Monitoring the ‘original’ panda: Impacts and outcomes of using infra-red trail cameras on captive red panda (*Ailurus fulgens*) behaviour

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Introduction: Cryptic species are often studied using trail cameras in the wild. However, their use may cause some animals to be attracted or repelled by them, skewing presence/absence studies, abundance/population estimates and general behaviour patterns. Red panda are an elusive and rare species, found in only the Himalayan mountain range. A recent study observed red panda examining trail cameras on their trails in the wild. Understanding how they respond to trail cameras may influence how cameras are used to monitor them in the future**.**

Aims: I assessed whether trail cameras affected captive red panda behaviour. I also determined time budgets and how they may differ with different observational methods.

Methods: I used three zoo study sites, Auckland Zoo, Hamilton Zoo and Currumbin Wildlife Sanctuary. Auckland Zoo had a male and female pair with their three-month-old male offspring. Hamilton Zoo had an older male, female pair with their four-year-old female offspring. Currumbin Wildlife Sanctuary housed a single older male.

A Kinopta Blackeye camera was set up on enclosure fencing to record continuously for the full study period. Study periods were split into three sections, with the first being labelled as *before* trail cameras, this just had the Blackeye camera. The middle third had trail cameras set up inside the enclosure and was called the *during* period. The last third of the trial (*after* trail cameras removed) had only the Blackeye setup, with trail cameras removed. During the entire study period, direct personal observations were also taken, noting typical significant factors, such as weather and temperature.

Statistical analysis was carried out using R studio, with a mixture of chi-square, negative binomial GLMs, emmeans, pairwise comparisons and AIC tests. Graphs were created with Excel and R studio.

Results: Sleeping was the most common behaviour, followed by locomotion, resting, eating and grooming. All other behaviours were less than 1% of all behaviours. The most active periods occurred in a crepuscular pattern, as with wild panda and in some cases, followed keeper timings. This led to the significant difference between zoo activity budgets. There was a significant difference in types of behaviours recorded with the two observational methods, showing that method does affect the type of data collected. Trail cameras affected behaviour at all zoos by changing the way red panda spent their time. Captive red panda were slightly more active with trail camera presence. Temperature also had a significant impact on length of behaviours. Red panda spent more time sleeping and resting at higher temperatures.

Conclusions: As trail cameras changed the way red panda spent their time (in a captive setting), care should be taken for using trail cameras in the wild. While stress responses and obvious signs of avoiding areas with trail cameras did not occur, if behaviour is being monitored, then it is likely to be skewed by trail camera presence. Red panda were more active during trail camera presence, which might suggest an inflated abundance estimate if using trail cameras in the wild.

Keywords: Trail camera, red panda, *Ailurus fulgens*, behaviour, wildlife management, captivity, activity budgets, observation methods

Dedication

For my parents, thank you for your constant love and support.

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I want to start by thanking my dog, Niya. For being my constant companion while reading, writing and analysing behaviour videos. Thank you for reminding me to take a break, enjoy the great outdoors and that midday naps and midnight snacks aren't the end of the world.

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Chapter 1

Introduction

Cryptic animals have mobile behaviour and are at low densities, are challenging to monitor in *in-situ* (Nichols et al., 2016). Trail cameras (or camera traps) have made it possible to study species that were previously thought to be too small or cryptic for direct observation. Cameras have been used since the 1880s, with varying levels of success (Meek et al., 2015). George Shiras, a game hunter, was the first person (in 1889) to develop an automated camera with a tripwire, or bait attached to a string, to take photos of game animals without being in the vicinity (Green et al., 2020: Bower, 2008). Shiras was also the first person to document the effects of white flash on wild animals, as white xenon flashes caused loud bangs from the magnesium powder used (Rovero et al., 2013: Bower, 2008). This started a new trend among hunters, who began to take "trophy" photographs, as they saw greater skill in capturing wild animals on film, rather than killing them (Bower, 2008).

Most trail cameras are designed with the hunting of larger game in mind (Meek and Pittet, 2012). A lack of functionality has previously slowed scientific studies in abundance, disease monitoring, behavioural research and wildlife management (Meek et al., 2015). Currently, trail cameras come with a range of different capture techniques. Differences include how cameras sense an animal, how cameras take photos or videos, shutter length and picture quality. Recently, infra-red (IR) flash and sensors have dominated research studies based on trail camera data. Cameras can have an active (AIR) or passive (PIR) sensor. AIR is like old film cameras with a tripwire, in that they require a camera with an IR beam and another sensor, to create an IR' tripwire' of sorts (Kelly and Holub, 2008). These AIR cameras are more challenging to set up than PIR as, if it is not perfect, a small animal may pass underneath the sensor, undetected.

Passive IR is often referred to as a 'heat-in-motion' camera, as the camera trigger detects differences in ambient temperature between the target and background (Green et al., 2020: Welbourne et al., 2016: Meek et al., 2015: Rovero et al., 2013). The optimum difference between target and background is ≥ 2.7˚C. However, pockets of hot air can sometimes set off PIR cameras, and if the sensor is blinded by the light or overheats (particularly in direct sunlight), then it will not trigger again until it cools down (Apps and McNutt, 2018: Rovero et al., 2013). In general, PIR performs better than AIR, and digital better than film (Wearn and Glover-Kapfer, 2019: Kelly and Holub, 2008) with digital cameras used from 2007 onwards (Green et al., 2020). However, AIR can result in less false triggers than PIR. Images taken with IR illumination can lack clarity and some detail due to their monochromatic characteristics (Apps and McNutt, 2018: Meek and Pittet, 2012), where white flash cameras produce better quality images but can scare animals when they are triggered (Glen et al., 2013: Rovero et al., 2013: Bower, 2008). The effects of white flash on wild animal behaviour are well documented, with animals being startled and fleeing from the area (Meek et al., 2014a). Kinkajou (*Potos flavus*) avoided previously frequented tree walkways when white flash photography was used (Schipper, 2007). Schipper (2007) considered trail cameras to be highly intrusive for kinkajou, considering their reactions. If repeated visits to an area are essential for analysis, then some types of trail cameras or their settings may introduce a bias to the study (Meek et al., 2014a).

Cameras are classed as non-invasive because animals are not captured or handled. Trail cameras were said to "provide a unique advantage by recording the undisturbed behaviours of animals within their environment" (Schneider et al., 2018). They are more effective (88%) at "capturing" animals (Wearn and Glover-Kapfer, 2019) and are less likely to affect behaviours than active traps (Claridge et al., 2004). Some forms of monitoring animals, such as live trapping, radio telemetry and pitfall traps, require animals to be directly handled, which can lead to trap happy (if baited) or trap shy (neophobic response) behaviour (Augustine et al., 2014), as well as being expensive, logistically demanding and requiring more ethical approval (Meek et al., 2014b). Tarugara et al. (2019) even managed to use trail cameras to take accurate measurements of wild leopards (*Panthera pardus*) from trail camera photos, which dispensed with live capture and immobilization of wild animals. Other hands-off methods, such as line transects, long-term direct observational studies and using signs of animals like scrapings, pugmarks and faeces, can all be time-consuming and, therefore, expensive (Bowler et al., 2016). Using sightings and signs of animals alone has been shown to underestimate populations (Jackson et al., 2006). Studies like Bowler et al. (2016) found the trail cameras worked better than other methods at detecting nocturnal and elusive species that observers could not. Trail cameras can help to rule out observer biases, answer multiple questions with a single survey, are less time consuming and less expensive as well, compared to live trapping or personal observations (Scheider et al., 2018: Caravaggi et al., 2017: Cutler and Swann, 1999). However, trail cameras' light and sound may be classed as intrusive (Meek et al., 2016). For example, coyotes can sense trail cameras and quickly leave an area (Sequin et al., 2013). Alpha coyotes were never photographed in their territories and would observe humans in their territories from high vantage points, thus avoiding trail cameras. This study was interesting because it is still questionable whether the coyotes avoid areas where humans have been and/or whether they have a neophobic response to the trail cameras.

Trail cameras can emit high-frequency noises, although they are relatively quiet, they can increase in volume when batteries are low. Most animals are thought to be able to hear this (Meek et al., 2014a). Other studies have noted the attractiveness of trail cameras to large felids, showing that they will go out of their way to investigate cameras (Meek et al., 2014a). There is increasing literature to suggest that trail cameras affect behaviour and could create bias in wild studies. Apart from mustelids (Newbold and King, 2009), very little is known about infra-red beam detection (Meek et al., 2014a). These responses may cause bias in studies and are an excellent reason to study animals' reactions so that these biases can be accounted for.

IR is marketed as being 'invisible to animals' because it is beyond normal human vision limits (Apps and McNutt, 2018). IR below 1000 nm does not emit any heat signatures. (Newbold and King, 2009). However, there are reports of researchers seeing the IR glow from a trail camera model in the 900-1000 nm range in a pitch-black room (Meek et al., 2014a). Newbold and King (2009) looked at how ferrets perceive IR light between 870-920 nm. Of their five male study subjects, three could see the light at 870 nm but not at 920 nm. They conclude that IR surveillance should be at the upper spectrum to avoid disrupting natural behaviours. Most standard IR equipment is set between 830-880 nm, which is commonly considered invisible to humans, even with many researchers being convinced they can see the light. Nocturnal animals, already sensitive to light, are likely to see IR flash and glow. IR beams between 870-950 nm saw possums and rats avoid or travel quicker through areas that were lit up with them (Newbold and King, 2009). An animal not overtly reacting to the light/stimulus does not mean that they do not perceive it.

Meek et al. (2014c) wrote a review paper on the use of trail cameras in scientific research. One of the conclusions drawn from this paper was how researchers mustn't be blind to the constraints of trail cameras because of their multiple advantages. While trail camera failure is rare, it is important to check their programming before surveys start and to have the right balance of how often they are serviced for battery life, storage and theft prevention (Caravaggi et al., 2017: Cutler and Swann, 1999). How cameras are set up can also affect surveys. Several studies found that two cameras side by side have higher detection rates and were better for individual identification, than just one camera (Farhadinia et al., 2019: Glen et al., 2013: Jackson et al., 2006). The "normal" horizontal orientation performs better than a vertical orientation. In a vertical orientation, a trail camera is placed on a pole and faces down towards the ground. This creates a smaller detection zone (Taylor et al., 2014). When cameras are placed in known areas of target species, detection rates are higher, so previous knowledge of behaviour is advantageous (Jackson et al., 2006). Many studies have also used lures in the form of baits (foods, scent and audio lures) to attract animals and encourage them to stay in the cameras' detection zone longer for better photos (Glen et al., 2013). However, the use of lures can introduce another bias to studies, as the age and sex of individuals may differ, as well as, certain lures repelling some animals and attracting others, making them "trap happy" (Mills et al., 2018: Meek et al., 2014b). Mills et al. (2018) also mentioned that the human scent trails could be either an attractant or repellent to different species. In general, baits are only useful for population studies where individuals have recognizable markings (Farhadinia et al., 2019).

Trail cameras are used in a variety of surveys and experiments including; behavioural observations of foraging, activity patterns, scent-marking, movement, predation, predator-prey interactions and abundance studies, ranging from simple presence-absence studies to, species distributions, and more complex capture-mark-recapture (CMR) studies (Caravaggi et al., 2017: Bowler et al., 2016: Meek et al., 2015). Management of endangered species is dependent on reliable information on precise population estimates, which can be difficult to obtain in dense forest, or for elusive species (Carbone et al., 2001). A simple presence-absence study using trail cameras helped provide the first account of the marbled cat (*Pardofelis marmorata*) residing in Nepal (Lama et al., 2019). This can now lead to its inclusion in conservation plans for the area. If animals have unique individual markings, then trail cameras can be used for accurate population estimations, using CMR (Carbone et al., 2001). These types of studies are commonly carried out with large felids, such as tiger (*Panthera tigris*), leopard (*Panthera pardus*) and snow leopard (*Panthera uncia*) (Noack et al., 2019: Jackson et al., 2006: Karanth et al., 2004). However, success has not occurred with all large felids, as Alexander et al. (2018) had some difficulties with agreeing with individuals' identifications. In fact, it was so difficult to distinguish the uniform pelage of cougars (*Puma concolor*), that they couldn't agree on even one identification. Carbone et al. (2001) came up with a method for trail camera CMR studies that did not use individual identifiers. Jennelle (2002) wrote a scathing reply, insisting that where individuals cannot be identified, trail camera surveys should only be used for presence-absence studies. Some studies use trail cameras in conjunction with other methods, such as hair traps in the Ramsey et al. (2019) study, where they had an 82% success rate of identifying American black bears (*Ursus americanus*), than with only trail cameras. This increased to 98.4% when genetic analyses were added to the hait tubes.

Surveys using trail cameras can be very cost-effective as multiple questions can be answered across multiple species. For example, Mazzamuto et al. (2019) conducted a study on porcupine abundance from a different target species' survey. Other studies such as O'Brien et al. (2003) and Tempa et al. (2019) assessed the threats that tigers (*Panthera tigris*) face, using trail cameras. Rees et al. (2019) also used trail cameras, to show the threat that feral cats (*Felis catus*) presented to native wildlife in Australia, while assessing abundance.

Recently, a master's thesis was carried out by Sonam Lama (2018), in Nepal, looking at using trail cameras for the first time in the Kangchenjunga region to detect red panda (*Ailurus fulgens*) (and other wildlife). From his photo images, it appears as though red panda are directly looking at the cameras. One even slept right in front of a trail camera for a few hours. Whether this is due to the infra-red (IR) light beams or noise the camera produces or because of novelty, remains unanswered. In 2011, Williams et al. conducted a pilot study for detecting red panda with trail cameras. Cameras were placed at known latrine sites, at varying angles. This study's images may be some of the first images of wild red panda caught on trail cameras. Krebs et al. (2017) also found that red panda spent longer than average looking at cameras when keepers were expected to arrive for feeding. Because red panda are an elusive, rare species, learning how they respond to trail cameras may influence how cameras are used to monitor them in the future.

1.1 Thesis structure

This thesis has been split into chapters, and is arranged as follows:

Chapter 1: The first chapter is a brief introduction to trail cameras and their use for studying wild, ellusive animals. I explore the benefits and restraints of trail cameras compared to other methods. I then discuss how trail cameras may affect wild animals' behaviour and introduce the study species, red panda (*Ailurus fulgens*).

Chapter 2: In this chapter, I provide a detailed literature review of the red panda. I explore their history, taxonomy, anatomy, diet, reproduction, care in captivity, threats they face in the wild and what is currently being done in their home range to minimise those threats. The chapter finishes with identifying research gaps and how trail cameras could be utilised to answer a good proportion of these questions. Overall aims and hypotheses of the study are also included.

Chapter 3: This chapter is a generic methods for the whole study, as many questions could be answered with the same experimental design.

Chapter 4: In this chapter, I compare the activity budgets of captive red panda at three different zoos, with two different observational methods.

Chapter 5: In this chapter, I investigate whether trail cameras, placed in enclosures, effect captive red panda behaviour, also using two different observational methods.

Chapter 6: And finally, in this chapter, I summaries my findings, discuss where future research may go and make recommendations.

Chapter 2

Literature review

2.1 Literature review

2.1.1 History

Red panda first became known to western science in 1825 when Frédéric Cuvier published a paper describing the species (as "quite the most handsome mammal in existence"; Cuvier, 1825). The red panda bore the name 'panda' for half a century before Père Armand David published a paper describing the giant panda (*Ailuropoda melanoleuca*) and naming it as such, due to perceived similarities (Glatston, 2011a). The notion of the two pandas being related would carry on for decades afterwards. However, Cuvier was not the first westerner to discover the red panda, that honour goes to Major-General Thomas Hardwicke. His paper was only published six years after writing it (Glatston, 2011a), giving Cuvier a chance to publish his paper first. Furthermore, the red panda was well known in the Himalayan region before western scientists described them. Still, reference to the red panda in local folklore and rituals is rare, likely due to its elusive nature and inaccessible habitat (Glatston and Gebauer, 2011). The first known written reference to the red panda occurs in scrolls dating back to the 13th century in China (Roberts, 1992, as cited by Glatston and Gebauer, 2011).

In Nepal and Bhutan, the red panda is a symbol of good fortune. The origin of the name panda is unknown, but likely related to one of the local names' nigalya ponya', which roughly translates to bamboo footed (Catton, 1990, as cited by Glatston, 2011a). Other native names include; fire fox, bear cat, wah, ye, thokya, woker, sankam and wokdonka (Roberts and Gittleman, 1984).

2.1.2 Taxonomy

Cuvier (1825) gave the red panda the genus name *Ailurus* based on its superficial resemblance to domestic cats (Kundrát, 2011: Roberts and Gittleman, 1984), and *fulgens* for its colouration, giving a meaning of "fire-coloured cat". Until 1902, the scientific community believed there was only one extant species of red panda, *A. fulgens*. Oldfield Thomas (1902, as cited by Glatston, 2011a) described another species, after studying a specimen with a much larger skull, from China's Szechuan province. This new species was named *Ailurus styani/refulgens* and to this day it is debated whether it is a subspecies or a species of its own accord (Groves, 2011: Li et al., 2005). However, recent genome sequencing by Hu et al. (2020) shows that the two are indeed separate species, having undergone a bottleneck after the Penultimate Glaciation (194,000- 135,000 years ago). The Himalayan red panda, *A. fulgens* have much less genetic diversity than the Chinese red panda, *A.*

styani (Hu et al., 2020). The main differences between the species are where they occur and their size. *A. fulgens* tend to be smaller with sharper profiles and weigh 4.5-5.5 kg. *A. fulgens* mainly reside on the western side of the red panda's range in Nepal, Bhutan, India and Myanmar, but can be found in China. *A. styani* are larger and weigh 6.5-7.5 kg. They can only be found in the southern Sichuan region of China (Groves, 2011).

