Trail cameras and thermal cameras: a comparative analysis for prospective users.

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Introduction

As technology improves, cameras are increasingly becoming integrated into conservation management as a non-invasive detection and monitoring tool. Two distinct camera types, each with their own strengths and weaknesses are currently available for use:

1. Trail Cameras: Devices with infrared (IR) activation sensors and the ability to record an image
2. Thermal Cameras: Devices that trigger on heat differentials using a thermal LWIR (Long Wave IR) sensor and record a thermographic image.

This report aims to provide insight into the real-world total cost of ownership as well as the advantages and disadvantages of these two types of sensor-activated cameras. A comparative analysis allows prospective users to make informed decisions on what camera type best suits their project.

Types of cameras considered

There are dozens of types of sensor-activated cameras available on the market. It is not the goal of this report to carry out an exhaustive review of such devices. For the purposes of this comparative study, we have chosen one camera to represent each type.

The Browning Dark Ops Pro XD was chosen to represent trail cameras. This off-the-shelf trail camera records either still images or videos on an SD card that will require collection in the field before processing is possible.

The chosen representative for thermal cameras is a device custom-designed by the Cacophony Project team for use in identifying invasive predators in New Zealand. The device is not just a camera but a minicomputer with a number of integrated accessories (Appendix I). This device is supported by a cloud-based software platform and can (when enabled with a modem) automatically upload recordings to the cloud platform where they will be automatically processed.

Use cases considered

The constraints and needs of each project are different. For the purposes of this comparative study, we have chosen two broad use cases into which most project goals can be fitted.

Monitoring

The monitoring use-case is characterised by a data gathering during a period with variable external factors. It usually involves gaining a sample measure of the animals within a study area. Typically, target animals are counted, and a subsequent population index produced. Like with footprint tracking tunnels, data collection and reporting are often periodic and may provide a seasonal, time-based snapshot of population index. Monitoring can also be repeated periodically to measure the effectiveness of any control measures.

Detect and respond

The detect and respond use-case is characterised by time constraints between data gathering and processing to allow for a timely response. This is usually applicable after intensive predator control and aims to allow users to swiftly respond to the presence of any identified threat in an area where predators are either suppressed or thought to be absent.

Camera recommendation

Project goals and budget size are two important factors that will dictate which camera tool can be recommended for a project. Both these factors are likely to play a role in the choice between camera types, as thermal cameras and trail cameras have different strengths and weaknesses and dissimilar cost structures. A non-exhaustive list of advantages and disadvantages of each camera type is described in the section below. Factors that directly influence and are exclusively associated with cost (e.g., battery life, staffing requirements) are described in the next section called ‘Total Cost of Ownership’.

Advantages and disadvantages

Table 1 below summarizes known differences between the two camera types, in no particular order. Each of these differences is described in more detail below.

Table 1: Summary of differences between trail and thermal cameras that are not exclusively associated with cost.

	Thermal cameras	**Trail cameras**
Sensitivity	Higher detection probability	Lower detection probability
Operational hours	Usually, night-time operation only. Day-time operation is possible but problematic	24hr operation
Detection feedback	Near real-time feedback of detection possible	No instant feedback possible
Image resolution	Lower image resolution - not possible to identify individual markings	Higher image resolution - sometimes possible to identify individual markings on animals
Detection area	Larger detection area	Smaller detection area
Technical support	Integrated technical support for processing footage	Limited technical support for processing footage

Sensitivity:

The two types of camera types use different triggering mechanisms. Thermal sensors have been shown to provide greater sensitivity for faster moving and smaller animals, which includes many of New Zealand's introduced predators (Glen et al., 2013). As trail cameras were originally designed for use in hunting, they provide adequate triggering for larger animals such as deer or pigs by using a PIR (passive infrared) sensor, but sensor performance could still benefit from improvement (Glover-Kapfer et al., 2019). Ross (2021) describes several methods to mitigate the mediocre performance of PIR sensors in trail cameras.

Operational hours:

The higher sensitivity of the thermal cameras as compared to trail cameras (see 'Detection Probability' above) also causes many false-positive triggers during daytime operation. As the thermal camera's sensor operates on temperature differentials, an animal walking in front of the camera at night will have an easily measurable difference to the background ambient temperature. During daylight hours, the background temperature is generally higher so the difference between the animal and the background will be smaller. The sensitivity of the camera sensor can be configured to be smaller for daytime operation so that animals are not missed but that same change will cause the camera to trigger much more often (for instance, when grasses in the foreground reach a higher temperature than the ground in the background) and will lead to many more false positives. This leads most users to utilize thermal cameras during nighttime hours only.

An increase in false-positive daytime triggers also occurs with trail cameras. It is unknown if there is a significant proportional difference between day-time false-positive between trail cameras and thermal cameras – the difference is likely to be dependent on environmental factors.

