NSW National Parks and Wildlife Service

Feral cat monitoring protocol

NPWS Ecological Health Performance Scorecards program

Acknowledgement of Country

Department of Climate Change, Energy, the Environment and Water acknowledges the Traditional Custodians of the lands where we work and live.

We pay our respects to Elders past, present and emerging.

This resource may contain images or names of deceased persons in photographs or historical content.

Artist and designer Nikita Ridgeway from Aboriginal design agency – Boss Lady Creative Designs, created the People and Community symbol.

Cover photo: Camera image of a cat captured as part of the Ecological Health Performance Scorecards program/DCCEEW

Published by:
Environment and Heritage
Department of Climate Change,
Energy, the Environment and Water
Locked Bag 5022, Parramatta NSW 2124
Phone: +61 2 9995 5000 (switchboard)
Phone: 1300 361 967 (Environment and Heritage enquiries)
TTY users: phone 133 677, then ask for 1300 361 967
Speak and listen users: phone 1300 555 727, then ask for 1300 361 967
Email: info@environment.nsw.gov.au
Website: www.environment.nsw.gov.au

ISBN 978-1-923285-70-5
EH 2024/0305
October 2024

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Introduction

The feral domestic cat (*Felis catus*) is ubiquitous across the Australian mainland, exploiting a diversity of habitats. Cats prey upon mammals, birds and reptiles, and have been implicated as a factor responsible for the decline of many mammal species (Woinarski et al. 2015). Consequently, predation by feral cats in Australia has been listed as a key threatening process under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* and Schedule 4 of the NSW *Biodiversity Conservation Act 2016*. Effective broad-scale control methods for feral cats are generally lacking and they remain a threat to many Australian faunal species (Department of the Environment 2015).

Given that predation by cats is a threat to many native species, the NSW National Parks and Wildlife Service (NPWS) Ecological Health Performance Scorecards program (Scorecards) aims to assess and monitor the distribution and density of cats across the NSW national park estate and understand how these parameters change both spatially and temporally. Camera traps are widely accepted as a highly feasible method for surveying cats and can be used to effectively estimate distribution, activity and density. This plan presents a camera-based approach to monitor the distribution and density of feral cats across the national park estate in New South Wales.

Summary

NPWS will measure and report on the distribution and density of feral cats across the national park estate. Systematic camera-based surveys will occur at 8 Scorecards sites to estimate cat occupancy for the park reserves. In addition, camera arrays will be used to estimate cat density.

Preferred metrics for reporting are:

1. Occupancy to monitor change in cat distribution. This metric should be estimated using occupancy-detection modelling approaches where sufficient data are obtained.
2. Density to monitor change in cat abundance. Density, expressed as the number of cats per km^2, should be estimated using spatial capture–recapture statistical techniques incorporating detections of uniquely identified cats.

The survey methods for monitoring distribution and density use camera trap-derived data. The Scorecards surveillance monitoring program will establish survey plots, incorporating cameras, stratified over different vegetation formations and along environmental gradients ensuring replication within stratification units to achieve park-wide representation to assess cat distribution.

Camera arrays using white-flash cameras will be used to estimate cat density. Site selection and the configuration of camera arrays will be designed on a park-by-park basis taking into consideration logistical constraints, any observed patterns of occupancy of cats and park management activities.

All surveys to measure cat density on the national park estate are to be consistent with the methods outlined within this document. Exceptions will require approval.

Survey methods for research projects addressing specific questions related to cats will be considered separate to this protocol.

Distribution of cats

While it is highly likely that cats occur widely across much of the NSW national park estate, there is little data available in corporate databases (such as BioNet) to reliably inform distribution or patterns of occupancy in relation to vegetation and disturbance regimes in most reserves. An important starting point for any monitoring program is to understand where a species occurs.

