populations compared to hair-traps (DNA identification), spotlighting and sand plots (Vine et al. 2009).

As part of the ongoing improvement of the Grampians Ark project, Parks Victoria commissioned the Arthur Rylah Institute for Environmental Research to investigate sampling designs to assess the design of camera monitoring protocols for red foxes and feral cats across the Grampians landscape.

We assessed occupancy rate of red foxes and feral cats in the Grampians National Park across a single broadscale area and four smaller separate sectors. The sector surveys revealed that occupancy rates for red foxes were relatively constant across the four separate sectors and not greatly dissimilar to the occupancy rate estimated from the single broadscale area survey. Models for feral cats from the sector surveys indicted occupancy was most likely constant across three sectors. Models of feral cats from the broadscale areas were rejected, and were a poor fit for describing occupancy rates.

The difference in survey design, i.e., broadscale versus smaller sector surveys, and occupancy estimates for red foxes and feral cats may be related to the scale at which these two species operate and the density of the cameras deployed in the broadscale survey compared to the focused area surveys. Cameras were deployed at higher densities in the sector surveys compared to the broadscale survey, thus the broadscale surveys may not have had a sufficient density of cameras to estimate occupancy precisely for feral cats.

Detection probabilities were influenced by a range of factors for both red foxes and feral cats. For red foxes, detection probabilities were higher within 5 m of roads than >100 m from roads, and there were indications that infrared flash cameras detected red foxes more often than the visible white-light cameras. While for feral cats, sector was a possible influence. No feral cats were detected in sector 3, the long-term non-baited area. The highest detection probability of cats

occurred within an area that has been consistently poison baited for red foxes since 2002 (sector 2). This observation warrants further investigation of the possible behavioural or numerical response of feral cats to the reduction in red foxes resulting from the long-term baiting program across the Grampians.

Recommendations

Based on the current work, a minimum of 125 sites would be required to assess a 50% increase in red foxes or feral cats with reasonable power (0.8) at the 80% confidence interval. The appropriate level of increase, power and certainty are policy issues for Parks Victoria to consider.

Given the high rates of detection achieved in this study for red foxes and feral cats we would recommend the following:

1. Parks Victoria state what level of change and at what level of certainty needs to be measured.
2. One camera per site and maximise the number of sites surveyed if camera numbers are limited. Cameras to be placed within <100 m of roads and tracks.
3. Surveys should be conducted on an annual basis.
4. Assessment of red fox and feral cat home ranges within the park would provide insights on the density of cameras required.
5. The model of camera to be standardised – preferably Reconyx infrared outdoor or professional series.
6. If incremental rates of change are important, that modelling using a dynamic-occupancy model be undertaken to examine the influence of colonisation and extinction rates on occupancy rates through time and to assess the ability of the sampling design to detect change.
7. In light of recent advances in DNA sampling techniques, that a comparison of the costs and the appropriateness of using such approaches and camera surveys be investigated.

1 Introduction

Predation by the Red Fox (*Vulpes vulpes*) threatens smaller native mammals, and ground-nesting birds, and may be partly responsible for several extinctions (e.g. Lunney 2001). Feral cats (*Felis catus*) probably became established in Australia soon after the arrival of Europeans, and wild populations now occupy most parts of the mainland, Tasmania and some offshore islands (Abbott 2002). Cats kill a wide range of native wildlife (reviewed in Robley et al. 2004), and for this reason are thought to reduce the distribution and abundance of many native species, especially on islands. Predation by red foxes and feral cats is listed as a key threatening process under the *Victorian Flora and Fauna Guarantee Act 1988* and the *Environmental Protection and Biodiversity Conservation Act 1999* (Commonwealth).

Although many agencies and organisations commit resources to managing red foxes and feral cats (Reddiex et al. 2004), there remains a high degree of uncertainty about the ability to accurately and precisely estimate the relative or absolute abundance of these introduced predators. This limits the ability of policy-makers and managers to judge the effectiveness of control operations, to justify the investment of resources in further operations or to understand potentially undesirable effects of management activities, such as the potential change in Red Fox and Feral Cat abundance or behaviour.

1.1 Grampians Ark

The Grampians Ark project is a partnership program between Parks Victoria and the Department of Sustainability and Environment. It monitors the effectiveness of landscape-scale fox control for the protection of native wildlife. The initiative plays a key role in the reintroduction of the critically endangered Brush-tailed Rock-wallaby (*Petrogale penicillata*) and protection of other threatened species across the Grampians landscape, such as Southern Brown Bandicoot (*Isoodon obesulus*), Long-nosed Potoroo (*Potorous tridactylus*), Heath Mouse (*Pseudomys shortridgei*) and Smokey Mouse (*Pseudomys fumeus*).

Fox-baiting programs have been implemented in the Grampians National Park since 1996. Monitoring of the response of native small mammals began in 2003 through Parks Victoria's Fox Adaptive Experimental Management (AEM) project (Fox AEM; Robley et al. 2008). The Fox AEM program ceased operation in 2007. However, the Victoria Government's Weed and Pests on Public Land initiative funded $1.2 million over four years (2007–2011) for the Grampians Ark project to extend the Grampians Fox AEM, joining the flagship statewide fox-baiting initiatives of Southern Ark and Glenelg Ark.

1.2 Detection methods

There are a number of indexes of abundance or activity that are currently used to measure changes in fox populations, and these are reviewed by Mitchell and Balogh (2007). Methods include spotlighting, the use of bait stations, and sand-plot monitoring. Spotlight counts can be biased due to changes in observers or changes in visibility and/or sightability due to differences in vegetation structure. There are a variety of methods for using either toxic or non-toxic baited stations to lure red foxes so that estimates of activity or abundance can be determined. Contagion, caused by learning, may increase daily visitation rates affecting accuracy. Other influences include the spacing of bait stations, bait presentation, habitat differences, frequency of operation and changes in tracking substrate. Track counts assume a relationship between counts and actual abundance; however, there have been few validations of this technique for red foxes. Most recently non-invasive DNA analysis has been used to quantify the change in fox abundance following instigation of poison baiting in arid Western Australia for red foxes (Berry et al. 2012). This method proved very successful at quantifying changes in abundance post control and will certainly improve managers' ability to assess reduction in fox populations – although its application in temperate environments remains untested.

Determining the success of Feral Cat control operations is problematic. Commonly used monitoring techniques (e.g., spotlighting, scat counts and sand-plot monitoring) for indexing changes in populations of other carnivores, such as the Red Fox (*Vulpes vulpes*) or Dingo (*Canis lupus dingo*) are either inaccurate or (in their application to feral cats) limited to islands or sandy environments (Mahon et al. 1998, Edwards et al. 2000, Saunders and McLeod 2007). Feral cats tend not to look towards spotlights and do not preferentially use roads or tracks (Mahon et al. 1998, Edwards et al. 2000). The proportion of toxic baits taken is also commonly used to report the success of fox and wild dog control operations. The cues used by cats to locate food are visual and auditory rather than olfactory, so buried baits are seldom taken by a Feral Cat, which significantly limits the use of bait take in monitoring feral cats in eastern Australia where these baits must be buried (Seebeck and Clunie 1997, DEWHA 2008).

1.3 Remote cameras

Remote cameras are an efficient means of collecting presence data over long periods of time (e.g. weeks) with minimal input of labour and minimal stress to the animals being surveyed. These features make remote cameras a particularly valuable tool for surveying mammals. Mammal survey data collected using remote cameras can be used in a range of wildlife planning and management applications. Camera trapping was found to be the most efficient method compared to hair-traps (DNA identification), spotlighting and sand plots for detecting red foxes (Vine et al. 2009), and Robley et al. (2010) evaluated camera sampling designs for feral cats and found one camera at 49 sites for 28 days provided robust estimates of occupancy rates.

