Guidelines for monitoring deer populations

A glovebox guide for practitioners

J.G. Cally and D.S.L. Ramsey

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Arthur Rylah Institute for Environmental Research

Arthur Rylah Institute for environmental research

Victoria State Government | Energy, Environment and Climate Action

Author

Arthur Rylah Institute for Environmental Research
Department of Energy, Environment and Climate Action
PO Box 137
Heidelberg, Victoria 3084
Phone (03) 9450 8600
Website: www.ari.vic.gov.au

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Front cover photo: Sambar deer from a camera trap deployment – Justin Cally.

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it.

We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

DEECA is committed to genuinely partnering with Victorian Traditional Owners and Victoria's Aboriginal community to progress their aspirations.

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Contents

Introduction to this glovebox guide

Background

Several species of deer (Sambar, Fallow, Red and Hog) have widespread established ranges across Victoria. Deer are valued as a recreational hunting resource but can also negatively impact biodiversity and agriculture. Preventing the range and/or abundance expansion of these invasive species can protect biodiversity, public safety, water quality, agriculture, and Aboriginal cultural heritage values.

Who is this glovebox guide for?

These guidelines are for land managers and local organisations undertaking deer control programs. We introduce simple and practical methods to detect deer presence in an area and to estimate relative deer abundance. These methods are relatively cheap and easy to implement and are suitable for monitoring deer at local scales (i.e. < 5,000 ha).

The methods provided here are abridged versions of a more in-depth exploration of monitoring in an accompanying technical report (Cally and Ramsey 2025).

Methods for monitoring the impacts of deer on native vegetation are not included in this guide but can be found elsewhere (Bennett *et al.* 2022).

How can monitoring benefit deer management?

Collecting data to determine deer presence or abundance can help target where and sometimes how to control deer. Monitoring deer can also help determine the effectiveness of control efforts.

Here we provide guidelines for how to (i) identify your goal for monitoring deer, (ii) select a monitoring procedure suitable for your goal, (iii) implement the method, and (iii) analyse and interpret the data from the method.

Accompanying this guide is an online site-selection tool/app that can be used to help design a monitoring procedure for an area using a relatively simple method based on camera trapping (https://arisci.shinyapps.io/deersim/).

How to identify your goal

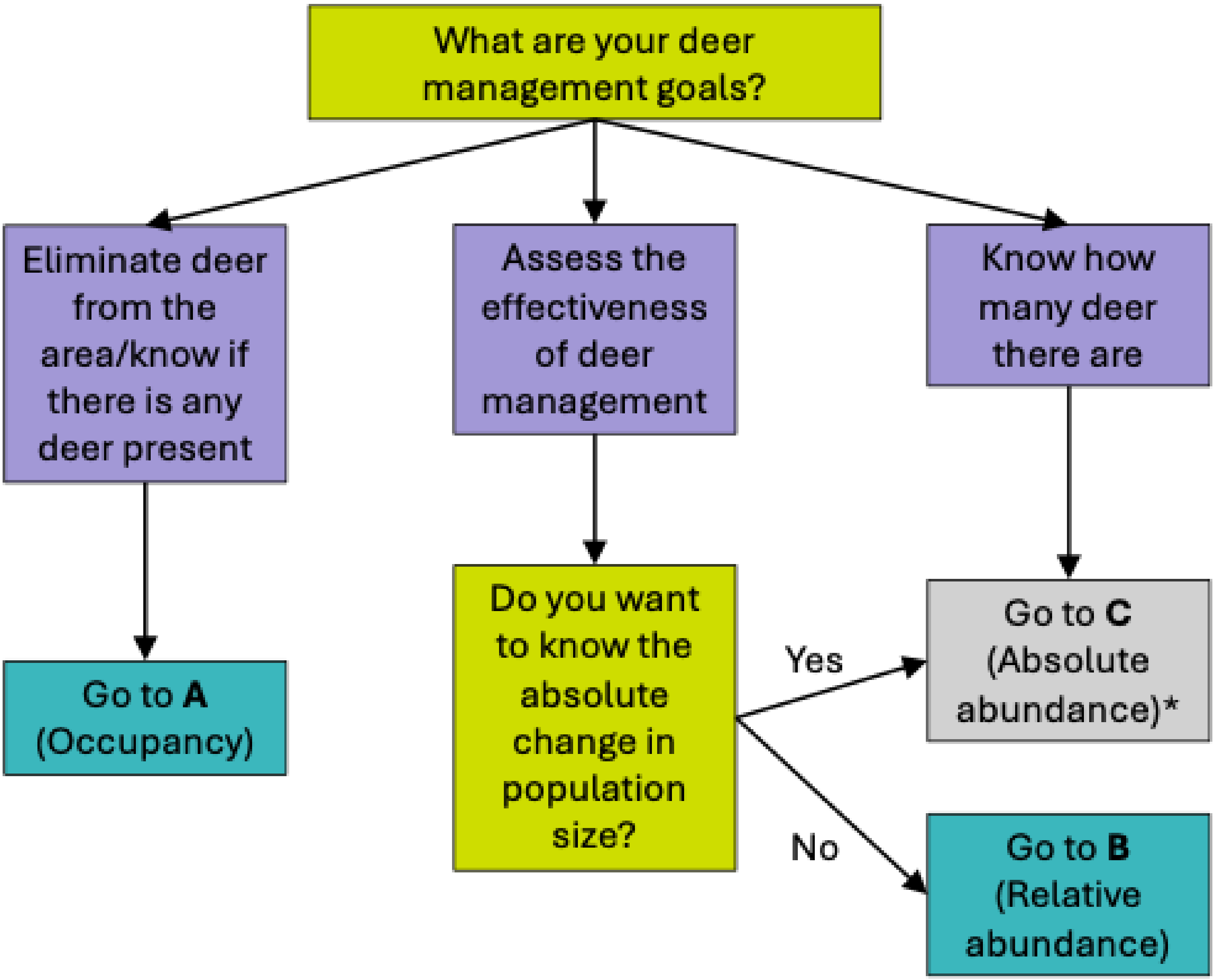
The data collected for a monitoring program must provide adequate information to help answer the management question(s). A management question can be as simple as, 'Are there any deer in my area?' This requires an estimate of deer *presence* or *occupancy*. Alternatively, 'I have just completed some deer control, but have I reduced the number of deer in my area?' This requires us to measure the *effect* of control, which could be measured using a *relative abundance index* (RAI).

Where the effect of a management intervention is small, we will need greater sampling intensity to detect it. Sometimes project budgets don't allow adequate sampling intensity to answer the question conclusively. In these cases, careful thought is needed about what questions can be answered using the information collected within the scope of the available budget.

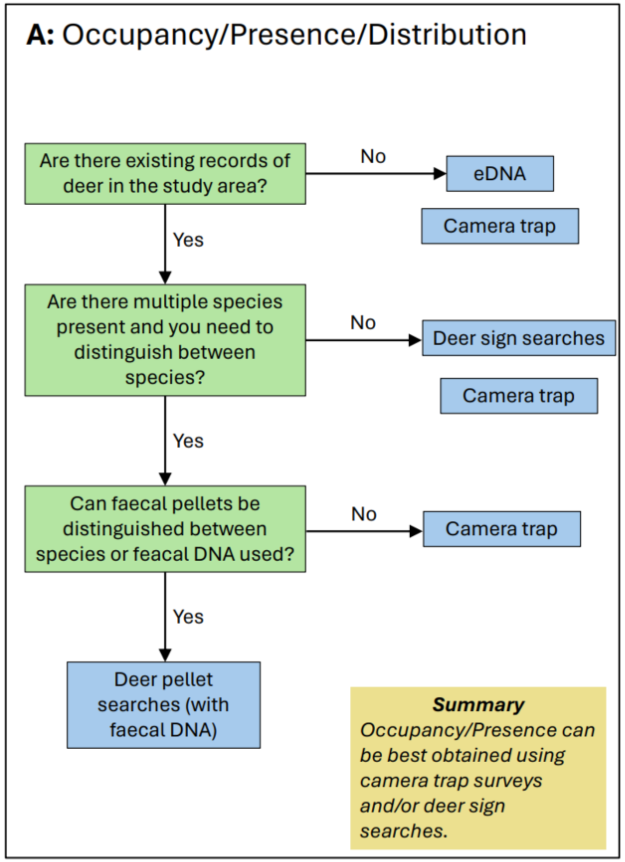
The following flowchart can help select an appropriate method. Further information about goal setting can be found in the companion technical report (Cally and Ramsey 2025).

