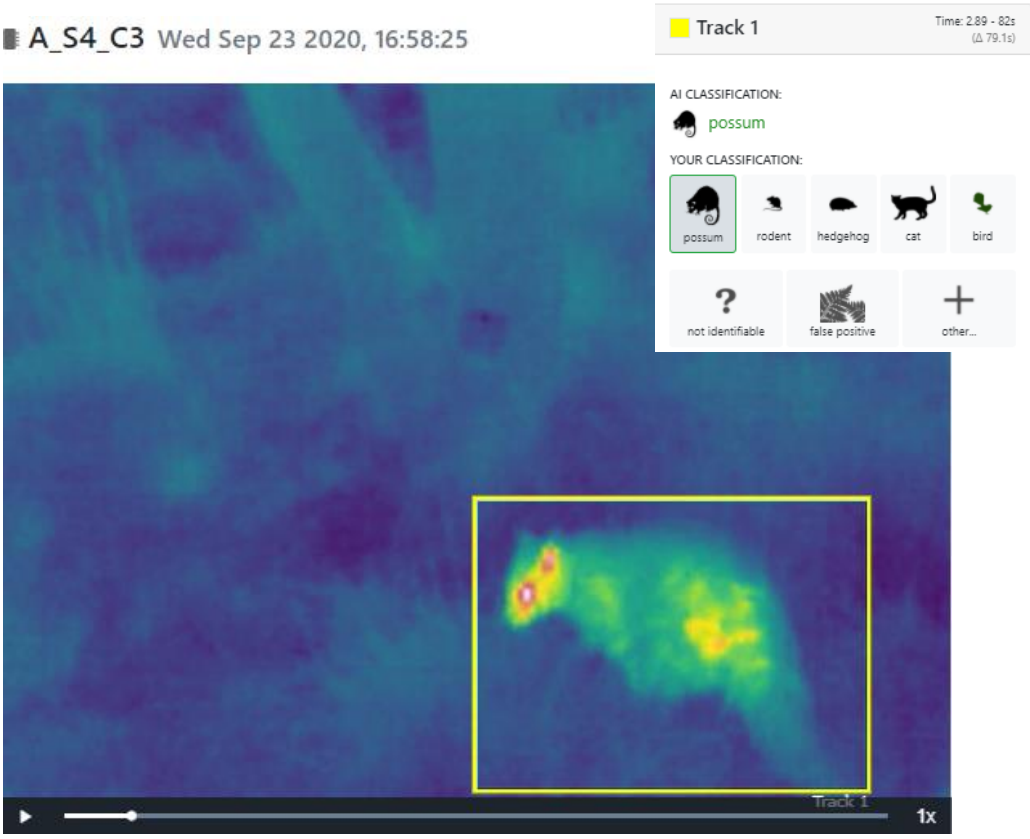
Invasive Species Monitoring and Predator Control via Innovative AI Technology

The Cacophony Project, Christchurch, New Zealand



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Chapter 1

An Introduction: Invasive Species and Conservation in New Zealand

1.1 Native Fauna and Flora

Surrounded by the Pacific Ocean, New Zealand totals 268,680 km^2 in landmass, distributed across two main islands (North Island and South Island) and a plethora of tiny offshore islands (~600) (World Atlas, 2021). Whilst similar in size to the UK, the population is 15 times lower with a population of 5.1 million (StatsNZ, 2021).

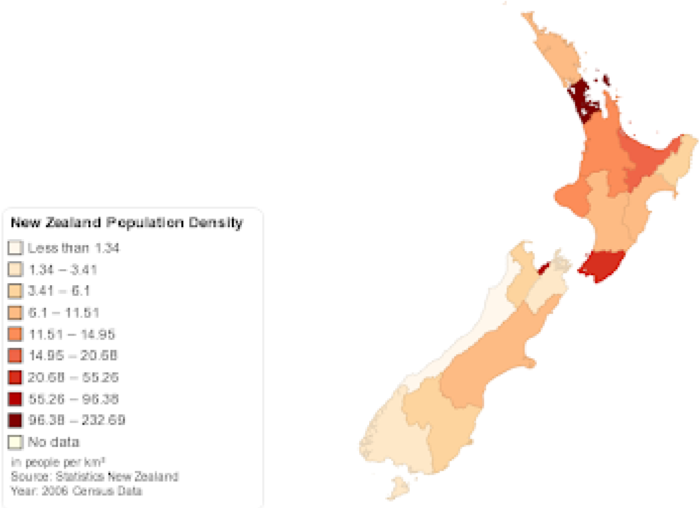

Figure 1. New Zealand Population Density (Stats NZ). The most densely populated areas are the Auckland region and Wellington region on North Island, whereas South Island is sparsely populated, and density decreases towards the southern point of the island. However, the lowest populated area across New Zealand is along the West Coast of South Island.

Due to its isolated geography, New Zealand is home to many unique, endemic species. Native flora varies from podocarp forests housing giant Rimu trees, to alpine landscapes dominated by native scrub and tussocks. These trees and plants are integral to their ecosystems and play major roles in sustaining the fauna of New Zealand. For instance, the Kōwhai tree, with their distinctive yellow flowers provide nectar to seven native bird species (DOC, 2021b). Despite its importance, native vegetation now only covers 10-15% of New Zealand's total land mass due to land use change and introduced flora (DOC, 2021g).

Unlike most large islands, native mammals are uncommon on New Zealand, with bats being the only solely terrestrial mammal to have evolved. The two extant species are prone to risk from anthropogenic disturbance resulting in the long-tailed bat considered endangered and the short-tailed bat classed as critically endangered. Most native mammal species on New Zealand dominate marine habitats and include: the Hector's dolphin (*Cephalorhynchus hectori*), the New Zealand Fur Seal, (*Arctocephalus forsteri*), the New Zealand Sea Lion (*Phocarctos hookeri*) and several whale species (DOC, 2021c).

Due to the lack of mammals Avifauna are the largest vertebrate group in New Zealand, with ~200 native species. Unfortunately, the synergetic impact of habitat loss, hunting, predation and resource competition has resulted in multiple previous extinctions and leaving many current species vulnerable (Innes *et al.,* 2009). Arrival of the Māori tribes in the 14th Century resulted in the loss of ~40 species including Moa (*Dinornithiformes*), and their natural predator, the Giant Hasst's Eagle (Robertson *et al.,* 2017; Allentoft *et al.,* 2015). Further spread of the Māori, as well as the European colonisation in the 19th Century led to a further loss of 19 species. Therefore, the country has seen a total loss of 59 (~40%) of their endemic birds since first human contact (Lal, 2008; DOC, 2021g; Robertson *et al.,* 2017). Several forested areas are now lacking the dawn and dusk choruses from songbirds, and many flightless ground-dwelling birds such as the Takahē (*Porphyrio hochstetteri*) are on the verge of extinction. Of the 200 species remaining 35% fall into the top three national conservation categories. Within the Nationally Critical class are currently 23 species, meaning they face an immediate threat of extinction. Another 15 are defined as Nationally Endangered and 33 are defined as nationally vulnerable. Therefore, the Department of Conservation (DOC) have worked relentlessly towards the conservation of birds in New Zealand (DOC, 2021g).

The second largest vertebrate group are reptiles. New Zealand has ~110 native lizard species, exclusively skinks and gecko, which is considered uniquely diverse for a temperate landmass (Hitchmough *et al.,* 2016). Lizards play important ecosystem roles for their associated flora, natural prey and predators. Facing threats such as habitat loss and predation from invasive species, most species are classed as vulnerable/at risk. Additionally, many species are considered data deficient due to a lack of suitable surveying methods. Despite this, conservation has prevailed and is ongoing within New Zealand. (DOC, 2021f). One of New Zealand's rarest reptiles is the Tuatara (*Sphenodon punctatus*), a 200-million-year-old native. Due to their rapid decline after European colonisation, they have been protected by law since 1895. Their main threats include habitat loss and poaching for the pet trade. Their small population size poses additional challenges such as low genetic diversity (DOC, 2021m). Regarding amphibians, New Zealand is host to three native species of frog (*Leiopelma*). These small, nocturnal frogs have been highly susceptible to environmental change (e.g. habitat loss) and a deadly chytrid fungal disease. Intensive conservation to combat these threats has resulted in an upgrade to their conservation status, however they remain vulnerable (DOC, 2021d). New Zealand is also rich in endemic invertebrates such as the widely recognisable Wētā, distinct for their large bodies, curved tusks, and spiny legs. These nocturnal, herbivorous invertebrates occupy multiple ecological niches, comprising of >100 species. The introduction of non-native mammals has caused a sharp rise in predation rate, thus leaving them very vulnerable (DOC, 2021e).

With a wide range of taxa and genera-specific threats, conservation in New Zealand is crucial to preserve the biodiversity. One commonality in threats is the introduction of invasive species, therefore one of the branches of conservation is looking into pest eradication.

1.2 Invasive Species

Alien species are prevalent in New Zealand and most are described as invasive, due to their ability to outcompete natives. For example, New Zealand now has the largest number of established non-native plants (excluding cultivation) on any island globally (Hulme, 2020). DOC highlights invasive mammalian predators as a large threat for most native fauna in the country and thus an issue needing urgent resolution. The earliest known non-native mammals were rats and dogs, introduced in the 13th Century by Polynesian settlers (Lowe, 2008). However, most invasive species arrived in the 1800s with the arrival of Europeans. Large species such as goats, sheep and red deer were introduced for food and hunting by James Cook are now widely established (DOC 2020i; Curnow and Kerr, 2017). Forest clearance for pastureland and resource competition now threaten many natives, including vulnerable ground-dwelling bird species (DOC, 2020i). Smaller invasive have since established also including rats, mice, mustelids, hedgehogs, possums, and rabbits. Most of these pest species are detrimental to native species either directly (predation) or indirectly (altering ecosystem services) (DOC 2020i).

European whaling ships are the main culprit for rodent invasion in New Zealand. Ship rats (*Rattus rattus*), Norway rats (*Rattus norvegicus*) now inhabit nearly every landscape in NZ (PFNZ, 2019). Their rapid breeding, resource use and incessant predation on natives has had dire impacts to food webs (Curnow and Kerry, 2017). Another invader, the House mice (*Mus* musculus) are considered a major limiting factor in native lizard survival. Mice are in direct competition with skinks both for food (e.g. fruit and invertebrates) and habitat (e.g. obstructing basking) (Norbury *et al.,* 2014; Lettink, 2009). Rabbits (*Oryctolagus cuniculus)* arrived with voyagers to establish a meat and fur trade. However, with short gestation periods, large litter sizes and producing multiple litters per year, this led to a major invasion. Rabbits established in dryland and semi-arid habitats and due to their destruction of pastureland are considered agricultural pests (DOC, 2021k). To control rabbits, several mustelid species (stoats, weasels, and ferrets) were introduced in 1879. Relentless hunters, these mustelids pose significant threats to native bird and lizards, able to target diurnal and nocturnal species across multiple habitat types (DOC 2021l).

Another major invasion was of Brushtailed possums (*Trichosurus vulpecula*), introduced from Australia in 1837 for the fur trade (Curnow and Kerr 2017). These nocturnal mammals are now widespread, with a population size of ~30 million even after heavy pest control measures. Able to inhabit most environments, they thrive in podocarp forests, an important niche for many endemic birds. As opportunistic omnivores they predate on lizards, birds and their eggs (Figure 2). They also induce interspecific resource competition as they also eat fruit, berries, and nectar (DOC 2021j)

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Figure 2. Brush-tailed possum (*Trichosurus vulpecula*) eating the egg of a Kererū/NZ Pigeon (*Hemiphaga novaeseelandiae*) (© Ngā Manu Images)

The European Hedgehog (*Erinaceus europaeus*) was introduced deliberately by the British in the late 19th Century and are prevalent country--wide (DOC 2021a). Being primarily insectivorous, they undergo resource competition with diurnal skink species which occupy the same ecological niche. There are also multiple reports of hedgehogs eating lizards, therefore high densities could have a larger scale impact to local reptiles than previously thought (Jones, Moss and Sanders, 2005).

All invasive mammals have significant impacts on native flora and fauna; therefore, several organisations have implemented control measures to combat pests in New Zealand. As of 2016, the government announced the formation of Predator Free 2050, which aims to eradicate all non-native predators within the next 30 years (Peltzer *et al.,* 2019). Predator Free 2050 encompasses multiple organisations (e.g. DOC), regional councils and Iwi, which are working both individually and collaborating to achieve the goal. One of these organisations is the Cacophony project, which has taken a unique approach by focusing on innovative technology to tackle the pest problem in New Zealand.