A common approach used to analyse presence/absence data that is readily generated by remote cameras is occupancy modelling (MacKenzie and Kendall 2002). The proportion of sites in an area that are occupied by the species in question is an alternative approach to using indices of abundance. The simplest approach to estimating occupancy is to derive a naïve estimate, i.e. the number of camera sampling sites with at least one detection divided by the total number of camera sites in the study area. This assumes that if a species is present on a site then it will be detected, i.e. the probability of detection is 1. This method will likely result in a negatively biased estimate of site occupancy, as it is possible that sites that are considered unoccupied could in fact have species present that were undetected. MacKenzie and Kendall (2002) proposed that an unbiased estimation of occupancy can be achieved by repeated surveying of sites.

For remote camera data, each day of a camera's deployment at a survey site can be treated as a distinct survey, during which the target species was or was not detected. The resulting sequence of detections/non-detections at each site is referred to as a 'detection history'. The set of detection histories collected during a remote camera survey can be analysed using a statistical modelling framework developed by MacKenzie et al. (2002, 2005), which infers the probability of detection associated with each survey (i.e. the likelihood that the target species will be detected by remote camera at occupied sites). The probability of detecting the target species is then incorporated into the final occupancy estimate to account for sites where the target species may have been present but was not detected during the survey.

It is often not possible to determine the necessary number of sites to survey using remote cameras prior to conducting the survey. In general, when conducting an occupancy-type survey, the aim of the survey design is to make the most precise estimate of the rate of site occupancy, given the available resources. The precision of statistical estimates of occupancy depends not only on the number of sites that are surveyed, but also on the daily detection probability of the survey method, and the number of repeat surveys that are carried out at each site (i.e. the number of days of camera sampling). In general, surveying more sites a greater number of times using the method with the highest probability of detection, will maximise the precision of the estimate of the rate of occupancy. However, there are usually conflicts and trade-offs between these three aims. For example, if limited numbers of cameras are available, then carrying out many days of survey at each site will limit the total number of sites which can be surveyed over the course of a survey season. The expected precision associated with a particular sampling program can be calculated if information regarding the occupancy rate and probability of detection are available prior to the survey.

As part of the ongoing improvement of the Grampians Ark project, Parks Victoria commissioned the Arthur Rylah Institute for Environmental Research to investigate sampling designs to establish a camera monitoring protocol for red foxes and feral cats across the Grampians landscape.

Here we report on two field trials in the Grampians National Park using digital cameras that collected information on:

1. the probability of detection
2. occupancy rates of feral cats and red foxes.

We used an occupancy modelling framework to analyse the data. We describe the current level of occupancy at a number of sites and explore the precision of the approaches used. We also discuss approaches to further developing a monitoring protocol for feral cats and red foxes across the Grampians landscape.

2 Aim

The aim of this project was to assess camera monitoring designs for the activity of the Red Fox (*Vulpes vulpes*) and Feral Cat (*Felis catus)*, and to develop a monitoring protocol that could be implemented across the Grampians National Park, Victoria.

2.1 Study area

The Grampians National Park is 167 219 ha in area and is the fourth largest national park in Victoria. It encompasses the Grampian Ranges which are a series of three north–south orientated ranges, consisting of abrupt escarpments and generally west-dipping slopes. Almost one third of the State's indigenous flora species are found in the park, which contains 40 Ecological Vegetation Classes – four of which are endemic. The park provides some of the last remaining contiguous habitat for 167 species of threatened flora and fauna and is particularly important for protecting small mammal fauna (Critical Weight Range) such as the *Pseudomys shortridgei* (Heath Mouse), *Pseudomys fumeu* (Smokey Mouse*), Potorous tridactylus* (Long-nosed Potoroo).

3 Methods

3.1 Camera survey designs

3.1.1 Focused area surveys

Parks Victoria staff identified four sectors of high conservation value within the Grampians National Park ranging in size from 4250 ha to 14 000 ha. These areas were divided into 250 ha hexagons using the Repeating Shapes extension (Jenness Enterprises, Arizona, USA) in Arcview 3.2 (ESRI, California USA). This represents approximately half the area of a typical fox home range (Saunders et al. 1995) and is approximately the lower size of a Feral Cat's home range (Molsher et al. 2005). A random point within each hexagon was generated using the Random Point Generator extension (Jenness Enterprises, Arizona, USA) in Arcview 3.2, and a subset of these points, representing 60% of available hexagons, were then randomly selected as locations for cameras. Some points fell in inaccessible locations and were relocated. No camera point was closer than 100 m to a formed road or track. The result was that sector one had 20 sites, sector two had 19 sites, sector three had 8 sites, and sector four had 22 sites. The average distance between camera sites in each sector was: sector one, 1.7 km ± 0.12; sector two, 2.4 km ± 0.36; sector three, 3.4 km ± 0.15; and sector four, 1.9 km ± 0.18.

We used two camera types, ScoutGuard SG550 infrared and ScoutGuard SG565 white-light cameras (HCO, Norcross, Georgia, USA) (Table 1). Cameras were set to take one image a second while there was motion detected, with no quiet period.

Cameras were attached to a tree and set 20 cm above the ground. A lure of chicken and tuna oil was placed inside a wire mesh cage secured to a wooden stake. Cages were set 2 m from the camera. All vegetation between the camera and cage was cleared. Cameras were left in place for an average of 23 ± 1.6 consecutive days in December/January 2011/2012.

We set two cameras (one of each type) at each of the selected points separated by approximately 100 m. One hundred and thirty-eight cameras were set at 69 sites across the four sectors (Figure 1).

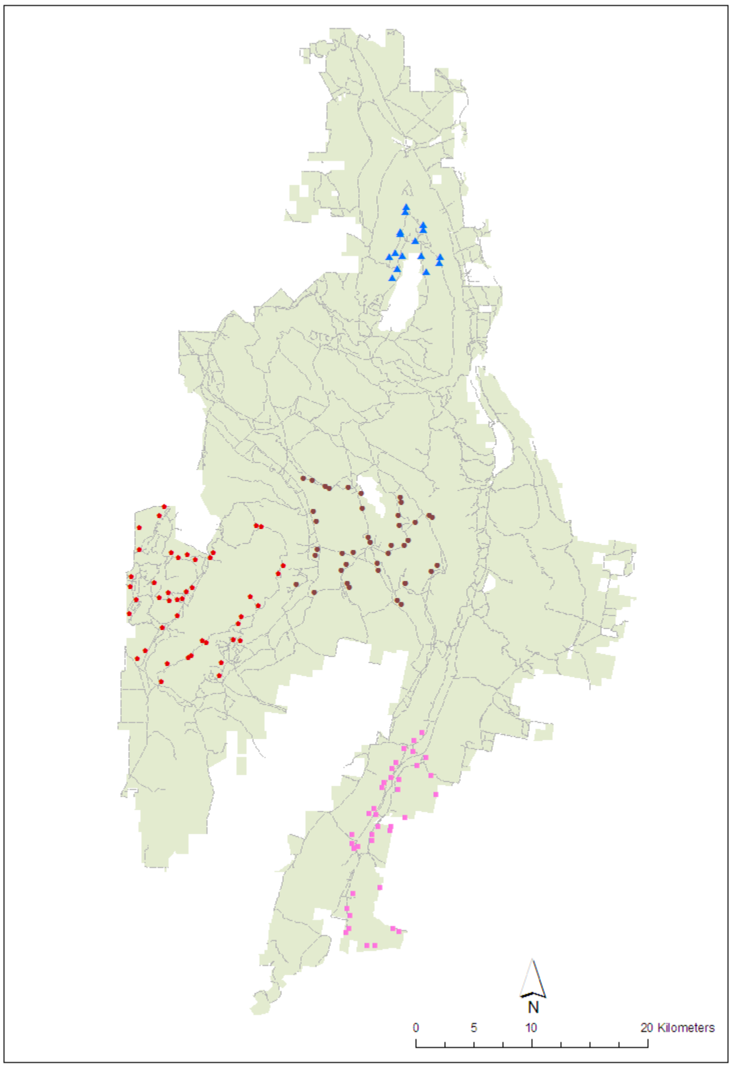

Figure 1. Location of cameras in the focused area surveys in the Grampians National Park. Sector one = brown circles, sector two = pink squares, sector three = blue triangles, sector four = red pentagons.