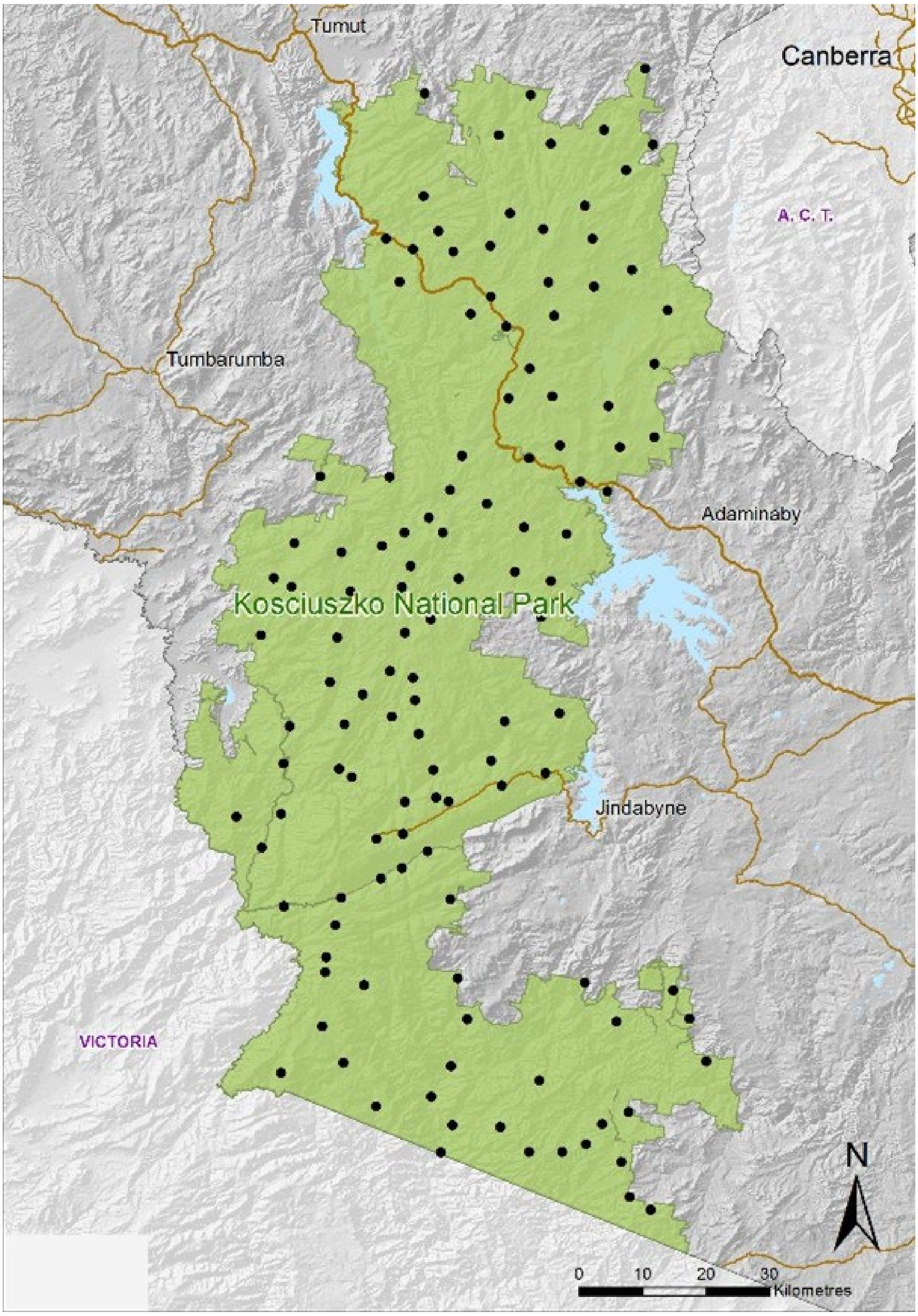
Survey method

As part of the Scorecards program broad-scale surveillance monitoring is being implemented across 8 park reserves, or park aggregates, which provides a model for understanding occupancy of cats and other species at the park scale (Figure 1). Within each of these 8 parks and aggregates, survey plots are stratified over different vegetation formations (dominant plant community type/s within each), and along gradients, such as elevation and fire history, ensuring replication within stratification units to achieve broad representation across the park (NPWS unpublished).