1.3 The Cacophony Project

Founded by Grant Ryan in 2016, the Cacophony project is a not-for-profit organisation based in Christchurch, South Island. The project aims to eradicate pests by developing modern technology to enhance pest control measures in New Zealand. The team are a collaboration of engineers, mechanics and IT technicians, working alongside key conservation groups (e.g. DOC) and university institutions (e.g. Lincoln University). As a non-for-profit organisation the project are paired with a sister company, 2040, to sell their products. With a focus on conservation the products are sold to cover manufacturing costs, and profit is restricted to wages for the teams involved. Additionally, the project wants to ensure anyone can use and/or improve the technology. Therefore, the software is open source, meaning it is publicly accessible, which invites an inclusivity feeling to the project (The Cacophony Project, 2021). Able to view conservation from a technological perspective, the project initially aimed to quantify bird population change. The first product developed was the Cacophonometer, an acoustic bird monitor which uses a microphone linked to a smart-phone application where data can be uploaded to a server ('cloud') and easily accessed online. The main goal of this device is to create an index to measure effectiveness of restoring bird populations by determining the success of conservation measures.

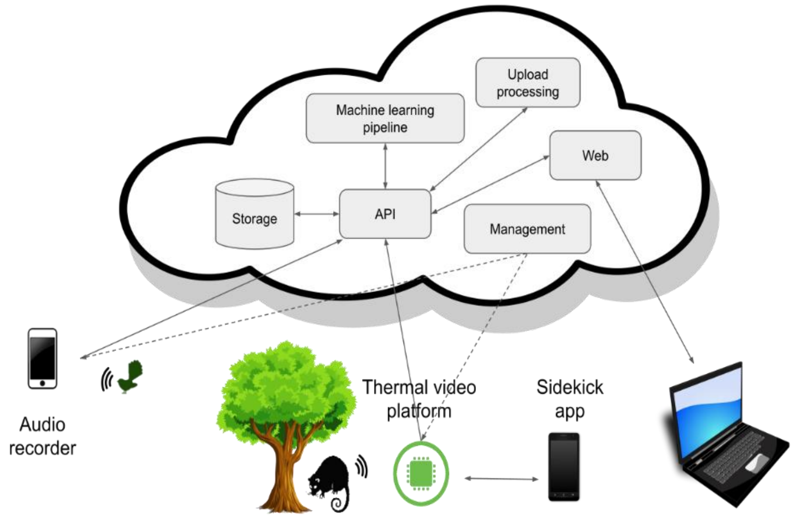

Figure 3. Neural Network concept showing the different Cacophony technologies developed for optimal monitoring and pest control programmes (© The Cacophony Project)

Furthermore, the project expanded its online system to incorporate pest monitoring and a new monitoring device was developed (Figure 3). Noticing a gap in the market, a standalone thermal camera was developed, which aims to efficiently monitor nocturnal predators in the field using thermal imaging. The cloud allows automatic data uploads, which can be immediately accessed and downloaded by the user. Simultaneously the team have developed machine learning software, which teaches computers to recognise patterns. The intention is to train the software to identify and automatically tag species in recordings from the thermal cameras. This would heavily reduce human labour needed for wide-scale monitoring. Preliminary tests using the software and equipment have already shown to 200x increase in analysis speed already (Ross and Ryan, 2019, unpub.; Ross *et al.,* 2020). Both devices are now in field-testing to improve the products and train the AI. Furthermore, audio lures have been developed to increase success rate of species presence and are in their preliminary test phase.

In conjunction with monitoring, the project is designing an innovative AI-based trap. This aims to use smart design with AI to target multiple pest species, eliminate non-target capture and significantly improve interaction rate (up to 30x higher than current traps). The design is important to appeal to multiple species and reduce trap shyness to eradicate individuals' other traps fail to. The first few prototypes have been manufactured and are amid vigorous field testing. After testing and refinement, the Cacophony project aim to integrate these technologies into standard monitoring and trapping practices country-wide. Thus, coming to the forefront of pest eradication conservation and contributing significantly to the predator free goal before 2050. For testing, the project uses private land owned by Living Springs on the perimeter of Banks Peninsula.

1.4 Banks Peninsula and Living Springs

East of Christchurch, the most prominent volcanic feature on South Island protrudes into Pacific Ocean (McLintock, 1966). Geologically formed 10-15 mya by two shield volcanoes, Lyttleton and Akaroa, climatic influence has eroded and shaped the 1165 km^2 of connected remnants known as Banks Peninsula (Figure 4) (McLintock, 1966, CCC, 2014; Hampton and Cole, 2009).

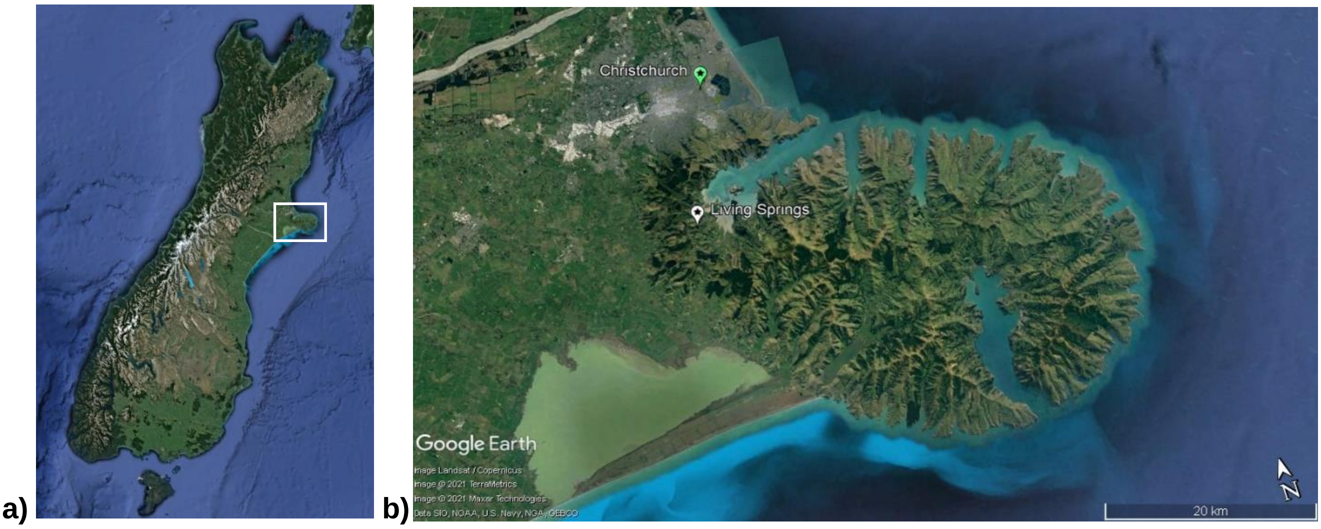

Figure 4. a) Satellite view of South Island, New Zealand with Banks Peninsula highlighted. b) Zoomed view of Banks Peninsula. The location of Living Springs (the field site) is pinned as well as the location of Christchurch (© Google Earth Pro 2021).

Originally covered by podocarp forests surrounded by rocky shores, Banks Peninsula has suffered significant land conversion. Between 1850 and 1900 over 99% of the forests were felled or burnt for pasture-land (Wood and Pawson, 2008). Of the 1% of forest left, predominately native vegetation remains, however ~15 species have been lost (Environment Canterbury, 2010). This severe habitat fragmentation has negatively impacted the native fauna.

Despite the habitat fragmentation ~47 bird species are present including: 12 native bush bird species e.g. translocated populations of Tūī (*Prosthemadera novaeseelandiae*) and Kererū/NZ Pigeons (*Hemiphaga novaeseelandiae*), as well as 12 native coastal species e.g. the nationally vulnerable Southern White-fronted Tern (*Sterna striata*) (Schmechel, 2010). Lizards also contribute to the biodiversity of Banks Peninsula, where there are currently five confirmed species. The skink species include the Common Skink (*Oligosoma polychroma*) and McCann's Skink (*Oligosoma maccanni*) as well as the rare Central Canterbury Spotted Skink (*Oligosoma lineoocellatum*). The two gecko species are the Jewelled Gecko (*Naultinus gemmeus*) and Canterbury Gecko (*Woodworthia brunnea*) (Lettink, 2008). There is also speculation about the Forest Gecko (*Mokopirirakau granulatus*) as there is trace evidence of its presence on Banks Peninsula (Bowie, Barker and Troup, 2010).

Other than habitat loss, the main threat for natives on Banks Peninsula are the invasive mammals. Currently 15 introduced species roam free including rodents, mustelids, rabbits and possums (Curnow and Kerr, 2017). Predator Free NZ is split into region, with the branch 'Pest Free Banks Peninsula (PFBP)' set-up in 2018 by a collaborative of 14 founding local organisations. The programme focuses on widespread predator control to preserve endemic biodiversity. PFBP have funded field-testing for the Cacophony Project, which takes place on private land owned by Living Springs.

Living Springs is a camp site and conference centre located in the Port Hills at the head of the Allandale Valley on the western perimeter of Banks Peninsula (Figure 5). This privately owned land stems 420ha with three major gullies descending west to east. The highest elevations of 450 masl drops to ~30 masl at the lowest point. The landscape is a mixture of native bush and pastureland. A long-term goal is to create contiguous bush linking to surrounding land, owned by private stakeholders and the council. The location is good for field-testing due to its abundance of invasive and native species. For monitoring the field site is split into three sections (A,B and C) using the gullies as natural divides (Figure 6).

Figure 5. Location of Living Springs: the field-testing site for the Cacophony Project (43°39'11.37"S 172°38'02.78"E). Pinned is the location of the camp and conference facilities. The three gullies are prominent features of the landscape and the mixed vegetation (native bush and pastureland) can be seen. (© Google Earth Pro and Google Maps 2021).

Figure 6. The three field-testing locations at Living Springs. Section A, B and C are split into the three natural gullies and highlighted on the map.

Over the course of the 12 weeks of my internship I undertook two projects with the field aspect of each centred at Living Springs: 1) Monitoring Pests and 2) Testing the prototype trap for a) interaction rate b) behaviour. Chapters 2 and 3 focus on each project individually.

Chapter 2

Project one: Monitoring Invasive Species at Living Springs

2.1 Introduction

The Department of Conservation (DOC) is responsible for the majority of New Zealand's monitoring as establishing good, standardised practise allows clear overviews of the ecological health of the country. Monitoring exists at three levels: 1) Broadscale, 2) Nationally Managed Places and 3) Research (Local-scale). All three segments provide a framework to assess performance and guide policy making. Regarding pest control, both biodiversity inventories and long-term monitoring programs need implementing (DOC, 2021a). As monitoring uses parameters at predetermined frequencies to measure trends in populations, it is a key element for predator control programmes as the success of interventions can be quantified. Several methods have been established to optimise monitoring across the wide range of pest species in New Zealand (Table 1).

Table 1. Main monitoring methods used for different pest species in New Zealand (DOC 2021b).

	Tracking Tunnels	Chew Cards	Waxtags	Trap Catch	Faecal Pellets	Distance Sampling	Night Counts	CPUE Indices
Rodents	✔	✔						
Mustelids	✔	✔						
Possums		✔	✔	✔				
Deer					✔			
Wallabies						✔		
Rabbits							✔	
Goats								✔

For smaller pests, excluding rabbits, the most common techniques are tracking tunnels and chew cards. These are cheap, easy to use, and target multiple species thus are considered efficient to monitor pest distribution (NZ Landcare Trust, 2014). Tracking tunnels are principally used for rodent and mustelid detection. They consist of corflute plastic folded into a tunnel with middle section covered with tracking ink. To entice animals' tunnels are baited with food (e.g. peanut butter). Tracking tunnels are placed along transects spaced 50 m apart and deployed for up to a week. The resulting footprints can be identified and tracking rates calculated (Gilles and Williams, 2013; Ruffell, Innes and Didham, 2014). Chew cards are another commonly used monitoring method. These channelled cards are filled with scented baits such as peanut butter, aniseed paste or soft meats. They are then attached to trees or posts for up to a week. The resulting bitemarks can be analysed using guides to identify rodents, mustelids or possums. Chew cards have higher detection rates than tracking tunnels and are relatively inexpensive therefore are often used for large-scale monitoring (Ruffell, Innes and Didham, 2014; Sweetapple, 2011).