Table 1. Camera survey sampling effort at Grampians National Park.
* Hexagon size sectors 1–4 250 ha, broadscale 500 ha.

	Number of cameras					
Area	**Infrared**	**White-light**	**Number of sites**	***Number of Hexagons**	**Percentage sampled**	**Cameras /1000 ha**
Sector one	36	4	20	36	56	2.2
Sector two	32	6	19	41	46	1.9
Sector three	16	0	8	17	47	1.9
Sector four	12	32	22	56	39	1.6
Broadscale	43	34	77	124	62	1.2

3.1.2 Broadscale area survey

The second approach was a broader scale survey over a single large area (Figure 2). Camera locations were determined in the same manner as for the four sectors, described above, with the difference being that 500 ha hexagons were used to divide the area into sampling sites. This represents the average area of a fox home range (Saunders et al. 1995) and approximately double a Feral Cat home range (Molsher et al. 2005).

Seventy-seven cameras (43 infrared and 34 white-light) were deployed for an average of 28 days ± 0.5 day in February/March 2012. The random allocation of cameras resulted in 25 cameras being placed less than 5 m from the edge of formed tracks/roads (17 infrared and 8 white-light) while the remaining 52 cameras (26 infrared and 26 white-light) were placed more than 100 m from formed roads/tracks. This was to assess the influence that the proximity to formed tracks/roads had on detection rates.

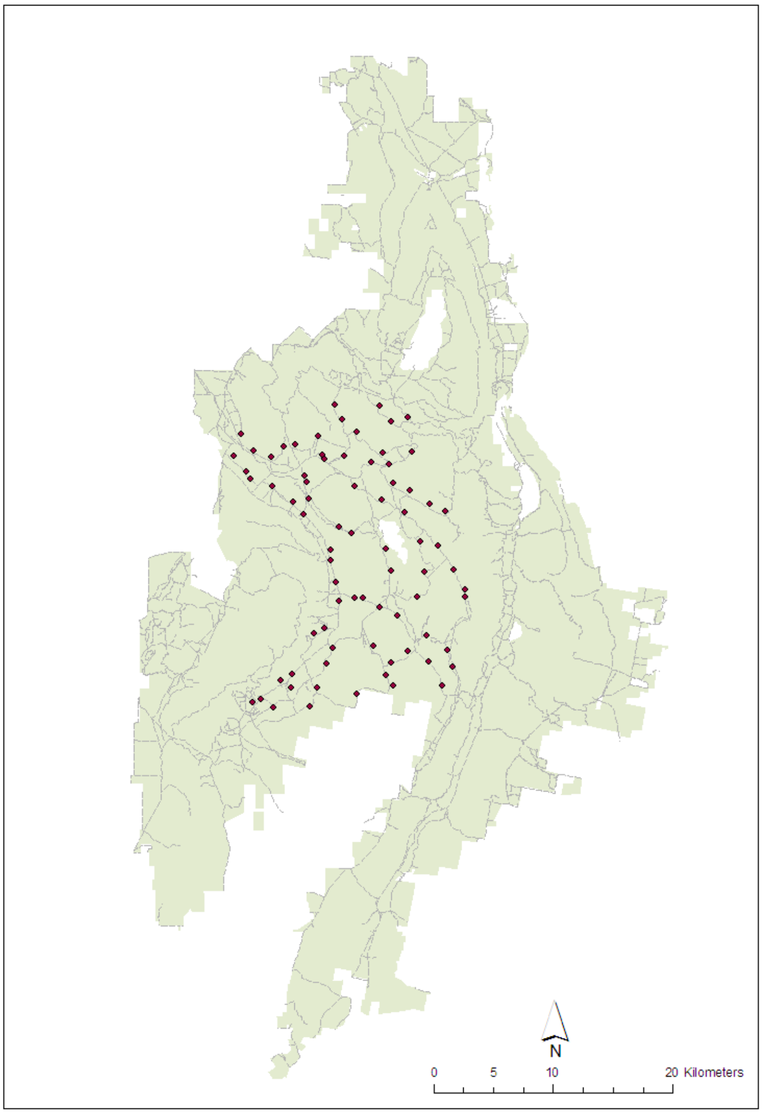

Figure 2. Location of cameras in the broadscale area survey in the Grampians National Park.

3.2 Image organisation

Images were organised following the method outlined by Harris et al. (2010) and using a set of software programs (DataOrganise and OccupancyMatrix) developed by James G. Sanderson (Small Wild Cat Conservation Foundation, Los Altos, USA).

We initially set-up folders with the following structure:

Sector_number/Site_number/species_name/number-of-individuals (e.g. 01 or 02). Upon retrieval from each camera, all images were renamed into the following format: year, month, day, hour, minute, second. Duplicate images were examined and either manually renamed or deleted. Renaming was undertaken using the freeware Renamer v5.60 (*www.den4b.com*). For each image we identified the species, counted the number-of-individuals of each species recorded, and stored the image in the proper folder: location/species/number-of-individuals.

We then ran all images through the DataOrganise software. This creates two files: AllPictures.txt and Input.txt. The Input.txt file is edited to ensure the proper start and finish dates of the survey are present. The dates initially produced represent the first and last image dates not the start and finish survey dates. This is corrected using some additional software. The final step is to use the OccupancyMatrix software. OccupancyMatrix reads and processes the AllPictures.txt and edited Input.txt files and creates occupancy matrices for all species and all camera locations. The occupancy matrices that are created were copied into program PRESENCE (Hines 2006). A "–" in the matrix means a camera was not active, a "1" means there was a picture in the camera occasion window, and "0" means the camera was active but did not capture an image of a species.

3.3 Data analysis

We used the proportion of camera sites within a monitoring area (i.e. focused area and broadscale area) that were occupied to assess occupancy rates. The phrase ‘occupancy’ is used here to mean the proportion of sampling units that contain red foxes or feral cats at a given point in time.

Data from the camera surveys were summarised into detection histories for each site, where $y_{ij} = 1$ indicated that the species was detected at site i on day j; and $y_{ij} = 0$ otherwise. For example, a five-day sampling program of a particular site, $y_i = [1,0,0,1,1]$ would indicate that cats were detected on the first, fourth and fifth days but not on the second or third.

It is typical of wildlife data that a species may be present on a site, yet not be detected on a given day. For example, a detection history such as $y_i = [0,0,0,0,0]$ could indicate that the species was either absent from site i, or it was present but not detected on any of the days. We used the occupancy modelling approach outlined by MacKenzie et al. (2005) to estimate occupancy accounting for imperfect detection. This approach allows us to remove the confounding between the occupancy rates and the detection probability.

Assuming the daily detection probability (p) is constant, the overall probability of each detection history can be calculated as:

$$\Pr\left(y_i \mid z_i^{\text{obs}} = 1\right) = \psi p^n (1-p)^{T-n}$$

$$\Pr\left(y_i \mid z_i^{\text{obs}} = 0\right) = (1-\psi) + \psi(1-p)^T$$

where ψ is the occupancy probability, p is the detection probability, n is the number of days that the species was detected, T is the total number of days cameras were deployed at the site, and $z_i^{\text{obs}} = 1$ indicates that the species of interest was detected at least once on site i, and $z_i^{\text{obs}} = 0$ otherwise.

This approach specifically accounts for spatial and temporal variability in the detection of species; it can incorporate site covariates and include the use of different detection methods, and requires relatively less effort and cost compared to more traditional methods of estimating abundance (Tyre et al. 2001; MacKenzie and Kendall 2002).

Detection probability was allowed to vary between camera type (infrared and white-light) and camera location (sector and road or bush). Occupancy could vary by sector or be held constant across sectors.

The probability of daily detection was modelled on the logit scale. Dummy variables were used for categorical variables, where for camera type a 0 denoted white-light and a 1 denoted infrared. Similarly, for camera location, a 0 denoted road and a 1 denoted bush. Models were specified using the software PRESENCE (Hines 2006). We tested eight a priori models for the focused area study to see which best explained occupancy rates.