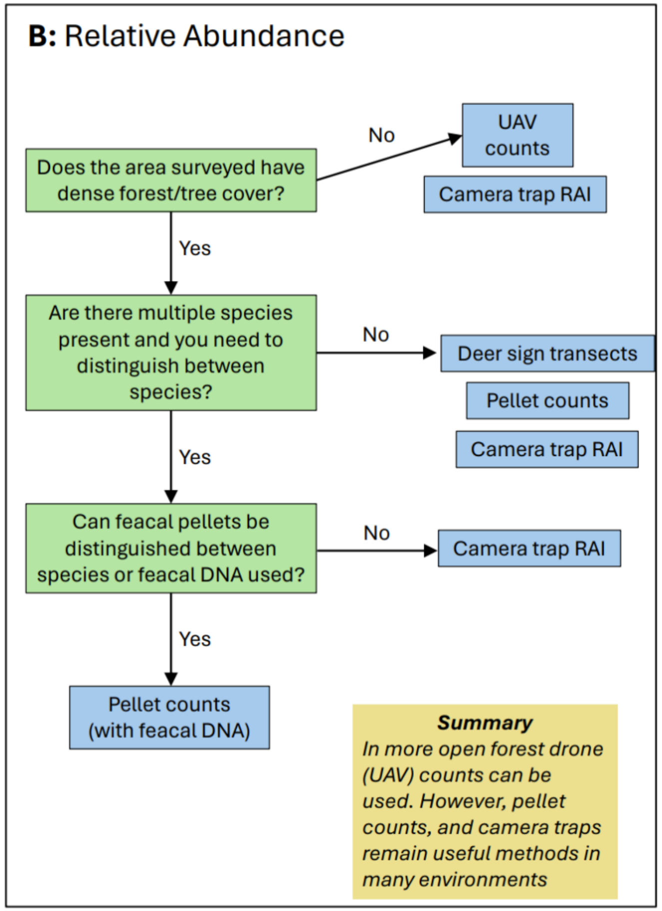
Selecting the right monitoring methods – Flowcharts

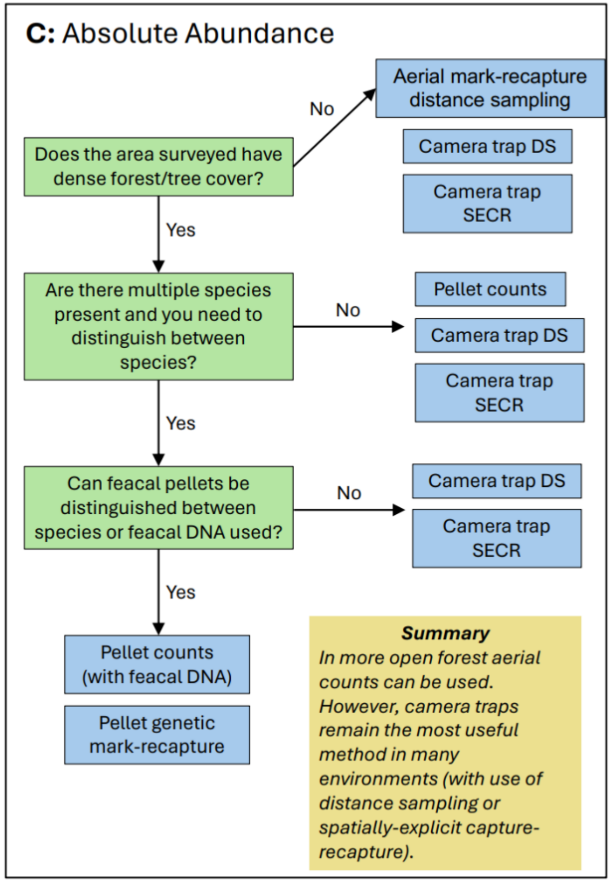
The following four flowcharts are provided as a tool to guide the selection of appropriate monitoring methods, based on the management objectives and an understanding of the habitat and species being surveyed.



* Absolute abundance methods are not provided in the 'glovebox guide'. For a more detailed description of these methods see the accompanying technical report (Cally and Ramsey 2025).







RAI refers to 'relative abundance index'.

SECR refers to Spatially Explicit Capture-Recapture, as detailed in the accompanying technical report.

Plan

Step 1: What do I want to do?

The aim is usually to reduce the number of deer. You might want to protect an asset or reduce safety risk in a particular area. Monitoring can be used to work out where deer are and where to do your control.

Another aim can be to work out how effective your control activities are. To do this, you'll need to monitor before and after deer control. You can either monitor changes in abundance of deer or changes in impacts of deer (e.g. browsing of a rare plant species).

Other times, presence-absence information is sufficient. Under different management objectives, the approach taken to monitoring and the information needed will differ (see Flowcharts).

Step 2: Where should I monitor?

The second step in monitoring design is to decide on the geographic extent of sampling (i.e. the study area). If the goal is simply to know if deer are present within a relatively small area (e.g. forest/woodland block < 100 ha), then a formal monitoring design is probably not required. Simply conduct monitoring as many locations as possible using one of the methods in this guide.

When selecting an area to monitor, it is important to understand two key principles: (1) sample sites can only be drawn from the extent of the study area, and (2) those samples only represent deer populations/activity within the extent of that area (and not outside it). Importantly, conclusions should only be drawn about the deer population within the area surveyed. Practically, this means if you are only drawing samples from within a given area (e.g. Kinglake National Park), you cannot use the results to predict what is happening in neighbouring areas.

If the study area is a publicly tenured land parcel (e.g. national park or conservation reserve) a potentially useful resource is the expected range and abundance of Sambar, Fallow, Red, and Hog deer (Cally and Ramsey 2023) and it can be accessed through DEECA's spatial DataShare.

Step 3: What monitoring methods should I use?

Step three entails deciding what type of technique and measure will be used for monitoring. Numerous methods exist for surveying deer and estimating deer abundance. In this glovebox guide, we describe two of the most useful methods suitable for a wide range of monitoring goals and situations; counts of deer sign (pellet counts), and motion-sensitive cameras (hereafter camera traps; Figure 1). A more comprehensive set of monitoring methods is described in the companion report to this guide (Cally and Ramsey 2025). The accompanying flowcharts be used to help select an appropriate method.

Step 4: Site selection and survey effort

Step four determines the location and number of sampling sites (sample size) and the survey effort (e.g. how long to leave camera traps out for, or length of deer search transects). Sites (e.g. camera trap locations or deer-sign transects) are selected from within the study area and should be representative of the study area/extent.

Non-random site selection (i.e. sites chosen in specific locations) should generally be avoided unless the objective is just to identify deer presence within a relatively small area (e.g. < 100 ha). In other cases, non-random site selection may result in biased estimates, and the conclusions drawn will generally be unreliable.

Random site selection (see accompanying online app: https://arisci.shinyapps.io/deersim/) ensures that sampling is representative of the area monitored and will provide unbiased estimates but may be relatively less efficient in the field due to the need to navigate to random locations.

Another alternative for site selection is the systematic placement of sites, with a random starting location. Systematic placement can be useful for ensuring good representation and coverage of the area and is relatively easier to implement in the field.