At each survey plot 4 cameras, a combination of infrared and white-flash, are deployed within a 1-hectare area with cameras spaced 40 to 70 m apart. Each camera is deployed in a different way (different camera heights and angles of focus) to maximise the detection of a variety of species. While detection rates of cats are typically low in most habitats and regions, this can be improved by using multiple cameras within a survey plot and deploying cameras for extended periods of time (e.g. greater than 30 days) (Stokeld, et al. 2015). A review of data collected in the early years of the surveillance monitoring program will be undertaken to (i) quantify the probability of detection of cats and (other species) given that they are present within a survey plot, and (ii) quantify various parameters relating to statistical power to ensure that changes in distribution and density can be reliably identified. Where required the monitoring approach (e.g., number of cameras per plot, duration of camera deployment, type of camera set-up, and number of plots) will be updated to achieve program aims.

Other programs such as the feral predator-free area program may incorporate alternate designs including cameras deployed on roads and trails and along fences as program objectives differ.

(a)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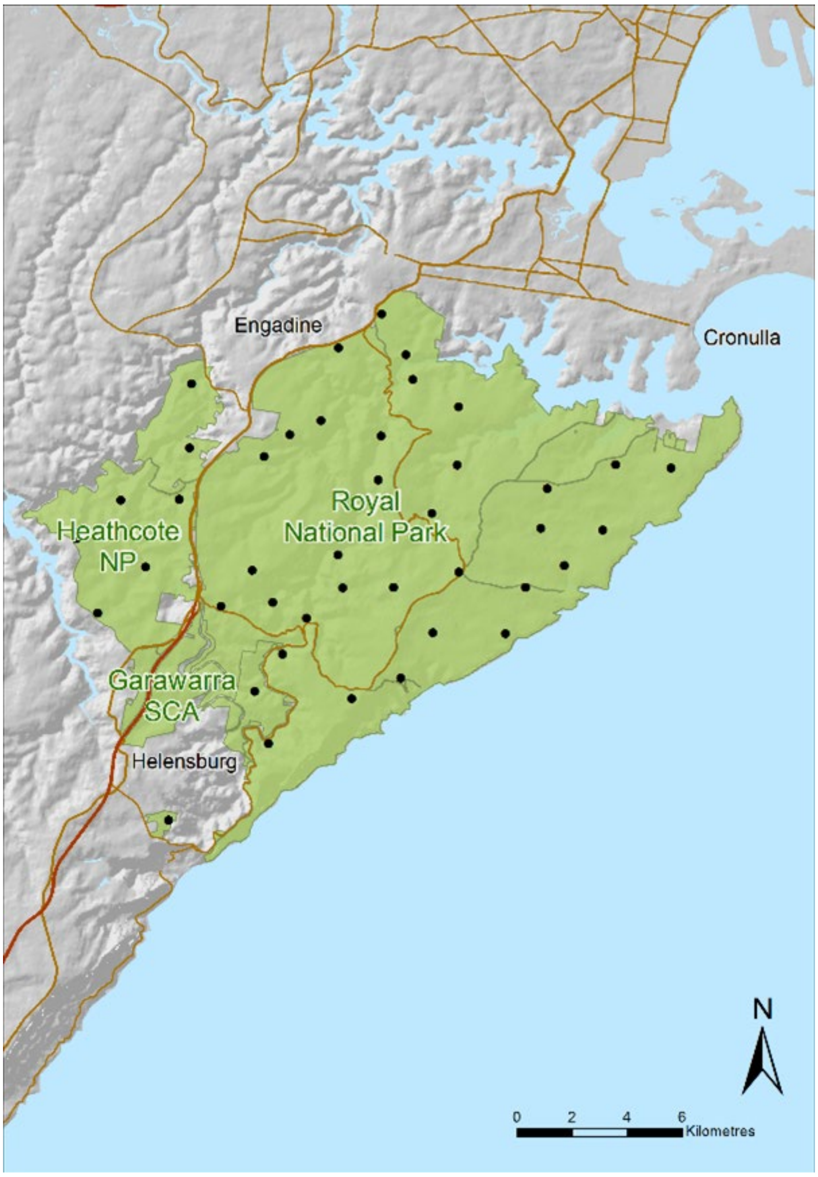