- Occupancy and detection were constant across all sectors, $\psi(.),p(.)$
- Occupancy constant and detection varied with sector, ψ (.),p(sector)
- Occupancy constant and detection varied with camera type, ψ (.),p(camera type)
- Occupancy constant and detection varied with sector and camera type, ψ (.),p(sector,camera type)
- Occupancy varied with sector and detection was constant, ψ (sector),p(.)
- Occupancy and detection varied with sector, ψ(sector), p(sector)
- Occupancy varied with sector and detection varied with camera type, ψ(sector),p(camera type)
- Occupancy varied with sector and detection varied with sector and camera type, ψ(sector),p(sector, camera type)

In the broadscale study we tested four a priori models.

- Occupancy and detection were constant, $\psi(.),p(.)$
- Occupancy was constant and detection varied with camera type, $\psi(.)$, p(camera type)
- Occupancy was constant and detection varied with location (i.e. road or bush), ψ(.),p(location)
- Occupancy was constant and detection varied with camera type and location, $\psi(.)$, p(camera type and location).

Model selection was determined using the Akaike Information Criterion (AIC), which is a measure of the relative goodness of fit of the model.

$$\text{AIC} = -2 (\ln (\text{likelihood})) + 2\text{ K}$$

where likelihood is the probability of the data given a model and K is the number of free parameters in the model. AIC scores are often shown as ΔAIC scores, or difference between the best model (smallest AIC) and each model (so the best model has a ΔAIC of zero). Burnham and Anderson (1998) indicate that a ΔAIC value of < 2 can be used as a guide in assessing the level of empirical support for the best models. AIC values provide a means for model selection. AIC does not provide a test of a model in the sense of testing a null hypothesis. Given a set of candidate models for the data, *the preferred model is the one with the minimum AIC value.*

To assess how accurately a selected model fits the data we used the goodness-of-fit procedure in program PRESENCE. (Hines 2006). This procedure calculates a Pearson chi-squared statistic and a parametric bootstrap procedure then determines whether the observed statistic is unusual indicating the model is a poor fit.

3.4 Power analysis

The power of a statistical test is the probability or chance of detecting a difference when in fact one does exist; in this case correctly determining that an increase in Feral Cat or Red Fox occupancy rate has truly occurred. As the power of a test increases, the chance of incorrectly rejecting the null hypothesis decreases. Three things can influence the power of a test: a) the sample size, b) the level of precision required, normally set at 0.05, and c) the effect size.

A power analysis was carried out to determine the possible level of power in detecting a difference in red fox and Feral Cat occupancy rate from a number of sampling scenarios. For red foxes we based the power analysis on the broadscale area surveys, i.e. cameras at 77 sites with each camera set for 28 days. For feral cats we based the analysis on the focused area surveys, i.e., 69 sites over 23 days.

We investigated the ability to detect a change in occupancy rate of 25%, 50%, 75% and 100% from that estimated from the data using 80, 100, 125, and 150 sites. For each combination we assessed confidence at the 0.80, 0.90 and 0.95 level. We also investigated the influence a range of starting occupancy estimates had on the results. For red foxes we set $\psi = 0.15$, 0.30, and 0.50 and $p = 0.516$ and for feral cats we set $\psi = 0.10$, 0.20, and 0.40 and $p = 0.811$.

All analysis was conducted in the statistical package R (The R Foundation for Statistical Computing 2012, version 2.15.1), using the package ‘unmarked’ (Fiske and Chandler 2011).

4 Results

4.1 Red foxes

4.1.1 Focused area surveys

Given the set of a priori models we tested, the model that explained most of the data for the focused area surveys was ψ(.),p(sector) (Table 2). However, there was little difference between this and the following three models, all with ΔAIC values < 2. This indicates that sector was influential on occupancy, and camera type had a negligible influence.

Table 2. Akaike Information Criteria values for competing models for red foxes in the focused area surveys.

Model	AIC	ΔAIC	AIC weight	No. Parameters	−2*Log Likelihood
psi(.),p(sector)	258.42	0	0.2796	5	248.42
psi(sector),p(.)	259.05	0.63	0.204	5	249.05
psi(.),p(sector, camera type)	259.17	0.75	0.1922	6	247.17
psi(.),p(.)	260.09	1.67	0.1213	2	256.09
psi(.),p(camera type)	260.52	2.1	0.0978	3	254.52
psi(sector),p(camera type)	261.05	2.63	0.0751	6	249.05
psi(sector),p(sector, camera type)	262.92	4.5	0.0295	9	244.92
psi(sector),p(sector)	270.9	12.48	0.0005	8	254.9

The goodness-of-fit test results for the global model indicate that there was insufficient evidence to reject this model (p-value = 0.082, ĉ = 0.6776), i.e., only 8% of the simulated outcomes were greater than the chi-squared test statistic.

The naïve estimate of occupancy for red foxes was 0.1045, taking into account the variability in detection rate across sectors the estimated rate of occupancy was nearly double, ψ = 0.2051 (SE = 0.064), or just over 20% of sites. Confidence limits around this estimate are broad indicating a reasonably imprecise estimate (0.1068–0.3576).

Detection rates varied across sectors. Detection was greatest in sectors two and four, with the cumulative probability of detecting a fox, if it was in fact present, reaching 0.75 and 0.70 in each sector respectively after 23 days.

4.1.2 Broadscale area survey

The best supported model was for occupancy rates to be constant with detection rates varying with location, ψ(.),p(location) (Table 3). The cumulative detection probability was greater for cameras set within 5 m of roads (0.85) than cameras set >100 m from roads (0.49) (Figure 3).

Table 3. Akaike Information Criteria values for competing models for red foxes from the broadscale area survey.

Model	AIC	Delta AIC	AIC weight	Number of parameters	−2 Log Likelihood
psi(.),p(location)	239.43	0	0.3097	3	233.43
psi(.),p(location, camera type)	240.79	1.36	0.1569	4	232.79
psi(.),p(.)	240.98	1.55	0.1427	2	236.98
psi(location),p(location)	241.38	1.95	0.1168	4	233.38
psi(location),p(.)	241.6	2.17	0.1047	3	235.6
psi(.),p(camera type)	242.51	3.08	0.0664	3	236.51
psi(location),p(location, camera type)	242.78	3.35	0.058	5	232.78
psi(location),p(camera type)	243.3	3.87	0.0447	4	235.3

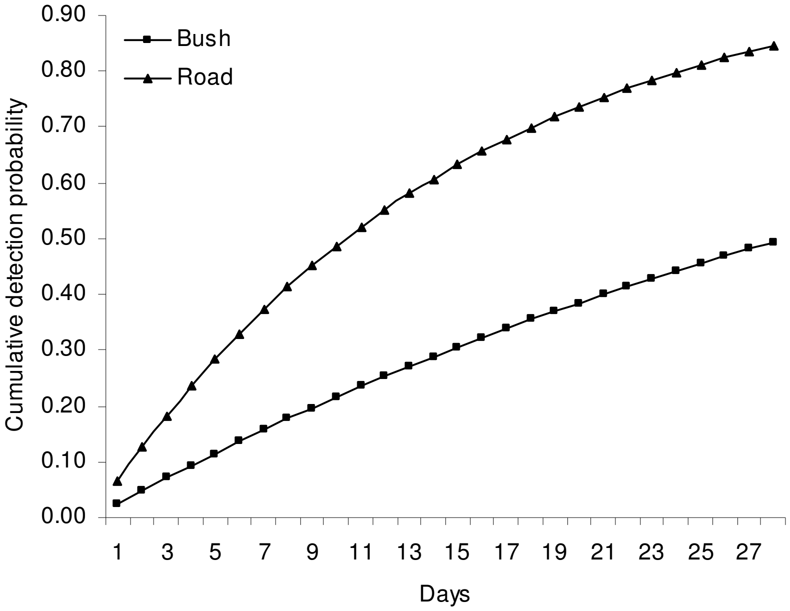

Figure 3. Cumulative detection probability of red foxes at locations < 5 m from roads (Bush) and > 100 m from roads (Road) in the broadscale area survey in the Grampians National Park.