Detection feedback:

The thermal cameras chosen for this study have an in-built modem that connects them to a mobile network, allowing them to upload recordings in near real-time. The cameras are supported by a rich software platform with an in-build AI that processes recordings. The platform will automatically classify animals, tag footage, and alert users all in the same instance. At the time of writing the following animal categories can be distinguished by this AI: possum, cat, mustelid, rodent, hedgehog, bird, leporidae, wallaby, dog, insect, human, unknown. As with any AI the accuracy and precision are not perfect (see Appendix II) but will continue to improve.

When thermal cameras are not within range of a mobile network, data is stored on the device's memory (an SD card) and can be downloaded via a supporting android app or by bringing the camera into WiFi reception.

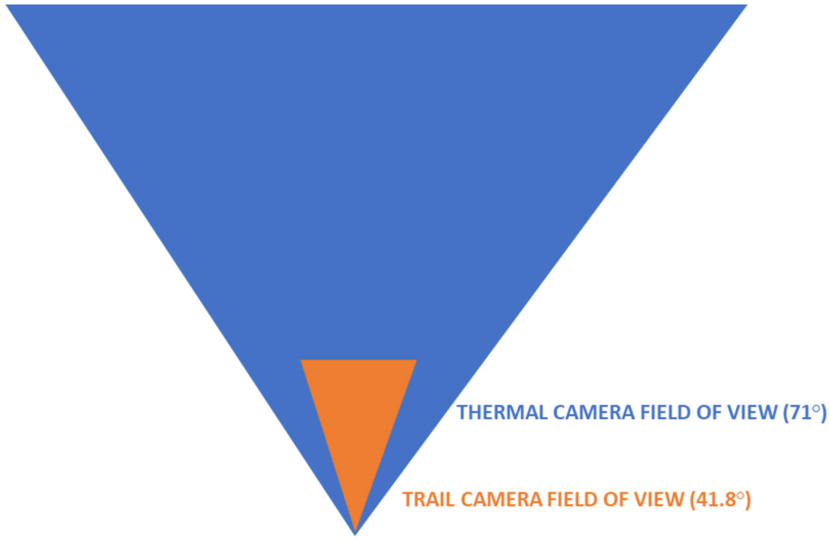
Trail cameras simply record collected footage on an SD card and currently have no in-build detection feedback system, although it should be noted there are trail cameras available that also utilize the mobile network.

Image resolution:

Due to the nature of the thermographic images collected by thermal cameras, detail is lost and identification between similar-looking species can become difficult or impossible. For example, it would be impossible to distinguish between a thrush and a blackbird, and difficult to tell a mouse from a rat. See the confusion matrix in Appendix II for a list of animals that the thermal AI can detect. In the same vein it is also impossible to read bird bands and may be difficult to accurately categorize animal behaviour. Trail cameras collect 'normal' pictures or videos with night-time footage only suffering from a lack of colour differentiation.

Detection area:

Thermal cameras produce a thermographic image that essentially highlights any endothermic animals within the field of view. This makes animals stand out, even when partially obscured by vegetation or in the distance. This aspect of thermal cameras will be partly responsible for the greater sensitivity described above, but it also allows for a larger area in which animals can be detected.



A visual representation of the detection area of the two types of device

The PIR system in trail cameras will need to be relatively close to small targets (e.g. rodents) to be able to confidently detect them and trigger the camera. Depending on project needs, this could lead to a distance between trail camera and bait holder of less than 2 metres, limiting the overall detection area.

Technical support:

As described in the 'detection feedback' section thermal cameras work with an integrated classifier-style AI that can distinguish between a variety of animal categories (see 'Detection feedback' for range of categories). Classified thermographic videos are uploaded to a website, where users can view, verify and correct AI decisions and download results.

At the time of writing there is some scope for technological features, including AI (Ross, 2021), to be used to assist with the processing of trail camera footage. However, none of these options are as comprehensive as those available for thermal cameras. A non-exhaustive list of programs that can be used to expedite trail camera footage analysis can be found in Appendix III.

Total cost of ownership

The total cost of ownership of each device is taken to include:

- Purchase cost – buying the cameras and any required accessories.
- Deployment costs – getting the cameras into the field
- In-field management effort – swapping batteries etc.
- Data collection effort – collecting memory cards, downloading recordings etc.

- Data analysis effort – analysing, classifying, and recording the data collected
- Report production effort – producing the desired output (e.g. seasonal monitoring reports, hotspot maps, detection alerts etc.)

Trail cameras can be setup to record either still images or videos, while thermal cameras always record videos. As there is a marked difference in the time required to process still images and videos, we decided to present the cost of running cameras for still image and videos for each of the use-cases, creating a total of 4 cost-models:

1. Monitoring, still images
2. Monitoring, videos
3. Detect and respond, still images
4. Detect and respond, videos

The below cost-models are taken from real-world projects and expanded. The basis and input values for the cost of ownership models can be found here: Public Camera TCO Model. It is worth noting that the models described below are a rough estimate. Actual costs will be mostly dependent on the amount of footage collected, which in turn will be dependent on camera location.