Despite their wide usage, these methods are extremely labour intensive and limited in data output. Therefore, to achieve pest eradication by 2050 other methods are needed to optimise wide-scale monitoring with reduced labour costs. Trail cameras are increasingly used globally due to their ability to study mammal occupancy, abundance, behaviour and distribution (Rovero *et al.,* 2013). The advanced development of infra-red trail cameras has greatly improved data output, with high quality photographs/videos stored onto memory cards and able to work nocturnally (Kucera and Barrett, 2011). Despite their high cost, it has been evidenced that their use is cost-effective over long-term studies (e.g. 5 years). Long-term studies also enable higher data output, thus explaining the method's popularity for large-scale monitoring programmes (O'Connell, Nichols and Karanth, 2011; Sam, 2011). Although conventional trail cameras have evolved significantly in sensitivity due to their high resolution, and are available for relatively cheap prices, they still present some major flaws. Trail cameras assume that detection is constant, however imperfect detectability is a common sampling error (Anderson, 2001; Yasuda, 2004). This has been highlighted in a study in North Carolina where the Passive Infrared Motion (PIR) detection in a model of trail camera often did not trigger and missed up to 14–16% of events with large, identifiable mammals (Urbanek *et al.,* 2019). Smaller species also cause a challenge as identification is difficult unless they remain still, unobstructed by vegetation and at close range. Several smaller mammals and birds often evade detection altogether as the PIR is not triggered (Urbanek *et al.,* 2019; Yasuda, 2004).

To reduce imperfect detectability yet maintain the advantages trail cameras provide, the Cacophony Project has focused on creating a standalone thermal camera to integrate into standard monitoring practises. Thermal cameras have been used in wildlife studies since the 60s and many handheld devices are widely available on the market (Karp, 2020). Thermal cameras work by detecting infrared radiation emitted by objects, which provides a heat signature against the background (Havens and Sharp, 2016). As the ambient temperature is significantly lower at night, the contrast in heat signatures easily highlights animal presence. The basic build is a simple camera, covered with thermal material and attached to a sensor. The sensor is a grid of pixels, which react to changes in thermal energy emission. These signals are then processed by the camera, producing a colour map which is used to render the display the user sees providing a simple yet effective device (FLIR®, 2021).

Recent technological advancements have seen the shift from handheld to drone and stand-alone thermal cameras. In 2016 a study to identify koalas from drones provided a 100% accuracy from up to 60 m distance, however this was dependant on low forest cover (Corcoran *et al.,* 2019). In New Zealand, Landcare Research demonstrated that these aerial thermal cameras have been successful for identifying large mammals, such as tahr, but that canopy cover poses a challenge for smaller species. For accurate detection of smaller mammals higher sensitivity is needed (Dymond *et al.,* 2000; Wilde and Trotter 1999).

Therefore, the new land-based thermal camera developed by the Cacophony Project in 2018 aimed to increase sensitivity and provide accurate multiple-species detection. Preliminary tests highlighted the high sensitivity (5x) compared to trail cameras for multiple pests including mustelids, rodents, and possums (Murphy *et al.,* 2019). Other aims included providing a low maintenance device, which yields both high quantity and quality data to optimise monitoring at a national scale. Integration of advanced software allows automated video uploads alongside their associated base data (e.g. date and time) and incorporation of Ai will eventually allow automatic species identification, thus reducing human labour and bias significantly. The lowered data-collection costs allow videos to be favoured over photos, which is often the opposite with trail cameras. Another advantage is that continuous uploads to serves via a cellular network means study areas can be monitored at an almost real-time level. The combination of these factors has meant preliminary field tests for the equipment have increased analysis speed by up to 200x (Ross and Ryan, 2019, unpub; Ross *et al.,* 2020). The device's first extensive monitoring experiment was conducted in Winter and Spring of 2020 looking to define a standardised methodology for the equipment and assess its successes and highlight its limitations.

2.2 Objectives

The main aim of the study is to establish a baseline dataset using a standardised methodology for the Cacophony thermal cameras. This field test will be completed with additional datasets produced in Summer and Autumn 2021. The overall objective is to use these datasets to guide the documentation for the equipment, which will be published for standardised use across New Zealand.

Individual objectives of this study were outlined as:

1. Determining data output quality and use in analysis
2. Training the AI and determining its accuracy
3. Highlighting differences between thermal camera monitoring and traditional methodologies
4. Understanding the limitations and assumptions of the study design
5. Noting issues with hardware or software and implementing improvements accordingly

2.3 Methodology

Prior to this experiment traditional monitoring was undertaken from the 16th June-23rd June 2020. Six transects were chosen in Section A avoiding overlap with proposed locations for the thermal camera transects. Forty baited chew cards were deployed along four transects at 20 m spacing (10 cards per line). Twenty tracking tunnels were deployed along two transects for tracking tunnels spaced at 50 m (10 tunnels per line). Both were baited with peanut butter and left for 7 days before collection. The data was then uploaded into Trap NZ and the Chew Card Index, Tracking Tunnel Index and Predator Abundance Index calculated (See Table 2).

The study site was Living Springs (Chapter 1) and monitoring was limited to Section A (~48 hectares) due to thermal camera availability and time constraints. The first half of the study was conducted across two periods: Winter (5th-26th August 2020) and Spring (2nd-30th September 2020), each survey lasting 4 weeks. In advance to the main study, software was downloaded, and camera trigger times were prepared. The thermal cameras were active from one hour before sunset and one hour after sunrise (adjusted automatically using software linked to local solar data).

Systematic sampling was chosen using four transect lines at sampling intervals of 200 m randomly placed in areas of native bush in Section A at varying elevations. To avoid saturation of the reserve with multiple cameras, a technique created by Matthew Hellicar (Project Lead) called “set deployment” was implemented. A “set” was defined as the number of cameras needed for one transect, calculated based on area of study. “Set deployment” was defined as the movement of a set across a predetermined number of transects over a specific period. The method recommends seasonal deployments to provide annual patterns of seasonal variation.

Figure 1. a) Location of the four transects for the thermal camera sets, labelled S1-4 to indicate the order for set deployment. Circles represent GPS location of each camera within a set. b) Location of traditional monitoring experiment prior to the study. Highlighted are the transects for chew cards (A1-4) and tracking tunnels (A5 and A6) (The Cacophony Project).

For this experiment three thermal cameras were installed on posts/tripods along transects at 200 m intervals. In total there were 12 locations across Section A for both winter and spring, with each monitoring their surrounding 4 hectares (Figure 1a). Elevation ranged from lowest (S1) – highest (S4) with varying vegetation: S1 = native contiguous bush (by stream) S2 = native contiguous bush, S3 = native patchy bush, S4 = forest edge.

a) b)

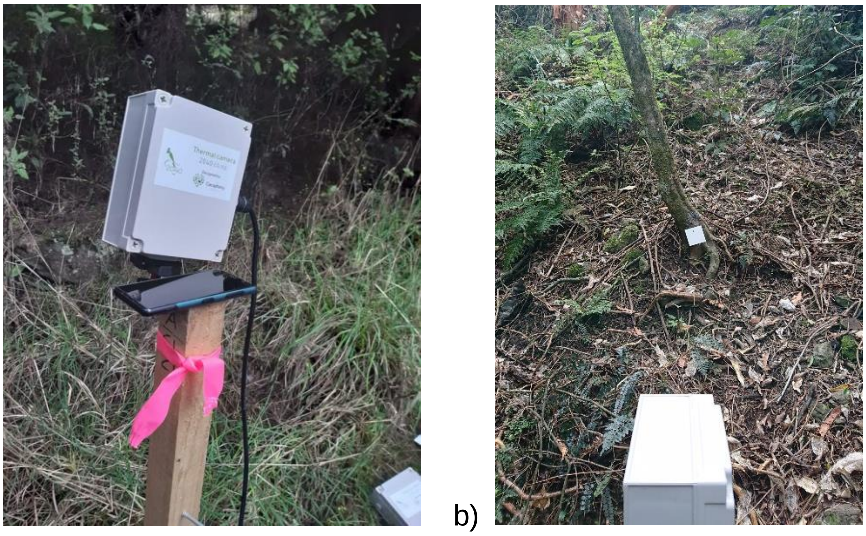

Figure 2. a) Cacophony Thermal Camera attached to a post. b) View of Camera 1 on transect S3 during the week start 12th August. View faces towards a baited chew card attached to a tree as a lure (The Cacophony Project).

Installation involved angling the thermal camera to ensure a lure (usually attached to a tree) was in the centre of the cameras view (Figure 2). The main lure was chew cards baited with peanut butter. Additional bait (e.g. dried rabbit meat) were also used to expand range of species attracted. Every Wednesday afternoon the cameras was moved to the next transect providing seven nights of data per transects per set. A detailed field protocol was produced and then refined during the experiment and can be found in Appendix I (A1).

The thermal camera was triggered if a heat source appeared and immediately recorded a video. Once deployed these recordings were automatically uploaded to the Cacophony Cloud. Recordings could then be classified by the Cacophony AI and sorted into both recordings and visits. Visits were defined as a predetermined period where the AI determines the recordings to include the same individual. With the AI still in training, manual tagging was necessary to check the accuracy, which was then calculated using excel to assist future AI learning. This also ensured data were spot-checked before analysis (Figure 3).

Figure 3. Example of a recording uploaded by Camera from transect S3 showing a possum, identified correctly by the AI and confirmed by the user for AI training and to ensure accurate monitoring results (The Cacophony Project).

Animals identified during the study were rodents, mustelids, hedgehogs, possums, cats, dogs, humans, sheep, birds and invertebrates. Videos with obstructions or fast movement were categorised as ‘Unknown’.

After each month, the datasets were downloaded as csv files, automatically produced by the server, and manipulated to fit into Trap NZ. TrapNZ is a free online service allowing monitoring records to be uploaded from multiple sources to store, present and analyse data. A guide for uploading into Trap NZ was created to assist anyone using Cacophony thermal cameras.

Presence/absence tables were made to calculate occupancy of each transect line per pest and non-target species. Occupancy per species across the study site was calculated as the Predator Presence Index (PPI). In addition, a simple Visit Abundance Index (VAI) was calculated. The results that previous traditional monitoring yielded also had basic statistics calculated including the Chew Card Index (CCI), Tracking Tunnel Index (TTI), and Predator Abundance Index (PAI) (Table 2).

Table 2. Indices calculated for all monitoring methods including their abbreviation, associated methodology, definition, and source (Ruffell, Innes and Didham, 2014; Blackwell *et al.,* 2002; DOC, 2021c, The Cacophony Project).

Indices		Method	Definition	Source
Chew Card Index	CCI	Chew Cards (CTC)	Proportion of chew cards bitten by a given species	Ruffell, Innes and Didham, 2014
Tracking Tunnel Index	TTI	Tracking Tunnels (TT)	Proportion of tunnels with tracks by a given species	Blackwell *et al.,* 2002
Predator Abundance Index	PAI	Chew Cards and Tracking Tunnels	Proportion of relative abundance calculated for all transect lines in the study (both chew cards and tracking tunnels)	DOC, 2021c
Predator Presence Index	PPI	Cacophony Thermal Cameras	Proportion of presence of given species across the study area	The Cacophony Project
Visit Abundance Index	VAI	Cacophony Thermal Cameras	Mean number of visits to a device by a given species	The Cacophony Project

Analysis was limited as only halfway into the study, but per season basic Trap NZ reports were produced and examined. A portion of data from the winter monitoring were extracted to compare with the traditional monitoring. The datasets were then discussed to prompt the initial documentation of a protocol for the thermal camera.

The assumptions the methodology made were noted: 1) Target species will walk in front of camera if in proximity 2) Target species will be clearly identifiable, 3) No pseudoreplication occurs 4) Populations are closed (no immigration or emigration), 5) Sets cover a range of animal territories, therefore multiple species will be recorded if present, 6) Sets are representative of nature as account for seasonal variability, 7) the sampling area is representative of wider habitat occupied by pest species, 8) All users can easily install the equipment, operate the online software and identify the animals accurately.

2.4 Results

In total the two seasons yielded 2026 results with 978 across the winter period and 1048 during spring. For analysis, several data were excluded including insects, sheep, dogs, humans and false positives. The remaining results gave a total of 975 visits in winter and 1041 in spring (including 'Unknown' data). These were used to create pivot tables in excel for both seasons. These data were displayed as a bar graph for visual representation (Figure 4). The data shown included the main pest species identified (Rodents, Mustelids, Rabbits, Hedgehogs, Possums and Cats), non-target species (Birds) and data tagged as 'Unknown' (presence of a species but unidentifiable). The results show high overall species occupancy during both winter (88%) and spring (75%), with the graph highlighting rodents having the highest no. of visits in both seasons. During winter rabbits were the only species not recorded, whereas during spring no mustelids nor cats were recorded. Unidentified recordings were also displayed to highlight imperfect detectability within the methodology.