However, in both cases, the number of sites required to be monitored (survey effort) needs to ensure estimates of deer occupancy or relative abundance have adequate precision. The precision of estimates of occupancy or relative abundance (e.g. deer encounters on a camera trap per day) is usually measured by the standard deviation, but a more useful measure is the relative standard deviation, also called the coefficient of variation (**CV**). The coefficient of variation is calculated simply as:

$$\boldsymbol{CV = \frac{SD}{Estimate}}$$

Where $\boldsymbol{Estimate}$ refers to the mean estimate of deer occupancy or relative abundance (e.g. 2.3 camera trap encounters per day) and $\boldsymbol{SD}$ is the standard deviation of the mean estimate. A good rule of thumb is to undertake enough sampling effort to obtain a CV 0.3 (Robson and Regier 1964).

The accompanying app (https://arisci.shinyapps.io/deersim/) can help select an adequate number of sites using different sampling methods (random or systematic) and sampling efforts within an area to obtain an adequate CV. To use the app to determine a sample size big enough to get precise estimates of relative abundance (CV < 0.3), select your area and run the simulation with between 20 and 40 sites at a starting point. If your CV is estimated to be above 0.3, add more sites and repeat the process until CV drops below 0.3. Note that if you are restricted in sampling by the equipment (number of camera traps), you can stagger camera trap deployments to allow for a given camera to be collected and redeployed at multiple locations. However, the longer that these redeployments last the more chance that seasonal changes in deer density may lead to more variable or biased estimates.

Figure 1 - Using the walktest mode when setting up a camera trap can help ensure the camera trap triggers. Photo by Nick Esser (Parks Victoria).

Step 5: Documenting survey methods and results

Once you have completed your field monitoring, you will have collected data on locations of deer sightings and/or signs. This survey data should be made available to state environment departments and included in fauna databases to help build a more accurate picture of deer in the landscape, improve the accuracy of population modelling, and inform management at landscape scales.

These are a couple of suitable options for recording the results of your monitoring program.

Victorian Biodiversity Atlas

The Victorian Biodiversity Atlas (VBA) is a tool for everyone interested in species information across Victoria. Government agencies, environmental consultants, researchers and the public can update and use the information in the atlas to understand what animals and plants we have in the state and where live.

Trail cameras and other survey data can be uploaded to the VBA. As a camera may collect multiple deer sightings throughout a monitoring period, a blank 'count' field can denote presence only. A 'zero' count field denotes that effort has been made to find but not discover any deer.

The basic information needed to form a record is who identified the species, when this was (start date), where it was (either pinpoint on the map or upload GPS coordinates), how you observed the species e.g. incidental or during a targeted survey, and finally which species you observed.

VBA is primarily a tool for sharing your observations and survey effort. If you wish to search and generate reports on Victorian biodiversity and species information please use the NatureKit.

Instructions for how to use VBA can be found here: www.environment.vic.gov.au/biodiversity/victorian-biodiversity-atlas/about-the-vba, noting that there are also data standards that apply.

FeralScan / DeerScan

DeerScan is a free resource that anyone can use to record sightings, damage and control of introduced and invasive species. Deer data records are desensitised, giving landholders the confidence to record local sightings.

DeerScan can be used to inform neighbours and local biosecurity authorities about current deer problems.

Trail camera images can be easily uploaded from an SD card. See instructions here - DeerScan wildlife camera image instructions.

You can access DeerScan via www.deerscan.org.au or download the 'FeralScan' App and follow the deer prompts.

Figure 2 - Sambar deer captured on Reconyx trail cameras (Cally 2024).

Monitoring methods

Camera trap surveys

Camera traps (Figure 2) can be used to estimate abundance and occupancy (Cally and Ramsey 2023; Bengsen et al. 2022). They can operate remotely for long periods, provide robust evidence of presence, are relatively quick and simple to set up and can provide extensive information about a target and non-target species that can help estimate abundance and occupancy.

Below we provide information about which cameras to use, how to program them and then how to deploy them.

We have also developed an online app to accompany these guidelines that can help with survey design for camera trapping (https://arisci.shinyapps.io/deersim/). This app can help select the number and locations of the sites to survey to achieve a desired level of precision (CV) in the camera trap relative abundance index (Figure 3, Figure 4).

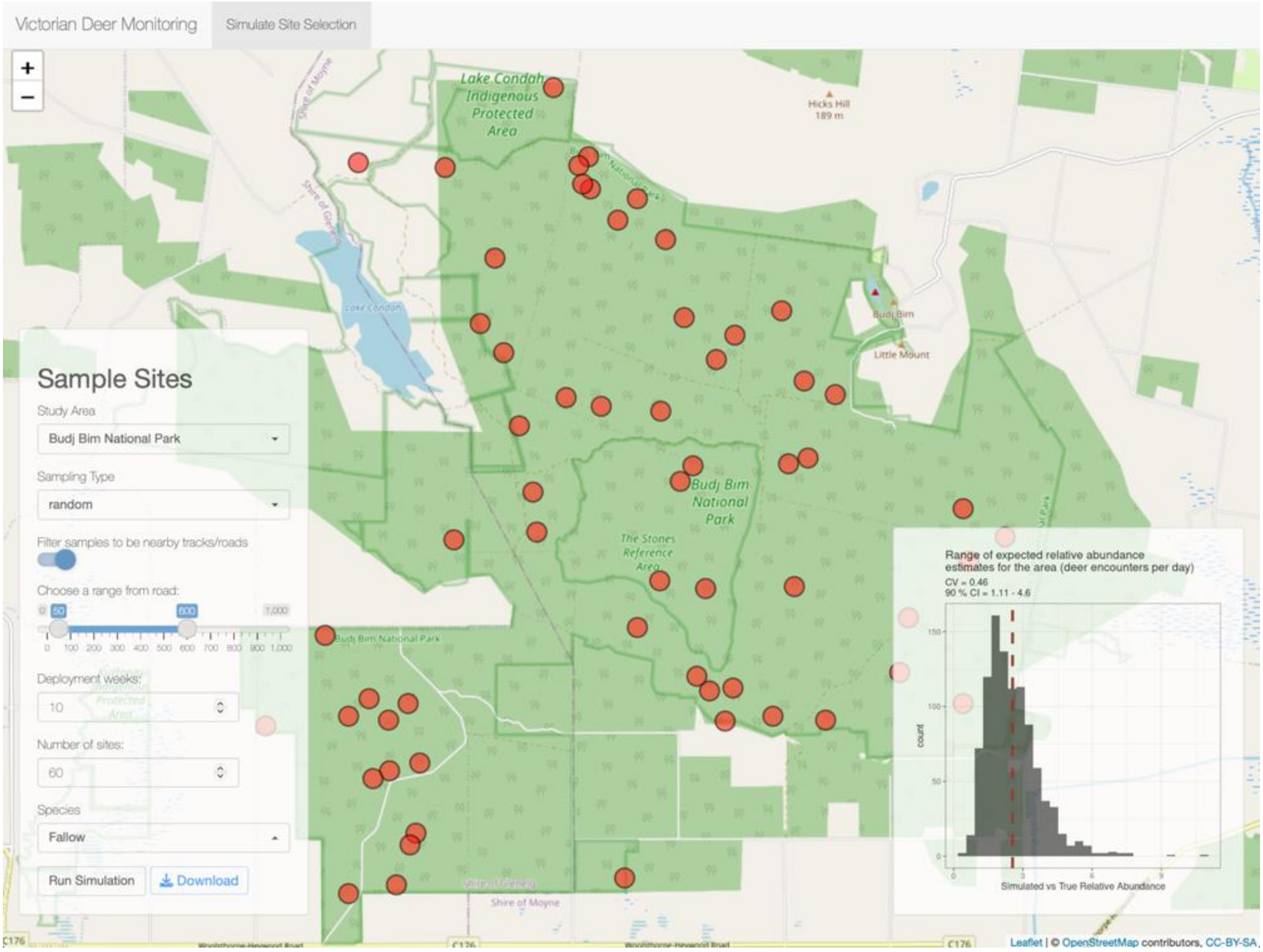


Figure 3 - A screenshot of the site selection simulation app (https://arisci.shinyapps.io/deersim/). Within a given area, sites are sampled, and a relative abundance distribution is simulated for that area. Site locations can then be downloaded as a shapefile.