Monitoring

In the monitoring use-case, we are interested in collating an overall sample of the population over a period of time. Cameras are deployed in the field for a certain number of nights, then data (still images or videos) are collected, collated, analysed, and the results recorded. The final report would show numbers of animals seen over the monitoring period. No intermediate results (during the deployment) are required.

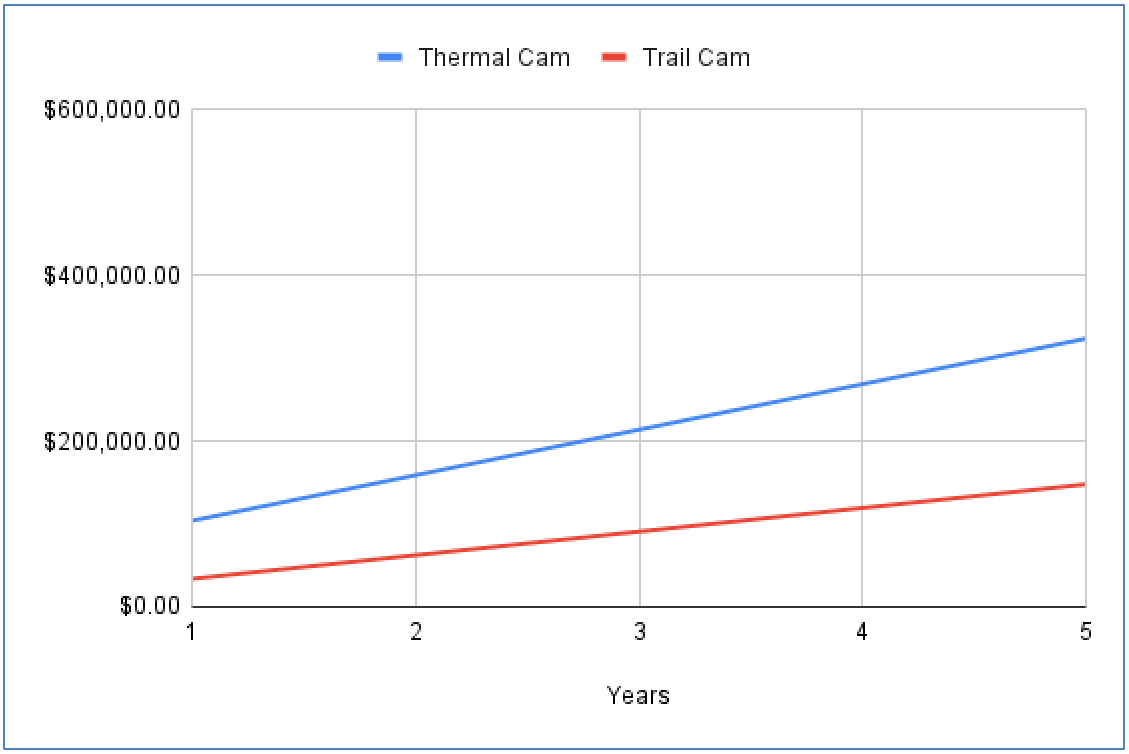
The model results shown in this section assume a uniform, static deployment of cameras in the target area. For details on a different deployment approach that may enhance the efficiency of deployment and allow for a reduction in equipment costs, see Appendix IV.

Monitoring: still images

The trail cameras are set up to record still images (photos) only. Processing time for a human looking at a still photo and identifying the animal therein (if any) is short.

The thermal cameras always record video footage.