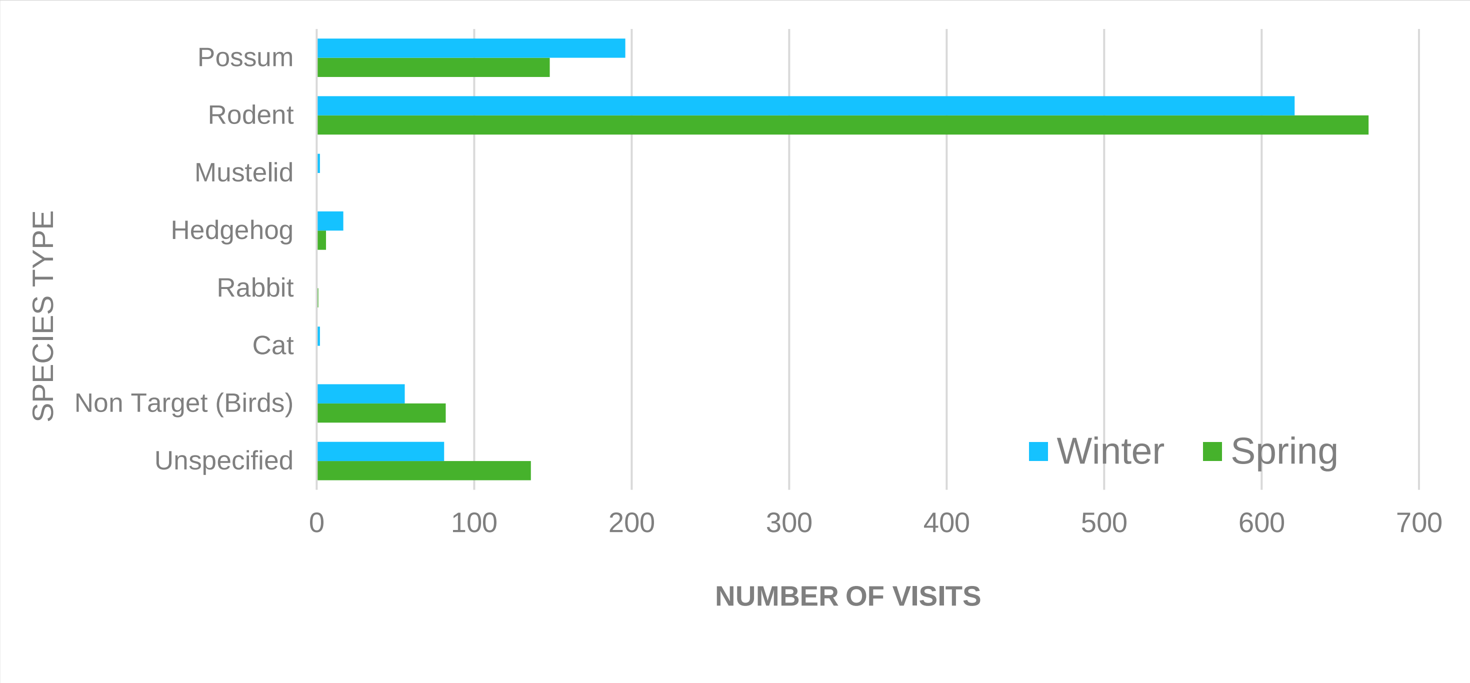

Figure 4. Total number of visits per season (Winter and Spring) by given species across all four transect lines in Section A. Rodents and possums were the most prevalent pests recorded during both seasons. Mustelids and cats were only present in winter, whereas rabbits were only recorded during spring. Unspecified shows the largest visible difference between seasons with 136 recorded in spring vs. 38 in winter.

Basic occupancy and abundance indices were calculated for each species per season (Table 3). The Visits Abundance Index shows rodents as having the highest abundance, followed by possums. Every other species had low values using this statistic. Occupancy was calculated by the Predator Presence Index showing full detection of rodents during winter, with only one location (S2, Camera 3) not detecting any rodents. The lowest PPI value of a present species were rabbits, with only one camera (S4, Camera 1) detecting an individual across both seasons.

Table 3. The total visits and calculated VAI (Visit Abundance Index) and PPI (Predator Presence Index) values for each species during both winter and spring results. Unknown data was removed, but one non-target species (birds) was included.

	Total Visits		Mean VAI		Mean PPI	
Species	**Winter**	**Spring**	**Winter**	**Spring**	**Winter**	**Spring**
Possums	196	148	16.3	12.3	75%	67%
Rodents	621	668	51.6	55.7	100%	92%
Mustelids	2	0	0.17	0	17%	0%
Hedgehogs	17	6	1.42	0.5	17%	17%
Rabbits	0	1	0	0.08	0%	8%
Cats	2	0	0.17	0	17%	0%
Birds	56	82	4.7	6.9	58%	75%

Once uploaded into Trap NZ, maps were produced to display areas of high pest occupancy (hotspots). Two maps were produced (winter and spring) for presentation to Pest Free Banks Peninsula and other organisations associated with predator control in New Zealand (Figure 5a and b). Full size of the maps at high resolution can be found in Appendix I (A2). Additional maps also including traditional monitoring results were also produced for reporting albeit are not included.

Figure 5. Total number of visits at each location from all pest species across S1-4 transects over monitoring periods of a) Winter (5th-26th August 2020) and b) Spring (2nd-30th September 2020) (Map Courtesy of Trap NZ).

Maps were also produced for each target pest species for each season individually and combined. These were used to identify high occupancy of a particular species for analysis. For example, Figure 6 shows the resulting map for possums (over both seasons) highlighting the highest occupancy was at the location of S4 Camera 2. Transect S1 shows full absence at the location for Camera 1 and 3 of possums across both seasons.

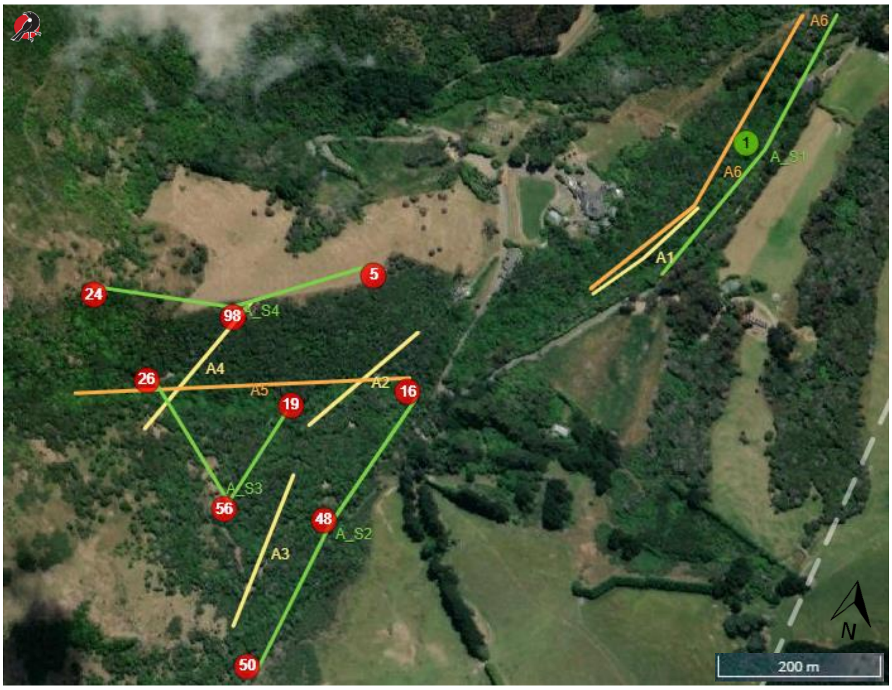

Figure 6. Total number of visits of possums at each location across S1-4 transects over both seasons. The highest occupancy is at S3 Camera 2, whereas the lowest is at S1 with only one sighting at Camera 2 (Map Courtesy of Trap NZ).

The traditional monitoring data were then analysed. Abundance indices including the Chew Card Index (CCI), Tracking Tunnel Index (TTI) and the Predator Abundance Index (PAI) were calculated for the three species of pest identified. The CCI results indicate a higher abundance of possums across the A1-4 than both rats and mice. TTI results show similar abundance levels of both rodent types, whereas rats were lower than mice, although this was not tested for significance.

Table 4. Abundance indices results for traditional monitoring (June 2020). Indices calculated were the Chew Card Index (CCI), Tracking Tunnel Index (TTI) and the Predator Abundance Index (PAI) for the three identified species (Possum, Rat and Mouse).

	Mean CCI	Mean TTI	Mean PAI
Possum	68%	N/A	68%
Rat	3%	35%	13%
Mouse	10%	40%	20%

Additionally, a table was produced to provide a visual comparison of the thermal camera data with the traditional monitoring (Table 5). Data were chosen following the criteria: 1) similar transect length and location and 2) same data collection length. The resulting datasets were the S1 transect consisting of three cameras (5th-12th August) and the A6 tracking tunnel transect consisting of 10 tracking tunnels.

Table 5. Comparative table showing interaction data collected from the transect S1 (thermal cameras) and A6 (tracking tunnels). NI = Not identified using this monitoring method.

	S1	A6
Rodents	195	6*
Birds	1	NI
Possums	2	NI
Unspecified	2	NI
Total	200	6

*could be identified as 5 mice and 1 rat

2.5 Outcomes and Conclusions

The study achieved its main aim as baseline data for two seasons were produced using a standardised methodology created for the Cacophony thermal cameras. In turn this led to multiple outcomes for the project. Being in preliminary stages of field testing, presenting, and documenting the data was the most crucial result. The results were presented to Pest Free Banks Peninsula to attract further funding as well as to introduce the monitoring methodology and equipment to other organisations and initiate collaboration. Developing the methods and highlighting limitations allowed for documentation. A field guide was created and can be refined with further field testing. Another important step was the creation of a protocol and with these results several aspects could be suitably documented. However, this is in draft and will need iterations after the study is completed.

<u>Objective 1: Data Output</u>

One objective was to determine data output quality and its use for analysis. Occupancy data was the most valuable output at this stage. Occupancy is defined as the proportion of a total area where a target species is present (Bailey, Simons and Pollock, 2004; MacKenzie and Royale, 2005). For this study, the Predator Presence Index was used to calculate occupancy as the proportion of species present at any of the 12 monitoring stations. Areas of high occupancy were deemed hotspots and regarded as top priority for pest control measures. As the goal of monitoring was to understand distribution of predators, using occupancy rather than relative abundance allows several limiting assumptions to be disregarded (e.g. pseudoreplication). For example, occupancy accounts for imperfect detectability by being robust to false absences (MacKenzie *et al.,* 2005). Therefore, absence of a species can be often attributed to factors other than detection probability.

The results showed similarities of presence between both seasons for all species, however the actual variance was not statistically calculated as part way through the study. Overall, the top pest hotspot was Camera 1 on S2 for both seasons. There was a high presence of rodents across Section A regardless of season, vegetation, or elevation. Using the thermal cameras, it was near impossible to distinguish between mice and rats, however both are pests, thus fulfilling the purpose of monitoring anyway. Regarding possums, transects S2-4 had high presence, whilst S1 had one visit over both periods. Possums typically den in thick forested areas within tree hollows of large diameter (Ji *et al.,* 2003). At Living Springs this habitat type is found at the higher elevations, which could explain the distribution. However, there could be multiple other reasons (e.g. human disturbance or food source) and as these factors were not analysed no solid conclusion can be drawn. However, it does highlight that pests are present in areas of low occupancy and should be considered when assessing control measures. Hedgehog occupancy was low, as anticipated due to the time of season. However, the two monitoring locations found activity in both winter and spring, indicating early emergence. There are multiple possibilities, such as climate change or disturbance of the hibernation site and with long-term monitoring in the area, these factors could be assessed to gain a better understanding.

Signs of mustelids are present at Living Springs, however only one video-capture occurred. In New Zealand stoats exhibit predominantly diurnal behaviour, thus making their detection probability extremely low in this study. However, ferrets and weasels display nocturnal behaviour and have been found in high abundance on Banks Peninsula, therefore it is unknown why the occupancy was low, therefore further data collection is needed (Curnow and Kerr, 2017). Mustelids have high movement speeds and therefore some of the 'unknown' videos could have been ferrets or weasels, although this cannot be verified either. There is also the possibility sensitivity of the cameras needs to be increased to improve detectability of mustelids. A cat was also detected during this study, although whether feral or not could not be identified. Therefore, the thermal cameras could be used for targeting feral cats in areas where pets are known to be absent.