There is also support for the following three models, all with ΔAIC < 2. Camera type had negligible influence on detection. The results from the goodness-of-fit test indicated that there was no reason to reject the global model (χ^2= 139228, p-value = 0.5395, ĉ = 0.0076).

The naïve estimate of occupancy for red foxes was 0.1733, taking into account the variability in detection rate across camera types the estimated rate of occupancy was just over 50% greater, ψ = 0.2780 (SE = 0.0858) or nearly 28% of sites. Confidence limits around this estimate are broad indicating a reasonably imprecise estimate (0.1427–0.4710).

4.2 Feral cats

4.2.1 Focused area surveys

Model selection procedures could not clearly separate out a single model for feral cats in the focused area surveys, with five of the eight models having a ΔAIC of < 2. Results suggest that both camera type and sector were influential in detection and that sector also contributed to occupancy. No feral cats were detected in sector three (Table 4). The results from the goodness-of-fit test indicated that there was no reason to reject the global model (χ^2= 143243, p-value = 0.5225, ĉ = 0.0454).

Table 4. Akaike Information Criteria values for competing models for feral cats from the focused area surveys.

Model	AIC	Delta AIC	AIC weight	Number of Parameters	−2*Log Likelihood
psi(.),p(.)	287.51	0	0.2467	2	283.51
psi(.),p(sector)	287.58	0.07	0.2382	5	277.58
psi(.),p(camera type)	288.25	0.74	0.1704	3	282.25
psi(.),p(sector, camera type)	288.38	0.87	0.1597	6	276.38
psi(sector),p(.)	289.3	1.79	0.1008	5	279.3
psi(sector),p(camera type)	290.54	3.03	0.0542	6	278.54
psi(sector),p(sector)	292.71	5.2	0.0183	8	276.71
psi(sector),p(sector, camera type)	293.64	6.13	0.0115	9	275.64

The naïve estimate of occupancy for feral cats was 0.1212. Taking into account the variability in detection rate across sectors, the estimated rate of occupancy under the ψ(.),p(.) model was ψ = 0.1695 (SE = 0.0461), or just over 16% of sites. Confidence limits around this estimate are broad indicating a reasonably imprecise estimate (0.0970–0.2796).

Detection rates varied across sectors. Detection was greatest in sectors two and four, with the cumulative probability of detecting a Feral Cat, if it was in fact present, reaching 0.80 and 0.70 respectively in both sectors after 23 days and 0.52 in Sector 1 (Figure 4). No feral cats were detected in sector three.

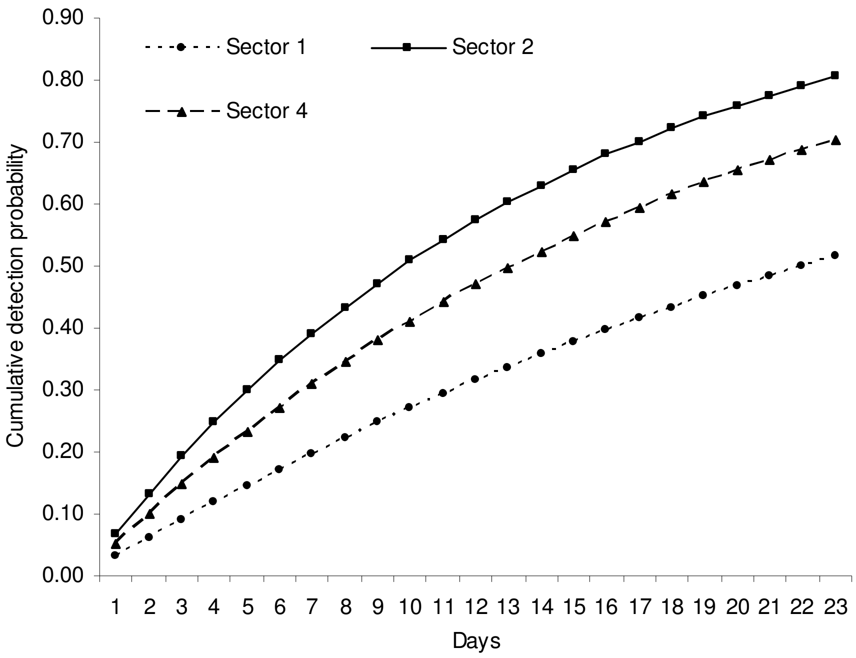

Figure 4. Cumulative detection probability for feral cats across three sectors in the Grampians National Park. Feral cats were not detected in Sector 3.

4.2.2 Broadscale area survey

There was very little support for any model for estimating Feral Cat occupancy across the broadscale area survey. The results of the goodness-of-fit test indicate that the data was a very poor fit for this model (p-value = 0.003).

Table 5. Akaike Information Criteria values for competing models for feral cats from the broadscale area survey.

Model	AIC	Delta AIC	AIC weight	Number of Parameters	−2Log Likelihood
psi(location),p(.)	248.32	0	0.2767	3	242.32
psi(location),p(location)	248.69	0.37	0.23	4	240.69
psi(.),p(.)	249.72	1.4	0.1374	2	245.72
psi(location),p(camera type)	250.05	1.73	0.1165	4	242.05
psi(location),p(location, camera type)	250.34	2.02	0.1008	5	240.34
psi(.),p(camera type)	250.94	2.62	0.0747	3	244.94
psi(.),p(location)	251.25	2.93	0.0639	3	245.25

Figure 5 shows the location of feral cats and red foxes detected during both the focused area and broadscale surveys.

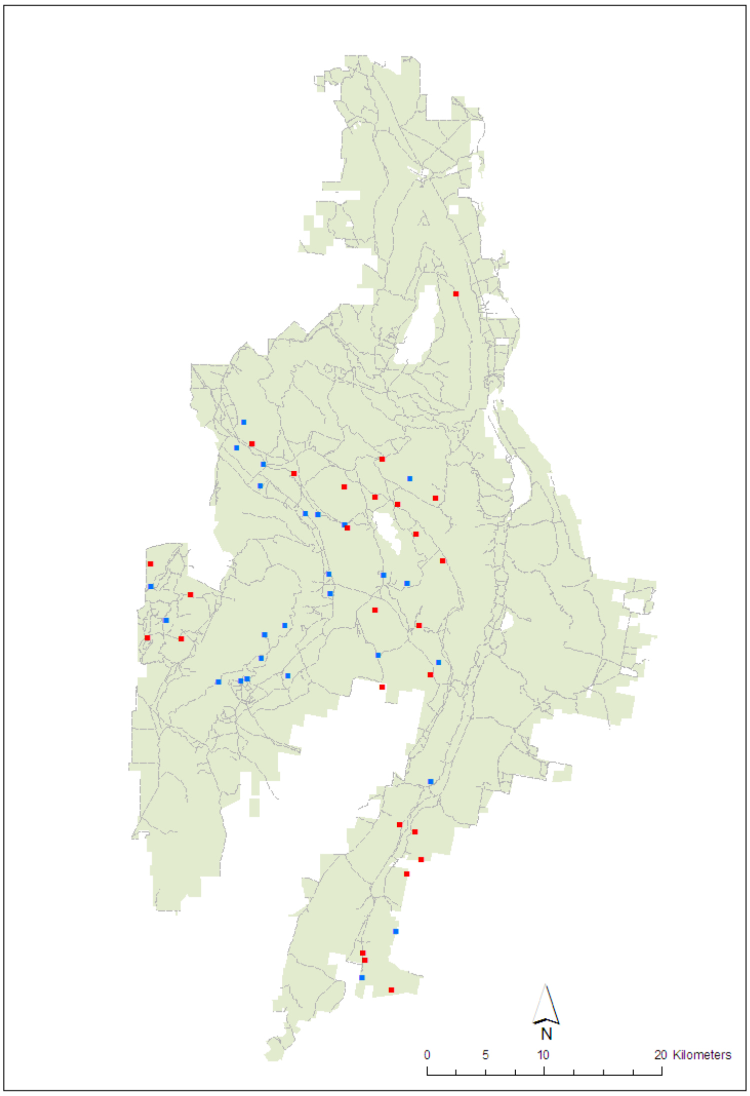

Figure 5. Location of feral cats (blue) and red foxes (red) detected during the focused area and broadscale area surveys in the Grampians National Park.