# of cameras in deployment	**15**



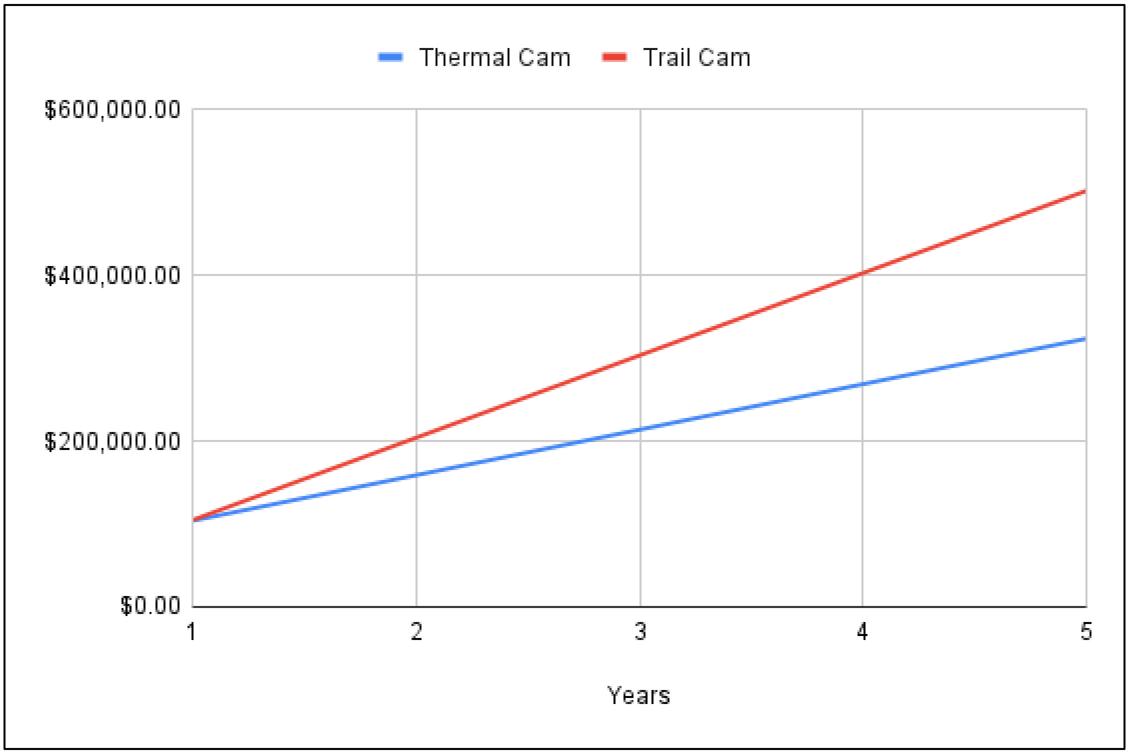
Insight	Thermal cameras have a higher cost of ownership
Outcome	Choose trail cameras
Caveat(s)	*Sensitivity:* Trail cameras have a lower detection probability so there may not be sufficient (or any) data to inform the user on low-density species. *Smaller detection area*: If the project goals include the monitoring of small mammals, the likely overall detection area is smaller for trail cameras.

Monitoring: video

The trail cameras are set up to record video only. Processing time for a human watching a video recording and identifying the animal therein (if any) is significant.

The thermal cameras always record video.

# of cameras in deployment	**15**



Insight	Thermal cameras are more cost-efficient
Outcome	Choose Thermal Cameras
Caveat(s)	*Operational hours*: Under normal circumstances, thermal cameras are only operational during nighttime. *Image resolution:* Thermographic image resolution may make it difficult to identify certain species.

Detection

The key difference in this use-case is that we need access to the data (the presence of a predator) as soon as possible. To allow for a useful response (finding and eliminating the animal), the data needs to be available near real-time. At worst, the data has to be available within 24 hours.

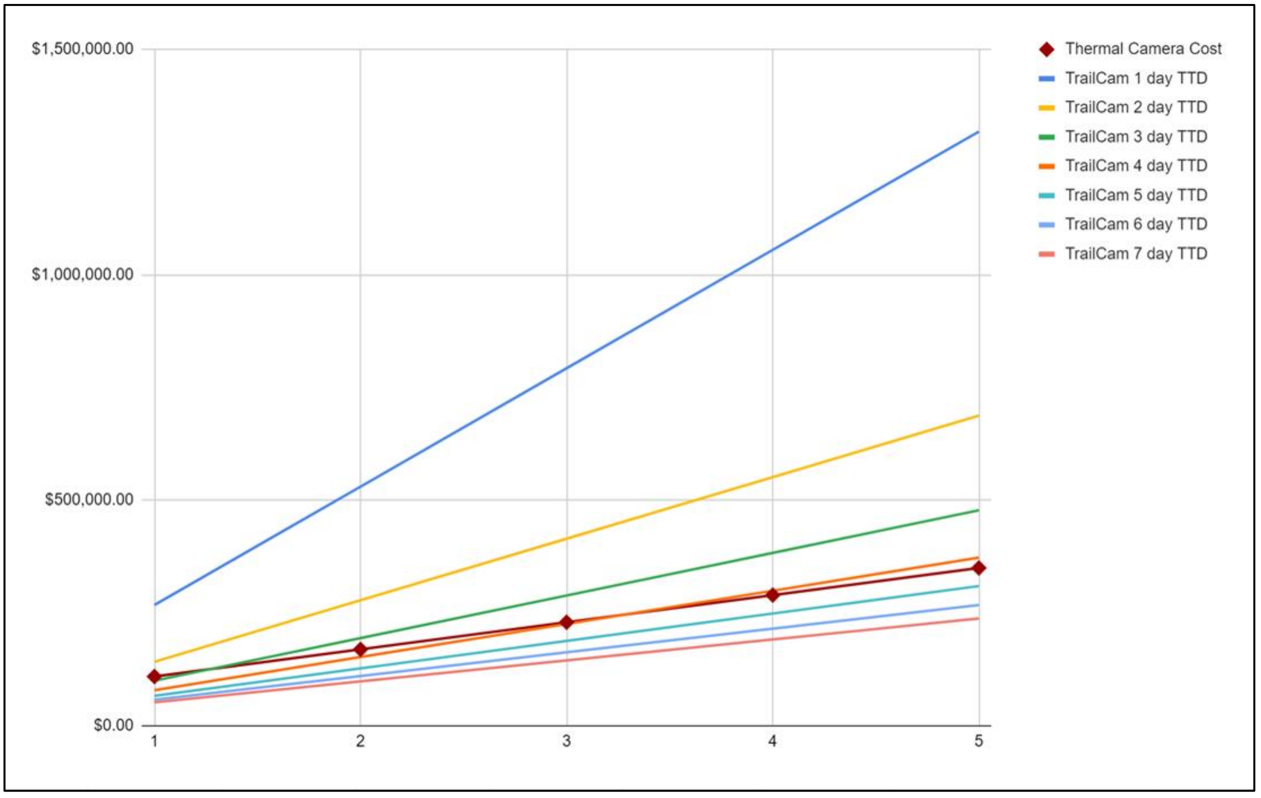
The conclusions in this use-case are highly influenced by how quickly we want access to the data, so a few notable examples are included below. The key differentiating measure is the time to notification of predator presence (we'll call this "time to detection" or TTD).