Figure 1 **Locations of Scorecards surveillance monitoring sites (black dots) across (a) Kosciuszko and (b) Royal national parks, which can be used to inform the distribution of cats at these parks**

Statistical methods and metrics

Statistical methods and metrics that can be derived from surveillance monitoring sites include:

- Naive occupancy: the proportion of sites at which a species was detected.
- Occupancy-detection models: a statistically derived model of probability of occupancy across sampled sites that takes into account the probability of detecting a species given that it is actually present at the site. Other factors such as environmental (e.g. forest type, weather) and methodological (e.g. camera type) can be incorporated to further explain species occupancy and detection.
- Count-based activity index: the total number of independent photo events (typically taken at 30-minutes time interval between repeat photos) per 100 camera trap-nights (O’Brien 2011).

Where cats are reliably detected from broad-scale surveillance monitoring, models can be derived to estimate species occupancy for the park reserve. These estimates can then be related to vegetation types and other ecological parameters. Using an occupancy-detection modelling approach considers imperfect and spatially varying species' detection, especially important when detection may co-vary with spatial variables such as habitat or temporal variables such as weather that are thought to influence presence (Gu and Swihart 2004; MacKenzie et al. 2006).

Where cat detections are insufficient to apply statistical modelling approaches, naive occupancy can be calculated as a minimum to provide a quantitative value to monitor over time. However, the NPWS WildCount program found a large difference between naive occupancy (16%) and modelled occupancy (38%) due to the low detectability of cats (NPWS, in review). Thus, naive occupancy will typically underestimate the distribution of cats.

An activity index can also be calculated and analysed using more sophisticated statistical techniques such as generalised linear models or generalised linear mixed models to assess changes in patterns over time and across sites (Hradsky et al. 2021). However, the use of these indices to make inferences about differences in abundance or density across time and space must be used with caution. For example, Sollmann et al. (2013) found that activity indices were biased by changes in home range, by how and where cameras were set up (e.g. on/off roads, camera models, ambient temperature), sample size, and changes in the detection of a species or individuals over time. While the use of a constant study design and comparable methods across sites may allow for some spatial and/or temporal replication, unmodelled variation in detection may obscure true underlying trends. Therefore, modelled occupancy or density are preferred metrics for long-term monitoring and will need to be balanced with available resources.

Density of cats

Spatial capture–recapture (SCR) analysis based on camera-trap images has been widely used to successfully estimate density of cats throughout Australia (WA: McGregor et al. 2015; NT: Stokeld et al. 2016, 2021, and Davies et al. 2021; Vic: Rees et al. 2019; SA: Hohnen et al. 2020). This combination of data capture and analysis thus offers a high probability of success in being able to estimate cat density in park reserves.

The metric that can be derived is density, typically expressed as the number of cats per square kilometre and includes a 95% confidence interval to provide an indication of the uncertainty around the estimate. The confidence interval represents the range of values (between the upper and lower interval) in which the true density lies with a probability of 95%.

Methods

Survey method

SCR models incorporate spatial information from detections with recapture data to estimate the density of a spatially distributed animal population which can be sampled with an array of detectors, such as cameras. The spatial arrangement of camera traps, the trap spacing, and the overall array configuration are important components of a good SCR survey design to generate high numbers of spatially dispersed individuals and associated recaptures (Sollmann et al. 2012, Efford and Fewster 2013, Royle et al. 2014).