4.3 Power analysis

As results indicated that the cumulative detection rates for both feral cats and red foxes were high, we held the number of days surveyed constant and varied the number of sites, the level of increase in occupancy and the confidence interval.

4.3.1 Red foxes

Exploration of the power to detect increases in fox occupancy from the estimated rate (i.e., $\psi = 0.3$, $p = 0.516$) showed that at the combinations of confidence (0.8, 0.90 and 0.95) and number of sites (80, 100, 125, and 150), there was little power to detect a small change (25%) in red foxes (Figure 6a–c). At the 90% CI, 80 sites would be likely to detect increases of 50% with reasonable power (0.7), and with an 80% CI, 80 sites would likely detect a 50% increase with greater power

(0.8). Generally increases of 50% and above could be detected with power greater than 0.8 with sites ranging between 80 and 150 (Figures 6a–c).

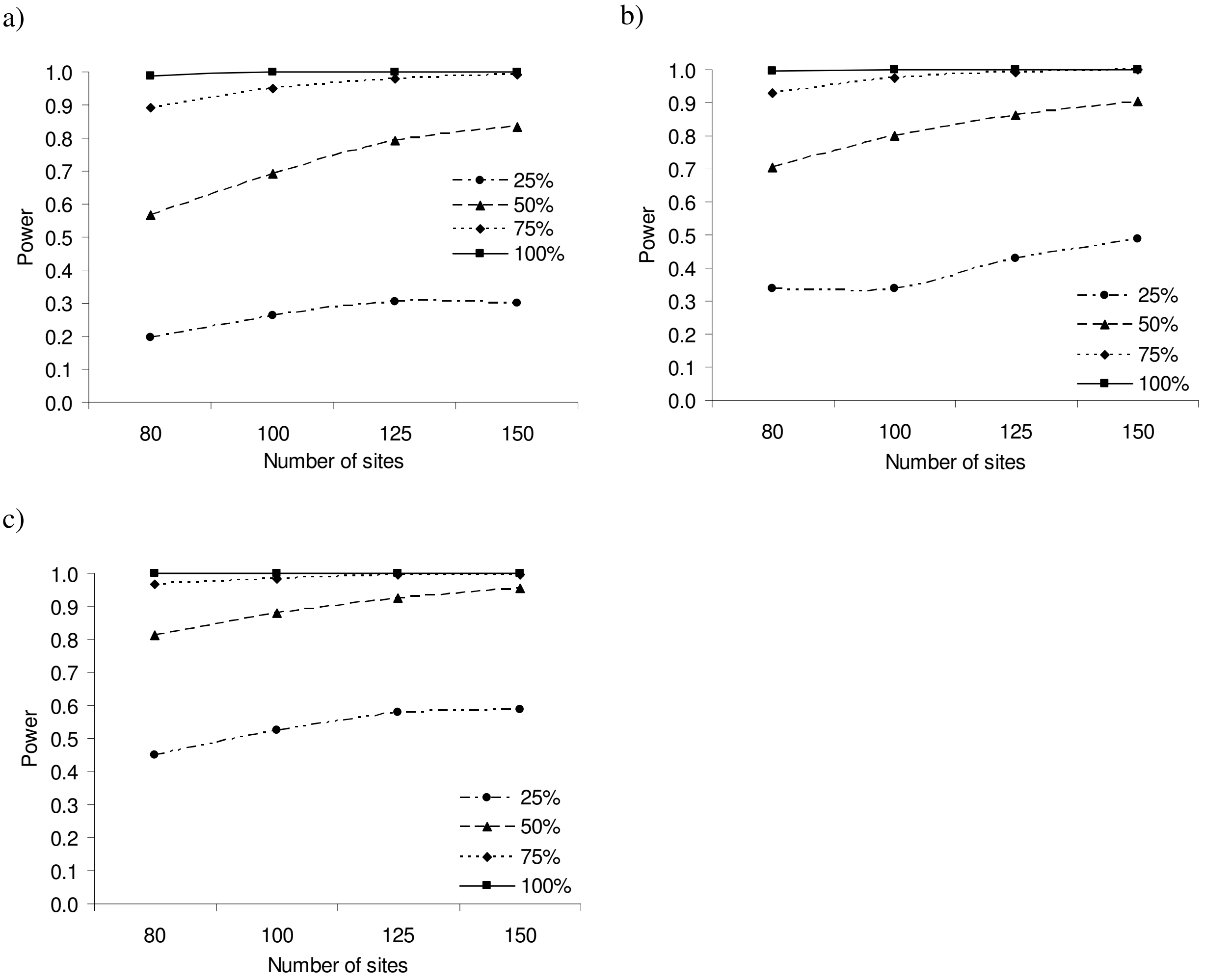

Figure 6. Power to detect an increase in fox occupancy rate of 25%, 50%, 75% and 100% with 80, 100, 125 or 150 sites over 28 days. a) with a 95% confidence interval, b) 90% confidence interval, c) 80% confidence interval. ψ = 0.3, p = 0.516.

The power to detect changes in occupancy of 25% was increased when we assessed a higher initial occupancy estimate (ψ = 0.5, p = 0.516). One hundred and fifty sites had a power of 0.83 to detect a 25% increase using this rate at the 80% CI (Figure 7a–c).