The important use-case here is getting access to data in near real-time, so we present a model of data available within a day as the key example. A second example of data being available within 4 or more days is also presented to illustrate the point at which the TCO benefits cross over.

It's important to note that the cost of collecting the data is fixed for Thermal Cameras (given the task is automated). So the models below show the costs of the Thermal Camera against the cost of the Trail Cameras across the Time To Detection (TTD) scenarios.

Detection: still images

how often we need the result (days)	**1-7**
# of cameras in deployment	**15**

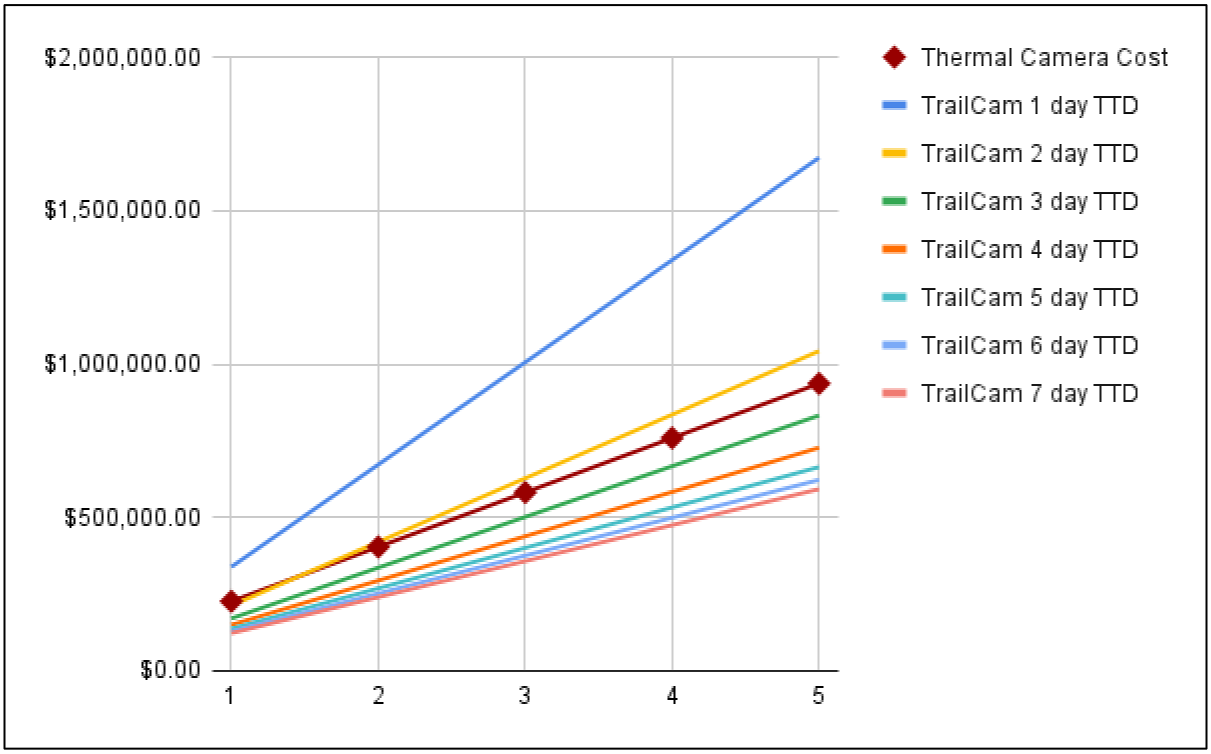


Insight	Time to detection is the differentiating factor. Cost-efficiency of thermal cameras increase with a decrease in required time to detection.
Outcome	If time to detection needs to be ≤ 4 days choose thermal cameras. If time to detection can be > 4 days choose trail cameras

Caveat(s)	*All advantages and disadvantages described in table 1 apply.*

Detection: video

how often we need the result (days)	**1-7**
# of cameras in deployment	**15**



Insight	Time to detection is the differentiating factor. Cost-efficiency of thermal cameras increase with a decrease in required time to detection.
Outcome	If time to detection needs to be ≤ 2 days choose thermal cameras. If time to detection can be > 2 days choose trail cameras
Caveat(s)	All advantages and disadvantages described in table 1 apply.