At Living Springs, most birds are passerine species including the introduced common blackbird (*Turdus merula),* the native bellbird (*Anthornis melanura*) and the reintroduced native NZ pigeon (*Hemiphaga novaeseelandiae*). Several birds were detected during this study but could not be identified (to 100% accuracy). However, several of New Zealand's endangered ground-dwelling birds which remain at highest threat from predators could be identified even at a high-level (Innes *et al.,* 2009). Using cacophony thermal cameras to monitor these species could highlight areas for protection, dispersal and establishment of translocated populations and assist in decision-making for pest control measures.

For more thorough analysis, occupancy of species could be calculated per transect for comparison of varying habitat type and elevation. Incorporating covariates into future field tests is important as time of night, home range, temperature, humidity, rainfall, and wind impact detection probability. Occupancy is also impacted by environmental factors (e.g. food sources) and disturbance (e.g. human activity) and is important to note if obtaining low occupancy results. Occupancy estimation provides more reliable results with repeated data (MacKenzie *et al.,* 2005). Therefore, after completion of this study it is recommended that baseline data for Section B and C are also collected to create a robust sample size for further statistical modelling. A larger sample size and incorporation of covariates would allow temporal and spatial population trends to be assessed. Measuring absolute abundance of small mammal populations is extremely difficult (Blackwell *et al.,* 2002). Therefore, within traditional monitoring DOC encourages using the CCI, TTI or PAI for direct comparison of habitat types, pre- and post-treatment studies or as a relative abundance estimate over time (DOC 2021). For the thermal cameras the Visit Abundance Index (VAI) did provide a basic statistic and often abudnance usually positively correlates with occupancy, however without the inclusion of covariates and noting that occupancy probability is resistant to abundance change, the current abundance results are not reliable (Karanth *et al.,* 2011; Tobler *et al.,* 2015). Although a relative abundance index in future studies could help understand population trends pre-and-post pest control measures and quantifying their success.

There were other important factors found about the data output. Data volume was high, yet limited labour was needed. The automation of uploads to the server provided an organised and fast way to access data. The ability to download data into a universal format (e.g csv file) also provides an easy option for people to store and analyse their data, and not rely solely on Cacophony software. The ease of reduced labour yet high data volume results in a high scalability, which is needed if to be implemented nationally. Multiple species detection was the other key advantage. The range of species was high, from tiny rodents to sheep. Additionally, all pest species known at Living Springs were detected, even if at a low occupancy (e.g. mustelids or rabbits). Not only were pests detected, but non-target species (e.g birds) were recorded. Traditional chew cards were used as lures, yet many recordings showed individuals never interacting with the lure. Therefore, highlighting the problem of imperfect detectability in traditional methods and evidencing improved interaction rate for the thermal cameras. Other factors contributing to improved interaction rate were identified as minimal habitat disturbance, lack of light source and high sensitivity to triggering. The Cacophony project has recently compared the main aspects of monitoring methodologies using data provided by DOC and Cacophony itself (Table 6).

Table 6. Monitoring method aspects and their associated rating in New Zealand as determined by DOC and the Cacophony Project.

Device	Deployment Effort	Data Collection Effort	Interaction Rate	Data Quality	Data Volume	Scalability
Chew Card	Medium	Medium	Low	Low	Low	Low
Tracking Tunnel	Medium	Medium	Very Low	High	High	Low
Trail Camera	Medium	High	Medium-High	High-Very High	High-Very High	Medium
Cacophony Camera	Medium	Low	Very High	Very High	Very High	Very High

Despite having a lower resolution than advanced trail cameras, behavioural observation could still occur at a small scale. Individual behaviours (e.g. movement) and inter/intra-species interactions (e.g. predation) could be described. For example, Camera 2 on transect S4 captured a mustelid chasing a rodent during the winter period. Thus, showing there are additional uses for the thermal cameras than basic occupancy. Overall, this preliminary experiment showed high data quality and quantity without compromise to labour efforts, inferring its' importance for predator control in New Zealand.

<u>Objective 2: AI Efficiency</u>

The second objective was to train the AI and determine its accuracy. The current version of the device already provides a more sensitive and automated way of analysing monitoring data than other monitoring methods. The AI is also more advanced than many other AI-integrated trail cams (often used by hunters). However, manual tagging was still needed as AI accuracy varied per species. For example, in a Cacophony Project dataset of 112 videos tagged as possums by humans, the AI had correctly tagged 69%. With more data there can be further AI training and improved accuracy.

Despite needing manual tagging to ensure accurate results, the process was speedy and efficient. The ability to daily with automated sorting of the videos with associated data (e.g date/time/GPS) and a user-friendly interface vastly reduced human labour. Future automation in tagging will also eliminate human bias once refined. Having worked with trail camera data in the past, I can confirm these was extremely fast to analyse in comparison – able to surpass 1000-2000 videos easily in a day with minimal worry of human error and bias skewing the results. Thus, the thermal cameras offer many of the advantages of trail cameras provide with the addition of reduced human labour. One downside of the current system is the inability to recognise multiple individuals of the same species in a video, however a tag can be added to train the AI further to refine this feature.

Another refinement needed is with the "visits" system in the Cacophony software. Currently the visits are classed by including any recording of the same species within five minutes. With the AI accuracy currently below 80% for most species, the recordings require tagging before the visits feature can be used. Sorting videos into visits is still beneficial over analysing recordings as it accounts for a level of pseudoreplication. It should be considered that species' biology varies, and standardised lengths of visits could be altered to fit different species for more reliable results.

Objective 3: Comparison with Traditional Monitoring

The third objective was to highlight differences between the Cacophony thermal cameras and traditional monitoring. Each monitoring method yielded abundance/presence indices, however due to their differing value type, they cannot be directly compared statistically. Therefore, to visualise the differences in data volume/quality between thermal cameras and traditional monitoring, data were manually compared. The traditional monitoring carried out only lasted 7 days but with the set deployment each thermal camera location was monitored for only 7 days during the month. Therefore, data could easily be extracted from one transect for comparison. Transects S1 and A6 were chosen due to their similar location (same elevation, terrain and habitat type). Important differences found were that tracking tunnels can only identify rodents and mustelids but have the benefit of identifying diurnal species. However, thermal cameras can identify a wider range of species as well as providing behavioural observation. Whilst tracking tunnels could differentiate between rodents (mice and rats), this is often irrelevant in pest control measures as both are caught using the same trapping techniques. However, it is important to note if unable to distinguish then both rats and mice needed to be targeted due to their own interspecies relationships (Curnow and Kerr, 2017). The largest difference between the methods was data volume, with the quantity of thermal camera data was 3333x higher than for the tracking tunnels over the same collection time. These magnitudes of difference in data volume are likely due to imperfect detection and interaction rate of the traditional methods. Further comparisons of traditional vs. thermal camera monitoring should be carried out in future research to evidence the validity of this result for use a key advantage over current methods used in New Zealand.

Objective 4: Limitations

Understanding limitations are key parts of any study and vital when developing surveying methods. The main limitation of thermal cameras is their ability to only identify warm-blooded, nocturnal animals. Fortunately, several pest species in New Zealand fall into this category and were detected during the study (Curnow and Kerr, 2017). Currently other organisations are using Cacophony equipment to monitor larger pests such as wallabies in other habitat types (e.g. open planes) and have highlighted a limitation. During installation the camera must not encompass any sky as this affects the thermal imaging thus skewing the data, but can be difficult if needing a wider scope of view for larger animals.

The Cacophony thermal cameras have a high cost (NZ$3000) due to their advanced technology. However limited devices are needed per site the cost thus can be considered an investment for long-term monitoring projects. It is also important to note the concept of Moore's Law, which states that the number of transistors on a chip doubles every two years (Padua *et al.,* 2011). This is relevant as it outlines the ideology that every few years technology becomes more advanced, yet the relative cost is reduced. Therefore, the price of the thermal cameras will reduce as their technology is improved further evidencing their cost-effectiveness, similar to the trend with trail cameras (Sam, 2011). The numerous other advantages of the device could negate the cost especially for large funding bodies such as Pest Free Banks Peninsula.

The assumptions listed in the methodology need to be accounted for if conducting occupancy and abundance studies using Cacophony thermal cameras. Assuming a population is closed in a wild population is near-impossible and will inevitably reduce precision of the study. However, several statistical models (e.g N-mixture) can account for this, thus can be incorporated into analysis when the study is complete (Dénes, Silveira and Beissinger, 2015). Imperfect detectability is a known challenge for most monitoring technique (Archaux, Henry and Gimenez, 2012). Despite the thermal cameras' high sensitivity and capture rates, there are still issues with unidentified data. Approximately 11% (8%

in Winter and 13% in Spring) of the dataset were classed as unknown. This was often due to obstruction by vegetation, direct blocking of the camera, or being partially in view. These data were excluded from statistics calculated but were kept in the overall results to highlight this as a limitation and to be accounted for in analysis of the results. One way to reduce this issue would be manual identification by the user, however this was avoided for AI training purposes.

Pseudoreplication is an abundant issue for monitoring and is defined as the erroneous treatment of non-independent data as independent (Jordan, 2018). Regarding video capture the assumption is that each individual per recording is different. As previously described, the Cacophony Project have reduced some pseudoreplication by creating a visit system in the software. Even with 100% accuracy in the AI and visits system, pseudoreplication can never be fully accounted for. For example, lures can alter behaviour increasing likelihood of returning to the monitoring location. Movement between camera location or transect is also possible due to species' home ranges or dispersal. The Cacophony project are using Living Springs as a field test site for a trap and hotspots can direct trapping experiments to target particular species (e.g. possums with joeys). Therefore, the assumption of pseudoreplication can be somewhat disregarded as it is irrelevant whether each visit is the same individual or not.

The low resolution of the thermals cameras reduces manufacturing costs, increases device robustness and battery life. However, it also makes the identification of animals at a species-specific level near-impossible, particularly by the AI. Stoats, weasels and ferrets are morphological different, yet are often indistinguishable with the thermal cameras and can only be classed at family-level (Mustelidae) (Law, 2019). It is also difficult to differentiate rodents; rats and mice form part of the superfamily Muroidea but encompass multiple species (Catzeflis, Aguilar and Jaeger, 1992). This limitation affects in-depth analysis as only generic trends at family-level can be done. However, presence of any of these species still indicates a need for pest control and measures can target all members at a family level. When the audio lure technology has been developed, identification could be possible as auditory characteristics differ between species.

Objective 5: Issues and Improvements

The final objective was to note issues with the equipment and software and act accordingly. Real-time uploads allowed continual checking of the cameras for issues. Therefore, bugs were flagged to the development team quickly and without hindering the study. Another note was that spot-checking data should occur even when the AI is highly accurate, due to issues such as animals knocking over the camera. Areas of no signal provide the biggest challenge due to needing manual collection, which still reduces labour time significantly but stops real-time monitoring, a key advantage for the user. One improvement highlighted was the need for automated integration of data into TrapNZ. This would provide an easy method of standardised reporting for anyone using the equipment.

Conclusion

The study so far shows there is the potential for the Cacophony thermal cameras to provide an efficient monitoring method with high scalability and reliability with a cost-beneficial investment and low labour requirements. The equipment could then be used nation-wide to make fast yet informed decisions for pest control measures. Further research relating to the thermal cameras is also in motion, with collaboration by Lincoln University researchers further investigating the sensitivity of the cameras and additional technologies (e.g. audio lures). This experiment has also helped shape the protocol for the thermal cameras. Matthew Hellicar and I collaborated to create this document, currently in its draft stages and will be refined with further testing. This protocol can then be implemented as a standardised method in NZ alongside traditional methods. Cacophony thermal cameras and the set deployment methodology is already being accepted at a regional level as an integral part of the Pest Free Banks Peninsula project and will likely be adopted by multiple local organisations within a couple of years.

In conclusion, this study has shown several advantages of thermal camera use for predator monitoring in New Zealand and could bring the country one step closer the full elimination of pest species by 2050 and help preserve the incredible unique biodiversity New Zealand has to offer.