Red panda are the only extant species of the family Ailuridae (Salesa et al., 2011). Early ailurids are likely to have originated in Europe, with one of the most represented fossil species, a puma-sized ailurid, *Simocyon* (Fig. 1) (Baskin, 1998, as cited by Salesa et al., 2011). Their fossils have been found all through North America, Europe and China (Salesa et al., 2011). These early species were likely to have been generalized carnivores, as they do not show the same dental adaptations of later forms (Glatston, 2011b). Simocyon likely moved to a life in the trees, which may have led directly to the group exploiting other food resources, such as flowers, and fruit (while still eating meat) (Salesa et al., 2006). Red panda are very different from the fossil record due to their extreme adaptations for a herbivorous diet (Salesa et al., 2011). What is interesting, however, is that the false thumb seen in extant red pandas (and the distantly related giant pandas) was also found in early ailurids and appears to be used for their arboreal lifestyle, rather than only in manipulation of food, as seen in giant panda (Abella et al., 2015: Salesa et al., 2006). The false thumb is a radial sesamoid bone that has migrated and is less pronounced in red panda than the giant panda (Abella et al., 2015). Salesa et al. (2006) described false thumbs in pandas as the "most dramatic case of convergence among vertebrates".

Image removed for Copyright compliance

Figure 1: Early, extinct Ailurids and present-day A. fulgens for comparison. Photo credit: Aaron Woodruff. https://redpandazine.com/2015/09/18/red-panda-ancestry-aaron-woodruff/

This convergent evolution case fuelled much of the early debate over whether the two panda species were related. Many early scientists classified red panda within Procyonidae (or a sub-family of), or as a separate new family with the giant panda (Groves, 2011: Slattery and O'Brien, 1995). What is clear, is that red panda belongs to the canid lineage of carnivores (with dogs, bears, pinnipeds, mustelids and procyonids), rather than the felid lineage. Researchers have proposed the following ideas of where to classify red panda: 1. within Ursidae, 2. in a sister taxa to Ursidae, 3. with a broad

Mustelidae clade (Flynn et al., 2000), 4. related to raccoons and other procyonids (Ahrens, 2012: Kundrát 2011), 5. a clade with Mustelidae and procyonids (Kundrát 2011: Sato et al., 2009), 6. or as a monotypic lineage of uncertain phylogenetic affinities within Arctoidea (Kundrát 2011).

Fossil evidence points to Ailuridae separating from procyonids as early as 38 Mya (Pocock, 1921, as cited by Groves, 2011). William Henry Flower was the first to suggest that red panda should have their own family, after creating a detailed description of their anatomy (Flower, 1870, as cited by Glatston, 2011). The consensus now is that red panda should be in their own family but placed close to Procyonids, as was the thought of some early taxonomists (Ahrens, 2012: Salesa et al., 2011: Kundrát 2011: Sato et al., 2009: Slattery and O'Brien, 1995: Flower, 1870, as cited by Glatston, 2011: Cuvier, 1825). However, Groves (2011) suggests "the red panda belongs to a family, Ailuridae, all by itself, long-separated from other Carnivora". Whereas, Ahrens' (2012) analysis showed red panda to be "deeply nested within Procyonidae". While the debate still rages over red panda's taxonomy, we can be sure that the giant panda is a bear (Ursidae), and not closely related to Ailuridae (Flynn et al., 2000: Slattery and O'Brien, 1995). It is not particularly important how red panda are taxonomically described, but monophyletic species do receive special treatment in conservation. If red panda are too closely related to other Procyonids then less time, effort and funding may be given to understanding this unique species.

Part of the order Carnivora, red panda are unusual within this order for a few reasons.

1. Red panda are specialist bamboo eaters with heavy microbial gut loads. However, their digestive system is closer to their carnivore relatives, with a simple stomach, no caecum and a short intestinal tract, comparable to a domestic cat (Flower, 1870, as cited by Nijboer and Dierenfeld 2011: Zhang et al., 2009).

2. Red panda can reduce their metabolisms without altering their internal body temperatures (AZA small carnivore TAG, 2012: Nijboer and Dierenfeld, 2011). On a day-to-day basis, their metabolism is similar to other similar-sized mammals (Fei et al., 2017). About 2603.3 kJ in spring to 3139.8 kJ in summer-autumn and 2740.8 kJ in winter (Wei et al., 2000a). Red pandas respond to temperatures below 19˚C by lowering metabolism, rather than increasing it (Nijboer and Dierenfeld, 2011).

3. Red panda have plantigrade locomotion with enlarged radial sesamoids that they use to climb head-first down trees and as a thumb-like appendage to grasp bamboo (Tanaka and Ogura, 2018: Conover and Gittleman, 1989).

4. Red panda soles of their paws are covered in fur, which is probably an adaptation for walking on snow (Fisher, 2011).

2.1.3 Anatomy

Red panda are often described as "handsome" or having a striking coat pattern. Their reddish-brown coat colour is relatively unique, with a white face mask and ears. The face mask of *A. styani* is more restricted than that of A. fulgens (Thomas, 1902, as cited by Fisher, 2011), which can be very pronounced and the whole face being much lighter than the body colour. Their paws' soles are also white, compared to the black fur that covers their ventral aspects (torso, and legs). When most people see a red panda for the first time, they assume they must be conspicuous in their natural habitat due to their seemingly bright colouring. Red panda are very cryptic and elusive in their natural habitat, with their fur colour blending into the canopy of fir forests, where the branches are covered in a reddish-brown moss and white lichens (Roberts and Gittleman, 1984). One of the most striking features of the red panda is their red and brown striped bushy tail. Its length reflects its use for arboreal locomotion (Fisher, 2011). Being solitary, olfactory communication is important, and red panda possess small scent glands on the soles of their feet, that leave scent trails as they walk. Red panda also have anal glands used in scent-marking displays (Gebauer, 2011: Roberts and Gittleman, 1984)). Sharp, curved, semi-retractable claws are also found on the paws and are used extensively during climbing. There is no sexual dimorphism (Roberts and Gittleman, 1984).

2.1.4 Reproduction

Most information on red panda age of sexual maturity, gestation length, litter sizes and reproductive behaviours, comes from captive studies (Glatston et al., 2015). Males and females of both species begin to reproduce around 1-2 years, peak at 4-8 years and taper off afterwards (Loeffler, 2011a: Wei et al., 2005). Red panda are a K-selected species, with low fecundity (Yonzon and Hunter, 1991). It is common in captivity to keep adults in monogamous pairs, despite being solitary outside of breeding season in the wild (Loeffler, 2011a: Roberts and Gittleman, 1984). Polyandrous groupings have led to increased female stress, and males will fight regardless of a female presence (Loeffler, 2011a: Wei et al., 2005). Adults rarely interact outside of breeding but can be seen resting together before mating occurs (Dechanupong, 2019: Northrop and Czekala, 2011). Females begin to scent mark more frequently during oestrus months (Roberts and Kessler, 1979) and both sexes will vocalise with huffs and snorts during mating (Cao et al., 2016: Gebauer, 2011). After mating, the pair will return to a steady distance apart again (Dechanupong, 2019). As red panda are seasonal breeders, relying on an increasing photoperiod after the winter solstice (Roberts, 1981, as cited by Roberts and Gittleman, 1984), we see pandas in captivity being six months out of sync with the other hemisphere (Glatston, 2011b). In their natural range, the breeding season is from late-January to mid-March, with births occurring in June and July (111-150 gestation days) (Budithi et al., 2016: MacDonald et al., 2005: Wei et al., 2000b). This variation in gestation supports evidence that females can delay the development of the embryo and implantation in the uterus (Roberts and Kessler, 1979). As there is no easy pregnancy test based on hormonal change for red pandas, behavioural changes may be useful for captive management (Dechanupong, 2019).

Early studies indicated a single 24 hour oestrous (Roberts and Gittleman, 1984), similar to the giant panda. However, Spanner et al. (1997) examined captive *A. fulgens* in New Zealand and suggested that red panda are induced ovulators. They found a strong correlation to a polyoestrous cycle which depended on male interactions. The female that was housed year-round with a mate showed a single peak of oestradiol and sustained levels of progesterone for 18 days following mating. Two females, who were only introduced to males once oestrous behaviour occurred, showed multiple peaks of oestradiol and no sustained levels of progesterone. Males were essential for increases in progesterone. Another study by Wei et al. (2005) also suggested induced ovulation was occurring. Induced ovulation is also seen in raccoons, skunks, mustelids and felids (Northrop and Czekala, 2011).

Females build nests for several days leading up to birth (Roberts, 1981, as cited by Roberts and Gittleman, 1984). In the wild, dams will nest in hollow trees, logs or rock crevices. Large trees in-situ are critical for neonate care (Reid et al., 1991). Nests are lined with any combination of twigs, branches, leaves, grass and moss (Gebauer, 2011).

Litters are often twins but range from one to four, and each cub weighs ~110 g (Northrop and Czekala, 2011). Young are highly altricial and stay in dens or nest boxes (in captivity), where the dam spends a majority of her time (~16 hrs a day) with them, leaving only to feed (Princée and Glatston, 2016: Gebauer, 2011). Development is slow, with around 98% of growth being postnatal (Grand, 1992, as cited by Gebauer, 2011). Mothers spend most of their time in the den allo-grooming, and resting with young (Dechanupong, 2019). Dams need to spend most of their time resting as lactation is a very costly behaviour in mammals (Starck and Ricklefs, 1998, as cited by Dechanupong, 2019).

When travelling, mothers pick up cubs by the back of their neck with their mouths. Cubs are moved between denning sites frequently; the more disturbed a dam is, the more she moves them (Dechanupong, 2019: Roberts, 1975). At around 50 days, cubs begin to show adult colouration, and by 70 days it is complete. At 60 days, they will play with siblings and their mother (Roberts and Gittleman, 1984). At this time, the mother will bring in sticks and other objects for cubs to manipulate (Gebauer, 2011).

At around 90 days or three months, cubs begin to explore outside the den (Northrop and Czekala, 2011: Roberts and Gittleman, 1984). When cubs are housed with their fathers, males usually avoid cubs at first but may begin to play with them as they get older (Gebauer, 2011). While adults rarely vocalise, cubs will regularly whistle and squeak while climbing (Gebauer, 2011). Cubs can also resist being carried by their mothers, by squirming and bleating when they begin to gain independence around 70 days. This behaviour completely stops at 105 days when cubs are too big to be carried (Gebauer, 2011). Full independence can be seen around six months in captivity but could be up to a year (Roberts, 1981, as cited by Roberts and Gittleman, 1984). Weaning occurs around 150 days when dams refuse to allow cubs to nurse, which results in cubs squealing and bleating at them (Gebauer, 2011).

Wild infant mortality is currently unknown; however, Australasia has the lowest captive infant mortality of any region, with North American having the highest at almost 50% (Loeffler, 2011a). This low mortality is likely due to careful management around temperatures and young staying with mothers until they are fully independent. Some North American zoos also remove their cubs at a younger age for hand-rearing. In captivity, survival of young is compromised when housed in a climate that frequently exceeded 19°C (Princée and Glatston, 2016). Roberts and Gittleman (1984) said that young survivorship is independent of maternal age and experience. Therefore, something else must be causing high mortality rates in North American and European zoos. Dechanupong (2019) wrote their master's thesis on cub mortality in North American and Chinese zoos. They found that dams who failed to rear cubs spent more time grooming compared to time spent resting. Dams who were disturbed more frequently moved their cubs more often and spent less time with them in dens, which we know from other studies is where they learn much of their behaviour to prepare them for the "harsh and complex environment" they live in (Glatston, 2011b). Mortality of young in the wild is unknown. However, other captive small carnivore species mortality rates of young, do not differ significantly from their wild counterparts (Kohler et al., 2016, as cited by Dechanupong, 2019).

Dechanupong (2019) also discussed how the dams in their study may have spent more time dedicated to thermoregulation behaviours, such as straddling, which left less time to self-grooming. The higher temperatures were also linked to spending less resting time in the den, which is also discussed by Gebauer (2011) in their chapter on maternal behaviour and infant development. In the wild, sleeping together in den helps to strengthen maternal bonds and retain vital heat (Gebauer, 2011). This behaviour does not usually stop until 8-11 months when cubs are typically already independent.

Loeffler (2011a) describes how in Chinese breeding facilities, it is common practice for cubs to be removed from mothers as early as 3-5 months old. They believe that their presence may interfere with breeding. However, many of these cubs die from such early removal and sudden weaning. Those that do survive can end up in isolation, developing depression and stereotypic behaviours. It should also be noted that these facilities house red panda in groups of up to 15-20 individuals in an area of 1000 m^2, who display behaviours of chronic stress and there is no control over breeding pairs so that inbreeding could become a serious issue. In China, it is also standard practice to supplement breeding programs with wild-caught individuals because reproductive success is so low (Leoffler, 2011b).

2.1.5 Diet

Most of what we know about wild red panda diets comes from collecting fresh droppings and drying them out (Wei and Zhang, 2011). Bamboo is, without a doubt, the most important part of their diet, with ~82% of their diet being made up of *Arundinaria* spp. across all seasons (Panthi et al., 2015). Even if there are many bamboo species in an area, red panda are likely to just focus on 1-2 species for 90% of its diet (Wei and Zhang, 2011). Pandas will pick the most nutritious leaves, and methodically nip leaves from bamboo branches (Zhang et al., 2009).

Depending on availability, red panda will also consume flowers, fruits, acorns and fungi (Wei and Zhang, 2011). In spring, nutrient-dense bamboo shoots and leaves are favoured, whereas in summer and autumn the fruits of *Sorbus* spp. are very important (Wei and Zhang, 2011). In winter, bamboo is almost the only food consumed (Wei and Zhang 2011). However, red panda are not strict herbivores and have occasionally been known to eat birds, rodents, lizards, and eggs, with pregnant females having the largest carnivorous appetite (Kundrát, 2011). As described earlier, red panda anatomy does not quite fit with their diet habits. Bamboo is low in protein and high in cellulose (Wei and Zhang et al., 2011). They may have to consume up to 1.5 kg of bamboo leaves or 4 kg of shoots daily to meet energy needs due to their rapid gut transit time and sub-optimal digestion for plant material (Nijboer and Dierenfeld, 2011).

2.1.6 Population and distribution

Red panda are currently listed as an endangered species under the IUCN Red List of Species and Appendix I in CITES (CITES, 2020). This is because of a recent rapid decline in numbers, 50% over the last 50 years (Choudhury, 2001). Estimation of current population numbers varies widely, as do the methods used to gain these numbers, with most countries relying on surveys for population studies (Thapa et al., 2018a). Numbers are estimated to be between 10,000-15,000, but due to lack of funding and research to accurately arrive at these estimates, these numbers could be as low as a few thousand (Kumar et al., 2016). Wei et al. (1999) estimated 6000-7000 in China, of both species.

Red panda are only found in the Himalayan mountain range across 23 districts of Nepal, 13 districts in Bhutan, from the northern rim of India and as far west as Sikkim, India, one northern state in Myanmar and across three Chinese provinces, Sichuan, Yunnan, and Tibet (Glatston et al., 2015: Groves, 2011). There were reports of red panda from Meghalaya, India, but it is unknown if they still reside there (Ghose and Kumar Dutta, 2011: Choudhury, 2001).

The Himalayas is a biodiversity hotspot and globally significant conservation area (Dorji et al., 2011). With more than 10,000 plant species, 300 mammal species and 900 bird species (Glatston, 2011b). Estimates of suitable habitat for red panda also vary. In Nepal, predictions range from 13,800-23,977 km² (Panthi et al., 2019: DNPWC & DFSC, 2018: Thapa et al., 2018b), with only 40% of this habitat in protected areas (Panthi et al., 2019)). One of the most untouched red panda habitats is in Bhutan (~5400 km²) (Glatston, 2011b). 51.4% of the country is in a protected area, though there are huge differences between protected and non-protected areas (Dorji et al., 2019). Myanmar may have up to 6400 km² of suitable habitat (Glatston, 2011b). In China, numbers of red panda are much higher inside reserves than outside (Wei et al., 2011). No official population count stands for India, but Choudhury (2001) estimated 5000-6000 individuals based on an encounter rate of one panda/4.4 km². Other studies found encounter rates of 1.67 km² (Pradhan et al., 2001) and 2.9 km² in Langtang National Park, Nepal (Yonzon and Hunter, 1991). Choudhury (2001) also estimated total potential habitat in India to be 12,500 km², with 85% of this within Arunachal Pradesh. However, much of the forests are not in a condition to house red panda and likely habitat areas are much less than estimates. In Sikkim, estimated habitat based on altitude and forest type suggests 1200 km² available, but in reality, it is much closer to 700 km ² of suitable habitat (Ghose and Kumar Dutta, 2011).