Overall Conclusion

The decision over which type of camera network to deploy depends on the use-case you're interested in, which is described by the type of data you wish to collect and how near real-time the data (an animal identification) is required.

The use-cases described in this report each lead to a useful rule of thumb to help guide decisions. The authors have no doubt that dozens (if not hundreds) of alternative use-cases exist that could be exercised in a similar way. The model used to create the graphs shown in this report is available for your own use (see References).

Both Trailcams and Thermal Cameras are useful tools in predator control programmes. The authors welcome further investigations into the use of each and encourage further comparative studies into the effectiveness of each in known predator control use cases.

End of Paper

About the Authors

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Appendices

Appendix I: Soft- and hardware accessories of the Cacophony custom-thermal camera

Base hardware	Raspberry Pi 3
Thermal camera	FLIR Lepton 3
Additional hardware	Custom interface hat ATtiny microcontroller 3G modem USB audio adapter Real time clock
Operating System	Raspbian
Key Software	lepton3 thermal-recorder thermal-uploader

Appendix II: AI Classification

The matrix below shows the current state of the Cacophony AI classification software. The number for each species (along the central diagonal) should be read as an indication of how successful the software is at identifying the species. A number of 1.00 would indicate a 100% success rate (based on all the footage the software has processed thus far). A number of 0.00 would indicate a 0% success rate. For example, 90% of the videos containing hedgehogs are correctly classified by the AI as containing hedgehogs, while 26% of videos containing mustelids are falsely classified by the AI as containing rodents.

AI accuracy detailed

User label \ AI label	bird	possum	rodent	mustelid	hedgehog	cat	wallaby	nothing	not known	other
bird	49% (131)	8% (22)	7% (18)		5% (13)	1% (3)	2% (5)	4% (10)	17% (44)	8% (20)
possum		87% (54)			5% (3)			2% (1)	6% (4)	
rodent		4% (4)	75% (79)		11% (12)	1% (1)		1% (1)	8% (8)	
mustelid	0% (1)	23% (87)	26% (98)	13% (48)	4% (15)	2% (6)	3% (10)	2% (9)	20% (74)	7% (26)
hedgehog			3% (1)		90% (26)				3% (1)	3% (1)
cat		13% (3)				58% (14)	4% (1)		8% (2)	17% (4)
wallaby										
nothing	2% (2)	1% (1)	1% (1)		1% (1)			86% (84)	4% (4)	5% (5)
not known			50% (3)		17% (1)			17% (1)	17% (1)	
other	5% (7)	9% (14)	1% (1)	1% (1)	3% (4)	1% (1)	1% (1)	9% (14)	5% (8)	66% (98)

The deep learning models used to achieve the above are constantly being “trained” with new footage as it is collected. The nature of the models means that the success rate is likely to continue to improve over time - the more footage available, the better the model tends to become.

Appendix III Technological support for trail camera footage processing.

The following is a non-exhaustive list of software than can support footage processing for trail cameras known to the authors at the time of writing. Some this software includes AI solutions, while others assist in annotating images.

Image annotating assistance:

- Speedymouse is an example of a free-to-download software that allows the user to quickly tag images by selecting animals from a list each time a picture is shown. There is a great diversity of similar programs available (Ogurtsov, 2019). For example, similar programs include: TrophyRoom, ViXeN, camtrapR, CPW Photo Warehouse, Wild.ID, Camelot and ZSL CTAP. Additional options can also be found here on this report published on the WWF website.
- A MS Access Graphic User Interface (see DOC-6555605) can be used to annotate images at a fast rate than conventional methods. (DOC-6306763, table 4), with programs that are approved for use on DOC systems.
- Zooniverse (https://zooniverse.org) is an example of a website that allows volunteers citizen scientists to provide image annotation.

Trail camera AI assistance:

- The Megadetector is a free-to-download object detection model that identifies animals, people, and vehicles in trail camera footage. This DOC-approved detector-style AI can therefore be used to exclude empty still images from footage sets. This tool does have some hardware requirements.
- AWS integrated cat classifier (more information needed)
- Evorta is a classifier-style AI currently being trailed by the National Eradication team.
- ClassifyMe is a classifier-style AI for the automated identification of trail camera footage (Falzon et al., 2020) originally designed for use in Australia.

Appendix IV A better deployment protocol?