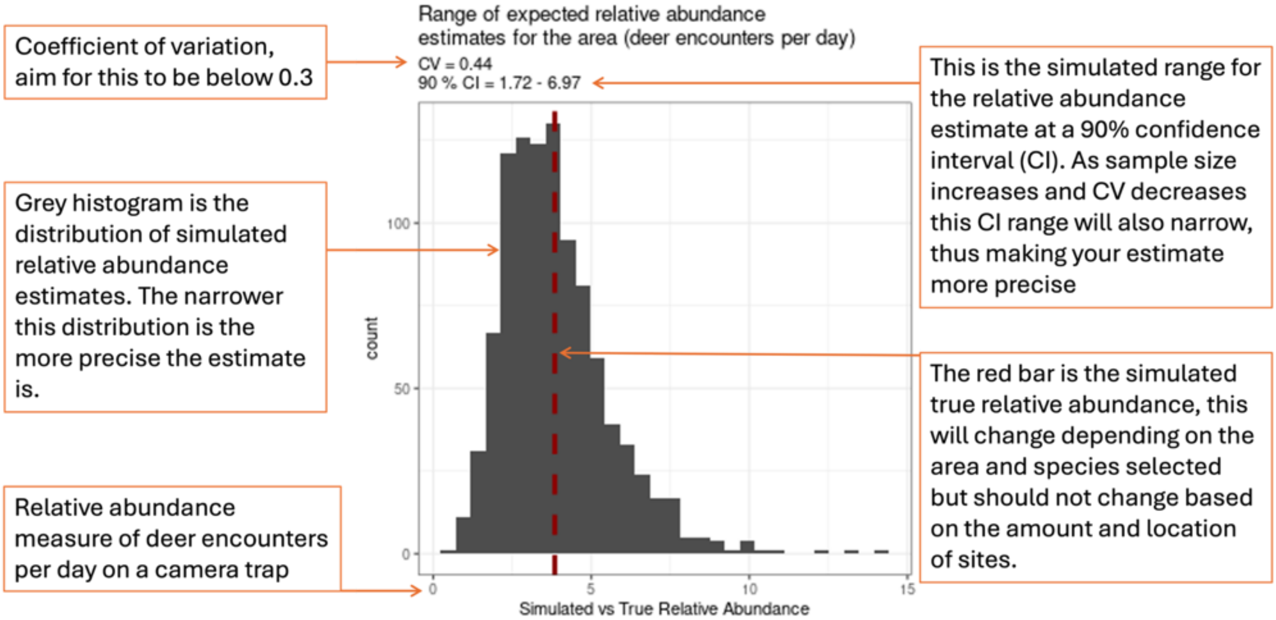


Figure 4 - Explanation of how to interpret the results from the site selection simulation app (https://arisci.shinyapps.io/deersim/).

Camera models

Several brands and models of infrared/motion-sensor camera traps can be used to survey deer.

Brands and models vary in cost, sensitivity, programmability, longevity, and image/video quality. ARI exclusively used Reconyx Hyperfire 2 HF2X camera traps for a recent statewide survey of deer (Cally and Ramsey 2023). This model provided a suitable balance between cost, reliability and image quality, but other models and brands may have been equally as effective.

For consistency in camera sensitivity across a project, we recommend using the same or similar models of cameras; otherwise, potential differences between models should be accounted for during analyses using more complex statistical models. Camera sensitivity refers to the amount of movement/thermal signature required to trigger the camera. A high sensitivity will allow more frequent capture of smaller animals, or animals further away; but may lead to more false detections (e.g. triggered by leaves blowing in the wind).

For these guidelines, we will refer to the programmable settings of a Reconyx Hyperfire 2 HF2X (Figure 5). However, any camera used should be able to operate nocturnally with covert infrared flashes.

Camera traps with white flash (e.g. Reconyx Hyperfire 2 HP2W) are not recommended as the flash may startle deer; species identification of deer is possible from black-and-white nocturnal photos taken using infrared/black flash.

Figure 5 - Reconyx HF2X camera trap mounted to a tree with a python-lock. Photo by Nick Esser (Parks Vic).

Camera settings

When choosing the programmable settings for a camera trap, the main goal is to reduce the number of photos with no animal in them (false positive) and reduce the number of times an animal has entered the field of view, and the camera has not fired (false negative).

Often, we may tolerate modest levels of false positives (false triggers) as they marginally increase processing time and storage costs. On the other hand, high rates of false negatives may have severe impacts on the accuracy of analyses and conclusions as cameras fail to detect deer that are present.

We also want to ensure that photos are taken rapidly enough and for long enough to give us the best chance of positively identifying the animal that triggered the photo. The programmable settings that were used in the recent statewide surveys for deer (Cally and Ramsey 2023) are shown in Table 1.

Depending on the goals and methods of your monitoring, camera settings may differ from those listed in Table 1, but we recommend these as a starting point. If your camera has a setting for a delay between camera bursts, ensure this is turned off so that there is no risk of animals being missed.

When setting the camera, users should ensure that the date and time are correctly set, and the type of batteries used are correctly entered when prompted (e.g. NiMH).

Users can also ‘geotag’ the camera deployment with latitude and longitude during camera programming; however, this is not necessary if the camera location is stored on other data sheets/apps.

A 32GB SD card can usually record 40,000 – 50,000 photographs on the HF2X, with this threshold only likely to be hit when excessive false triggers occur (although this will depend on the duration of the deployment).

Good-quality rechargeable batteries should allow continuous operation for at least three months.

Table 1. ARI camera and deployment settings used for statewide deer monitoring. Users should refer to product manuals for more information on the purpose and customization of settings.

Type	Specification	Selection
Camera Settings	Brand	Reconyx
	Model	HF2X Hyperfire 2
	Method	Motion
	Number of pictures	5
	Time between pictures	Rapidfire
	Motion video	Off
	Quiet period	Off
	Sensitivity	High
	SD card	32 GB Scandisk SD
	Batteries	12 Rechargeable Fujitsu NiMH AA (1900 mAh)
Deployment Settings	Camera height	1 metre above ground
	Camera angle	Horizontal to match slope
	Camera bearing	South-facing or as-close to as possible
	Camera slope	Flat or gentle slope (if possible)

Camera deployments

Camera deployment should be consistent across sites. The number of sites can be determined by using our accompanying app (https://arisci.shinyapps.io/deersim/) or in more technically complex simulations, statisticians and ecologists should be consulted.

The number of cameras being deployed will depend upon budget, the area being surveyed, an acceptable level of precision and the underlying expected density of deer (i.e., if deer are very scarce, more cameras will likely be needed than in cases where deer are prevalent). Camera height, angle, bearing, and slope should be the same across sites, and obstructing vegetation should be minimised at each site (see Table 1).

Using the settings in Table 1 should optimise the probability of detecting deer up to 12.5 m away from the cameras. Below we provide the detailed steps you should take when deploying a camera trap to monitor deer:

1. Check the camera has charged batteries and a blank SD card before walking into the site. Numbering/labelling the SD card can be a good strategy to ensure the photos can be correctly matched up to the site location. To minimise theft, camera deployments should not be visible from the road (e.g. 100+ m).
2. Note that if cameras are deployed to target microhabitats where you think deer will be more active (e.g. at a wallow), then estimates of abundance will be biased. Cameras should be deployed randomly without specifically targeting such microhabitats, unless you are only interested in monitoring deer use of those microhabitats.
3. At the location where you plan to deploy your camera, find a suitable tree on which to mount the camera. In treeless landscapes, cameras will need to be mounted to stakes/posts, which you will need to bring to the site. The tree you mount the camera on should be sturdy enough to avoid being swayed under strong winds, but not too large so that straps/python locks cannot wrap around the tree (e.g. DBH between 50 cm – 1.5 m).
4. Ideally, cameras should be orientated southward to avoid glare from the sun, and where possible on a flat or gentle slope.
5. Once a suitable tree and orientation are chosen, ensure that there is good visibility in

front of the camera (up to 12.5 m). In certain environments, pruning of vegetation and moving debris will be required (e.g. areas with recent fires usually have dense understorey). Vegetation in the field of view that may sway/move in the wind can cause excessive false detections and block the view of the animal triggering the camera.