Chapter 3

Project Two: Prototype Trap Experiment

3.1 Pest Control in New Zealand

There are currently three main approaches to tackle species invasion in New Zealand: Ecosanctuaries, Kill-Traps and Pesticides. Currently two types of ecosanctuary exist, either on offshore islands or in areas using predator-proof fencing. Offshore islands provide ideal havens for native species to thrive due to their low reinvasion potential. However, their capacity is limited, and they do not tackle the wider issue of restoring biodiversity on the mainland. Therefore, currently 33 predator-proof fences protect >8000 ha of land across North and South Island (Scofield, Cullen and Wang, 2011; Bell, 2014). These fences prevent all pests by disabling tunnelling (fence is built 1 m below ground) and climbing (built 2 m above ground with a lipped hood). They have been key to the rescue of many species including the North Island Black Robin (*petroica tracversi).* Allowing visits to ecosanctuaries provides an immersive education opportunity to highlight the importance of pest-free habitats. Like offshore islands, these sanctuaries are considered fragments, which cannot be considered complete replicas of their former habitat. Frank Preston in 1962 faced the quandary of preserving biodiversity using a similar concept (national parks) and established fragmented areas cannot reproduce ecosystems in their original state (Quammen,1997). This is particularly true with fenced areas due to the demand of human disturbance for upkeep and eco-tourism purposes. Despite this, fenced areas have the benefit of encouraging dispersal of the flying species to surrounding areas. For example, with passerine species such as Whiteheads (*Mohoua albicilla*), which now inhabit Wellington after emigrating from the 225ha Zealandia Ecosanctuary (Innes *et al.,* 2012). A major downfall of fences are their maintenance costs, to avoid breaching – with some areas requiring up to $326,000 per year (Curnow and Kerr, 2017). Therefore, whilst beneficial short-term, predator-proof fences are not long-term solutions and currently must be used alongside other control measures.

The top control measures used are trapping and pesticides. Larger-scale control operations targeting rodent and possum invasion opt for pesticides. The most common poison is 1080 (synthesized sodium fluoroacetate) which is integrated into cereal-based pellets and usually deployed aerially. It acts by inducing heart failure within 6–18 hours of eating poisoned bait. However, a major risk with this method is poisoning of non-target animals both directly and indirectly (Wright, 2011; Environmental Protection Agency, 2018). For instance, during August 2020 three Takahē individuals (*Porphyrio hochstetteri*) were lost due to an aerial 1080 operation in Kahurangi National Park (South Island) (DOC 2020). Issues like this have triggered much noise from animal activists, and whilst this poison is deemed effective and safe at an official level, there is much contention around its usage by other conservationists and industries e.g. concerns to livestock (Eason *et al.,* 2017; Green and Rohan, 2012). With most poisons presenting the aforementioned consequences, there is the move towards advanced kill-traps as well as research into non-lethal methods (e.g. gene editing).

Trapping in New Zealand is vigorously regulated, and the Animal Welfare Act 1999 states the importance of ensuring kill-traps are humane (Curnow and Kerr, 2017). The National Animal Welfare Advisory Committee (NAWAC) have developed trap-testing guidelines to provide a standardised process for assessing traps. The test states “from a sample of 20 animals there must be no more than 3 retaining their corneal reflexes after 3 minutes and no more than 1 retaining its corneal reflex after 5 minutes” (NAWAC, 2019). To achieve this both single-use and resetting traps are available (Figure 1). The most effective single us traps are the DOC 250 or Sentinel. These are baited trip-trap and snap the body or neck of an animal once triggered. They target rodents, hedgehogs and mustelids. These traps do require high maintenance to remove corpses and reset the trap. Self-resetting traps (e.g. Goodnature A12/A24) often employ concentrated gas-dispensers to target rodents, possums and stoats. They require minimal maintenance and can be left for several months, ideal for larger-scale operations (Albright *et al.,* 2019). However, self-resetting traps cannot target all pest species and have lower capture-rates, therefore most pest control operations rely on a combination of self-resetting and single use traps.

a)  b) 

Figure 1. Examples of widely used traps in New Zealand. a) DOC 250: single-use trap, works by snapping the head or body of any rodent/mustelid which enters the trap (© PredatorFreeNZ 2021), b) Goodnature A24: self-resetting trap, works by poisoning the target pest, which dies and the corpse is removed by scavengers (demonstrated in diagram) (© GoodnatureTraps 2021).

Trapping requires baits to lure target pests and are important for reducing trap-shyness. Several studies have shown that pre-feeding traps significantly increased the capture-rate per volunteer effort (Albright *et al.,* 2019). Traditionally the most prevalent baits are food, which differs per species. Rodents have a preference for higher fat content e.g. chocolate spread and cheese, whereas possums prefer peanut butter and eggs. Fish-based baits attract omnivores such as hedgehogs, whilst fresh/dried meat attracts carnivorous mustelids (Albright *et al.,* 2019; Jackson, Hartley and Linklater, 2016). There is variable success between food lures, with the most effective being fresh and therefore perishable. Whilst the development of dispensers is in progress, many trappers currently rely on multiple-species long-life baits provided by trapping companies as easy use product and compromise. Several studies show the addition of visual or olfactory lures increase interaction rate with traps. Flour and icing sugar mixes patted onto trees are effective visual lures for both possums and rodents. Additionally, products such as Spray and Blaze (Lure-it™) incorporate aniseed/cinnamon scents with a visual white spray and have significantly enhanced possum attraction (Waters *et al.,* 2016). Due to the effectiveness of scent lures many are now available as stand-alone products and are widely used across New Zealand. The Cacophony Project has also collaborated with Professor James Ross of Lincoln University to investigate the development of audio-lures. There are two types being considered: 1) conspecific (e.g. using calls of rivals or potential mates) and 2) heterospecific (e.g. calls of prey species).

Predator Free 2050 has led to nation-wide assessments of current traps and their effectiveness for large scale projects. Recently, a study by Warburton and Gormley (2015) produced a model assessing maximum animal-capture likelihood for single-use and self-resetting traps. The results stated more single-use traps would be more cost-effective than fewer, multiple-capture traps. Conversely, a study assessing pest control options for Banks Peninsula highlighted the opposite. In proposed scenarios for both self-resetting and single-use traps, both had the same initial and annual costs, yet single-use traps would prolong the operation by 5 years in comparison to self-resetting due to labour and maintenance costs (Curnow and Kerr, 2017). With 116,000 ha to cover, Pest Free Banks Peninsula are looking to organisations to provide alternative or improved methods to either reduce labour costs of single-capture traps or improve efficiency of self-resetting traps. Therefore, the Cacophony Project aims to design a cost-effective, multiple species capture, and self-resetting trap to tackle the flaws of both traditional trap types. Before trap design could start, market research was needed to understand current trap efficiency rates and a model was designed to standardise results across multiple studies for comparative purposes.

3.2 Trapping Efficiency

Trapping operation efficiency varies across regions, habitats and the projects implementing them, with most studies using traditional monitoring (e.g. tracking tunnels) to quantify their success. For example, in a study at Fiordland National Park, tracking indices decreased from 68%-0% for ship rats (*Rattus rattus*) over a 4-month pest control operation (using Goodnature A24 self-resetting devices) in a 200ha area (Carter and Peters, 2016). Trapping studies often shows decreased population size over time, yet Lal (2008) notes that this does not quantify the success of control measures due to trapping bias. For example, trap avoidance or the loss of the 'novelty factor' where inquisitive species initially interacted more due to curiosity. Species-specific factors include 1) Pest species presence (occupancy should be monitored and reinvasion potential should be assessed) 2) Pest species density (abundancy should be monitored), 3) Trap type used (to ensure optimised capture), 4) Bait used (e.g. fish baits are more effective for omnivores than carnivores), 5) Social organisation of target population (interactions impact home-range and occupancy), 6) Presence of non-target species and their associated risk (e.g. ground-dwelling birds like Kiwi) and 7) Trap-shyness (can reduce capture rate due to lack of interaction). Environmental factors (seasonality/weather) affect species' behaviour and occupancy should also be accounted for. Operations should also factor in the functionality of the operation such as maintenance and labour costs, skill level of trappers, difficulty of terrain and public accessibility (Lal, 2008).

One of these crucial factors, Trap-type efficacy, has been seldom tested since the 90s, leaving NAWAC guidelines as the only standardised quantification. A 2-year study across 1500ha of the Macraes flat in Otago (South Island) reported the modified Victor trap (single-use) to have the highest capture-rate compared to 5 other traps (Lal, 2008). Despite this, the study reported an average of only 1 predator caught every 147 trap nights when using all 6 trap types. Therefore, with limited comparative studies on trap-type efficacy, the Cacophony project have focused on trap interaction rate to understand how to enhance trap design. A simplified model was produced to help create a standardised method of assessing trap operation efficiency based off four main factors: trap interaction rate, kill rate, number of devices and pest density (Figure 2). The model defines interaction rate as "the chance a predator interacts with a trap in a 10 hectare area over one week". The idea is for projects' to alter the input factors (e.g. population) and calculations (annual capture-rate per trap) until the graph simulates their results and then assess the associated interaction rate. As this model is simple, there are multiple assumptions it makes: 1) All traps are automatically reset, 2) All traps are automatically rebaited, 3) The population is closed (no immigration/reinvasion or emigration) and 4) Population growth is consistent. These assumptions give the model the most optimistic results for studies and should be considered when interpreting results.

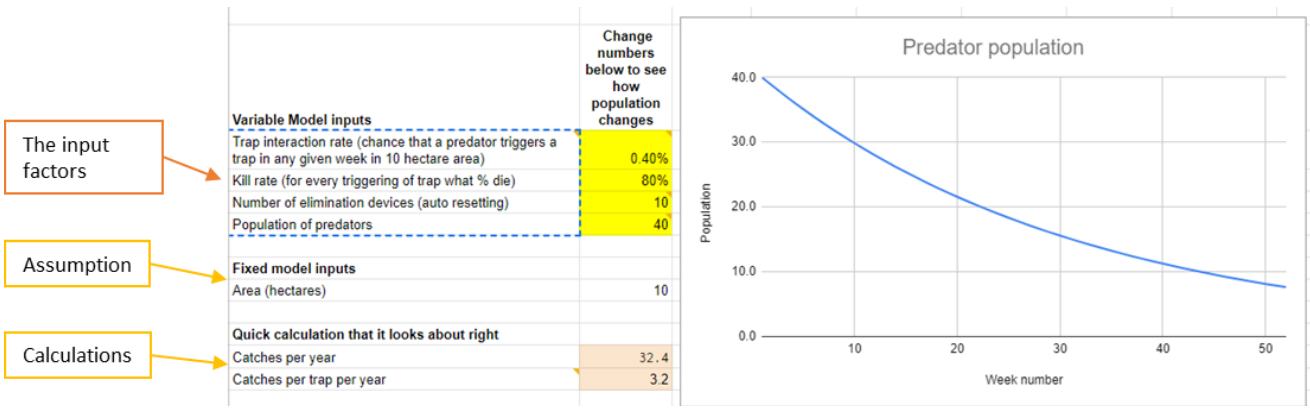

Figure 2. Trap efficiency model designed by the Cacophony project to assess interaction rates of traps (The Cacophony Project).

Annual capture-rate per trap for 60 projects around New Zealand were extracted from TrapNZ and input into the model. The best-case scenario showed an interaction rate of 0.4, meaning <1% chance of an interaction with a trap per week in a 10ha area. Whilst several assumptions are not accounted for, it highlights a major flaw with current traps. Therefore, increasing interaction rate provoked the need for an innovative trap design, which is currently in progress (The Cacophony Project 2021).

3.3 Aims

The high-level aim for the Cacophony trap is to provide an efficient yet cost-beneficial auto-resetting and multiple species-capture trap to improve large-scale pest control operations in New Zealand.

There were multiple questions considered to tackle flaws in current trap design and reduce trapping bias of the trap:

1. Trap Interaction Rate - can the design be optimised to increase interaction rates of species and reduce trap-shyness in populations?
2. Multiple Species Capture – can the trap be designed to target all pest species of small-medium stature
3. Non-target species – can AI be integrated to avoid bycatch of vulnerable native species?
4. Scalability – will the trap be cost-and-labour beneficial, therefore used for large-scale projects?
5. Low Maintenance – will the trap need maintenance; will it be self-resetting and can it reduce labour needed?
6. Cost-effective – Is the initial cost of the trap worth its value? What is the longevity and scalability of the product?
7. Additional features – can baits and lures be improved to enhance interaction rates (e.g. dispenser, audio lures etc)

3.4 Trap Design

The first design was headed by CEO Grant Ryan and Mechanical Engineer Lincoln Sell and the first prototype trap was manufactured (Figure 3).