To estimate the density of cats, large arrays of cameras (i.e. 60 to 70 cameras) should be deployed in grids or clusters to generate high numbers of spatially dispersed individuals and recaptures. As a rule, large arrays will be required to increase the number of unique individual cats ‘captured’, especially in areas where density is low, and cameras should be spaced such that as many individuals as possible are captured on multiple cameras to increase precision of density estimates (Royle et al. 2014).

If trap spacing is considerably larger than general animal movement then problems arise for SCR models. Precision of model estimates are highest when trap spacing is 1.5 to 2.5 times sigma (Efford and Fewster 2013, Royle et al. 2014). Sigma is a scale parameter in SCR models that provides an index of home range size, and for some species, such as cats, values of sigma may increase with decreases in density (Harmsen et al. 2020).

Previous studies in Australia have used arrays of 70 cameras which have achieved high-confidence density estimates even in areas with low density (Stokeld et al. 2016, 2021; Rees et al. 2019; Davies et al. 2021). These studies deployed a single camera at each location within the camera grid, Values of sigma estimates ranged from 300 to 700 m (Stokeld et al. 2016, 2021, unpublished data; Rees et al. 2019). In a regularly spaced grid of cameras (uniform grid), single cameras should be approximately 500 m apart so individual cats can be detected by multiple cameras within their home range. However, irregular grids and clustered designs can effectively use a range of spacings relative to sigma (500 m). The configuration of camera arrays can be flexible and adapted to the landscape, especially where difficult terrain will constrain camera placement (e.g. steep ravines).

Some studies advocate deploying cameras along roads and management tracks, primarily for logistical reasons, or to increase the detection of cats. However, this may facilitate a higher incidence of camera theft. Cats may move along linear features (roads, dry creek beds) for short distances (McGregor et al. 2015), but their preferential use of such features varies depending on circumstances. Stokeld et al. (2016) found that there was no influence of roads/tracks on individual detection and Hohnen et al. (2020) observed that detection was not consistent within habitat types. Further, the sole use of roads and/or management tracks for camera deployment can introduce bias and affect data interpretation (Sollmann et al. 2013). Ideally cameras should be placed away from roads (minimum 50 m), both for safety reasons and to minimise camera theft. However, placement of camera grids should ideally overlay road/track networks to improve accessibility. To increase the detectability of cats off roads, cameras should be placed in natural clearings/open areas, at ecotone edges, or along animal pathways. Based on previous studies, deployment duration should be approximately 8 to 12 weeks (Stokeld et al. 2015).