6. Secure the camera to the chosen tree 1 m above the ground and try and align the angle to match the angle of the slope. Cameras can be attached with straps, or python locks (or both) to minimise theft.
7. Test the camera is functioning and able to detect motion up to 10 m by using the 'walktest' function (Reconyx models); this mode flashes a red light when motion is detected (but does not take a photo). Based on the feedback from the 'walktest', you may need to slightly angle the camera up/down/left/right, this can be easily done by wedging a small stick behind the camera. Alternatively, if the 'walktest' mode is not available for your camera, you may need to check sensitivity by arming the camera, taking test photos, and then viewing them with an SD card viewer/laptop/handheld digital camera before finally arming/deploying the camera.
8. Once you are content with the results/feedback from the 'walktest', you can exit the field of view of the camera. Reconyx cameras will automatically arm after several minutes of no detections when operating under the 'walktest' mode. This is useful as it means you do not have to open the camera trap and 'arm' it manually, which could knock out the alignment of the camera.
9. Additional covariates in the detection or activity of deer can be recorded on a separate data sheet at this point for use in the analyses (e.g. woody understorey cover, and other structural vegetation properties). These covariates may impact detection probability and thus influence abundance estimates. Taking these into consideration during analysis may minimise bias.
10. Before you leave the location, make sure that data regarding the deployment has been recorded. Importantly the date/time and the location (latitude/longitude) should be recorded on data sheets/apps and GPS devices. Data can be recorded on paper field sheets or phone/tablet applications such as Survey123 (https://survey123.arcgis.com), or ProofSafe (http://www.proofsafe.com.au), the latter of which is used by ARI to record data during most wildlife ecology fieldwork. At a minimum, it is paramount that you can at least record the data spatially and temporally by matching the camera's SD card data with geographic coordinates.

Camera retrieval

We recommend cameras be left out on site for between six and twelve weeks. This ensures a higher likelihood of detection if deer are present.

In sites with medium to high densities of deer present, it is more likely that you will detect at least one deer during a deployment. However, in areas where deer density is lower (e.g. 1 deer per km2), the likelihood of detecting at least one deer will be lower (Cally and Ramsey 2023).

Cameras should be deployed for the same duration at each site in a study. If not, you must account for varying deployment durations during analysis.

The process for retrieving cameras is relatively simple:

1. Attend the camera location, switch off the camera (press 'okay' first if using any Reconyx camera) and unmount it from the tree or stake. If the camera was secured using a Python lock, make sure you have the correct key/combination.
2. Record the date-time of retrieval and other valuable information (e.g. camera condition).

Photo storage

Camera trap surveys come with a burden of storage costs for images and/or videos.

For many analyses, data can be extracted from image metadata (e.g. date-time and species tags), tabularised and then analysed; with the original photos no longer required. For instance, at ARI, a database has been created to store image metadata, and associate camera trap deployment details (e.g. where, and when).

However, when extracting metadata, certain information may not be tagged and extracted from the images (e.g. distance, sex, age) initially and the images may have wider uses after the original project (e.g. studies on other species or use of images to train image recognition software). Therefore, images must be stored in a structured, secure, and accessible format for future needs.

Cloud-based or local server/hard-drives may be used to store images.

An ideal directory structure allows for easy navigation through survey periods and sites. An example structure for a survey across two repeat survey iterations (seasons/years), three sites, and each site having two cameras may look like the following:

```
Deer-Project-|
        |-Iteration-1-|
        |       |- SiteA -|
        |       |- SiteB -|
        |       |- SiteC -|
        |       |       |- Cam1 -|
        |       |       |- Cam2 -|
        |       |       |       |- IMG01.jpg
        |       |       |       |- IMG02.jpg
        |-Iteration-2-|
```

Data can also be stored and tagged using third-party cloud and image recognition tools such as Wildlife Insights (https://www.wildlifeinsights.org). Subscriptions to such platforms may reduce storage and image processing burdens for large datasets.

Photo tagging

If using manual species tagging protocols (as opposed to trained automated tools such as Wildlife Insights or MegaDetector), users can use software such as digiKam, ExifTool, or Lightroom to tag photos with species, distance, group size and other important information.

Guidelines for this tagging process in digiKam have been included as supplementary material in the more detailed technical report accompanying this glovebox guide (Cally and Ramsey 2025). This tagging process has been used by ARI, other DEECA staff, consultancies and the Forest Protection Survey Program (FPSP) for a variety of camera trap surveys.

Camera trap data analysis

Camera trap presence-absence

In its simplest form camera trap data can be used to construct simple presence-absence information at a locality. Obtaining presence-absence data from camera trap photos would simply involve summarising which sites had photos of deer and which did not. This method could be used to:

1. Determine the species of deer present after discovering deer signs at a site
2. Investigate whether deer now occupy a locality of interest (that they didn't before)
3. Investigate whether deer still occupy an area after control efforts.

While the observation of deer on a camera trap confirms the presence of deer at that location; it should be remembered that an 'absence' record does not necessarily mean that species is not present; just that it was not detected. The non-detection may be due to various factors related to the camera sensitivity, amount of obscuring vegetation in front of the camera, camera operating duration, camera angle, microhabitat, as well as the density and availability of deer at that location.

In cases where deer density is low (< 1 deer per km2), it is more likely that there will be no photos of deer using the standard camera set-up. Thus, survey effort (deployment duration) or the number of cameras deployed will likely need to be higher for low-density populations, than high-density populations to ensure good detectability.

To circumvent issues regarding non-detections being falsely ascribed as an "absence" (false negatives), we would recommend the use of occupancy analyses that account for imperfect detection (MacKenzie et al. 2002). For more information on these analyses see the technical report accompanying this glovebox guide (Cally and Ramsey 2025).

Camera trap relative abundance index (CT-RAI)

In some cases, absolute abundance estimates may not be essential or cost-effective for monitoring; such cases might be when you wish to compare the relative abundance of deer pre- and post-control.

A relative abundance index (RAI) can be a useful alternative because they are easy to calculate (encounters per day) and linearly correlate with absolute abundance (Palmer et al. 2018).

Programs that want to locate deer ‘hotspots’ within a management area, or determine if control impacts deer abundance, could use measures of relative abundance.

To have the necessary information to calculate a camera trap RAI (CT-RAI), camera traps should be deployed as previously described.

For each camera trap deployment, the relative abundance index can be calculated by dividing the total encounters of species by the deployment duration (e.g. days).

In many cases, animals will not be solitary and photos with multiple individuals should be multiplied by the number of individuals in the photo. The resulting RAI metric in this case would be the average ‘encounters per day’.

Sequential photos can be grouped into ‘encounter’ periods (e.g. within 10 minutes of each other), to avoid inflated counts of CT-RAI when many photos are taken of a single animal within a short space of time. The CT-RAI at a site can be calculated as:

$$\boldsymbol{CT\text{-}RAI} = \frac{\boldsymbol{total\ number\ of\ encounters}}{\boldsymbol{days\ the\ camera\ was\ deployed}}$$

The average relative abundance within an area/survey block can be calculated as the mean CT-RAI across cameras for a given survey period (sum of each site/survey CT-RAI divided by the number of site/surveys). The variation associated with this calculation can be obtained from determining the coefficient of variation (CV), with relatively precise estimates usually having a CV of less than 0.3:

$$\boldsymbol{CV} = \frac{\boldsymbol{standard\ deviation\ (CT - RAI)}}{\boldsymbol{mean\ (CT - RAI)}}$$

CT-RAI can be used to monitor the change in relative abundance of deer over time (possibly due to some control measure). You may need to seek statistical advice to help with this calculation.

Pedestrian sign count surveys

Pedestrian sign counts can be cheaper and less equipment-intensive than camera traps, as well as being able to be used in a wide variety of environments. However, they do require observer training and sufficient time to walk transects.

Deer can be difficult to observe where they are in low densities. Their cryptic behaviour, use of heavily forested areas, and crepuscular/nocturnal activity mean that direct counts of deer from walked transects may often be unsuccessful.