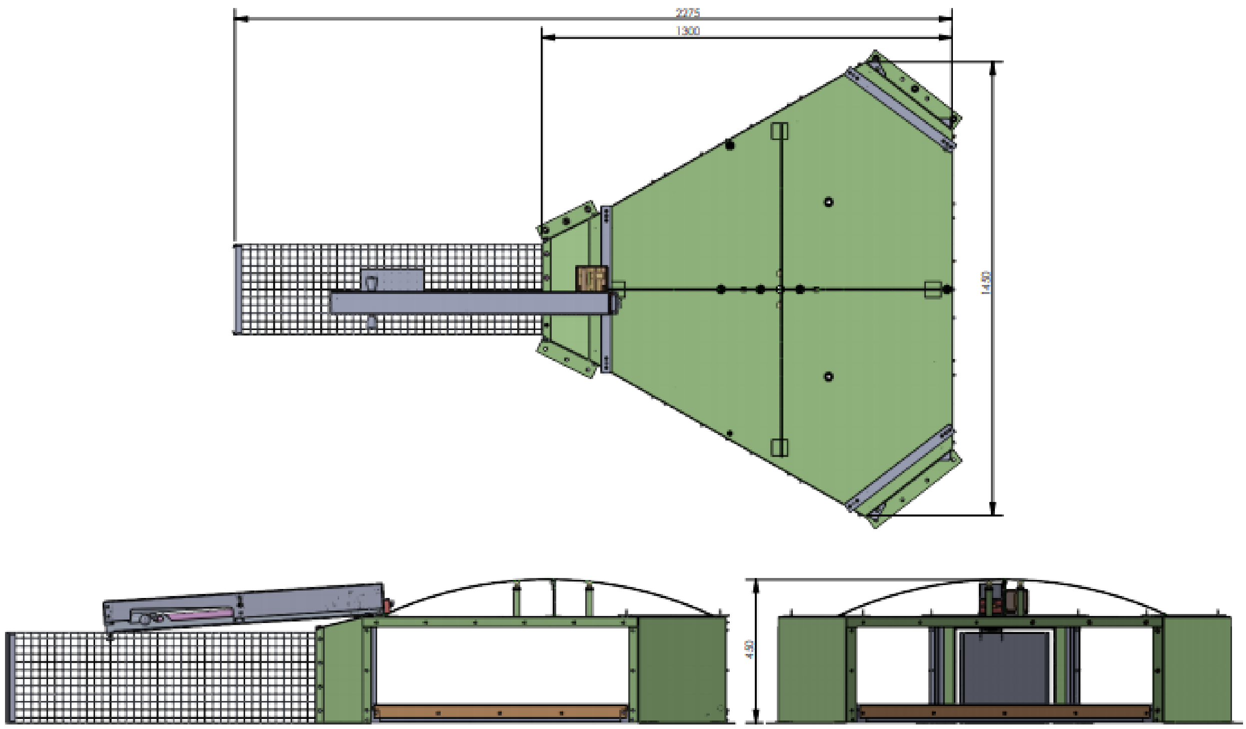

Figure 3. Schematics of the first prototype trap for the Cacophony Project Trap: a) aerial view, b) side view, c) front view (© Lincoln Sell, The Cacophony Project)

The trap works by creating a non-caged area with both cover (attractive to tunnelling animals) and three open sides tall enough to fit small-medium pests. This area can be baited species-specific or multi-species lures. Additionally, hazing can installed around the trap to guide mammals in. Once the animal walks into the trap, the AI sensor is triggered, and the three sides are closed via blinds. The back cage is then opened and once the animal walks through another sensor shuts the door to trap the animal.

This first prototype acts as a live-capture trap and must be checked within 12 hours of sunrise. The animals are then killed or released accordingly (NZ Landcare Trust, 2016). The AI sensor currently does not identify the animal within the trap at this stage of design.

3.5 Trap Set-up

During August and September 2020, the first field-test of this prototype took place at Living Springs. Figure 4 highlights the area chosen (43°39'19.4"S 172°37'53.4E), which was an accessible forested area with low human disturbance. As occurring within the same timeframe as the monitoring project, the location was chosen to avoid transects S1-4 (Chapter 2).

Figure 4. GPS location (43°39'19.4"S 172°37'53.4E) of the test site at Living Springs for the prototype trap. Trap is located in Section A at an elevation of 211 masl (© Google Earth Pro 2021).

The trap was set up on the 13th August. The placement utilised an area of bare ground and the trap was secured using pins due to its downhill angle. Hazing was then installed by the front two corners (Figure 5). The initial field-test lasted three weeks, before the trap was moved and reiterated for more field testing.

Figure 5. Photographs of the Cacophony prototype trap at the first field-test location at Living Springs (43°39'19.4"S 172°37'53.4E): a) Front view, b) Side View. Additionally, these photos align with the view of the Cacophony thermal cameras used to monitor the trap: a) TrapCam02, b) TrapCam03 (© Saphy Hampshire).

Cacophony thermal cameras and standard trail cameras were installed to monitor the trap from multiple angles. As a live capture trap, there were always staff present on site to release and kill trapped individuals when necessary. To account for avoidance of non-target species (diurnal bird species) the traps were set to trigger an hour after dusk and an hour before dawn. Multiple scent and food lures were then added around the trap to increase attraction (Table 1).

Table 1. Scents and foods used as multiple-species lures during the field testing of the first Cacophony prototype trap.

Scents	Food
• Milk Concentrate • Cinnamon • Aniseed • Rat Bedding (Female) • Rat Bedding (Male)	• Peanut-butter filled Chew Cards • Cat-food Pellets (Fish Flavour)

3.6 Trap Schematics

I produced schematics to document the process and for comparative purposes with later prototypes and tests (Figure 6,7 and 8).

The first two weeks were used to monitor basic behaviour, interaction and to allow weathering of the trap to assess its functionality in the field (Figure 6 and 7). The AI sensor was disabled so no animals could be caught. Varying baits and lures were used and replenished/moved weekly (Table 1).

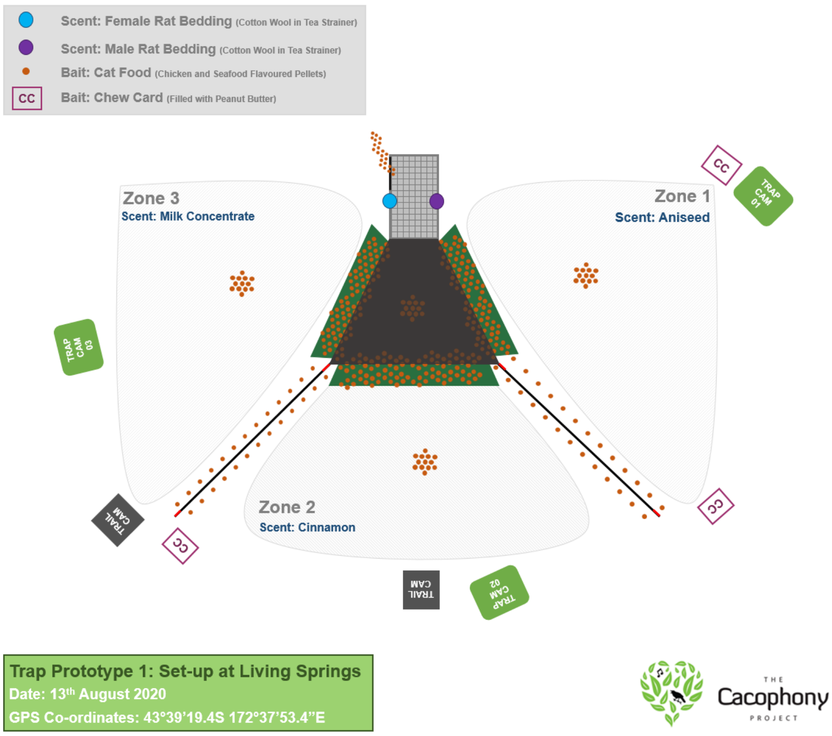

Figure 6. Cacophony Trap Prototype 1 Schematic, Week 1 (13th August 2020). Placement of chew-cards, scent lures, cat-food and cameras (trail and thermal) is shown. Trap not active.

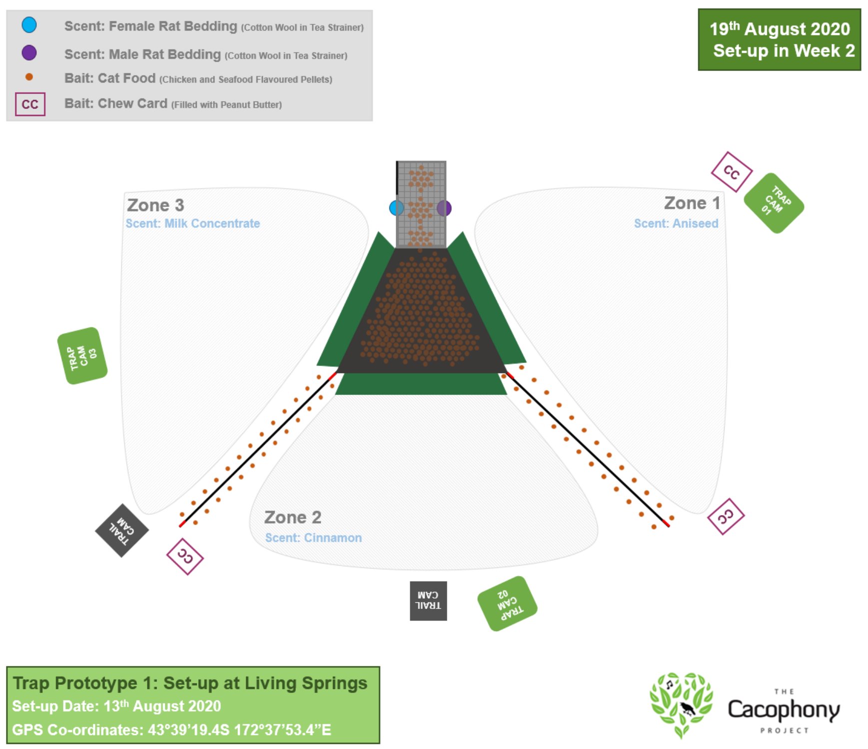

Figure 7. Cacophony Trap Prototype 1 Schematic, Week 2 (19th August 2020). Placement of chew-cards, scent lures, cat-food and cameras (trail and thermal) is shown. Trap not active.

During week 3 the AI sensor was enabled and blinds set to trigger. The thermal camera footage was then monitored to detect successful capture. Staff were the notified and were sent to dispose of the animal if identified as a pest species. Bait and lures were replenished and altered (Figure 8).

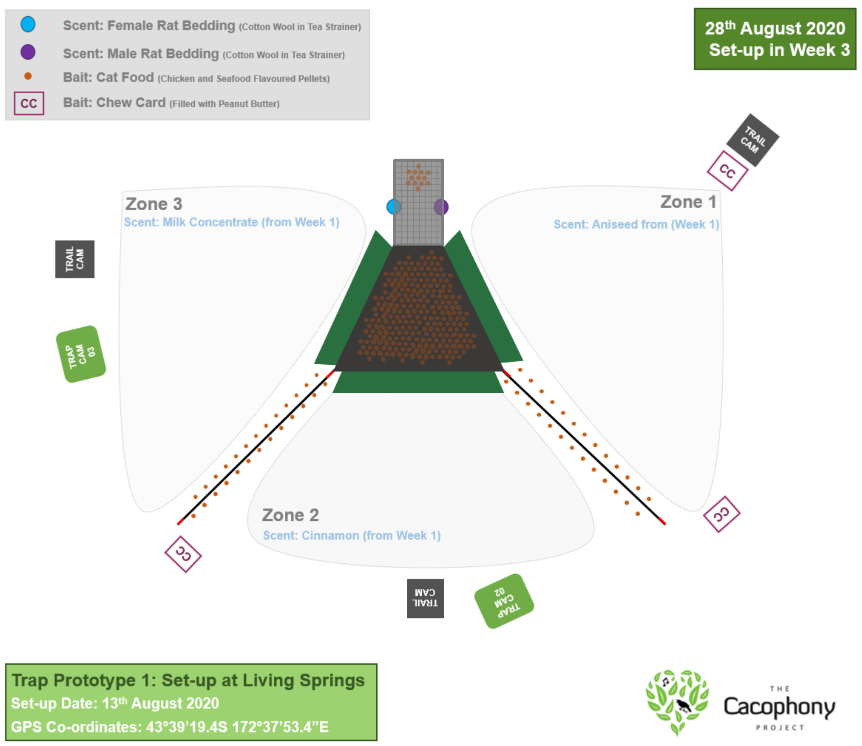

Figure 8. Cacophony Trap Prototype 1 Schematic, Week 3 (28th August 2020). Placement of chew-cards, scent lures, cat-food and cameras (trail and thermal) is shown. Trap active.