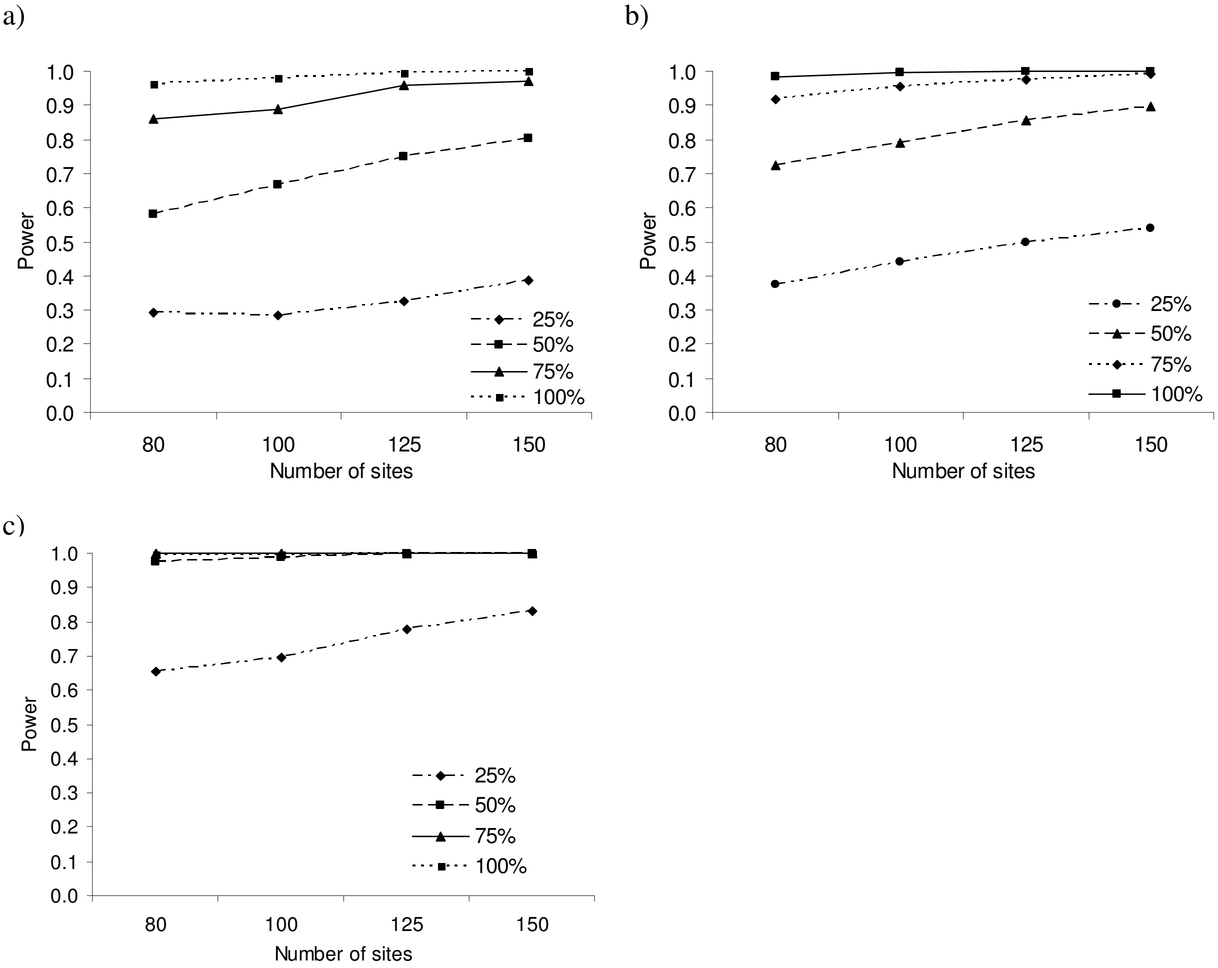

Figure 7. Power to detect an increase in fox occupancy rate of 25%, 50%, 75% and 100% with 80, 100, 125 or 150 sites over 28 days. a) with a 95% confidence interval, b) 90% confidence interval, c) 80% confidence interval. ψ = 0.5, p = 0.516.

4.3.2 Feral cats

An exploration of the power to detect increases in Feral Cat occupancy from the estimated rate (i.e., ψ = 0.2) showed that the current survey effort would have little power to detect moderate changes (25%) in feral cats at the 95% confidence level (Figure 8a). At a less precise level of confidence (90% CI) 150 sites could detect a 50% increase with approximately 0.8 power (Figure 8b). Relaxing the confidence intervals further to 80% (i.e., a 20% chance of missing an increase when it actually occurred) would allow for changes of 50% to be detected with 125 sites (Figure 8c). However, smaller increases of 25% in occupancy rates (30% of sites occupied increasing to 38% of sites) could still not be detected with any confidence even with 150 sites at the 80% confidence interval (Figure 8c).

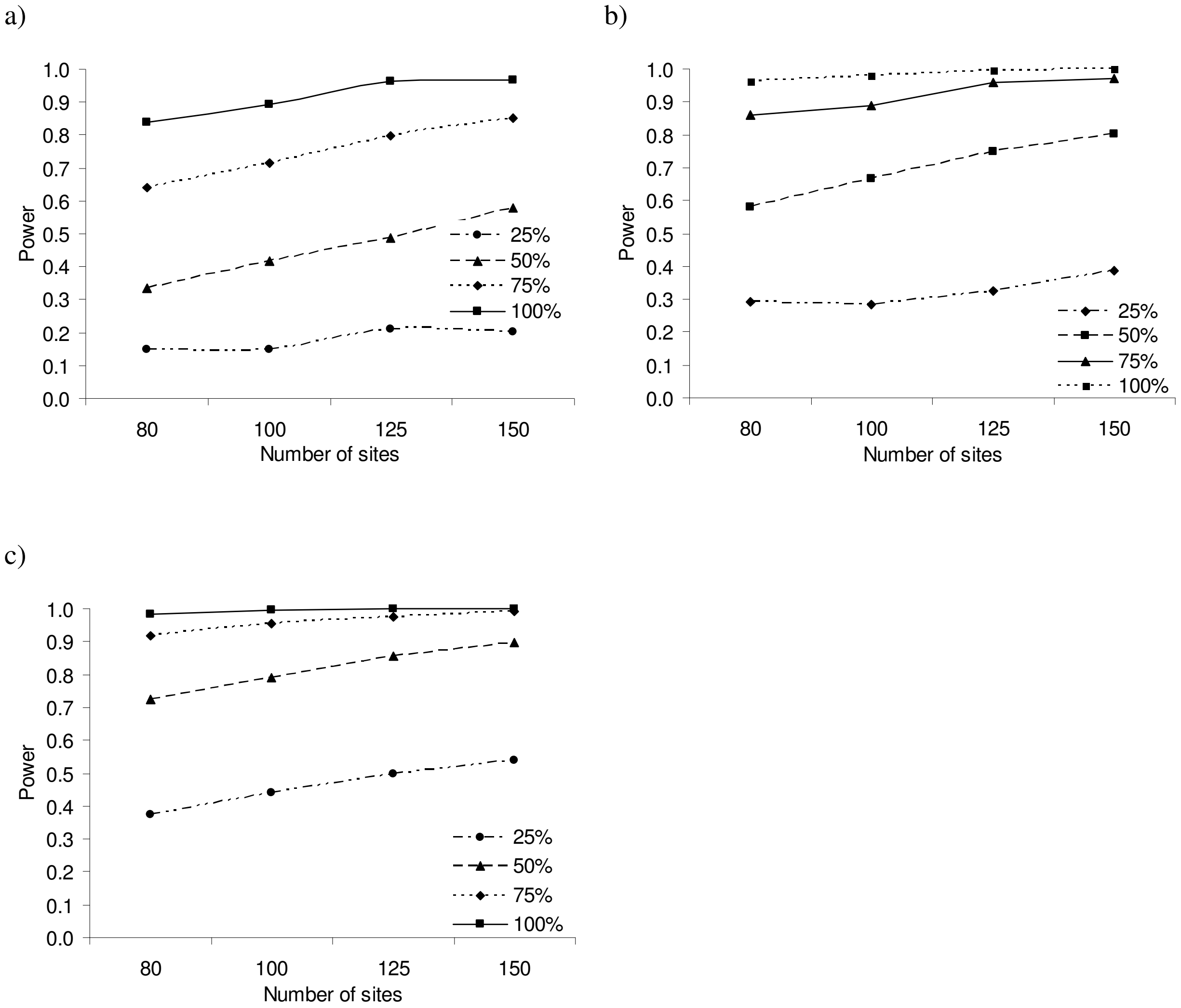

Figure 8. Power to detect an increase in Feral Cat occupancy rate of 25%, 50%, 75% and 100% with 80, 100, 125 or 150 sites over 23 days. a) with a 95% confidence interval, b) 90% confidence interval, c) 80% confidence interval.

5 Discussion

The best supported models and those with the best fit for the data for red foxes came from the broadscale area survey and for feral cats from the focused area survey. For red foxes, the best model with the most support was for constant occupancy with detection probability varying with location, with a greater chance of detection closer to roads/tracks. There was also some support for detection being influenced by camera type. This model indicated that red foxes were likely to occupy 28% (range 14%–47%) of the 77 sites. While the data was a good fit to the global model, the broad range in the estimate limits the ability of the sampling design to detect small changes in occupancy. The detection rates of the camera brand used in this study have been shown to be lower than others in the market (Robley et al. 2010), likely due to the narrower field of view of the motion sensors and the slower shutter speed. While the best model for fox occupancy was from the broadscale area survey, there was a marginally significant fit of the global model from the focused area data. The best model from this survey was $\psi(.)$, p(sector). This sampling design was likely compromised by the low number of sites in each sector (8–22) and the low proportional coverage of cameras within each sector (39%–56%). This coupled with a probable low density and spatially dispersed fox population resulted in the low precision of the estimates and generally poor fit of the data from the focused area survey.