Sweep Protocol Example

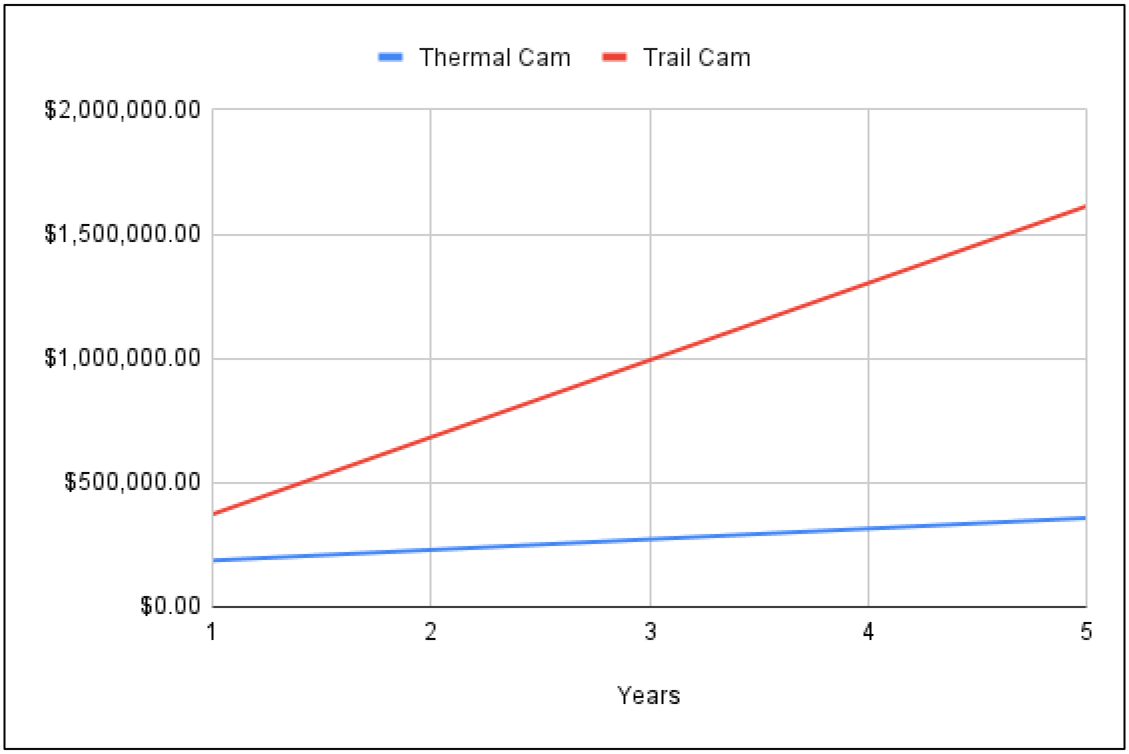
All of the above examples assume that the area is saturated with cameras that are placed in permanent grids with each camera at a fixed location over the period of the operation. This is not likely to be the most efficient way to deploy a camera network.

A more resource-efficient method is to achieve coverage of the area by “sweeping” the cameras through the area in question. For example, a set of cameras can be moved to a set of locations (aka a “set”) each week. If a monthly monitoring effort is desired, that would reduce the number of cameras required to one quarter of the total. This method is likely to be highly suitable for thermal cameras due to their higher sensitivity. The same method could be applied to trail cameras but their lower sensitivity is likely to produce less reliable results (the trail cameras will make substantially fewer recordings than the thermal cameras).

Sweep Thermal Cameras Only

You may have noted above that, in the monitoring use case, the outcome suggested that a trail camera network is likely to be more cost-efficient. The example below shows the same use case but with the thermal cameras using the “sweep” protocol (being moved to a new set of locations each week).

Monitoring Period (days)	**28**
# of Thermal cameras in deployment	**44**
# of Trail cameras in deployment	**175**