2.1.7 Habitat

Red panda are a high-altitude specialist (1400-4800 m), that struggle in temperatures above 23.8°C and require protection for average temperatures above 27˚C (Glatston et al., 2015: AZA small carnivore TAG, 2012: Loeffler, 2011a: Roberts and Gittleman, 1984). Typically, *A. styani* is found at lower altitudes, 1400-3400 m, compared to *A. fulgens,* which is found between 1500-4800 m. There have been reports of red panda in native habitats as low as 200 m above sea level (Choudhury, 2001). The majority of *A. fulgens* habitat is found around 3000 m, with bamboo being a key factor for their distribution (Lama et al., 2020: Thapa et al., 2020). They prefer sloped (>45˚) habitats (Zhou et al., 2013: Dorji et al., 2011), with plentiful fallen logs, tree stumps and rocks, that allow them to reach food sources (Wei et al., 2000b). Bamboo-thicket understories are the main predictor for red panda distribution (Bista et al., 2019). Within this they can be found in a variety of forest types; montane (Glatston et al., 2015), mixed broadleaf and coniferous (Zhou et al., 2013), fir (Thapa et al., 2020: Dorji et al., 2011), and perhaps even the tropical forests of Meghalaya, India (Duckworth, 2011). These other tree species do not necessarily provide sustenance, but may instead offer shelter, nesting and potential water sources (Bista et al., 2019). Close water sources are also an essential factor in red panda habitat, as proximity to water, reduces energy requirements (Bista et al, 2019: Glatston et al., 2015: Zhou et al., 2013). Faecal pellets are usually found within 100 m of a water source (Lama et al., 2020), except in the Sharma et al. (2014) study where they found no influence of water on red panda occupancy (except that most of their plots were <100 m from water). Seasonal precipitation is also a significant variable for distribution (Bista et al., 2017).

2.1.8 Home range size

Studies on home range sizes are rare, but it seems that red panda do not develop territorial behaviours due to abundance of bamboo and the little energy that they receive from it (Wei and Zhang, 2011: Zhang et al., 2009). Patrolling and maintaining territories is energetically costly. Home ranges tend to overlap extensively (10.7-70.6%) (Wei and Zhang et al., 2011) with male home ranges larger (~2.6 km^2) than female home ranges (~1.7 km^2) (Zhang et al., 2009). Juveniles can take up to eight months to establish a stable home range, roaming further and further from their natal home range, each day (Reid et al., 1991).

2.1.9 Threats – dog attacks and diseases

While primarily arboreal, red panda come to the ground to defecate, forage and move between trees (Delaski et al., 2015). This puts them at direct risk from domestic dog (*Canis lupus familiaris*) attacks (NCD, 2019: Dorji et al., 2012: Ghose and Kumar Dutta, 2011: Williams et al., 2011). Not only do free-ranging dogs hunt red panda, but they can pass on the highly fatal canine distemper virus (CDV) (DNPWC & DFSC, 2018: Dorji et al., 2012). It is common for local herders to keep dogs to protect their livestock from predators (Williams et al., 2011). Domestic dog populations are on the rise due to popularity, and no sterilization/population control (NCD, 2019). If dogs are vaccinated, it is likely only for rabies and not for CDV (Princée and Glatston, 2016).

There is very little information on infectious diseases in red panda, but we do know that CDV is a significant problem disease (Philippa and Ramsay, 2011). Even in zoos, it can be a problem, though less so from domestic dogs, but rather through vaccinations (Glatston, 2011b). Canine distemper virus has a worldwide distribution, affecting not only canines but also procyonids, ursids, mustelids, viverrids, hyaenids and larger fields (Beineke et al., 2015). Some captive facilities vaccinate their red panda against CDV, but panda are so sensitive to this disease that they can be killed by standard, live vaccines (Glatston, 2011b). They require killed CDV or multivalent vaccines that include modified live CDV (Princée and Glatston, 2016); i.e., two red panda died two weeks after a live CDV vaccination was given at National Park, Washington D.C (Bush et al., 1976). Clinical signs of CDV include: "depression, anorexia, (oculo-) nasal discharge (serous to mucopurulent), tachypnoea, central nervous signs (convulsions/seizures, paresis/paralysis, incoordination, myoclonus), hyper- or hypothermia. Affected individuals may also have skin lesions" (Kotani et al., 1989, as cited by, Philippa and Ramsay, 2011).

Red panda can also be susceptible to rabies, but luckily the commercially available inactive vaccine approved for ferrets is suitable (Philippa and Ramsay, 2011). Symptoms of rabies in red panda do not differ from rabies in other mammalian species (Philippa and Ramsay, 2011). Toxoplasmosis has also been reported in some captive facilities and may be of concern, but clinical signs and how red panda are infected are still unknown (Loeffler, 2011a: Qin et al., 2007). A recent study showed that red panda may be an intermediate host of toxoplasmosis (Yang et al., 2019). Another reported on a geriatric panda dying of toxoplasmosis in a zoo setting (Ashley et al., 2020). Ringworm (Dermatophytosis) is common in young cubs in hot areas of China (Loeffler, 2011b). These cases are often treated only once, with a single shot of antibiotics, resulting in the loss of tails or death of cubs.

2.1.10 Threats- livestock

Livestock in the Himalayas are often unaccompanied by herders/shepherds (Dendup et al., 2016). Several papers cite livestock to be a threat to red panda (Panthi et al., 2019: Zhang et al, 2017: Glatston et al., 2015: Zhou et al., 2013). Direct competition with livestock for resources may not be important (Yonzon and Hunter, 1991) as livestock generally graze below 1 m and red panda above that (Acharya et al., 2018). Trampling of bamboo is probably the main cause of conflict between red panda and livestock, as panda avoid areas disturbed by livestock, regardless of bamboo cover (Dendup et al., 2016: Yonzon and Hunter, 1991). When livestock disturbs wildlife at water sources, they will likely move or adjust temporal activity (Zhang et al., 2017). However, this may be difficult for red panda to change timings, as they spend many hours each day foraging on bamboo. There is a great need for community education around sustainable grazing practices, as there is major overlap with gazing areas and suitable red panda habitat (Lama et al., 2020: Sharma et al., 2014: Panthi et al., 2012).

2.1.11 Threats – anthropogenic effects

With livestock numbers increasing, so too does the threat of human encroachment on red panda habitat. Not only would education about grazing be helpful, but so would general information about red panda, as Dangol (2015, as cited by Bista et al., 2020) discovered locals herders and rural dwellers were killing red panda in apparent retaliation, thinking they had killed their goats, lambs and game birds!

Bamboo is used for housing, furniture, scaffolding, roofs and cooking in the Himalayas. As more and more bamboo is cut down for the ever-increasing human population, human settlements not only remove precious red panda habit but move closer to it as well. This is a significant threat to red panda as they avoid human settlements and high disturbance areas (Panthi et al., 2017: Dendup et al., 2016: Dorji et al., 2011). Acharya et al. (2018) found that disturbance in Nepal was significantly higher in non-protected areas. Around 70% of suitable red panda habitat is outside of protected areas. Bamboo is also prone to mass die-offs, which can put red panda in a vulnerable position (DNPWC & DFSC, 2018: Bista et al., 2017).

Habitat fragmentation and loss is often cited as the most critical threat to red panda and indeed the whole of the Himalayan region (Panthi et al., 2019: DNPWC & DFSC, 2018: Bista et al., 2017: Glatston et al., 2015: Wei et al., 1999). Bhutan's road network is expanding at >300km/year and leads to fragmented forests (Dorji et al., 2012). The driver for this expansion is an increasing tourism load. Unregulated and inefficient tourism is also a threat to red panda, due to disturbances, especially during mating season (Glatston et al., 2015: Dorji et al., 2012). In a recent study by Acharya et al. (2018), human presence was the only negative variable that influenced red panda presence. Therefore, maintenance of garbage and designated walking tracks are going to be important considerations for future tourism.

Anthropogenic effects upon red panda are numerous, and it is likely to be the main limiting factor for increasing numbers, even in reserves (Fei et al., 2017). In Yonzon and Hunter's study (1991) in Langtang national park, Nepal, they found that 57% of deaths in their study area, were directly human-related. Poaching of red panda has always been an issue, as their fur was previously used to make fur hats for newly married couples (Wei et al., 1999: Bista et al., 2020). However, this is less of an issue today as pelts found by Xu and Guan (2019), in China were all over 30 years old, from before China's wild animal protection law came into effect. Red panda are classed as a category II species under this law, which means they cannot be caught, hunted, sold, transported, imported or exported without a permit (Wei et al., 2011). However, it does allow capture of red panda for "farming for utilization" (Loeffler, 2011b). It is unclear how many red pandas are taken from the wild for captive breeding purposes (Loeffler, 2011b).

Reports of poaching and hunting are rare, but this may be because when poachers are captured, it is not classed as newsworthy (DNPWC & DFSC, 2018: Loeffler, 2011b). Hunting is non-existent in Bhutan (DNPWC & DFSC, 2018: Dorji et al., 2012), although regular hunting and poaching have been reported in Myanmar (Glatston and Gebauer, 2011). Red panda flesh is rarely consumed, except for a recent trend in China (Glatston and Gebauer, 2011). There is currently an increase in pelts found in Nepal (Bista et al., 2020). Most people surveyed in Nepal were aware that trapping, killing or trade of red panda was illegal, but ~83% had no idea about their conservation status (Bista et al., 2020). Perhaps, luckily, in economic terms, red panda fur and meat has limited use and appeal, and therefore, the capture of wild animals is low. Wearing of their skins is rare in modern times, but their fur has been used in wedding ceremonies in the Yunnan province as a symbol of good fortune for grooms (Glatston and Gebauer, 2011: Wei et al., 1999). As with any cute, small mammal, the capture of cubs for the pet trade is an issue (Loeffler, 2011b: Pradhan et al, 2001). Early reports on red panda by Hodgson (1847, as cited by, Glatston and Gebauer, 2011), suggested that "due to their gentle disposition and lack of smell, they would make good pets for ladies".

2.1.12 Conservation efforts

Due to their high level of charisma, red panda serve as a flagship species for their entire ecosystem (DNPWC & DFSC, 2018). Protecting their habitat, in turn, protects habitats of Asiatic black bears (*Ursus thibetanus*), golden langurs (*Trachypithecus geei*), crimson horned pheasant (*Tragopan satyra*), snow leopard (*Panthera uncia*) and takin (*Budorcas taxicolor*) (Bista et al., 2018). The forests in which red panda inhabit are called the "lungs of South Asia" and if they're not functioning properly, not only do the animals suffer but so to do the people (e.g., water supplies) (Wei et al., 2011). Chalise (2009) suggests that red panda may be an indicator species for forest health in their natural range.

The IUCN (Glatston et al., 2015) webpage notes that only 5/13 significant conservation actions are in place for panda and their environment, with a serious need for more research, monitoring, land/water protection and species management. One area that is well covered is education. The Red Panda Network (RPN) in Nepal puts a lot of effort into education, with more people knowing about red panda outside of protected areas than within (Dangol, 2015, as cited by Bista et al., 2020). RPN has been engaged with communities in education and training forest guardians in Nepal since 2006 (Williams et al., 2011). There is no education program in Bhutan (Dorji et al., 2012), and no information for other countries.

The Himalayan region is typically an impoverished region with very few resources for conservation, limited professionals with knowledge and other human resources (NCD, 2019). However, there are some promising projects, such as the reintroductions of red panda into Singalila National Park, India (Jha, 2011). The area was first studied and deemed suitable due to the high density of wild red panda. Two females were initially released, with two more females shortly afterwards in 2004. One of the females received a lot of attention from potential mates at the release site. Monitoring occurred after release, but no breeding was seen that year (Jha, 2011).

Educating farmers in Eastern Nepal has changed perspectives from the forest being a resource to something that should be protected. The farmers have become great supporters of the red panda, with a sense of pride and ownership of the forests (Williams et al., 2011). A project called 'Punde Kundo, conservation in action' takes community-based monitoring and trains forest users to become forest guardians to monitor red panda and other wildlife (Williams et al., 2011).

2.1.13 Captivity

The first red panda to appear in a captive facility outside its native range was a sole survivor of four, that travelled by boat from Darjeeling, in horrific conditions, to London Zoo (Jones, 2011: Glatston, 2011a). This animal arrived on May 22nd, 1869 and died in December that year. Eight years later (1876), another individual arrived at London Zoo and survived much longer than the first (died 1881) (Jones, 2011). Apart from these two pandas and one other that lived in Calcutta Zoo in 1877, there are no records of red panda in captivity again until Philadelphia Zoo had the first one brought to America in 1906 (Jones, 2011). Between 1908 – 1941 a mere 50 red pandas were held around the world in zoos. San Diego Zoo had four red pandas from 1940 and set the bar for care in captivity (Jones, 2011). In the early years, all animals were kept in large family groups (Jones, 2011).

In 1977, the international studbook for red panda was created (Glatston, 2011b). All red panda that are part of the cooperative worldwide breeding program are accounted for so that their genetics can be managed. *A. fulgens* are mostly found in Europe, North America, Australia, New Zealand, South Africa, India and Japanese zoos (Princee and Glatston, 2016: Leus, 2011). *A. styani* are only found in North America and Japan (Princee and Glatston, 2016: Leus, 2011). Red panda of both species can be found in sizeable numbers in Chinese facilities, but these are not yet cooperatively managed with the rest of the world (Leus, 2011). Captive populations would greatly benefit from integration with Chinese facilities. Still, due to lack of record-keeping on the management and the husbandry of the species there, this is a long way off (Loeffler, 2011b).

In Chinese zoos, red panda show many symptoms of being stressed, due to being kept in large groups, sub-standard enclosures and fed poor diets. Fighting and associated injuries are common in overpopulated enclosures, with bite wounds that go unnoticed until abscesses form (Loeffler, 2011b). Several animals have had tails amputated because of this. Their diets often include milk and other dairy products, which was common worldwide in other zoos until the 1980s (Glatston 2011a: Loeffler 2011b). They also receive very little to no bamboo and high levels of carbohydrates (Loeffler, 2011b). Because the pandas in these facilities are stressed, receiving poor diets and fighting, their reproduction output is very low. The population is continuously being supplemented with wild animals, but it is difficult to know how often this is happening without record-keeping (Glatston, 2011b).

Zoos around the rest of the world are subject to species survival management plans (SSP), in which there are studbook keepers in each region that have records of all breeding. Zoos may receive recommendations to breed certain animals or not. These studbook keepers are also involved with moving individuals around their region and cooperating with other regions for genetic variation. With carefully managed genetics, populations in captivity are more viable, and there is a much lower chance of supplementation from wild populations.

The recommended minimum enclosure size for a single or pair of red pandas is just 80 m^2 and 4 m high, with full-time access to the outside (Loeffler, 2011a). The North American SSP recommends only half of this and maybe a reason for the high mortality in their facilities (Loeffler, 2011a). When Eriksson et al. (2010) sent out a survey to zoos (69 responded), the average enclosure size was 300 m^2 (ranged from 23-1100 m^2). In over 80% of enclosures, the highest climbing structure was over the 4 m recommended. Husbandry protocols also state that enclosures must have a variety of substrates, use of vertical space, shade and hiding areas (privacy) (Loeffler, 2011a). Surface water/ pools may also be very important for temperature regulation (Eriksson et al., 2010). SSP require red panda enclosures with summers over an average 22.5˚C to have cooling areas, such as misters, or air-conditioned dens (Princée and Glatston, 2016).

In captivity, red panda should be offered fresh bamboo, at least twice a day, due to wilting. However, a variety of natural vegetation is recommended as they will eat a variety of grasses and other leaves (Loeffler, 2011a). Natural vegetation will provide the ability to forage and individuals to dictate their activity patterns. It also provides privacy, shade and nesting materials. Multiple feeding stations and food presented in a variety of ways may also help to encourage foraging behaviours (Loeffler, 2011a).

2.1.14 Research gaps

Reading this literature review it might seem like we have a lot of knowledge about red panda and their behaviour; however, there are numerous gaps in the literature. Taxonomically their position within Carnivora and their relatedness with Procyonidae is still unconfirmed (Ahrens, 2012: Salesa et al., 2011: Sato et al., 2009). There are still current debates surrounding whether there are two species of red panda or if they are sub-species (Hu et al., 2020: Groves, 2011: Li et al., 2005). We have no published data on reproductive behaviours in the wild (Glatston et al., 2015). This includes; mating behaviour, nest building, moving between nests, gestation length, age of sexual maturity and dispersal. All that we know comes from captive studies, and we cannot be sure that this translates directly to the wild. Other wild behaviours are still unconfirmed such as home ranges; previous studies are only preliminary or lack enough data (Wei and Zhang, 2011: Zhang et al., 2009).

There are hypotheses that red panda do not defend territories, but there is no data on how they react to another red panda in their space (Wei and Zhang, 2011: Zhang et al., 2009). They can be seen frequently scent marking in captivity, so there must be some kind of territorial behaviour or communication happening (Gebauer, 2011: Roberts and Gittleman, 1984). There is a pretty good understanding of diet and habitat preference, as these studies were done through non-invasive methods such as scat collection (Wei and Zhang, 2011).