For feral cats the model with the most support and the best fit to the data was for occupancy and detection probability to be constant in the focused area survey. This model showed that feral cats were likely to occupy 16% of the 96 sites across three sectors (range 10%–28%). The cumulative probability of detection for feral cats was greater in sectors two and four, and less, although still reasonable ($p = 0.51$) in sector one. No cats were detected in sector three. There was some support for camera type influencing detection for feral cats. There was no support for any of the *a priori* models tested in the broadscale area survey, with the global model being rejected as an adequate fit of the data and no clear difference in model selection.

There are several factors that may have combined to provide the conditions that resulted in the observed outcomes. Firstly, broadscale and continuous fox control has been in place in the Grampians since 2001, resulting in a low density and possibly spatially dispersed fox population. Secondly, the sampling rate (number of sites/1000 ha; Table 1) in the focused area was double that in the broadscale area survey, however, the total area covered was much less in the focused area 9375 ha v 68 000 ha respectively. Thirdly, red foxes and feral cats operate on different spatial scales. Home ranges (or territories) for red foxes vary with habitat richness, from 30 ha in urban areas to an average of 1600 ha in resource-poor alpine habitat; home ranges from 200 to 800 ha have been recorded in Australian forests (Phillips and Catling, 1991; Saunders et al., 1995). Home range (or territory) for feral cats has been less well studied in forested habitats in Australia. Buckmaster (2011) estimates the mean home range of eight feral cats in tall mixed forest in eastern Victoria (280 ha ± 89), he also reviewed the range of reported home ranges in the literature. For studies conducted in temperate environments in Australia and New Zealand estimates ranged between 105 ha (females) to 455 ha (males). Estimates of movement rates also differ between the two species. Molsher et al. (2009) investigated movement patterns of feral predators in an arid environment and found that the average minimum daily distance (non-linear) moved by red foxes (4553 m) was significantly higher than for cats (1519 m). Fourthly, detectability of a species can be influenced by behavioural factors, seasonality, density, local environmental factors, sampling designs, and specific methods (e.g. camera type). It is possible that detectability was influenced by one or a combination of these factors. In recent years there has been a series of large scale environmental disturbances in the Grampians National Park. In January 2006 a large landscape-scale fire burnt out 130 000 ha of the park and surrounding land, encompassing sectors one and three. Then in spring 2010 and summer 2011 severe floods also affected the park. Sectors two and four are located at the boundary of the park bordering private land. Sector one was located centrally, and sector three in an area without any ongoing fox control, while the broadscale area survey was located centrally in an area that has received constant fox control. Interestingly, Feral Cat and Red Fox detection rates were highest in sectors two and four, and these areas were not burnt in the 2009 wild fires. What influence these factors might have on distribution, behaviour and the physical environment and how it might affect detection and occupancy is unclear.

The data collected from the designs used fitted the occupancy models for red foxes and feral cats, but the power of these sampling designs to confidently measure a change in occupancy was limited. The results from the power analysis indicated that to be able to detect a moderate increase in either red foxes or feral cats, increasing the number of sites (approximately 125–150 sites) was required, and relaxing the risk (80% CI) of making a false-negative conclusion (i.e., falsely concluding an increase did not occur when in fact it did).

Robley et al. (2010) investigated the use of cameras to assess occupancy rates of feral cats and red foxes in forested areas of south-west Victoria. They estimated occupancy rates using two different sampling designs: a) two cameras within a 1 km^2 area at two separate locations (n sites = 22 and 15, n days = 21) and b) 1 camera within a 2 km^2 area (n sites = 49, n days = 28). Both designs were able to provide robust estimates of Feral Cat and Red Fox occupancy rates. Robley et al. (2010) investigated the power of their sampling design to detect changes in feral cats following control actions. The results indicated that there was little ability to detect a small change in feral cats; however the sampling design used would be able to detect a 43% reduction with >80% power. This is not dissimilar to results in this study, which indicate that a 50% increase (change) using 125 sites with 80% confidence would have a power of 0.8 for feral cats.

What level of increase in fox and/or Feral Cat occupancy rates should trigger a management response is a key unanswered question. For red foxes, the broadscale area survey indicated that 30% of sites were occupied; a 50% increase would suggest 45% of sites would become occupied. The relationship between this level of increase in occupancy and the impact on biodiversity within the park is practically unknowable. A precautionary principle might be that even a moderate increase in fox or Feral Cat occupancy should trigger some management response.

One difficulty in elucidating the causal relationship between a decline in fox populations and an increase in at-risk native species is the requirement to either relate indices of change to fox or Feral Cat abundance, or in estimating actual abundance of red foxes or feral cats. Enumeration of fox populations has been successfully undertaken in semi-arid Western Australia using DNA sampling techniques (Berry et al. 2012). This approach has the advantage of determining both current densities and changes through time which can be linked to management actions. This approach also has the possibility of understanding rates of turnover in the population and rates of re-colonisation. We would recommend that further work be undertaken to determine if this approach is applicable to the Grampians environment.

The analysis we undertook was based on the outcomes of the single-season occupancy model. MacKenzie et al. (2003) provides an important and potentially very useful extension of the basic single-season occupancy model which allows for season-to-season changes in the occupancy status of sites. This model (termed a ‘dynamic-occupancy model’) extends the basic occupancy model to allow for local extinction and colonisation processes which lead to changes in the prevailing rate of occupancy over time. Where a set of survey sites are monitored using remote cameras over the course of multiple years, the dynamic-occupancy model can be used to determine how occupancy rates change over time. This is particularly useful for monitoring studies, where knowledge of changes in the status of a species within a defined area is required, or for assessing the effects of management actions over time (e.g. the effect of control of an introduced predator on rates of site occupancy by both introduced predators and their prey). If camera monitoring is to be used to assess changes in red foxes or feral cats through time, i.e., to assess incremental changes over a number of years rather than the single between year assessment, we recommend that the dynamic-occupancy modelling approach be used and that the power analysis be redone using the results of that modelling process.

An unbiased camera monitoring protocol of red foxes and feral cats for the Grampians National Park is possible. The surveys undertaken in this trial provide the information for determining the number of survey sites and the number of repeat surveys required. In addition it is possible to explore trade-offs between bias (precision and accuracy) with cost.

5.1 Recommendations

In light of our findings and our previous experiences in using cameras to assess the occupancy status of red foxes and feral cats we recommend the following:

1. Parks Victoria state what level of change is required to be measured and at what level of certainty does this need to be measured. This is critical to setting the sampling design and will determine the number of sites needed. Based on the current work a minimum of 80 sites would be required to assess a 50% increase in red foxes, and for feral cats 100 sites with reasonable power at the 80% confidence interval.
2. Given the high rates of detection achieved in this and other studies of red foxes and feral cats we would recommend one camera per site and maximising the number of sites surveyed if cameras were limited. Cameras to be placed within 100 m of roads and tracks. It would be possible to undertake surveys in say two sessions, for example if only 50 cameras were available, these could be set at 50 sites for 28 days and then moved to another 50 sites for another 28 days. However, a critical assumption in the modelling is that the populations are closed (no births or deaths). Extending the sampling period beyond a single season breaches this assumption.
3. Surveys are conducted on an annual basis.
4. Assessment of fox and feral cat home ranges within the park would provide insights on the density of cameras required. At present the sample site is a point in space and unrelated to home range size and dispersion. Efford and Dawson (2012) question the reliability of occupancy estimates in continuous habitat that does not explicitly take into account home range size and dispersion.
5. While differences in camera type can be taken into account in the modelling process, we would recommend that the camera model be standardised, preferably to Reconyx infrared outdoor or professional series cameras.
6. Our modelling is based on an instantaneous change from one time point to the next using a single-season occupancy model. What may be of interest is the incremental change in fox and feral cats through time. This would require surveys to be conducted over more than two years and using a dynamic-occupancy model. We recommend that this be undertaken to examine the influence of colonisation and extinction rates on occupancy rates through time and the ability of the sampling design to detect change.
7. We would also recommend that in light of recent advances in DNA sampling techniques, a comparison of the costs and the appropriateness of using such approaches and camera surveys be investigated.

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