In Australia, direct counts from vehicles with spotlights have been used to survey for Fallow deer (Lethbridge et al. 2019), and transects walked during daylight hours have been used to conduct distance sampling (Amos et al. 2014). However, in many Victorian environments, we do not recommend direct counts as an efficient method to estimate deer abundance, unless in very homogenous and open areas, where they are more easily seen (e.g. alpine grasslands or farmlands). In forests and woodlands, deer would not be easily observed as there will be more obscuring vegetation and because they easily scare, this limits the ability to make distance measurements.

While direct observations of deer along transects remain challenging; detecting deer signs along transects or in pre-defined plots/quadrats will likely yield more data. Signs of deer presence (e.g. faecal pellets, footprints, rubbings, wallows) are usually distinguishable from other species (although feral goats may have similar scats and prints) but are more challenging to differentiate between deer species (Claridge 2010).

The handbook ‘Introduced Deer Field Identification Guide for the Australian Alps’ (Claridge 2010) is a key resource in understanding the appearance of deer pellets, footprints, rubbing and wallows. Figure 6 shows what each of these four deer signs look like in the field.

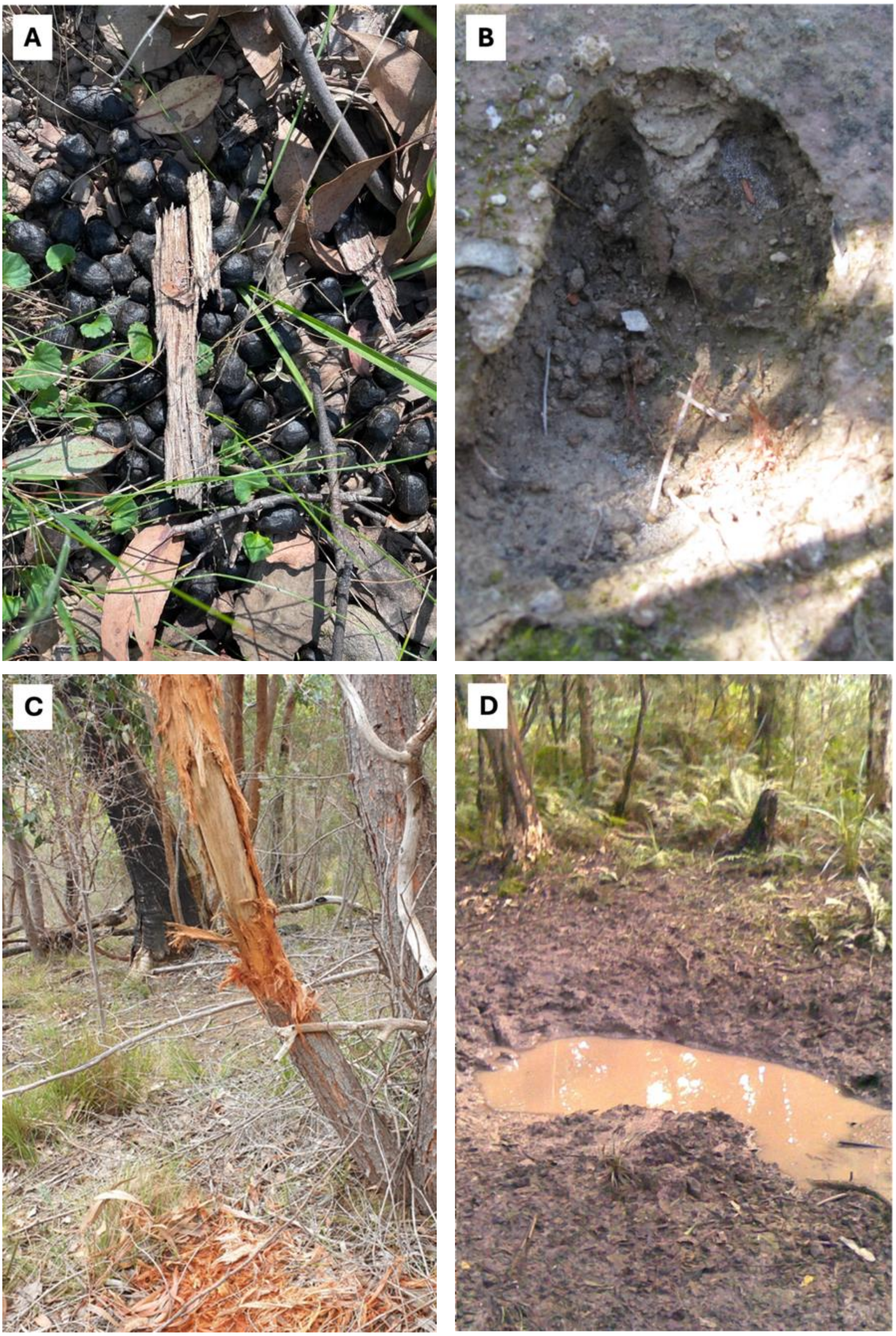


Figure 6 - Deer signs can be searched for along transects. Surveyors can confirm the presence of deer by detecting (A) pellets, (B) footprints, (C) antler rubbings, and (D) wallows.

Transect searches

Transect searches are a simple method involving walking a defined length, noting sightings of live or dead deer, tree-rubbings, tracks, cast antlers, wallows, footprints and faecal pellets. This method can provide estimates of relative abundance or occupancy.

Transect searches for deer signs have been successfully used in Victoria to help estimate the occupancy of Sambar deer (Gormley et al. 2011) and the abundance of Sambar, Fallow, Red, and Hog deer (Cally and Ramsey 2023).

By themselves, transect searches cannot be used to estimate absolute abundance, but they can provide estimates of occupancy or even relative abundance.

For this method, survey effort can be controlled by:

(i) the length of the transect/s at a site,

(ii) the number of transects at a site, and

(iii) the number of observers/times the transect is walked.

We generally recommend that survey effort is consistent across sites; however, variations can be accounted for in the analysis if recorded.

Sign transects that are subjectively located to follow a route more likely used by deer (e.g. along a watercourse or a trail) may have a higher likelihood of detecting deer. However, this type of monitoring should only be used to determine deer presence in an area. If unbiased estimates of occupancy or relative abundance are required, then systematic placement of straight transects (with a random start point) will yield more robust results.

Along the transect (and close on either side), any sign of deer can be noted: sightings of live or dead deer, tree-rubbings, tracks, cast antlers, wallows and faecal pellets (Gormley et al. 2011).

Previous studies have shown a single transect of 400 m has a detection probability of 0.75 for Sambar deer (Gormley et al. 2011), with three independent transects of 150 m (total = 450 m) walked back and forth (out and back along a single transect) also having a combined high detection probability when deer were present (Cally and Ramsey 2023). Tri-point transects at 0°, 120° and at 240° from your coordinate, can measure occupancy and relative abundance with 90%+ detection probability (if deer are present).

Deer signs can be either recorded as a binary variable for each type of sign along the transect (e.g. pellet – YES, footprint – NO, rubbing – NO, wallow – YES), or as a count along the transect (e.g. pellet – 3 mounds, footprint – 0, rubbing – 0, wallow – 1).

It is advised that unless combined with other methods, multiple transects should be walked at each site for each survey to provide multiple observation events. Previous studies found three transects (150 m in length) walked bi-directionally from a centre point to be an efficient yet thorough way to survey deer. In an area with a low-medium density of deer (3 per km2), the combined detection probability of these transects was 93.5% (Cally and Ramsey 2023).

To analyse data from transects, simple presence-absence summaries for each site can be compiled to show which sites/transects detected deer and which did not. Alternatively, the number of signs on each transect (e.g. counts of pellet groups, footprints or rubbings) can be used to estimate relative abundance (e.g. number of signs per km of transect).