Only recently have domestic dog attacks been cited as an issue (NCD, 2019: Dorji et al., 2012), but just how much of an issue are these attacks and is CDV an issue for wild red panda, with the rise in feral dog populations (DNPWC & DFSC, 2018: Dorji et al., 2012). As with a majority of endangered species, the main issue continues to be anthropogenic pressures. Red panda are a cryptic species who prefer to move away from human settlements (Panthi et al., 2017: Dendup et al., 2016: Dorji et al., 2011). Does this mean that increasing tourism in their habitat is also forcing them into even smaller suitable habitats?

Education is taking place in Nepal thanks to The Red Panda Network's efforts but is seriously lacking over the rest of their range (Williams et al., 2011). Very little is known about red panda in Bhutan and Myanmar due to the difficulties of studying there, with limited resources and knowledge from locals (Dorji et al., 2012). Reports of red panda in Meghalaya, India need to be confirmed (Ghose and Kumar Dutta, 2011: Choudhury, 2001). If red panda do still reside there, then they may be genetically different from their high-altitude counterparts. Population estimates wildly vary from a few thousand to 15,000 across their range (CITES, 2020: Kumar et al., 2016: Glatston et al., 2015: Choudhury, 2001). If a proper estimate of remaining red panda can be carried out, then conservation efforts can be allocated appropriately.

Many of these research gaps and questions could be answered with the use of trail cameras. If trail cameras do not significantly affect red panda behaviour, researchers can use them for accurate population estimates as they have for other species. Trail cameras could also help to answer behavioural questions. For example, home range sizes are still unknown, with the combined use of GPS and trail cameras we could begin to understand how home range and if/how territories are defended. Breeding biology could also be better understood with the use of trail cameras. If potential nest sites are sourced before parturition, then trail cameras could be installed outside nests and even inside to gather information on an event like when cubs leave nests, and how often dams come and go.

Therefore, understanding whether trail cameras affect red panda behaviour is vital, so that we can answer these other questions with certainty.

2.2 Aims and hypotheses

2.2.1 Aims

In this study, I aim to assess whether trail cameras affect captive red panda behaviour. They may spend more or less time in areas with trail cameras or be unaffected. Time budgets (proportions and total time) will be calculated to see if camera presence affects behaviours such as; foraging, movement, sleep, play etc. I will also look at how red panda behaviour is captured across different observation types, including; direct human observation, trail cameras and a video camera placed outside of the enclosure going 24/7.

2.2.2 Questions

1. What is a typical red panda time budget? Are these consistent across zoos and different management types?

2. Do different observational methods provide a similar picture of red panda behaviour?

3. Are trail cameras a genuinely passive form of monitoring captive wild animals? Or does the behaviour of captive red panda change with exposure to this novel stimulus?

2.2.3 Hypotheses

1. I hypothesise that activity budgets will vary slightly between zoos, but that basic behaviours will be the same.

2. I hypothesise that direct observations will show slightly different results to a camera going 24/7.

3. I hypothesise that red panda will initially investigate cameras, and after a short initial investigative period, that captive red panda will not be affected by trail cameras. Behaviour in the medium to long-term will remain unaffected.

Chapter 3

Generic methods

3.1 Study sites and individual red pandas

I conducted research at three zoos within New Zealand and Australia. All 24 Australasian zoos are part of the Red Panda Species Protection Plan (SPP) (18 zoos currently house red panda), and thus, all individuals are individually managed by a species coordinator. Zoos are given recommendations on when and which animals can breed. Initially, all three zoos in New Zealand that house red panda were contacted. Research proposal forms (Appendix 1-3) and my accepted university master's proposal were sent to Auckland and Hamilton Zoos. We then organised a single day visit to each of these zoos to check equipment, to meet keepers, organise any paperwork and finalise dates for the full project. I then went to Auckland Zoo, from the 21st of March to the 9th of April 2019. Hamilton Zoo was second, from the 29th of April to the 15th of May 2019. Last, I went to Currumbin Wildlife Sanctuary, in Australia from the 3rd to the 12th of December 2019, to collect extra data as my original third zoo in New Zealand, was not available.

3.1.1 Auckland Zoo

Auckland Zoo had five red pandas in three enclosures. Two enclosures were viewable by the public. I studied the enclosure with three red pandas, one adult male (Ramesh, nine years old), one adult female (Khela, six years old) and their juvenile son (Tashi, four months old at the time of the study). The enclosure (Fig. 2) had many trees (Moreton Bay fig (*Ficus macrophylla*), magnolias, coprosmas, cabbage trees (*Cordyline australis*) and Italian alder (*Alnus cordata*)), none of which are specifically Himalayan in origin. The largest trees in the enclosure were the Italian alders and Moreton Bay fig.

The biggest Italian alder was where Ramesh spent most of his time sleeping, as did Khela, when she was not in the nest box, or the off-display den, with Tashi. There were three nest boxes for Khela to move Tashi between. One was situated in the off-display den area, and the other two, joined together, behind a small hill in the enclosure (Fig. 3). Both had small holes for entry and were lined with straw. There was a platform in the middle of the enclosure with a roof and a litter tray (latrine site) filled with wood shavings and cleaned daily. Branches from the largest tree overlapped with a dead tree where the keepers feed the panda, during public talks and encounters. The keepers frequently stabbed quartered pear and kiwifruit onto hanging logs, with nails, for the panda to manipulate in the afternoons. There was a medium-sized pond that had very little water in it due to Tashi being so young. For the most part, ground cover consisted of grass, with a mulched area around the platform and feeding area. The off-display den had a concrete floor. Overall, the enclosure was 170 m².

Figure 2: Auckland zoo red panda enclosure. Images show a left to right public view of the enclosure. Source: Kathryn Bugler.

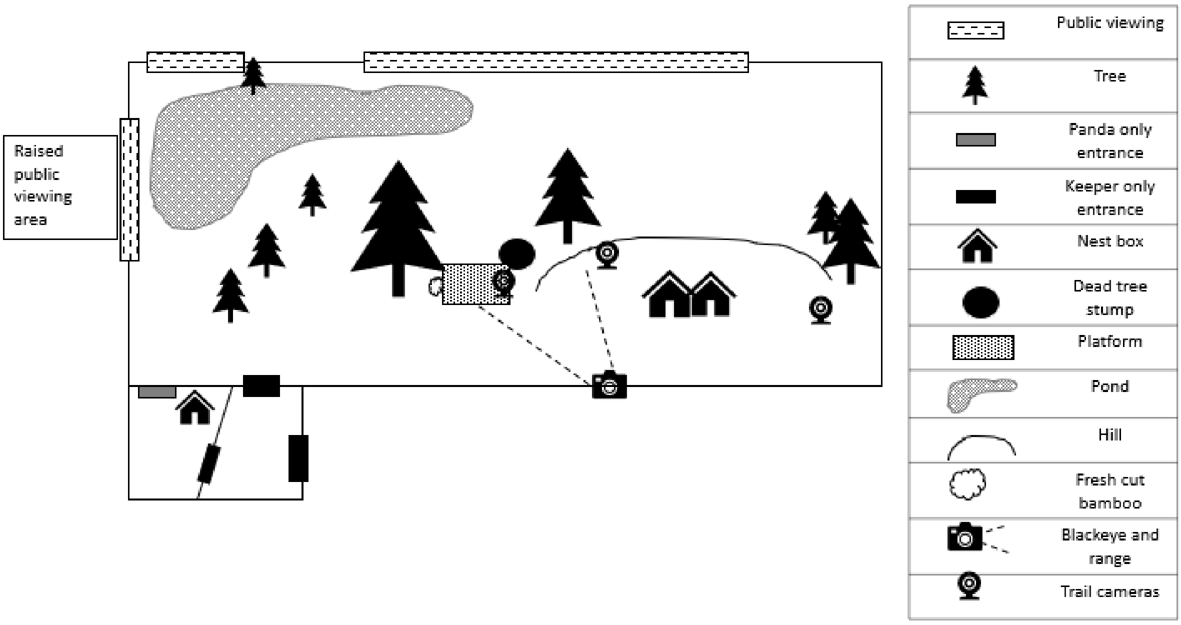

Figure 3: Line drawing of Auckland zoo red panda enclosure. Red pandas had access to all parts of the enclosure during the study. The nest boxes behind the hill are out of public view. Source: Kathryn Bugler.

3.1.2 Hamilton Zoo

Hamilton Zoo had three red pandas living in the same enclosure. Pandas in this enclosure consisted of one male (Chito, 16 years old) and two females (Taylor, ten years old, and Jamuna, four years old). Jamuna is Chito and Taylor's daughter and is very distinguishable from her parents due to a visibly floppy ear. Chito is castrated, due to his age, as the SPP recommends that Chito and Taylor do not breed again. This also allows their female daughter to continue to live with them. Khela (at Auckland Zoo) is the sister of Jamuna and offspring of Chito and Taylor.

The enclosure is adapted for elderly panda, as both Taylor and Chito are very old for red panda. Many extra platforms act like stairs to get into the main tree and stair-like extras on walkways for grip (Fig. 4). The main tree, where all pandas slept, was a plane tree (*Plantanus spp*.). Bamboo thickets can be seen around the left and back of the enclosure (which hides the keeper's entrance) (Fig. 5). There were two towers with multiple platforms on either side of the enclosure, linked to the feeding platforms, latrine site and main tree by walkways. All three feeding platforms had roofs, and there are two metal automatic treadle feeders (feeders that require an animal to stand on a platform to open) that are moved by the keeper's day to day, between these three platforms.

The pandas used four latrine sites in the enclosure. The main latrine site was behind the main tree, trunk, on a raised platform with a roof. Two more were located by the off-display area. One was in a small kennel by the panda's entrance to the off-display house, and the other was inside the house. The last latrine site was on the left tower (this must be hosed to clean and too high for keepers to place litter trays). All litter trays were filled with wood shavings and cleaned daily.

The off-display house had a red panda entrance and a human entrance that was closed unless a keeper was in there to clean. Inside the house was a litter tray, a banana box full of straw, a nest box on a raised platform, also full of straw, and a ledge on the other side of the nest box. There was a ramp up to the ledge and nest box. The pond at the front of the enclosure was empty as fresh, clean water is provided for the panda, by automatic filling bowls on the side of a feeding platform and near the off-display house. As seen in figure three, most of the enclosure ground cover was grass, except for the off-display house, which had a wooden floor. This enclosure was by far the biggest of the three enclosures, at 529 m^2.

Figure 4: Hamilton Zoo red panda enclosure from the public viewpoint. Top left shows the main tree where the pandas sleep. Bottom right shows off display house in the background. Source: Kathryn Bugler.

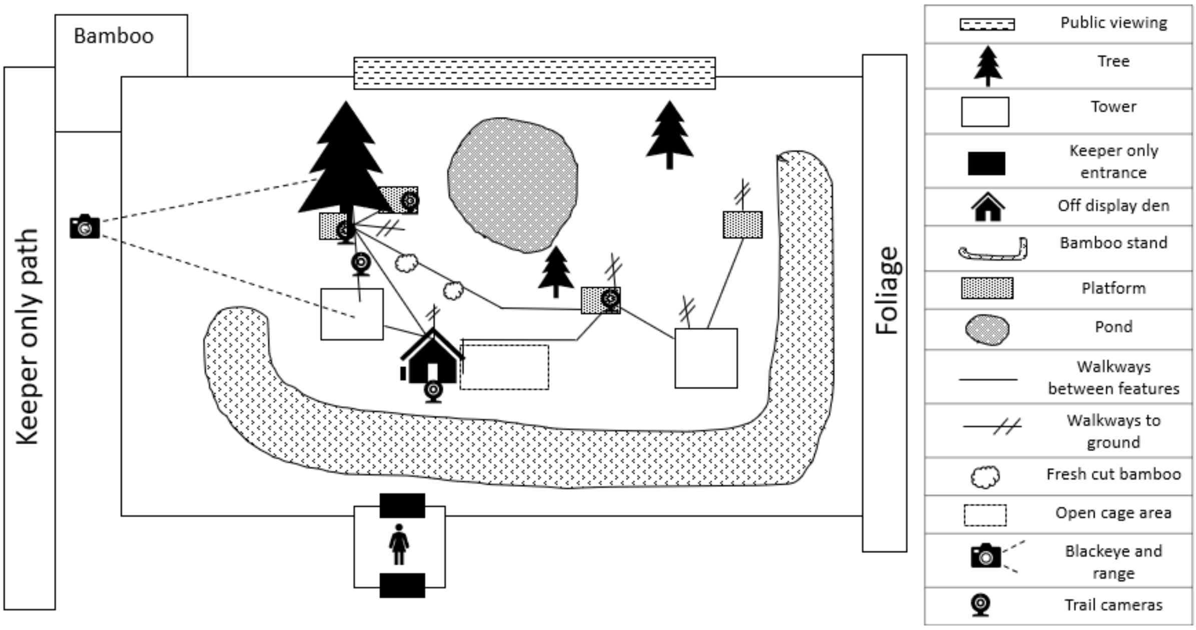

Figure 5: Line drawing of Hamilton Zoo's red panda enclosure. Red pandas had access to all parts of the enclosure during the study. Source: Kathryn Bugler.

3.1.3 Currumbin Wildlife Sanctuary

Currumbin Wildlife Sanctuary, Gold Coast, Australia had two red pandas in two separate enclosures, due to them both being male. I set up cameras on the oldest male's enclosure because he spent most of his time where the Blackeye camera could record him. Pasang (16-year-old male) had, 4 months prior, moved from Australia Zoo. The enclosure had many walkways consisting of branches that connected three platforms and the ground with gradual inclines for the older panda (Fig. 6 & Fig. 7). During observations, there were several tree species; juniper (*Juniperus spp.*), birch (*Betula spp.*), Lilly pilly (*Syzygium smithii*) and palm trees (*Arecaceae*). The juniper has since died, due to the extreme heat. There is a water mister in the middle of the enclosure that, with the right breeze, reaches the main platform that Pasang spent most of his time on. The mister was turned on every day due to the significant temperatures and his reaction to them. The main substrate of the enclosure was mulch, and the off-display den had a concrete floor. The nest box inside the den was lined with straw. The litter tray (latrine), like the other zoos, was filled with wood shavings and emptied daily. Unlike the other zoos, Currumbin's viewing area was above the enclosure, giving the public a full view of the enclosure, while maintaining the pandas' perceived privacy needs. This enclosure was ~117 m².

Figure 6: Currumbin Wildlife Sanctuary, Pasang's enclosure. Public view of the enclosure. With off display den underneath public path. Mister vapour is visible. Source: Kathryn Bugler.

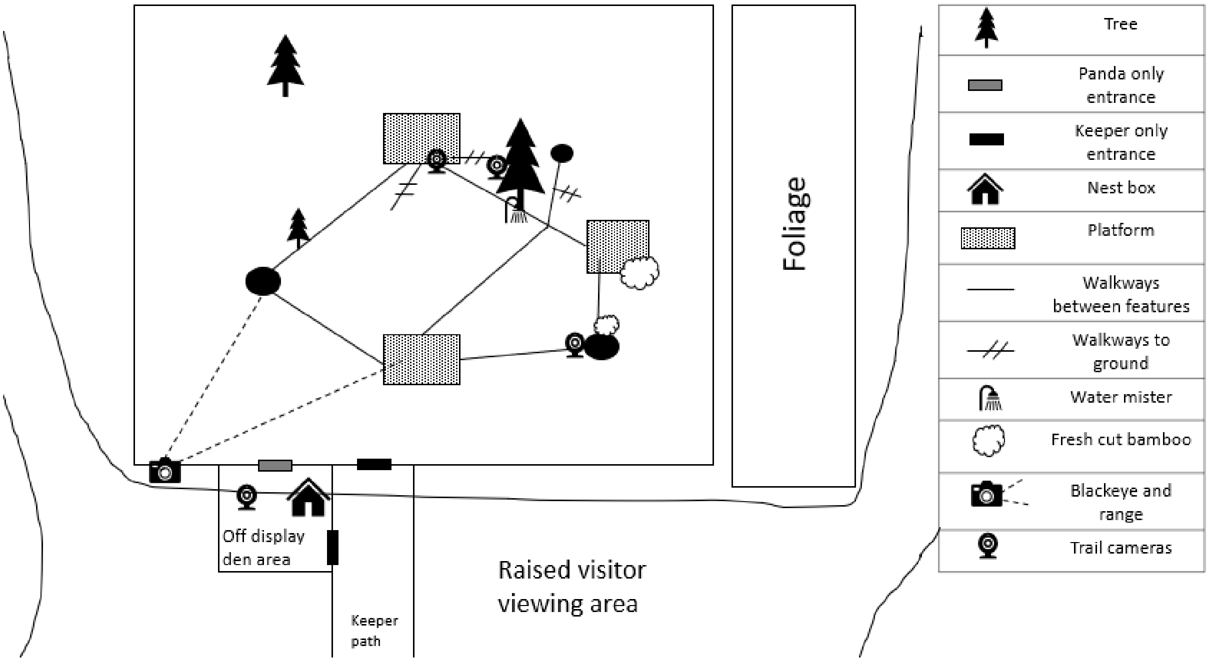

Figure 7: Line drawing of Currumbin Wildlife Sanctuary's red panda enclosure. The red panda had access to all parts of the enclosure during the study. Source: Kathryn Bugler.