3.7. Results

As the primary purpose of these early experiments was to gauge the trap's functionality out in the field the experiment had several assumptions not accounted for. Therefore, the results and outcomes are limited to improving the mechanics of the trap, as well as some preliminary interaction rates and behavioural observations.

3.7.1 Trap Mechanics

Highlighting reiterations, the trap needed was a key objective of the field-tests. During site visits, the lead mechanic, Lincoln Sell, would assess trap robustness (resistance to damage by weather, water, or mammals). When the AI sensor was activated, the AI accuracy, range and speed could be monitored and assessed.

3.7.2 Behavioural Observation

Cacophony thermal cameras and standard trail cameras were used to monitor mammal interaction with the trap (Figure 9). Trail camera footage provided high resolution videos with multiple species detected across the study period. High resolution videos allowed for clear behavioural observations: For instance, it was determined that mice only ran along the outside edges of the trap. Due to the high data volume and manual collection/organisation, analysing this footage was extremely laborious, therefore used secondary to the thermal camera data.

Figure 9. Example of footage from one of the trail cameras (Bushnell) monitoring the Cacophony prototype trap (Front View). The image shows the interaction of a cat (undetermined if feral) with the front part of the trap. Footage is with AI sensor disabled, during the weathering/monitoring period of the field-test (© The Cacophony Project).

The thermal camera data was regularly monitored via the real-time uploads and therefore the team could determine if the trap had been interacted with, triggered and if an animal was trapped. It also highlighted behaviour such as the movement of an animal from the front area of the trap into the back cage (Figure 10).

Figure 10. Example of footage from TrapCam01 (Cacophony thermal camera) monitoring the Cacophony prototype trap (Side View). The recording shows a possum trapped in the back cage of the trap and an overlay has been added to highlight the trap outline on the recording (© The Cacophony Project).

3.7.3 Interaction Rate

During the first two weeks (not triggered) a basic interaction rate was determined to help shape trap design and understand increasing attraction of multiple pest species. The interaction rate was defined as the number of times an interaction from a mammal would trigger the trap over a set period. The period was defined as the 13th August (evening) to the 28th August (morning).

Thermal Camera footage was chosen as automatically organised and uploaded daily provided an efficient basis to tag, download, and analyse the data. An additional bonus was the ability to tag the videos with “interaction with trap”. To avoid overlap in data only TrapCam2 was chosen (Figure 6). This was due to its wide scope of view due to its upward angle; able to detect animals at the front, sides and back of the trap. Over the two weeks TrapCam2 produced 353 recordings, 98 of which were tagged as interactions with the trap. The data were downloaded to excel and total number of visits and interactions with trap were collated per species (possums, rodents, hedgehogs, cats, unknown pests, and birds). Unknown pests were defined as videos which could be manually identified of a type of pest species which the AI could not detect. However, these were left as unknown due to AI training.

The interaction rate was then calculated as:

Number of Interactions ÷ Number of Visits

This was calculated both per species and as a total of pests excluding unknowns and pests including unknowns (Table 2 and 3). The highest interaction rates were found for cats and hedgehogs, whereas the lowest were the rodents. Despite visiting the trap area, both possums and birds did not interact with the trap. The overall interaction rates for all species (excluding birds) was ~30% dependant on the inclusion or exclusion of unknown pests.

Table 2. Number of visits and interactions with the prototype trap for each species identified from 13th-28th August. The interaction rates for each species have been calculated as *number of interactions/number of visits*. Unknown pests are 'Unknown' videos which have been identified manually as pest species (but left as unknown on the server to train the AI).

Animal	Number of Visits	Interactions with Trap	Interaction Rate
Possum	9	None	N/A
Rodent	127	18	14.17%
Hedgehog	148	69	46.6%
Cat	22	12	54.5%
Bird	9	None	N/A
Unknown Pests	81	15	18.5%

Table 3. Number of visits and interactions with the prototype trap for pest species both including and excluding unknown pests, from 13th-28th August. The interaction rates have been calculated as *number of interactions/number of visits*. Unknown pests are 'Unknown' videos which have been identified manually as pest species (but left as unknown on the server to train the AI).

Animal	Number of Visits	Interactions with Trap	Interaction Rate (Interactions/No. Visits)
Pests (incl. unknowns)	387	114	29.5%
Pests (excl. unknowns)	306	99	32.4%

3.8 Conclusions

As the first prototype of this trap was live capture, the ability to check the thermal camera footage allowed fast reactions (< 2 hours) to animals being trapped. Thus, a staff member at Living Springs could humanely dispose of the pest (in accordance with the Animal Welfare Act 1999). As the trap is likely to stay live-capture for the next few prototypes, one improvement to reduce actively checking is creating a notification system which notifies the user if the trap is triggered. The most valuable outcomes were the fixes and improvements the trap needed from a mechanical standpoint as well as the behavioural observations from the footage from trail and thermal cameras.

Calculating the interaction rate was useful for design purposes but had many limitations. Due to the changing nature of the study, and many assumptions not accounted for, the rates produced have a high sampling error, thus are not reliable for scientific study. For example, due to the training of AI some human-identifiable predators within recordings were tagged as "Unknown" and therefore skewed species-specific data. Another major limitation was pseudoreplication. For example, the hedgehog was likely the same individua as visits dropped to 0 after its capture and death. Whilst this is anecdotal it highlights that pseudoreplication needs to be accounted for in future calculations of interaction rates of the trap and will be key is used comparatively against other traps. Additionally, possums were not recorded interacting despite observed, yet further testing showed interaction after this time period, highlighting imperfect detectability and reducing the reliability of the interaction rate results.

Ultimately the interaction rates gave the project an idea of which species did and did not interact with the trap and ideas for iterations and changes to the field-testing methods, thus having value. Therefore, the trap is being continually improved and advanced towards the Cacophony Projects target trap design. Additionally, different lure options are being considered based off initial tests. The team is planning its next set of tests at Living Springs as well as offering prototypes to other companies for further testing.

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Left: Buddy manning the reception desk, Right: Kelso admiring the view (of a stick) at LS (© Saphy Hampshire)

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Appendix I

A1: Field Protocol for Thermal Cameras. In-depth field guide for preparing, deployment and installation of the Cacophony Project Thermal Cameras (Produced by Saphy Hampshire and Matthew Hellicar).

A2: High Resolution Maps as found in Chapter 2: Figure 5. Maps show the total number of visits at each location from all pest species across transects S1-4 over monitoring periods of a) Winter (5th-26th August) and b) Spring (2nd-30th September 2020). Maps Courtesy of TrapNZ.

FIELD PROTOCOL:
THERMAL CAMERA

THE Cacophony PROJECT

PREPARATION

NB. Read checklist in advance and remember to prepare sufficient equipment for each camera you are installing/moving

(✓)	**Equipment**	**Notes**
	Rucksack/Backpack	Use: to safely carry the equipment between locations
	Smartphone with Sidekick App Installed	Ensure you have prepared the Hotspot: bushnet (password: feathers) on the phone (Case Sensitive)
	Freshly Charged Camera Batteries	Quantity: 1 per camera If available place rubber cap on end of power cord
	String/Cord	Use: for hanging battery/ies Ensure rope is appropriately fitted to battery for hanging
	Lures	Quantity: 1 baited chew card per camera, 1 additional bait per camera if available Ideal if can be nailed to a tree e.g. Erayz
	Clout Nails	Use: Fixing lures to trees/posts
	Claw Hammer	Use: Fixing or removal of lures to/from trees or posts
	Electrical/Duct Tape	Use: Securing camera mountings
	Map (printed off or on phone app: sidekick/trapNZ)	Must show: New camera locations and current locations (if in moving camera process)
	Tripod / Pole with Foot Mount*	Use: Mounting camera in new location

**If installing a pole bring lumphammer and flagging tap, pole should be prepped to correct height, with a screw for the battery and foot mount for the camera*

(✓)			Steps	Action	Additional Notes
C1	**C2**	**C3**			
			Step 1: Locate Camera	Find Location via (1) Project map OR (2) GPS coordinates specified on cacophony device browser or on trap.nz	If used flagging tape will also indicate location when searching
			Step 2: Wake up Camera	Press button to wake up camera: (Will be in sleep mode during daytime)	What the different flashes mean: A. If no light comes on then the battery is likely dead, therefore you will need to disconnect the old battery and temporarily connect new battery. B. Slow pulse with two flashes between means the camera hasn't booted yet C. Slow pulse with no flashing between - Camera has booted and is connected to the hotspot D. Slow pulse with one flash between - Camera has booted but not connected to the hotspot
			Step 3: Set-up Hotspot	Turn on hotspot feature on phone If required rename hotspot to "bushnet" AND Set the password to “feathers”	Case sensitive
			Step 4: Locate Device	Open Sidekick app and select “Devices”. You may need to refresh the screen (from top right)	
			Step 4: Collect Recordings	If device states that recordings are available: • Go to bottom of screen and click "Get Recordings from Devices" • Wait until all recordings have been downloaded (e.g. 68/68)	Selecting devices will locate camera and recordings if not uploaded due to lack of signal If this doesn’t occur check that the camera has booted (flash = C)
			Step 5: Remove Battery	• Disconnect the battery from the camera • Detach battery from mount/tripod	The battery will need to be brought back to base for charging
			Step 6: Remove Camera	Remove the camera from mounting shoe (of tripod/pole)	The camera will need to be carried to the next location

(√)			Steps	Action	Additional Notes
C1	**C2**	**C3**			
			Step 1: Locate New Deployment Site	Find Location via (1) Project map (2) GPS coordinates specified on cacophony device browser or on trap.nz	Add flagging tape to near-by trees to indicate location for locating in future
			Step 2: Place Pole/Tripod	Find ideal placement: 1-2 metres from a tree • Pole: Fix into ground using lump hammer and attach the mounting foot • Tripod: Place on ground and secure using tent pegs	Ensure the pole or tripod is stable and in a sturdy position
			Step 3: Attach Battery to Mount/Tripod	Hang battery from the tripod OR the screw on the pole	Ensure this is hanging securely and the cords are not twisted
			Step 4: Mount Camera	Install camera onto mounting foot on either the tripod OR the pole	
			Step 5: Connect Battery to Camera	Plug the battery connector into the camera and wait for the camera to start-up	Battery connector differs from other connectors (e.g. for sound lures)
			Step 6: Set-up Hotspot	If required Turn on hotspot feature on phone • Rename hotspot to "bushnet" • Set the password to "feathers"	Case sensitive
			Step 7: Locate Device	Open Sidekick app and select "Devices"	It should display the camera with the previous location's name
			Step 9: Update Camera Location on App	• At top right of "Devices" screen select the three vertical dots symbol and select "Update devices location" • A message will appear "Getting Location" • If successful a message will appear stating the location has been "updated to an accuracy of __"	Note that it can take a few moments to update

CONTINUE TO STEP 10 ON NEXT PAGE

(✓)			Steps	Action	Additional Notes
C1	**C2**	**C3**			
			Step 10: Rename Camera on App	• On the Sidekick App, in the "Devices" screen, select the camera name in the list – this takes you the Admin page of the camera • On the admin page there will be a menu of blue buttons shown, select "Advanced" and then "Rename" • Type in the name of the new location you are placing the camera in and then select "Rename" again - a message will appear to confirm that the name has been updated • A "Reboot" button will appear, select "Reboot" and wait for the camera to restart • Close and open the Sidekick App again and select "Devices" - it should display the camera with the new name.	To allow analysis of the data according to the locations where it was collected, it is key that each camera has the name of the location when it is deployed there • The app does not allow any '.' characters, therefore be sure to replace them with an underscore '_' (e.g. A_S1_C1).
			Step 11: Attach Lure	• Write location name and date onto chew card • Install baited chew card by fixing to the target tree using a clout nail a few inches off the ground • Attach additional bait to the tree near the chew card using a clout nail	1) The chew card name should match both the location name shown on your app/map and the device name you have now renamed the camera on Sidekick 2) Ensure the nail is not too close to the edge of the chew card (so it cannot be pulled off by a possum!) 3) Note down which bait is within the chew card (e.g. peanut butter) 4) Note down which bait is attached to the tree near the chew card (e.g. Erayz)
			Step 12: Check Camera Angle	• On the Sidekick App, in the "Devices" screen, select the camera name in the list to get to Admin section • Select "Camera" • Adjust the angle of the camera so the chew card is visible close to the middle of the frame	This will show you a live image of what the camera is seeing
			Step 13: Take a Photo	For reference take a photo using the smartphone of the location from the angle that the thermal camera is at	Ensure you name/add a note to the photo so you are aware of which location the photo matches

A2 a)

Winter (5th-26th August 2020)

A2 b)

Spring (2nd-30th September 2020)