When multiple transects are walked, presence-absence summaries can also be used to estimate deer occupancy and relative abundance accounting for imperfect detection. A Royle-Nichols (RN) model can be implemented to relate detection frequency to relative abundance (Royle and Nichols 2003). Alternatively, occupancy can be estimated with various other approaches (MacKenzie et al. 2002). Occupancy analyses that account for imperfect detection can use software such as the 'unmarked' R package. Some level of statistical expertise is required to undertake these more complex analyses.

Pellet counts

Faecal pellet counts have been used to estimate absolute deer abundance in Victoria (Davis et al. 2017). The density of individuals can be inferred by considering the density of pellets/pellet groups, the rate of pellet production by the deer and the longevity of the pellets before decay.

To estimate relative abundance an existing set of guidelines/field manual has been created for use in jointly assessing relative deer density and vegetation impacts (Bennett et al. 2022). We highly recommend following these guidelines if the objectives are to conduct deer surveys and assess their impacts on native vegetation. The methods for this survey method are available here: https://osf.io/8tpj2/ (Bennett et al. 2022). Here, relative abundance is calculated as deer faecal pellet counts per m2 (FPC/m2). For deer, faecal pellet groups (≥ 6 pellets) can also be counted instead of individual pellets to estimate density (Smith 1964).

Surveys for pellets follow the methodology of Bailey and Putman (1981), however, these methods have been adapted and slightly changed for various studies (Bennett et al. 2022; Davis et al. 2017). Users can broadly follow these methods but should consider appropriate sampling effort (e.g. transect length, plot frequency and plot size).

Broadly, pellet counts follow these steps:

1. For a sampling unit, a transect with a random bearing and length of 100 m+ is set.
2. At 10+ equally spaced locations along the transect, a plot of a given radius (e.g. 3 m) is established.

   Ensure that plots do not overlap. Larger plots will increase sampling effort but take longer to complete.

   Previous plot sizes for Hog deer used a 3 m plot radius (for 100 m-long transects) in Summer and a 5.64 m plot radius (for 200 m-long transects) in Spring, with plot size modified to optimise efficiency and minimise zero counts across seasons (Davis *et al.* 2017).

   Alternatively, surveys in forested environments (primarily for Sambar deer) have used a plot with a radius of 1m for 30 survey plots along a 150m transect (Bennett *et al.* 2022).
3. Search plots for intact pellets (Figure 7). Vegetation can be pushed aside. However, avoid disturbing leaf litter except when a deer pellet is visible, and you are searching for additional pellets in the group.

   Count both the number of pellet groups and the number of pellets in each group and record them in separate columns (Table 2).
4. If pellet groups are found, ensure they are deer pellets by consulting field guides (Claridge 2010). Pellet size and shape may be able to aid deer species identification if it is known that multiple species of deer occupy the survey area (e.g. Fallow and Sambar deer). However, if species confirmation is needed, then genetic swabs of the pellets can also be taken.

   Fresh pellets and pellet groups should both be counted. See Table 2 for an example on what data is collected on a transect.
5. Remove pellets from plots. By removing pellets from the plot, the accumulation of new pellets can be used if repeat surveys of the plots are required (e.g. before and after deer control, monitoring annual changes in abundance).

Pellet counts can then be used to model absolute abundance if the rate of pellet production and the rate of pellet decay is known (Davis et al. 2017). Pellet production and decay rates will likely require additional research and estimation for a given species and environment.

Alternatively, pellet counts as described can provide measures of relative abundance that are related to absolute abundance (Forsyth et al. 2007), which may be sufficient for meeting most management objectives. See Bennett et al. (2022) for methods on calculating relative abundance from faecal pellet counts.

Table 2 - Example data that should be collected for a faecal pellet count.

Plot	Pellet Groups	Total Intact Pellets
1	1	36
2	0	0
3	3	12, 42, 25

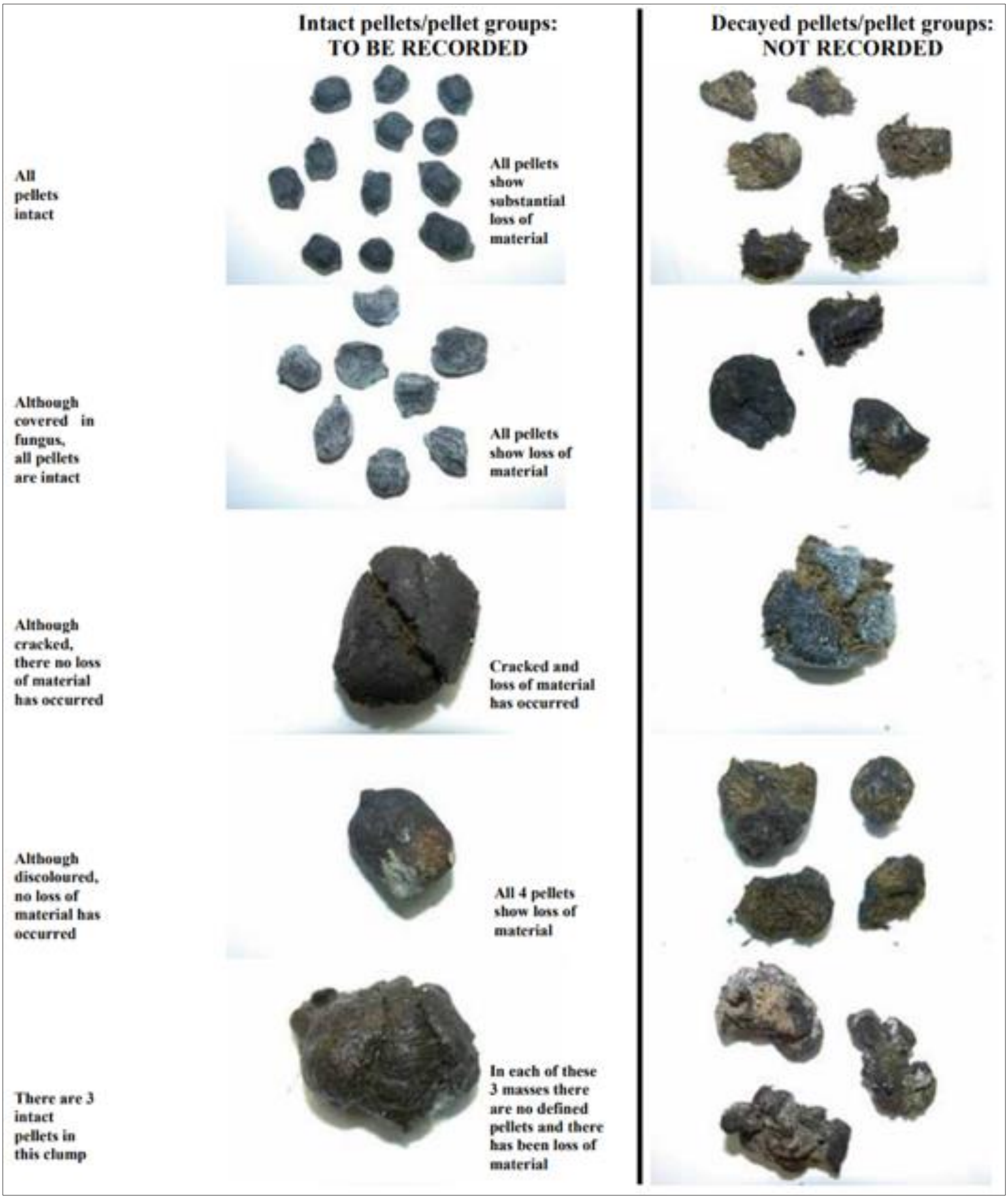


Figure 7 - Definition of intact pellets (Forsyth 2005).

UAV surveys

UAVs (Unmanned Aerial Vehicles, a.k.a. drones) are rapidly becoming adopted as a tool to survey wildlife. They can be useful in conducting surveys in low to medium-cover forested habitats and can be less costly than crewed aerial surveys (helicopter or fixed-wing aircraft).