3.2 Equipment

I used two main types of camera. The first was the Kinopta Blackeye BE2-W (hereafter, referred to as 'Blackeye', Fig. 8) (http://kinopta.com/). This camera recorded, continuously, from the outside of enclosures. The Blackeye can take 1-4 photos per second, which can be turned into videos for behavioural analysis. Its design allows researchers to leave the camera in the field for extended periods. It could be checked daily by a Wi-Fi signal it produced, that I could access with my phone. The internal storage (128GB) was designed for two weeks of continuous recording at two photos per second. It was also possible to only download images where activity was detected.

Figure 8: An example of the Blackeye camera setup, at Hamilton zoo. Middle image shows external lead acid battery connected to camera. Source: Kathryn Bugler.

I also used two different models of trail cameras: the Bushnell Trophy Cam Aggressor (model number: 119874) and Browning Dark Ops sub micro-series (Model number: BTC-6). Both cameras featured a no glow LED IR (infra-red) function with "invisible" flash at night and are labelled as "undetectable" (by humans). I primarily used Bushnell cameras in the main areas of the enclosures (Fig. 9). Browning cameras were used secondarily, as Hamilton zoo staff asked if I could add some into other areas of the enclosure that they were interested in recording. A Browning, in video mode, was used in Hamilton Zoo's off display house and Currumbin's off display den (See appendix 4-6 for full camera settings). These PIR trail cameras take photos (or videos) when something that is a higher temperature than the background temperature breaks the infra-red beam. However, even though both models have a trigger speed of ~0.2 seconds when activated, these types of cameras can fail to trigger, especially if the target is small and/or fast-moving. They can also be prone to false triggers if a hot pocket of air passes the detection zone. As videos and photos have similar detection rates, and videos being better for behavioural studies (Glen et al., 2013), I used a combination of both. Photos were primarily used, as they take up less storage space than videos.

Figure 9: An example of the Bushnell trophy cam aggressor trail camera setup, at Currumbin Wildlife Sanctuary. Source: Kathryn Bugler.

3.3 Methods

3.3.1 Auckland Zoo (21/03/2019 - 09/04/2019)

Auckland Zoo was used as a pilot 'test' study for the other zoos. I initially set up two Blackeye cameras to obtain a full view of the enclosure. The Blackeyes were different models, one (Kinopta Blackeye BE2NP/W on a brush stick fence opposite the enclosure and the other (Kinopta Blackeye BE2-W) on the back wall of the enclosure. After two days, both Blackeyes were checked. The one on the fence opposite the enclosure began to have problems, and no footage could be downloaded off it. The study continued with only the camera at the rear of the enclosure. This worked out much better as there were no interference possibilities from the public or footage of them. The rear camera was pointed towards the main latrine site, feeding area, and aerial walkways (Fig. 10). The remaining Blackeye camera (model: BE2-W) was checked every 2-3 days for battery life and to take footage from it.

I also observed red panda behaviour, from outside the enclosure, in the public area, for 1.5 hours during each session (during public opening hours), twice a day, for the full three weeks (*before*, *during* and *after* trail cameras were installed). Observation times were varied throughout the day to construct a general picture of daily behaviour. I noted every behavioural occurrence from all pandas for 10 minutes with a 5-minute break between each 10-minute time slot. This was an all occurrences, interval sampling technique, as behaviours could happen any time during the interval, and length of behaviour may be cut off by the end of the interval. Any behavioural observations should be long enough to obtain the average length and frequency of a behaviour, but not so long that the observer becomes fatigued (Jule et al., 2009). The first week of observations also helped to identify frequented routes for optimal trail camera placement. I wanted at least one camera in a frequented area and at least one in a less-frequented area. Also included in observations was the time of day the behaviour occurred, current weather conditions, keeper presence, which panda performed the behaviour, and the total length of the behaviour in seconds (to the nearest 10 seconds).

Table 1: Ethogram of red panda behaviours.

Locomotion	Movement, on all four paws, that would shift an individual from one area to another, such as running, walking or climbing
Resting	Lying, sitting or standing, eyes open, responsive to surroundings, staying in one area
Sleeping	Lying down, curled in a ball or flat, eyes closed, unresponsive to surrounding noise or activity
Eating	Eating food brought by keepers, either fruit, bamboo or pellets (sometimes grass or leaves already in the enclosure may also be eaten)
Drinking	Drinking water in enclosure, either in an artificial bowl or stream
Grooming/scratching	Grooming (licking) or scratching own body
Scent marking	Frequent rubbing of genitals and/or urination on objects around enclosure
Defecation	Urination, or defecation (usually at a latrine site)
Playing	Spontaneous actions, that are voluntary and internally motivated. These are not associated with the direct need for survival. Can be self-play or with others but is always non-aggressive

Camera (interaction)	Any interaction with a trail camera e.g., scent marking, sniffing or aggressive behaviour
Interaction	Between two pandas, overall non-aggressive
Keeper interaction	Interacting non-aggressively with a keeper
In den	Out of sight while in den
Hamilton house CT specific behaviours	Box – Often play but unable to see what was happening while the panda is in the box Pause – A panda pausing at the entrance, looking inside and then continuing without entering the house
Aggressive behaviour	Vocalization, staring or aggressive displays towards a con-specific. Aggressive displays include; standing on hind paws with forepaws raised above head, head bobbing and slamming forepaws on ground (This behaviour was not seen during the study)

After one week of baseline behavioural observations, on the 29th of March, I set up three Bushnell trail cameras in the enclosure. One at ground height near a nest box entrance, the second at the main latrine sight, and a third on a frequented path (Fig. 3). Trail cameras were checked for battery life and storage, when the Blackeye camera was checked every 2-3 days. The trail cameras were left in the enclosure for one week. At the end of this week, they were removed on the morning of the 5th of April. The Blackeye camera continued filming until the study concluded in the early hours of the 11th of April when the camera ran out of battery (it was scheduled to be taken out later, in the morning).

Figure 10: Blackeye camera screenshot of Auckland Zoo focal area. Source: Kathryn Bugler

3.3.2 Hamilton Zoo (29/04/2019 - 15/05/2019)

Like Auckland Zoo, one Blackeye camera was set up on the perimeter fence of the enclosure. Due to the size of the enclosure at Hamilton, much of it was out of view of the Blackeye, which necessitated a focal area to be chosen. This area encompassed a large tower, many aerial walkways and a latrine site (Fig. 11). This time it was on the side of the enclosure where there was a keeper only path that I could access whenever I needed to. This made it much easier to check battery life and storage. The camera could be checked every morning, and as a result, much less footage was lost.

Like Auckland zoo, I took personal observations in the public viewing area for the entire length of the study. The first week was a baseline behavioural study, before trail cameras were put into the enclosure.

On the morning of the 7th of May, trail cameras were set up in the enclosure. They were increased from three to five cameras on request by the keepers, who wanted to investigate who was going to the feeders at night. I had the same three Bushnells used at Auckland Zoo and added two new Brownings. One extra camera failed, and data was lost, so Hamilton Zoo had one extra trail camera dataset. One feeding platform had the Bushnell and the other had the Browning. The latrine site that the Blackeye camera was focussed on had another Bushnell aimed at it and one of the main walkways. The last Browning was inside the main house, in video mode, as keepers had questions about what the pandas did in there at night (Fig. 5). Trail cameras were checked twice over the week for battery life. They were removed from the enclosure on the afternoon of the 13th of May. The Blackeye camera remained on until the early hours of the 15th, when like it did in Auckland, ran out of battery slightly early.

Figure 11: Blackeye camera screenshot of Hamilton Zoo focal area. Source: Kathryn Bugler.

3.3.3 Currumbin Wildlife Sanctuary (03/12/2019 - 12/12/2019)

Currumbin was set up as a slightly shorter study with trail cameras going in after only three days of personal observations due to this survey's shortened timeframe. On the 7th December three Bushnell trail cameras were set up inside the enclosure, one on the feeding platform, one on a well-used aerial walkway and one on the ground. One Browning trail camera was set up in the den area, on video, like Hamilton Zoo (Fig. 7). They were then taken out three days later (in the afternoon) on the 10th, for a further two days of observations. The Blackeye camera was also set up in an easy to reach perimeter fence, so that it could be checked daily. This camera focused on the front platform where the panda slept, as well as a majority of the aerial walkways (Fig. 12). Personal observations were also taken from the public viewing area as at the other two zoos.

Figure 12: Blackeye camera screenshot of Currumbin Wildlife Sanctuary focal area. Source: Kathryn Bugler.

Table 2: Dates of Blackeye camera, observations and trail cameras in enclosures at all zoos

Zoo	Observation type	Date in	Date out
Auckland Zoo	Direct observations	21/03/2019	09/04/2019
Auckland Zoo	Blackeye camera	10:50 22/03/2019	01:00 11/04/2019
Auckland Zoo	Trail camera	10:10 29/03/2019	09:30 05/04/2019
Hamilton Zoo	Direct observations	29/04/2019	15/05/2019
Hamilton Zoo	Blackeye camera	11:00 29/04/2019	01:00 15/05/2019
Hamilton Zoo	Trail camera	10:00 07/05/2019	10:30 14/05/2019
Currumbin Wildlife Sanctuary	Direct observations	03/12/2019	12/12/2019
Currumbin Wildlife Sanctuary	Blackeye camera	09:15 03/12/2019	16:00 12/12/2019
Currumbin Wildlife Sanctuary	Trail camera	08:00 07/12/2019	13:10 10/12/2019

3.4 Statistical analysis

I summarised my data by creating pie charts, in Excel®, to show percentage time spent performing behaviours for the *before* trail camera period. I then created histograms to show the same data in a way that was easier to compare methods and behaviours. Chi-square tests for this dataset were carried out in R studio (version 1.3.959). Lastly, I created time-series graphs to show when active behaviours occurred throughout a normal captive red panda day (Chapter 4).

Using R studio (version 1.3.959), I started by creating models using the 'glm' function (from the packages MASS, version 7.3-51.6 and lme4, version 1.1-23). Length of time spent performing an individual behaviour was plotted using the 'hist' function to check its distribution. Length of time was the predictor variable with behaviour and trail camera presence as factors (fixed effects), formed a basic model, which I then fitted a normal distribution glm, a Poisson glm and a negative binomial glm. Model fit was assessed using the AIC function to compare models, and I selected the negative binomial distribution having the best fit. Using the drop1 feature on the chosen model, I was able to test which variable was significant.

To test the robustness of the model, other factors were also added, such as temperature, date, position in the enclosure and an interaction term between behaviour and trail camera presence. These were all tested with the drop1 feature until we had a model that only had significant terms. Using the 'emmeans' function from the package emmeans (version 1.4.7), I then examined how behaviour and trail camera presence effected the response (length of time) on means plots, as well as pairwise comparison tests to test for differences between levels of categorical factors (Chapter 5).

Chapter 4

Activity budgets of captive red panda

4.1 Results

4.1.1 Activity budgets

Proportion data from all zoos in the *before* trail camera period were combined to estimate an overall activity budget from direct observations (Fig. 13a) and Blackeye footage (Fig. 13b). Sleeping was the most common behaviour at 68% (observations) and 44% (Blackeye footage). The next most common behaviours were: locomotion (13%-22%), resting (7%-15%), eating (6%-12%), and grooming (6%-3%). Less common behaviours were: defecation, interactions, scratching and scent marking, with all other behaviour less than 1% for both observational methods still included in the analysis to give a full picture of red panda behaviours.

When the data was analysed with R studio, a significant interaction between observation method and behaviour type was discovered (χ^2= 923.56, DF= 17, P= <0.001).

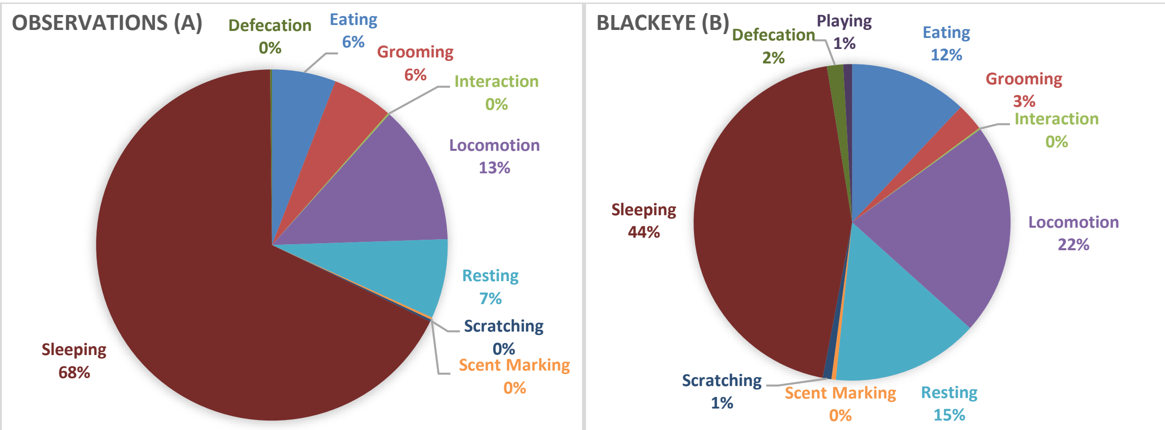

Figure 13: Activity budgets of red panda across all zoos surveyed, with personal observations (a) and Blackeye camera (b). This was from observations made '*before*' trail cameras were placed in enclosures.

The data was then split into the separate zoos. Auckland Zoo observations (Fig. 14a) showed sleeping (67%) to be the most common behaviour. However, the Blackeye camera (Fig. 14b) showed locomotion (33%) and eating (29%) to be the most common behaviours. Sleeping (13%) was only the fourth most common behaviour on the Blackeye camera. Hamilton Zoo observations (Fig. 14c) showed sleeping (74%) to be the most common behaviour. However, the Blackeye camera (Fig. 14d) showed locomotion (50%) and eating (22%) to be the most common behaviours. Sleeping (<1%) barely registered on the Blackeye camera at Hamilton Zoo. At Currumbin Wildlife Sanctuary observations (Fig. 14e) also showed sleeping to be the most common behaviour (42%). However, for this zoo, the Blackeye footage (Fig. 14f) showed that sleeping was consistently the most common behaviour (76%).

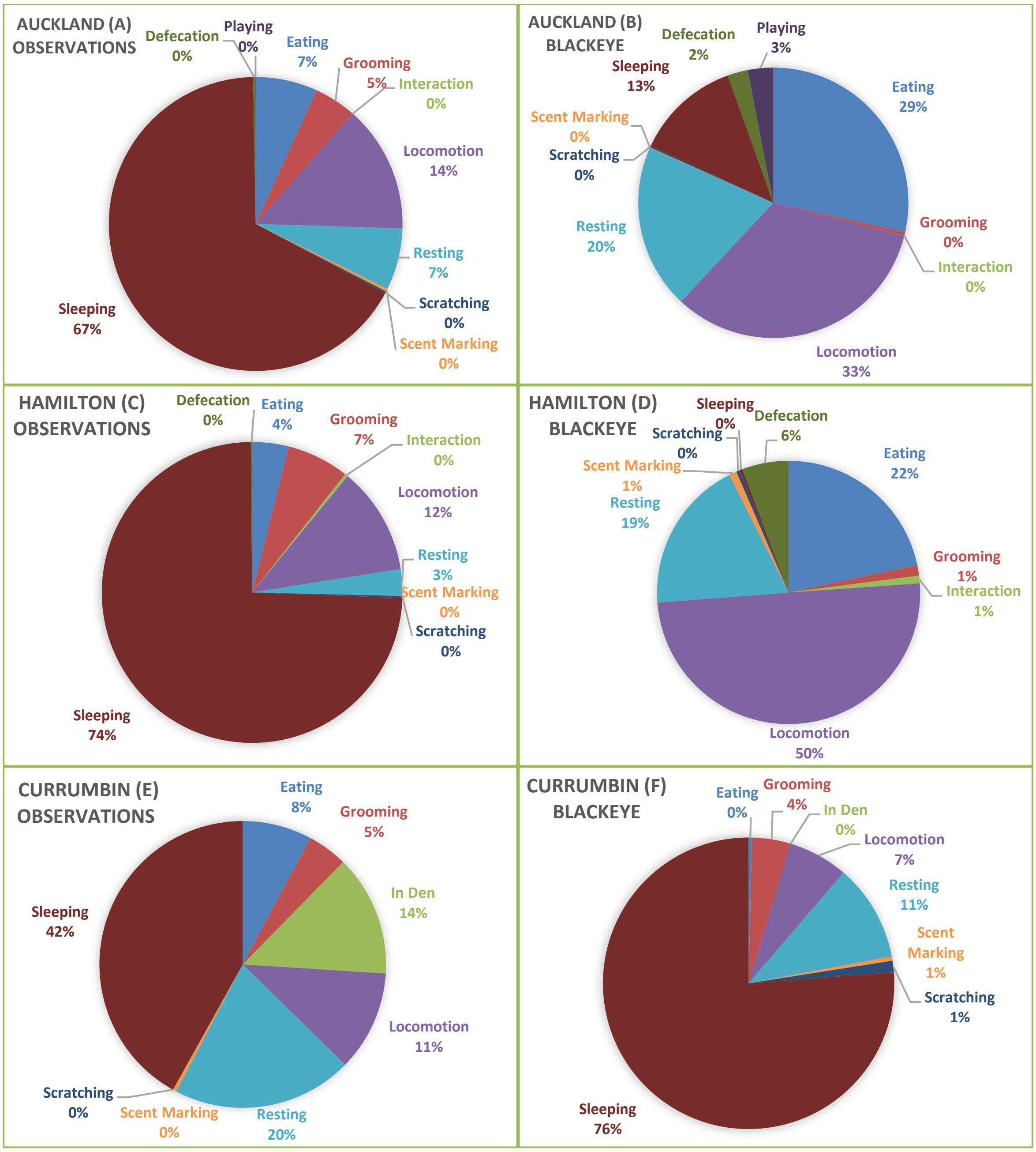

Figure 14: Activity budgets of red panda at different zoos as observed by direct observations and Blackeye camera footage. Using only data from '*before*' trail cameras were placed in enclosures.