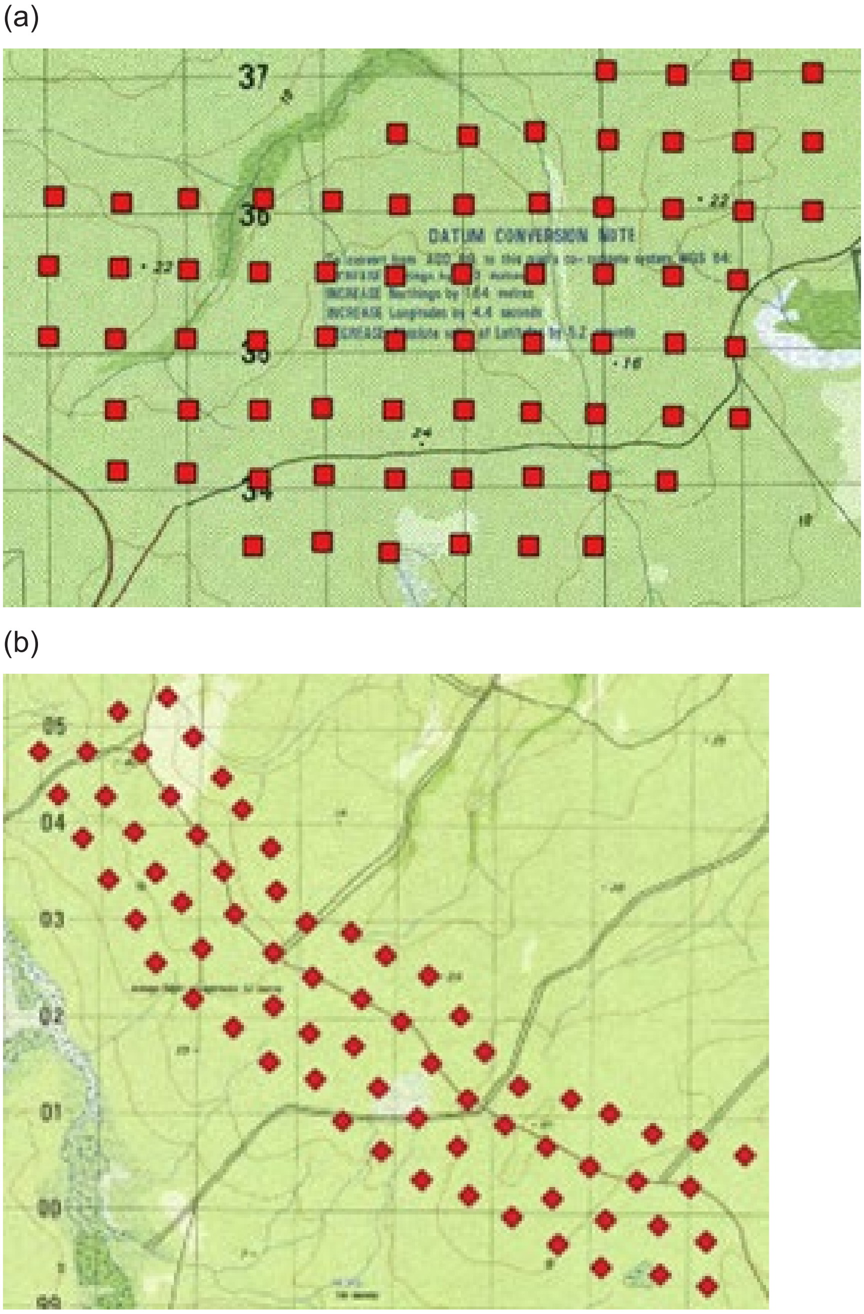

Figure 2 Examples of camera arrays utilising road networks for access. Red squares represent individual cameras

Site stratification

Park-wide estimation

Site selection of camera arrays for estimating cat density should be informed by the observed patterns of occupancy of cats where such information is available. To obtain robust park-wide density estimates, camera arrays should be stratified across different habitat types and across a gradient of high- to low-occupancy, and/or activity of cats, to encompass variation across each park estate.

Strategies to optimise the configuration of trap arrays over large study areas have been assessed by several practitioners (Efford and Fewster 2012, Sun et al. 2014, Royle et al. 2014). In general, uniform designs provide the most precise and accurate estimates of density (or the number of individuals). Cluster designs, being the primary alternative considered, can provide good estimates provided the clusters of cameras are spatially representative (i.e. randomly placed within the area of interest) and cluster spacing is not considerably greater than the movement of the species of interest (2 times sigma or less [≤ 1000 m]; Efford and Fewster 2012, Sun et al. 2014). As detection rates of a species decrease, more traps per cluster are necessary to detect individuals and subsequent recaptures (Sun et al. 2014). Recently, a design optimisation function, using a genetic algorithm, has been developed, which can incorporate logistical constraints (Dupont et al. 2021) and is available as a function in the R package oSCR (Sutherland et al. 2016). This allows for customised sampling designs to be developed.