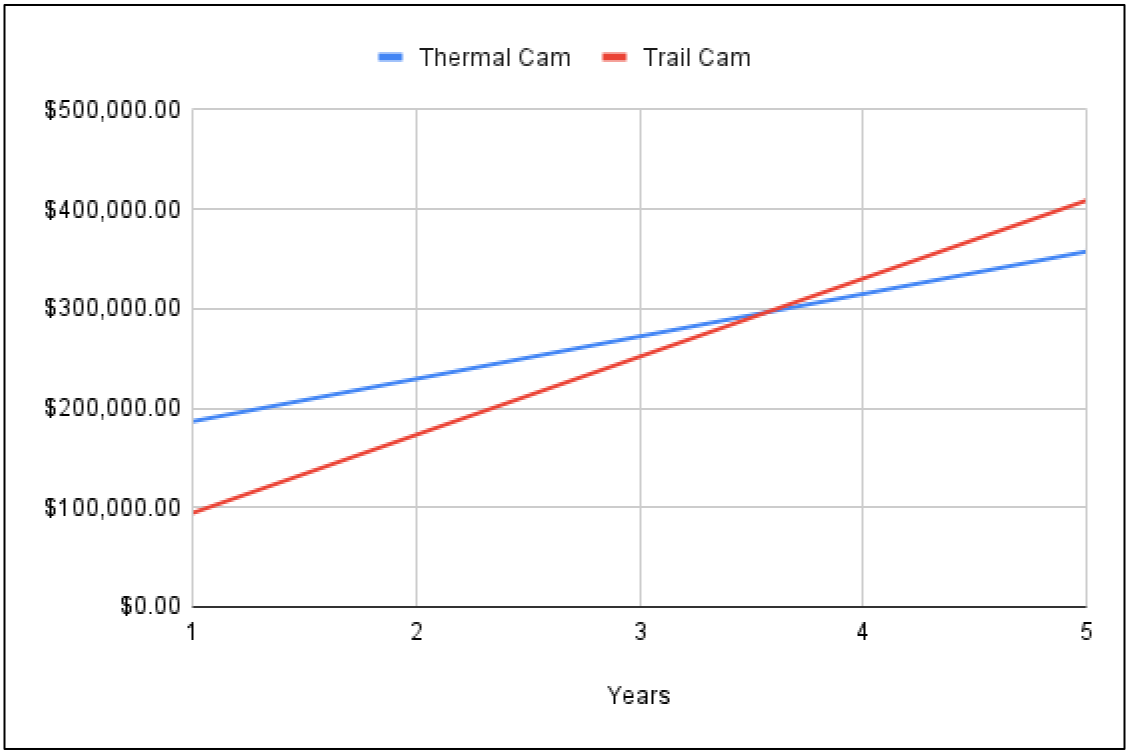


Insight	Thermal cameras have a lower cost of ownership if a sweep protocol is implemented
Outcome	Choose Thermal Cameras
Caveat(s)	If an animal only appears at a thermal camera location after the camera has been moved, it will be missed. The quality of the sample may be compromised - likely only to apply to far-ranging animals such as cats or mustelids

Sweep Both Thermal and Trail Cameras

The example below shows the same use case but with both trail and thermal cameras using the "sweep" protocol (being moved to a new set of locations each week).

Monitoring Period (days)	**28**
# of Thermal cameras in deployment	**44**
# of Trail cameras in deployment	**44**



Insight	Thermal cameras have a higher cost in years 1-3 but are more cost-efficient in year 4 onwards
Outcome	Choose Thermal Cameras if your project's lifespan is longer than 3 years
Caveat(s)	Trail Cameras moved after a week are likely to have made far fewer recordings. The quality of the sample is compromised

References and further reading

1. Anton, V; Hartley, S; Wittmer, H U; 2017: Evaluation of remote cameras for monitoring multiple invasive mammals in New Zealand
2. Falzon, G.; Lawson, C.; Cheung, K.-W.; Vernes, K.; Ballard, G.A.; Fleming, P.J.; Glen, A.S.; Milne, H.; Mather-Zardain, A.; Meek, P.D. 2020. ClassifyMe: a field-scouting software for the identification of wildlife in camera trap images. *Animals 10*: 58.
3. Glen, A.S.; Cockburn, S.; Nichols, M.; Ekanayake, J.; Warburton, B. 2013. Optimising camera traps for monitoring small mammals. *PloS one 8*: e67940.
4. Glover-Kapfer, P.; Soto-Navarro, C.A.; Wearn, O.R. 2019. Camera-trapping version 3.0: current constraints and future priorities for development. *Remote Sensing in Ecology and Conservation 5*: 209-223.
5. Ogurtsov, S.S. 2019. Review of the software for processing and analysis of data from camera traps; latest new, working with video and GIS. *Nature Conservation Research 4*: 95-124.
6. Ross, J. 2021. The use of AI in New Zealand for the sorting of images and classification of animal pest species.

The basis and input values for the cost of ownership models used in this report can be found here: Public Camera TCO Model.

Further Reading

Ross, J; Ryan, G: AI heat camera more sensitive and cheaper than trail cameras for possum detection

- https://cacophony.org.nz/trial-results-ai-heat-camera-more-sensitive-and-cheaper-trail-cameras-possum-detection

Blake, D; Ryan, G: Rat Detection Rates – device sensitivity

- https://cacophony.org.nz/thermal-camera-5-20-times-more-sensitive-rats
- https://cacophony.org.nz/trial-update-rat-detection-rates-10-50-times-better-trail-cameras

Finlay-Smits, M: Why specialised thermal cameras are well suited to NZ predator management

- https://cacophony.org.nz/why-specialised-thermal-cameras-are-well-suited-nz-predator-management

Ryan, G: New Thermal Cameras are about 5 times more sensitive than off-the-shelf trail cameras

- https://cacophony.org.nz/new-thermal-cameras-are-about-5-times-more-sensitive-shelf-trail-cameras-1