When comparing direct observations to Blackeye footage, the differences in how red panda spent their time are noticeable (Fig. 15-17). Sleeping at Auckland (Fig. 15) and Hamilton (Fig. 16) Zoos has the biggest difference between observational methods. When red pandas are directly observed, sleeping is the behaviour that takes up most of their time. If only Blackeye footage was observed for these two zoos, then sleeping would be close to 0% of their daily activity pattern! However, at Currumbin Wildlife Sanctuary, direct observations and the Blackeye camera recorded sleeping as the most common behaviour. Initially, it looks as if all behaviours vary across observational types, except for grooming at Currumbin Wildlife Sanctuary (Fig. 17).

All three zoos had a significant interaction between method of observation and behaviour. Types of behaviours observed differed with observational method. Auckland Zoo (χ^2= 110.41, DF= 7, P= <0.001), Hamilton Zoo (χ^2= 232.14, DF= 7, P= <0.001), Currumbin Wildlife Sanctuary (χ^2= 36.80, DF= 7, P= <0.001).

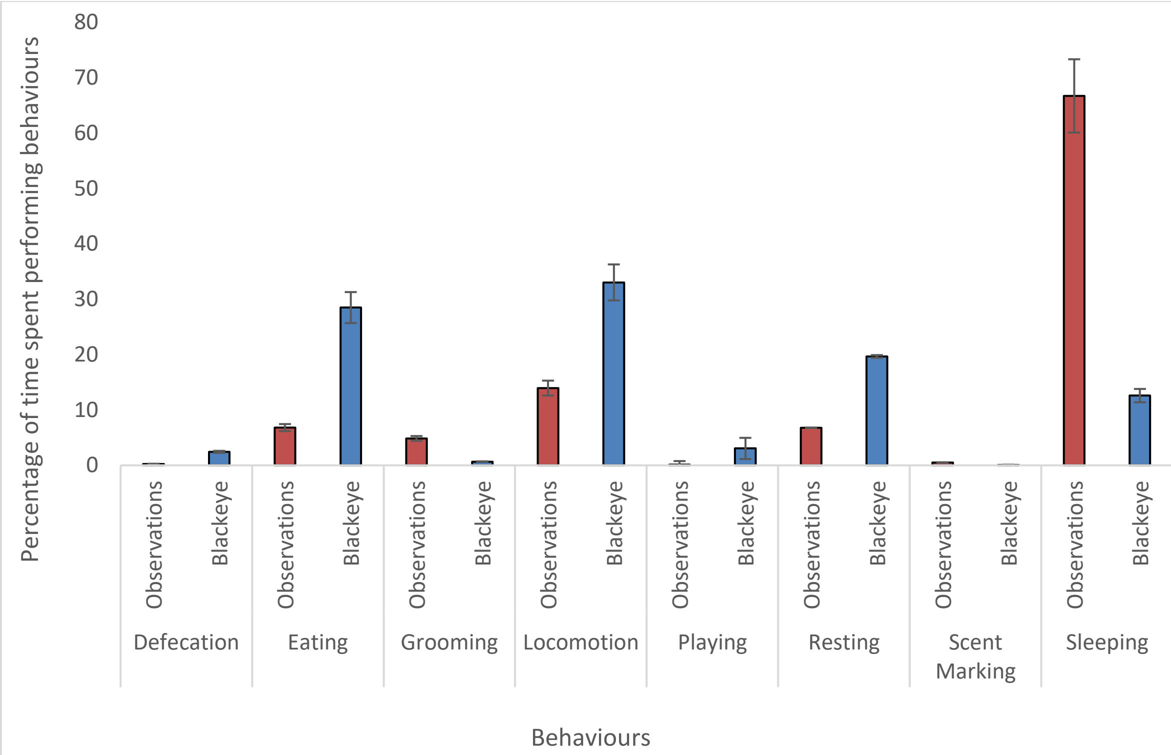

Figure 15: Observational methods change the perception of how red panda spent their time (+ SE) at Auckland Zoo (Using only data from '*before'* trail cameras were placed in enclosures).

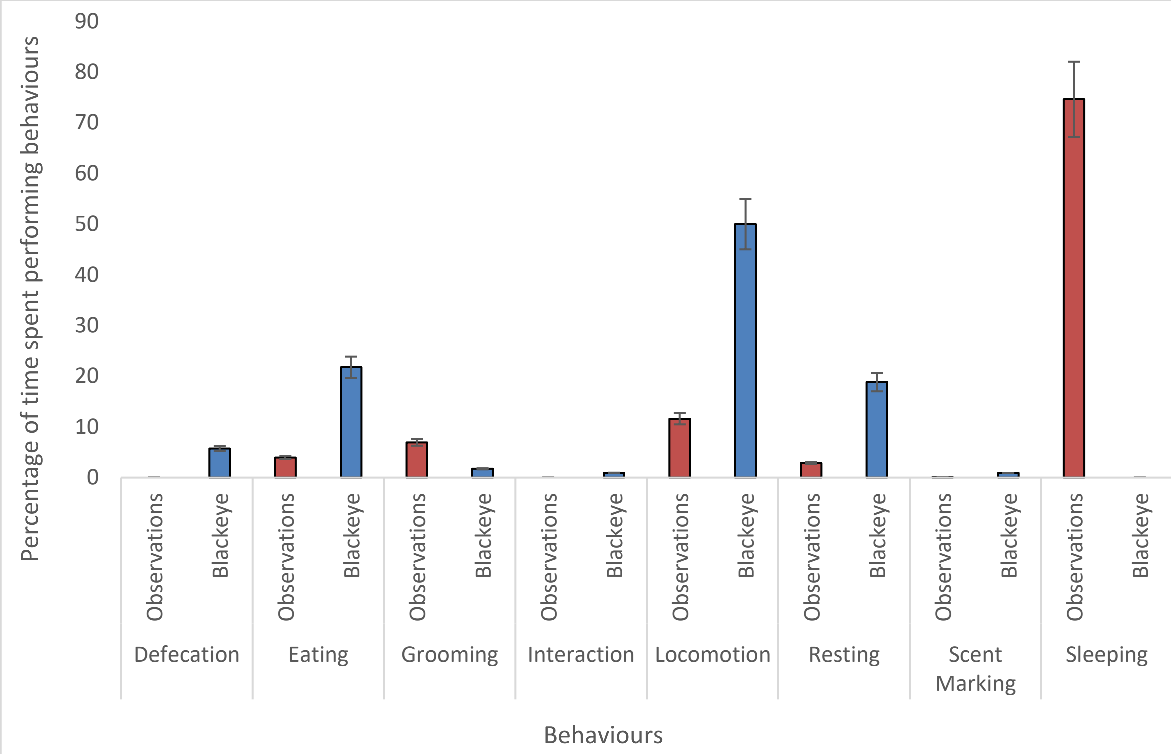

Figure 16: Observational methods changes the perception of how red panda spent their time (+ SE) at Hamilton Zoo (Using only data from '*before*' trail cameras were placed in enclosures).

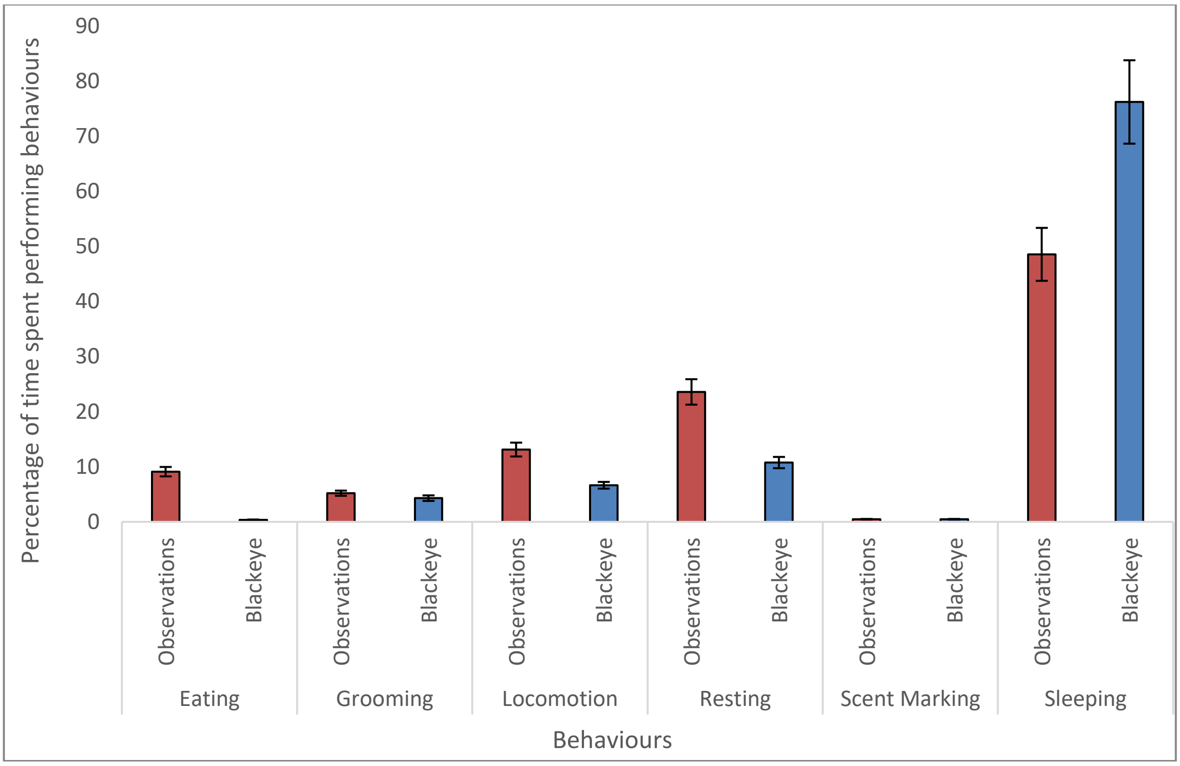

Figure 17: Observational methods changes the perception of how red panda spent their time (+ SE) at Currumbin Wildlife Sanctuary (Using only data from '*before*' trail cameras were placed in enclosures).

All zoos combined

Data from all zoo *before* periods were combined to assess differences between zoos. A negative binomial GLM (AIC= 56104.88, compared to Gaussian= 79935.73 and Possion= 536209.29) was carried out to create a model to then preform drop1 tests for significant factors. Residual plots were assessed (see Appendix C, figure C. 1) and deemed suitable. Drop1 testing showed that all factors in the model had significant effects on length of the behaviour (Behaviour: χ^2=14629.8, DF= 11, P= <0.001) (Zoo: χ^2= 6650.2, DF= 2, P= <0.001) (Method:) χ^2= 6959.3, DF= 1, P= <0.001).

Emmeans testing showed some overlaps in zoos (Fig.18), but no overlaps in method type (Fig.19). Pairwise comparisons showed that there was differences in average length (seconds) of behaviours between all zoos (Auckland/Currumbin: P= <0.0001) (Auckland/Hamilton: P= <0.0001) (Currumbin/Hamilton: P= <0.0001). While both factors are significant, between zoo variation is less significant. The key result being that observation method shows differences in average length of behaviours.

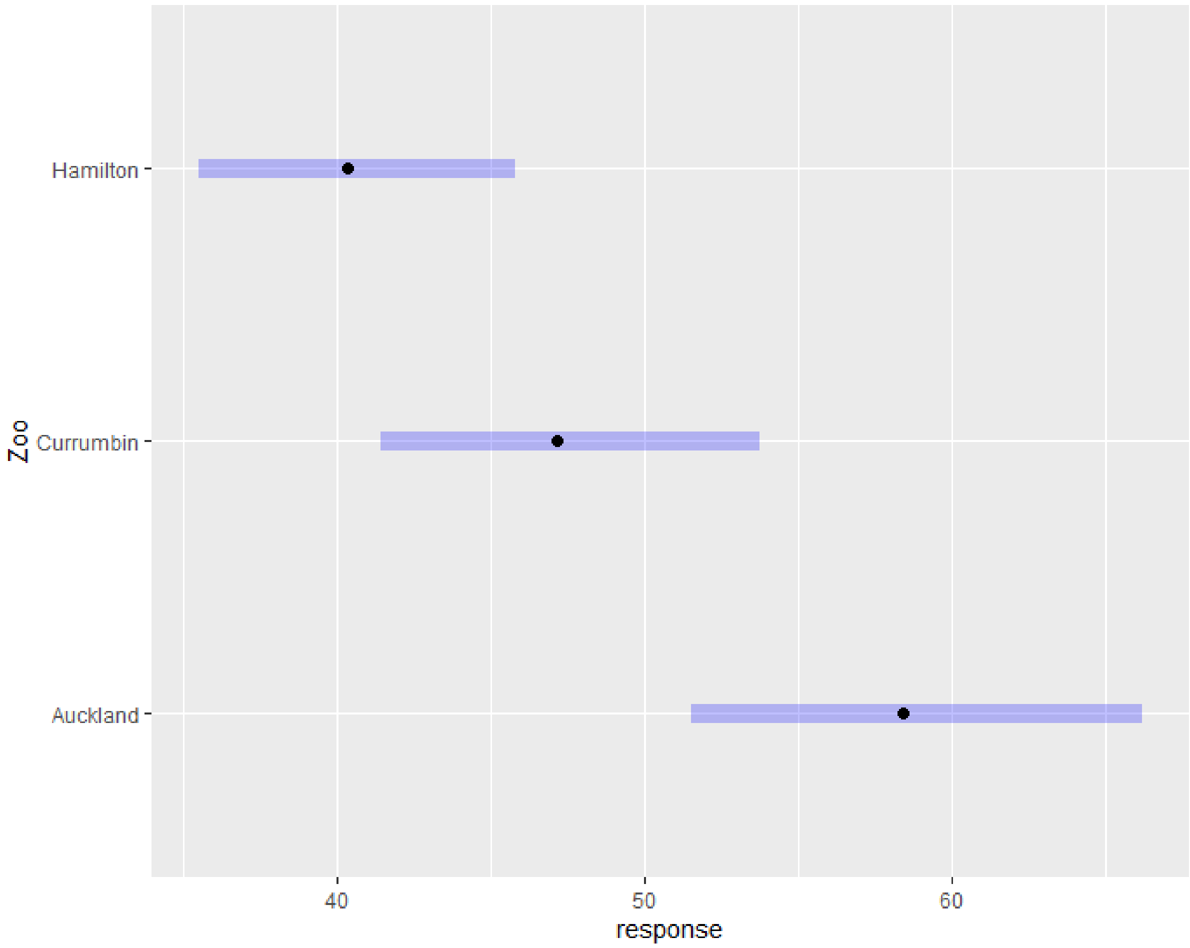

Figure 18: Emmeans plot output (+ 95 CI) from R showing responses in relation to length (seconds) of behaviours for individual zoos for the all zoos combine data in the '*before*' trail camera period.