Three design options are proposed for estimating cat density dependent on the geographic area of interest and logistical constraints that limit accessibility within the study area:

1. Replicate uniform or irregular camera grids

This design would be most applicable to small parks, or focal areas, where access constraints are not an impediment. Arrays of 70 cameras spaced ~ 500 m apart, as described above, are placed in at least one area of high occupancy and one area of lower occupancy and/or activity of cats, where this is known. Camera grids should be replicated to capture environmental variation (i.e. elevation, vegetation, fire regime).

For example, in Royal and Heathcote national parks and Garawarra State Conservation Area (18,169 ha) this would likely result in 2 camera arrays being deployed across the extent of the park aggregate as an initial design.

2. Camera grid combined with clusters

This design would be applicable to larger areas where accessibility constraints may be variable. This approach creates one large array across a high- to low-occupancy gradient, and/or activity of cats, and contains the environmental gradients of interest. Density estimation within the grid is modelled as a function of the spatial covariates.

The design combines uniform or irregular camera grids of 20 to 30 cameras combined with multiple clusters of 4 to 8 cameras to increase the area covered. Cameras are spaced ~500 m apart and clusters should be spaced approximately 1000 m apart (e.g. 2 times sigma*)* to maximise the chance that individual cats will be captured across clusters.

For example, in Kosciuszko National Park (689,726 ha) this will likely involve up to 560 cameras deployed strategically across the landscape capturing different elevations and vegetation types as an initial design.

3. Design optimisation implemented in oSCR

For any area of interest, an optimised design incorporating logistical challenges that limit accessibility such as remoteness and slope can be implemented in R using the 'oSCR' package and the scrdesignGA function. For more information see Dupont et al. (2021) and https://bookdown.org/chrissuthy/oSCRvignettes/criteria.html.

As with all survey designs, those proposed above will require ongoing review and optimisation following a period of data collection.

Management effectiveness

Where there is an objective to measure the effectiveness of a specific management regime for cat control, a Before-After-Control-Impact (BACI) design should be implemented. Such research should, however, be targeted at innovative management regimes or regimes where the effectiveness of cat control is not already understood.

Where a BACI design is justified, comparable treatment and non-treatment areas need to be identified with replicated sampling within each. Treatment and control areas need to be broadly similar environmentally. Importantly, monitoring needs to commence across treatment and non-treatment areas prior to the specific management intervention, then be repeated following the intervention.

For example, the Feral Predator-Free Area program will implement a BACI design as part of an approved ecological health monitoring plan for each site. Where practicable, each plan will be consistent with this design. However, there may be some variations to the methodology based on optimisation for target species (e.g. changes to the number and type of cameras, their placement – on and off roads – and the duration) and resource constraints.

Camera traps

Spatial capture–recapture analysis is a statistical technique used to estimate the local density of a target species. These models require that individuals are uniquely identified from individual markings. For this reason, white-flash cameras (Reconyx models PC850 or HP2W) are better for individually identifying a higher proportion of cats in both day and night images. Previous studies have shown that camera trap type (infrared and/or white flash) does not bias the detection of feral cats (McHugh et al. 2019; Taggart et al. 2020). However, the capacity of observers to identify individual cats from night-time photos is severely limited when photos are in black and white (in the absence of white flash). For example, Sparkes et al. (2021) found that less than 20% of cats could be individually identified in night images on infrared flash cameras. Furthermore, photos of ginger cats taken at night with infrared flash cameras are often overexposed reducing the ability to individually identify this cohort (Hradsky et al. 2021; Cove et al. 2022).

Standardisation of camera set-up (height, angle) is important to minimise variations in detection probability (Risler 2017). Cameras should be set at a height of 40 cm – heights of 30 cm (Rees et al. 2019) to 45 cm (Stokeld et al. 2016) have been used previously – and aimed at a lure 2.5 m away. Previous studies have shown that the use of scent lures (cat urine, peanut butter and oats, chicken neck, tuna oil) have no discernible effect on the detection of cats (Stokeld et al. 2015, 2016; McHugh et al. 2019). However, where cats encounter scent lures they remain in front of the camera longer and more photos are taken, capturing different angles of the cat (Stokeld, unpublished). Therefore, a scent lure should be used with all camera set-ups. Cameras should be programmed to take at least 3 consecutive photographs when triggered with no quiet period between trigger events.