Aerial surveys using UAVs (Figure 8) are often conducted by flying structured and relatively closely spaced transects, with thermal imagery/videos being taken throughout. UAVs can often be equipped to operate in both day and night conditions; with the latter requiring the use of thermal cameras and additional permissions. Trained models or observers are then used to process the imagery to highlight the locations of the animals. Additionally, artificial intelligence models automatically detect target species from photo/video footage (Kellenberger et al. 2018), which can reduce manual labour workload and costs by up to 84% (Sudholz et al. 2022).

UAV surveys have been shown to provide similar but more efficient density estimates than those derived from pellet counts (McMahon et al. 2022). If drones are used to conduct one round of transects in an area, then the count of the number of deer seen provides an index of relative abundance.

If the objective of monitoring is to evaluate the effectiveness of deer control, then drone surveys need to be conducted both before and after deer control using the same transects. The relative difference between the before and after counts can be used as estimate of deer control effectiveness. For this to be reliable, drone surveys should be conducted as close to the start and finish of deer control operation as possible and under similar conditions (time of day/night).

UAV technology and methods are rapidly evolving, and we expect changes to operating procedures and tools in the future.

Specialised skills, equipment and permits are needed for undertaking UAV surveys, so they are often contracted to specialists, especially if the drones are required to fly outside the “line of sight”.

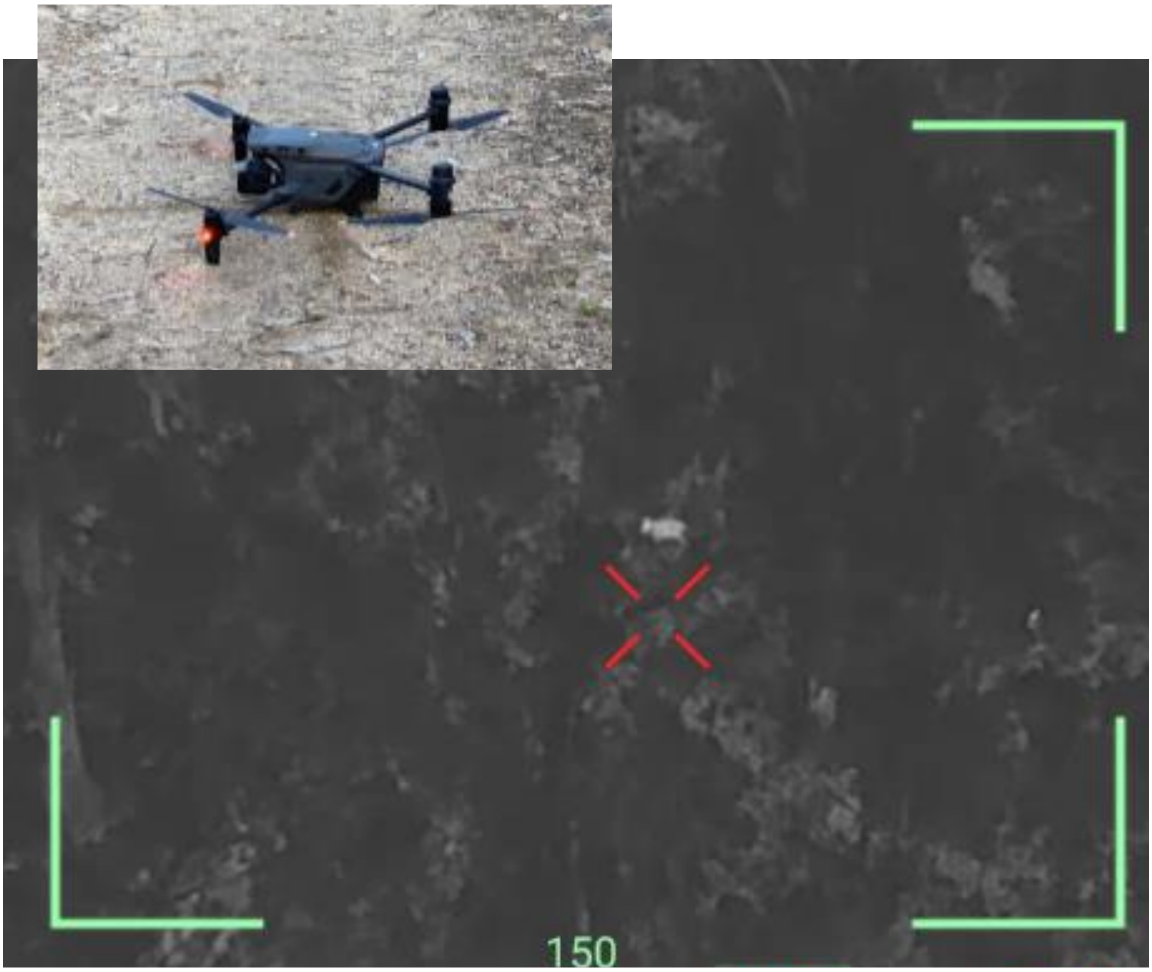


Figure 8 - A UAV (drone) and a still image captured from the UAV using thermal imagery.

FAQs

Why can't I just count deer where I know they are, instead of putting effort into sites where I already know I'm not going to find any?

Counting deer by targeting sites that are known to be visited by deer can lead to biased estimates of absolute or relative abundance. This sort of monitoring should be avoided unless the only objective is to confirm the presence of deer in an area.

What if our random site selection misses all the good sites and I end up with zero deer when I know they are there?

If the number of monitoring sites is adequate, then "good" sites are likely to be represented in the random or systematic site selection procedure. Targeting just "good" sites should be avoided as they can lead to biased estimates of relative or absolute abundance.

How can I incorporate monitoring into current control practices without doing extra, because I have no funding for monitoring?

If undertaking deer control using aerial or ground shooting, information on the locations of shot deer as well as the amount of search effort expended (i.e. hours or distance spent searching by a helicopter or ground hunters) can sometimes be used to derive estimates of relative or absolute deer abundance. One measure of relative abundance derived from such data is catch-per-unit-effort (CPUE) which is calculated as the number of shot deer divided by the amount of search effort over a specified period. At least 3 measurements of a CPUE statistic (e.g. deer shot per km) are required to derive an estimate of absolute abundance. However, CPUE can also be used as a standalone relative abundance measure to track control effectiveness over time, with a lower catch for the same effort indicating that there are less deer.

I have some new equipment (e.g. cameras/drones) that I want to use. I know from sign counts and pellet counts that deer are in my area. Will using cameras or drones help? What extra information will they provide that signs and pellets don't?

Camera trap monitoring can be used to derive absolute or relative abundance of deer while drone surveys, pellet and sign surveys are usually used to derive relative abundance of deer. Monitoring with drones will usually only be practical in more open forests. Camera trap monitoring can also provide information on population demographics, as it is often possible to determine adults as well as juvenile deer from their size.

What is the best method for monitoring deer?

This depends on the objectives of monitoring. The flowchart provides a guide to selecting monitoring methods that will be suitable for different objectives and conditions.

Why is camera trapping better than thermal binoculars?

Camera traps are usually deployed for several weeks so are likely to have a high chance of detecting the presence of deer in an area. They can also be used to derive relative or absolute estimates of deer abundance. Thermal binoculars are also useful for detecting deer, but unlike camera traps, they are unlikely to provide data useful for estimating relative or absolute abundance. Hence, thermal binoculars are most useful as an aid during ground or aerial shooting.

What is the best time of year to monitor?

If there are strong seasonal changes (e.g. in Alpine environments) there will be different numbers of deer in the landscape between seasons. The rut period (April) and periods where male Sambar move long distances (autumn-winter) might result in higher estimates. This is not an issue if repeat monitoring is at the same time each year. If long-term trends are desired, ensure annual monitoring is at the same time each year. Spring-summer is a common time to monitor using pellets, avoiding heavy rain periods that can degrade pellets.

What is the most cost-effective monitoring method?

It will depend on the hourly cost of the persons undertaking the monitoring. Camera trapping is broadly an effective monitoring strategy, however as camera trapping involves installing and retrieving cameras and substantial time to analyse thousands of images, it can be a more expensive option than pedestrian sign counts. UAV monitoring costs increase with the size and difficulty of terrain but can be a quick and relatively affordable option for small sites.

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