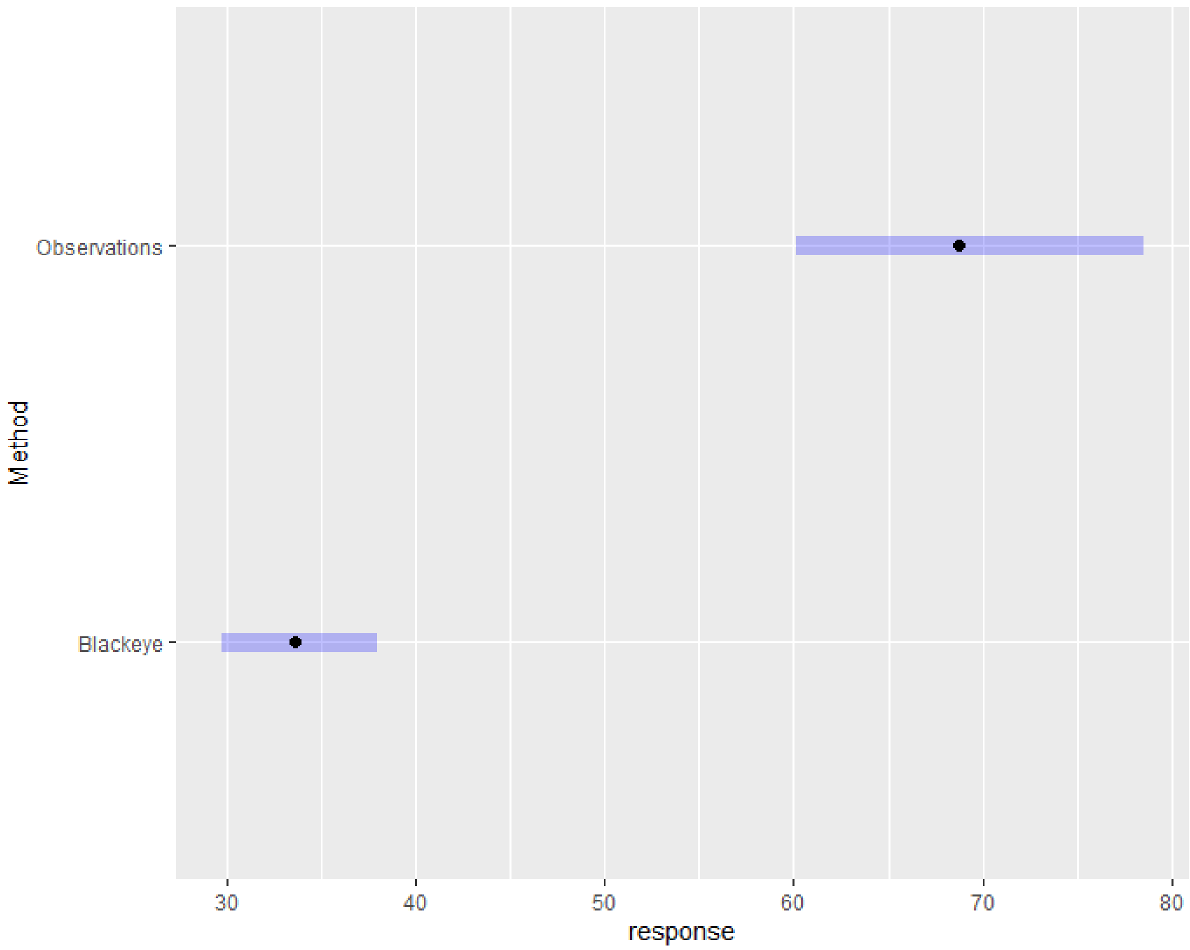

Figure 19: Emmeans plot output (+ 95 CI) from R showing responses in relation to length (seconds) of behaviours for method type for the all zoos combine data in the '*before'* trail camera period.

4.1.2 Active behaviours

The active behaviour data were assessed to build up a picture of when red panda were active and how activity differed across observational methods. Auckland Zoo (Fig. 20) observations showed a rise in activity in the afternoon, which dropped to 'no active behaviours' due to zoo closing hours and no longer observing them, but when compared to the Blackeye footage, shows red panda are active all through the afternoon and into the early hours of the evening, significantly dropping off around midnight.

At Hamilton Zoo (Fig. 21), Blackeye camera and observations showed two peaks in activity around 9-11 am and 4-6 pm. Observational data points finished around 4-5 pm due to the zoo opening hours.

At Currumbin Wildlife Sanctuary (Fig. 22), there was an increase in activity between 8-9 am with both observational methods when keepers first arrived with food and clean water. However, the Blackeye footage showed that the morning peak starts much earlier, around 5 am. There was another spike in activity in the afternoon when keepers feed again and reduces further around 6:30 pm.

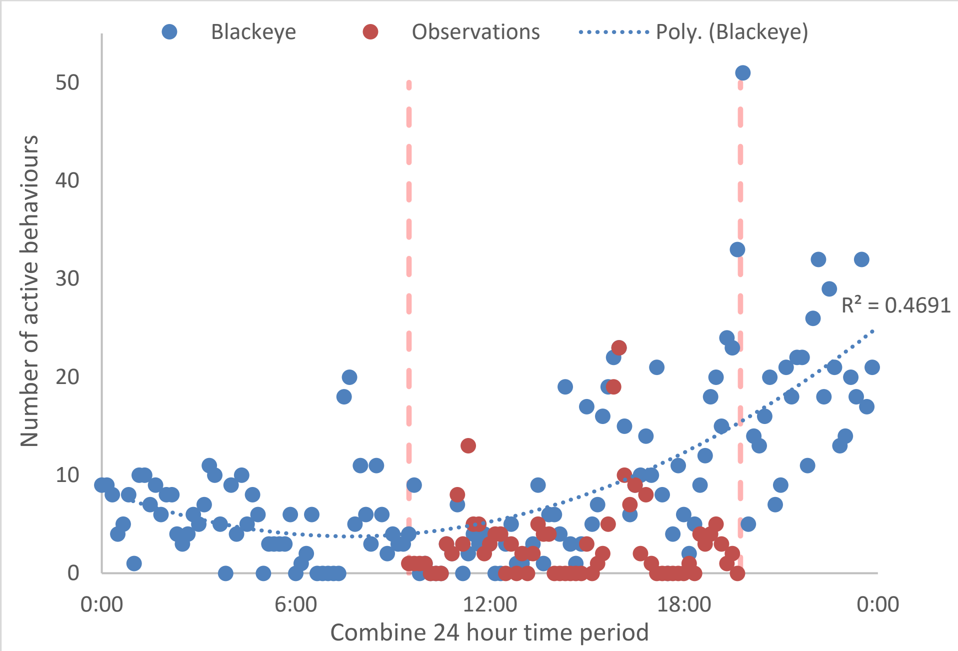

Figure 20: Frequency of active behaviours for red panda at Auckland Zoo, in 10-minute intervalsThe red lines show when direct observations were carried out (9:30 am – 7:45 pm). R^2 values are calculated from a nth order polynomial line. Combining all data from the *'during'* period (6 pm 21/03/2019 – 10:10 am 29/03/2019) to give the overall picture.

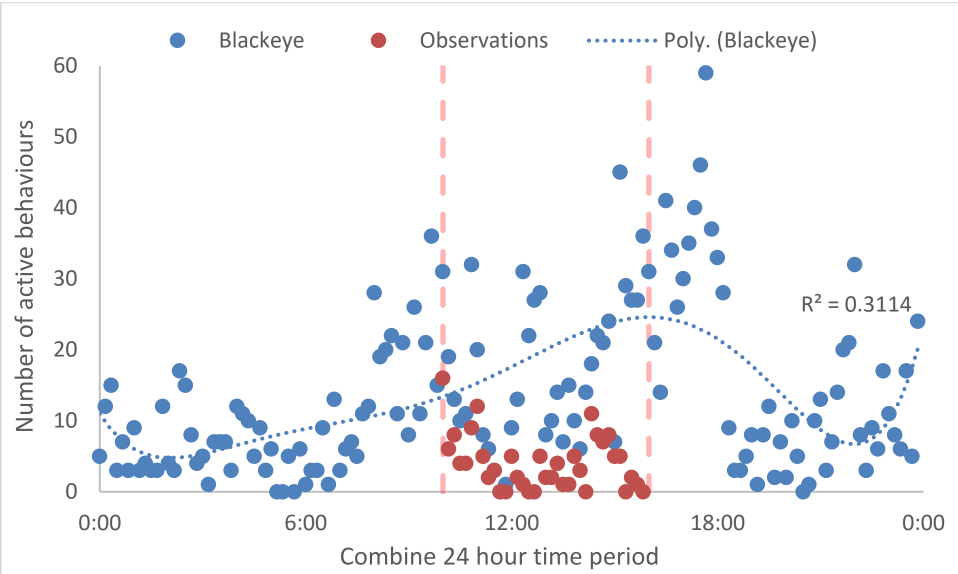

Figure 21: Frequency of active behaviours for red panda at Hamilton Zoo, in 10-minute intervals. The red lines show when direct observations were carried out (10 am – 4 pm). R^2 values are calculated from a nth order polynomial line. Combining all data from the *'before'* period (10:56 am 29/04/2019 – 9:53 am 07/05/2019) to give the overall picture.

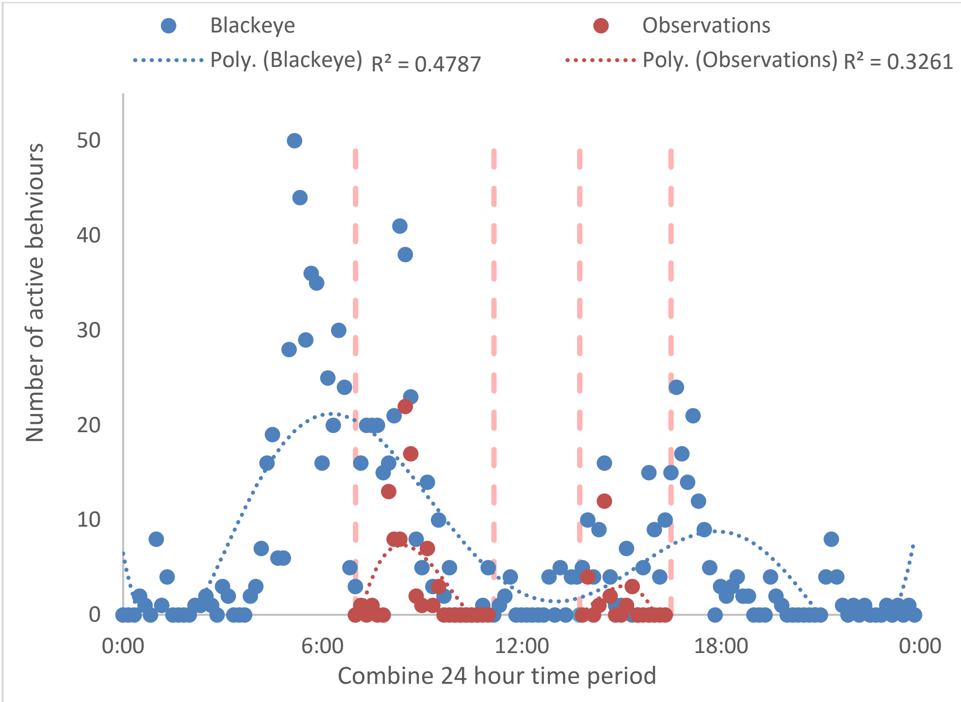

Figure 22: Frequency of active behaviours for red panda at Currumbin Wildlife Sanctuary, in 10-minute intervals. The red lines show when direct observations were carried out (7 am-11:10 am and 1:45 pm-4:30 pm). R^2 values are calculated from a n^{th} order polynomial line. Combining all data from the '*before*' period (9:15 am 03/12/2019 – 8 am 7/12/2019) to give the overall picture.

4.2 Discussion

In this chapter I aimed to answer what a typical captive red panda's time budget would look like, and whether or noth this different between zoos and management types. I did this by recording baseline behaviours of captive red panda, without trail cameras (Fig. 13). I used a combination of personal observations and a Blackeye camera outside the enclosure that recorded continuously. When all zoo data were combined, sleeping was the most common and lengthy behaviour performed by captive red panda (68% observations, 44% Blackeye footage). This is a similar result to Gebauer (2011), who reported that sleeping took up 60% of their day. The same study found grooming could take up to 16% of a red panda's activity budget. My research found grooming, on average, was only about 6% of their day. The next most common behaviour was locomotion which included walking, running and climbing (13% observations, 22% Blackeye footage).

The second question I aimed to answer was, "do different observational methods provide a similar picture of red panda behaviour?" I found that there was a significant interaction term between observation method and behaviour performed for all three zoos (tested individually). Type of behaviour recorded was influenced by method type. The two methods show different percentages of what takes up a captive red panda's time. This is likely because direct observations were only carried out during public opening hours (or slightly earlier if I had permission). Sleeping takes up a lot more of a red panda's time in the observation data (Fig. 13a, Fig. 14). Red panda are hypothesised to be crepuscular (Reid et al., 1991), so this would make sense, from only day-time observations, that they would sleep frequently. When trail camera videos and hand-held camera videos of wild boar (*Sus scrofa*) were compared, Kovács et al. (2017) found it more challenging to identify behaviours and drew many incorrect conclusions from shorter videos.

When active behaviours were assessed (Fig. 20-22), direct observations showed red panda to be most active during the morning (8-11 am) and later in the afternoon (4-5 pm). Observations finished before 5 pm most days, due to the zoo closing. These peaks in activity also coincided with keepers entering enclosures. The most obvious example of this was at Currumbin Wildlife Sanctuary (Fig. 20b), where the keepers would first enter the enclosure around 8 am with a bowl of food and would wait until Pasang came down and had his medicine before leaving. Cleaning would occur shortly afterwards. Keepers then arrived again around 2 pm with another bowl of food, then taken away around 4 pm. There were no direct observations of active behaviours between 11:10 am and 1:45 pm in the *before* trail camera period, although the only behaviours seen from 9:30 am to 11:10 am are sleeping or resting. Auckland Zoo observations (Fig. 20) were carried out slightly later than the other zoos (until 8 pm) as the zoo had late nights for the first two days of observation. There was the same peak of activity in the afternoon, but the drop off was also observed.

Blackeye cameras on enclosures were able to record 24/7 active behaviours within the areas on which they were focused. According to Blackeye camera footage, active periods at Auckland Zoo (Fig. 20) were similar to observations, with a peak in activity in the afternoon, beginning around 3 pm and extending until midnight. There was a significant drop in activity around 4 am, which slowly increased around 10 am when enclosures were usually cleaned. Management of food at Auckland Zoo looked significantly different to Currumbin Wildlife Sanctuary. Fruit was not left out for pandas; instead, keepers would come into the enclosure and stand at the feeding area offering them 'panda cake', which was a mixture of speciality biscuits soaked overnight with baby food and pear juice. This was also done during encounters (once a day) with grapes. In the afternoon, pears were put onto a hanging log with nails so that the pandas had to manipulate them off the device to eat. This was the beginning of their peak activity period.

Hamilton Zoo (Fig. 21) had a less prominent peak in activity. There is an increase in activity around 9 am when keepers arrived with food. Chito, like Pasang, would receive medicine in the morning via keepers. Cleaning usually took place after the first lot of fruit was delivered to covered feeding stations, that panda could stand on to open (chicken hoppers). As with all zoos, bamboo was always on offer. Activity began to slightly decrease for a short time between 1:30-2:30 pm. Activity was at its highest between 3 pm and 5 pm, with another short peak about 10 pm. Zhang et al. (2011) also found red panda to be least active at night.

Length of time a behaviour was preformed was significantly affected by which zoo it was recorded at. Therefore, management of red panda has a direct effect on their activity budgets (as far as you can extrapolate from three zoos and seven individuals). However, the strongest factor seen with this testing, was that observational method has a bigger impact than zoo/ management type. Red panda can only differ so much in their natural behaviours. Within species variation is limited but how that variation is recorded can cause a major impact on final results.

Behaviours, such as scent marking, registered <1%, as the behaviours themselves were incredibly short in length (1-5 seconds). So while red pandas scent marked frequently, this does not show as a very common behaviour. Other studies have shown that males scent mark more than females, with females increasing scent-marking behaviours during the mating season (Conover and Gittleman 1989: Roberts and Gittleman, 1984). Similar to Conover and Gittleman (1989), the pandas in this study showed a preference for particular marking sites, including branches or other prominent features, and frequented walkways. Red panda at Hamilton Zoo were even seen scent marking the trail camera inside their den. Lynx in a study by Tang et al. (2019) also used trail cameras as new scent-marking sites. Whether or not this was due to human scent, or because trail cameras protrude from trees remains unstudied.

Direct observations are beneficial in a dynamic landscape and discovering the best time to observe animals in the wild is helpful. Comparing active behaviours between both observation methods shows that observations alone clearly miss active behaviours. Edwards et al. (2010) showed continuous sampling to be the most accurate form of observing behaviour and cluster or time sampling (as a modification of continuous sampling) was not as accurate as interval sampling for activity budgets. In future, I would recommend observing captive red panda earlier in the morning between 5-9 am and a later afternoon period of 3-9 pm with an altered sampling interval for specific behaviours, i.e., shorter bouts, more frequent observations for shorter behaviours.

Other studies show bimodal activity patterns at dawn and dusk (Lama, 2018: Zhang et al., 2011). Wild trail camera studies showed the highest peak of activity was between 4-6 am and another between 10 am and 2 pm (Lama, 2018). There were no trail camera photos between 10 pm and 4 am. This pattern was almost found at Currumbin Wildlife Sanctuary from Blackeye footage. Pasang would sleep from 7 pm to the early morning hours when he'd scent mark before keepers arrived. His bimodal pattern of activity during the day clearly followed keeper timings. It seems that the activity of captive red panda was influenced by keeper presence and management, slightly deviating from wild patterns. Krebs et al. (2017) found that red panda in their study showed anticipatory behaviours before keepers arrived and increased movement once they left. Coyotes have shown stereotypical pacing and a significant change in behaviours when humans are present, even in captivity where this is normal (Schultz and Young, 2018).