Individual cat identification

Camera trap images of cats are grouped into independent detections, usually based on a 30-minute time interval between repeat photos of the same animal. Three observers should be used to independently identify discrete detections of a cat to a unique individual based on coat colour and pattern variation on the front legs, torso, tail and across both flanks. To be repeatable and editable, one observer should invest considerable time in identifying each detection and developing a dossier for each unique cat which notes unique pelage patterns, morphology and features. The other observers review all the images of each identified cat and benchmark (and edit) against the dossier to ensure correct identification. When consensus across all observers is achieved a daily capture history can be generated for each individual cat for analysis.

Some cats will be unidentifiable from camera images, such as black cats. These will be assigned as ‘unmarked’ individuals. Other images may be blurred making confident assigning to an individual difficult and may be identified as ‘uncertain’.

Data analysis

SCR models incorporate spatial information from detections with recapture data to estimate the density of a spatially distributed animal population, which can be sampled with an array of detectors, such as cameras. SCR models have increasingly been used for combining capture–recapture data with variable levels of individual identity information to estimate population density and other information (i.e. animal movement, habitat selection, population turnover).

In SCR models the probability of capture (detection) is modelled as a function of the distance between an individual’s activity centre and the camera trap location where an individual is photographed. Density is then estimated with a Poisson point process model (Efford et al. 2004). As inaccessible areas in the landscape (i.e. rivers, lakes) affect the geometry of the home range of animals, a habitat mask should be developed to define the boundary of accessible habitat around the camera array and to restrict the state-space in the model (see Efford 2022a).

The simplest SCR model utilises all detections of an individual cat. This can be run in the R package ‘secr’. A guide to implementing these models can be found in Efford (2022b).

To model variation in density over the landscape as a function of a variable such as elevation or vegetation type, spatial datasets can be used in the habitat mask and the variables used in the ‘secr’ model. A guide to implementing these models can be found in Efford (2022c).

An extension to SCR is spatial mark–resight (SMR) which enables estimation of density when only a portion of the population can be individually identified (Sollman et al. 2013). This model can also be implemented in the R package ‘secr’. A guide to implementing these models can be found in Efford (2022d).

More recent extensions to SCR models include the random thinning spatial capture–recapture model (Jiménez et al. 2021) and the categorical SCR model (Augustine et al. 2019). These models have now been combined to allow for unbiased estimation of density when photos can and cannot be identified to individual (Cove et al. 2022). This combined model incorporates coat characteristics to better account for the variability in identifiability across individuals and more effectively remove individual heterogeneity in detection. It thus increases the precision of density estimates across a wider range of values, even when density is low. Implementing this model requires advanced statistical skills and is fitted in a Bayesian framework.

Resources

For 70 cameras the following equipment and approximate staff resources are required:

Equipment

Cameras: 70 Reconyx PC850 or HP2W

Batteries: 840

SD cards: 70

SD card reader/s for camera set-up

Approximate equipment cost: $50,000

Personnel

Equipment preparation: 2 people, 2 to 5 days, dependent on use of rechargeable versus non-rechargeable batteries

Camera deployment: 2 people for 5 to 8 days, dependent on terrain (8 to 14 camera deployments per day)

Camera retrieval: 2 people, 3 to 6 days, dependent on terrain

Equipment maintenance: 2 people, ~ 3 days

Image analysis and entry: 2 people 6 to 10 weeks dependent on number of images and platform used for image processing

Cat identification: 3 people, ~ 2 days dependent on number of cats

Data analysis: 3 to 5 days dependent on model run time

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