Red panda in this study were less active than reports from other studies on wild red panda. These studies report red panda as being active 45-56% of the time (Yonzon and Hunter, 1991: Reid et al., 1991). This is likely due to increased foraging needs of wild red panda. In captivity, panda are brought a selection of bamboo, fruits, specialised biscuits, and the occasional day-old chick or mouse. This increase in fruit in the diet may lead to more short rests as the stomach fills more rapidly (Reid et al., 1991). This can be seen in wild red panda when they have a high frequency of short rests in spring when fruit and new more nutritious, shoots of bamboo are available (Zhang et al., 2011). Glatston (2011b) summarises that because "captive diets do not occupy enough of the red panda's daily activity. Pandas may compensate for this activity "vacuum" by over-grooming and eating hair." Luckily in this study, grooming was lower than found in others, so no stereotyping of over-grooming was found.

Studies of other animals have shown that captive and wild activity budgets do not vary much, but between zoos and management types can differ significantly (giant panda: Zhang et al., 2015) (Giraffes: Bashaw, 2011) (Sulawesi crested black macaques: Melfi and Feistner, 2002) (Boars: Blasetti et al., 1988). Weller and Bennett (2001) studied captive and wild ocelot (*Leopardus pardalis*) activity budgets. Their findings showed that the captive cats were less active than their wild counterparts but that their activity patterns (of dawn and dusk) lined up with wild cats. Their diet was fed in the morning, contributing to far less activity at night, due to a lack of hunting. The cats between zoos had similar behaviours and activity budgets. They also attributed certain activities to keeper proximity (Weller and Bennett, 2001).

In the next chapter, I look at the effect of trail cameras on captive red panda behaviour.

Chapter 5

Behavioural changes of captive red panda, with the introduction of trail cameras

5.1 Results

Like chapter four, initial pie charts were created to show a visual display of the proportion of time spent doing behaviours was over the study period. These pie charts are of a proportion of time; however, the rest of the data, in this chapter was tested by length of time.

5.1.1 Auckland Zoo

Observational data

Length of behaviours was statistically tested and visually found to be bimodally distributed. I tested the model fit using a GLM with a negative binomial against Gaussian and Poisson error distributions. AIC was used to compare the different model types (negative binomial: AIC=10998.24, Gaussian: AIC=11221.89, Poisson: AIC=87827.74). The negative binomial model with an interaction term between trail camera presence and behaviour had the best fit. Qqnorm testing showed a less than ideal fit (see Appendix C, figure C. 2a), but as the binomial distribution showed the best model fit in terms of AIC and no outlying data points were identified, I continued with this model.

The drop1 feature was used to test significant terms in the model. The behaviour and trail camera presence interaction were significant, indicating a change in behaviour with trail camera presence (χ^2= 1894.02, DF= 28, P= <0.001). Temperature (χ^2= 977.66, DF= 1, P= <0.001) and date (χ^2= 1004.82, DF= 17, P= <0.001) were also both significant factors with changes in length of behaviours (Table 3).

Sleeping was the most common behaviour, followed by resting, locomotion, grooming, and eating as observed with direct observations (Fig. 23).

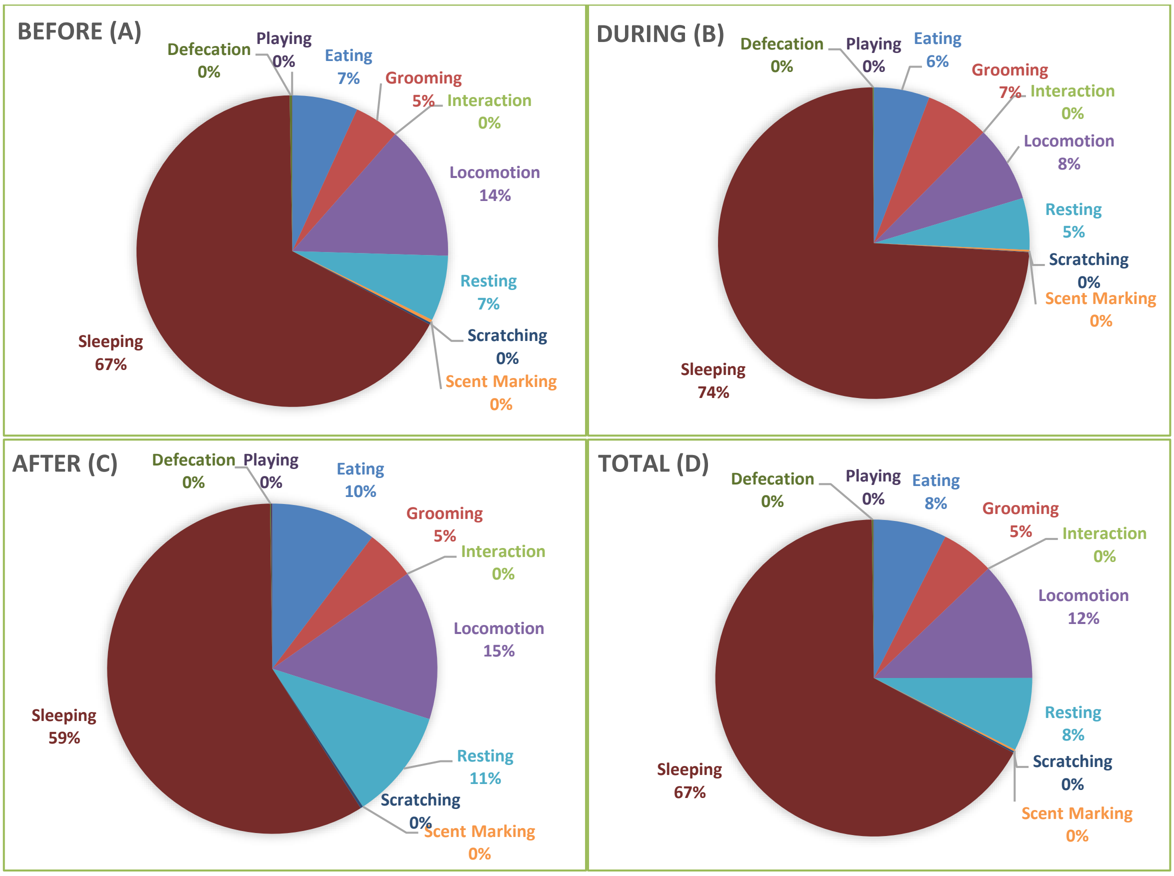

Figure 23: Percentage of time spent doing all behaviours recorded by observations (This is not a full activity budget, due to observations being ~3 hours a day during open hours). A- *'Before'* 21/03/2019 to 28/03/2019. B- *'During'*, once trail cameras were put into the enclosure, 29/03/2019 to 04/04/2019. C- *'After'* 05/04/2019 to 11/04/2019. D- *'Total'* is all observations, 21/03/2019 to 11/04/2019. Drinking was absorbed into eating for these graphs.

Emmeans testing showed some overlaps and some differences in behaviours over the study period (Fig. 24). When pairwise comparisons of behaviours between periods of *before*, *during* and *after* were compared, there were no significant differences in responses at the behaviour level (Table. 4).

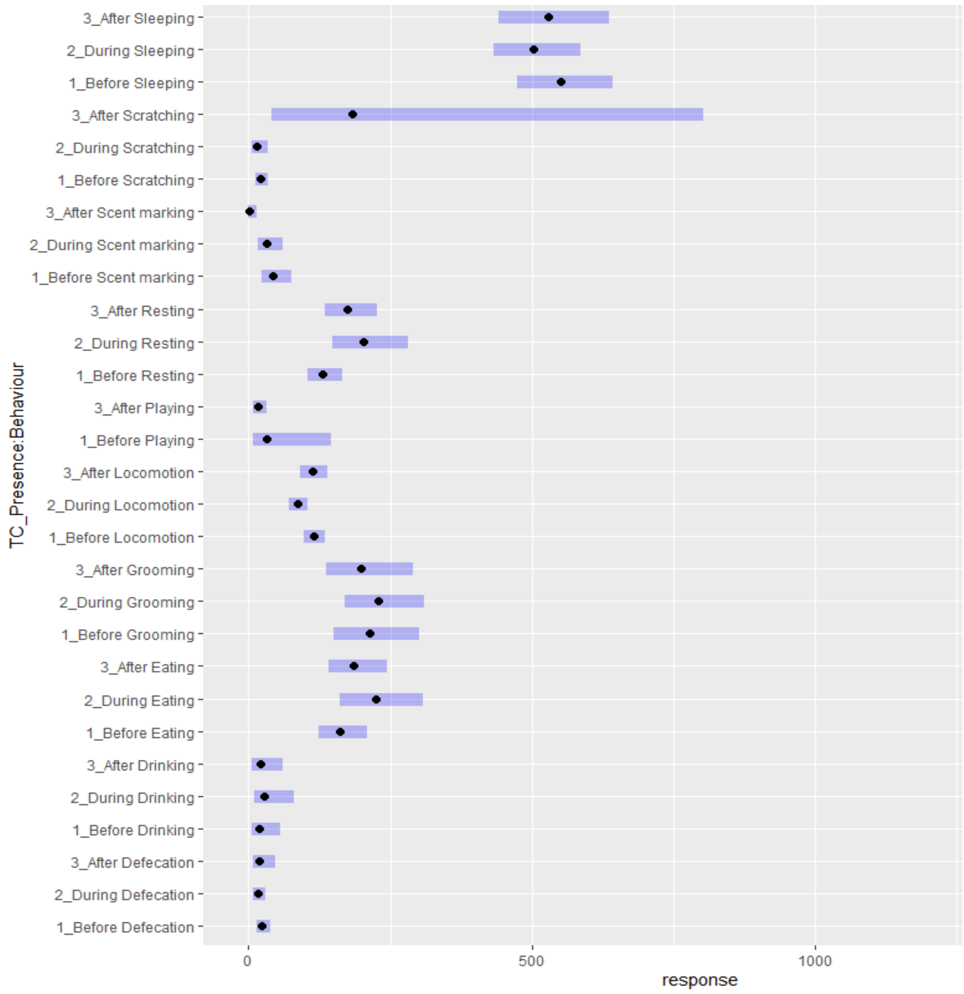

Figure 24: Emmeans plot output (+ 95 CI) from R showing responses in relation to the behaviour/trail camera presence interaction for observational data at Auckland Zoo.

Finally, I examined how behaviour was affected by temperature (χ^2=977.66, DF=1, P= <0.001) (Fig. 25). Long and short behaviours were carried out over a temperature range at Auckland Zoo, with a small decline as temperatures rose.

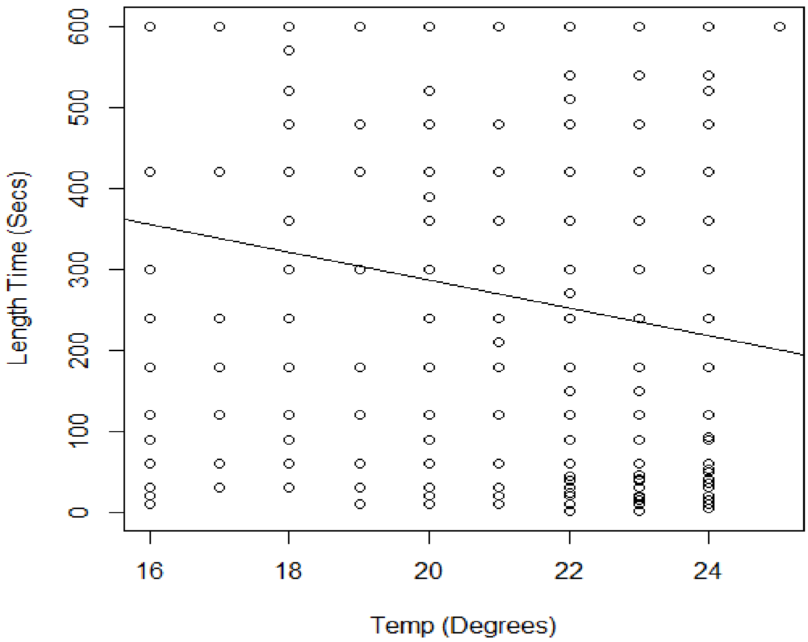

Figure 25: The duration of behaviours was positively influenced by increasing temperature.

Blackeye camera footage

The model with length of time as the dependent variable was tested with Gaussian (AIC= 48846.23), Poisson (AIC= 246465.56) and negative binomial (AIC= 35383.2) error distributions to assess the best fit. The negative binomial model with an interaction term between trail camera presence and behaviour had the best fit. Qqnorm testing showed a less than ideal fit (see Appendix C, figure C. 2b), but as the binomial distribution showed the best model fit in terms of AIC and no outlying data points were identified, I continued with this model.

The drop1 function was used to test for significant terms in the model. The initial model with the interaction term between behaviour and trail camera presence was significant (χ^2=9085.5, DF=30, P=<0.001). The temperature was not collected reliably for the Blackeye footage and was left out of this model and further Blackeye models (Table 3).

Locomotion (average= 29%) and eating (average= 29%) were the most common behaviours seen with the Blackeye camera at Auckland Zoo (Fig. 26). Resting (average= 21%) and sleeping (average= 16%) were also significant proportions of time spent, followed by defecation (average= 2%), playing (average= 2%), and grooming (average= 1%).

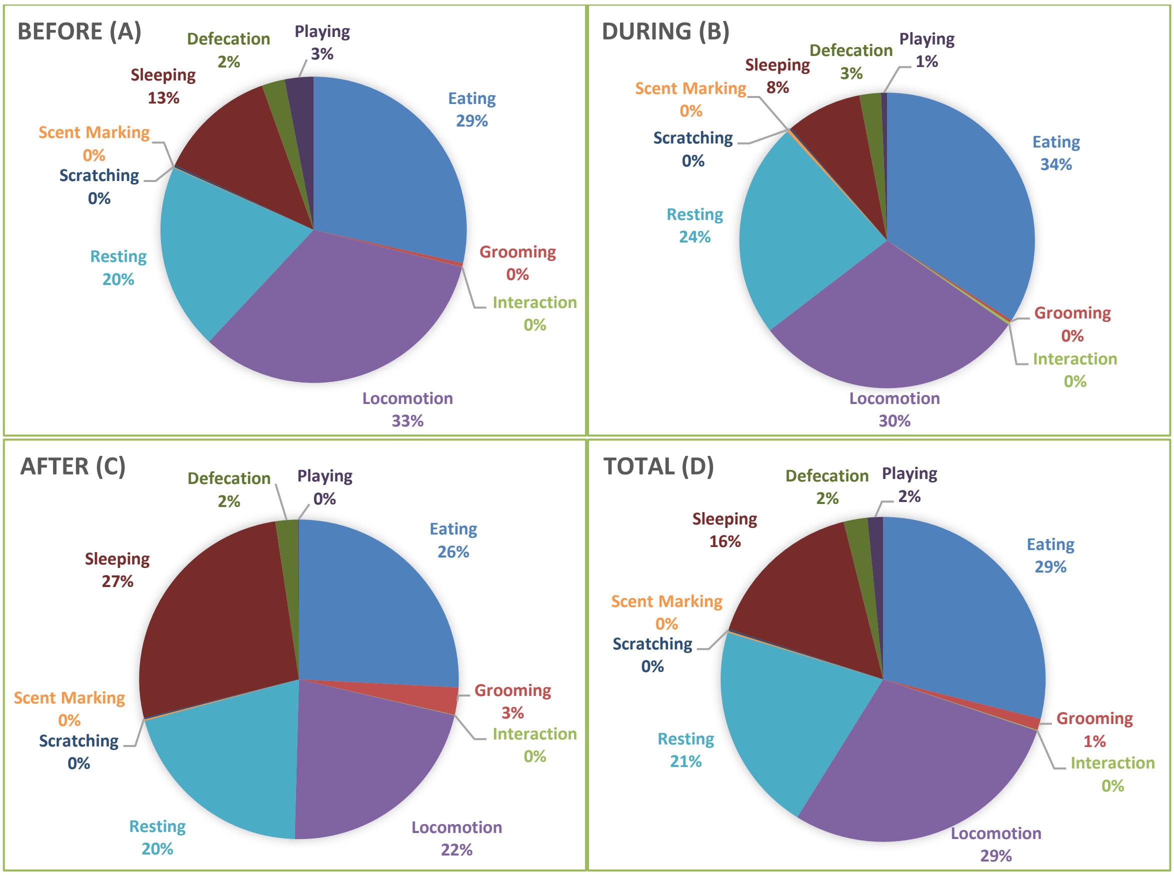

Figure 26: Percentage of time spent doing all behaviours as recorded by the Blackeye camera. A- *'Before'* 21/03/2019 to 28/03/2019. B- *'During'*, once trail cameras were put into the enclosure, 29/03/2019 to 04/04/2019. C- *'After'* 05/04/2019 to 11/04/2019. D- *'Total'* is all observations, 21/03/2019 to 11/04/2019. Drinking was absorbed into eating for these graphs.

Again, length of time of *during* and *after* are very similar (Fig. 27) but the before period is likely to be different. Pairwise comparisons of behaviours showed some significant differences in some behaviours. For example, locomotion was significantly different when *before* was compared to *during and after* (*before-during* P= <0.001, *before-after* P=<0.001). However, *during and after* were not significantly different. Other differences included play (*before-during* P=0.01) and resting (*before-during* P=0.002, *before-after* P= 0.02). All other behaviours were not significantly different between periods (Table. 4).

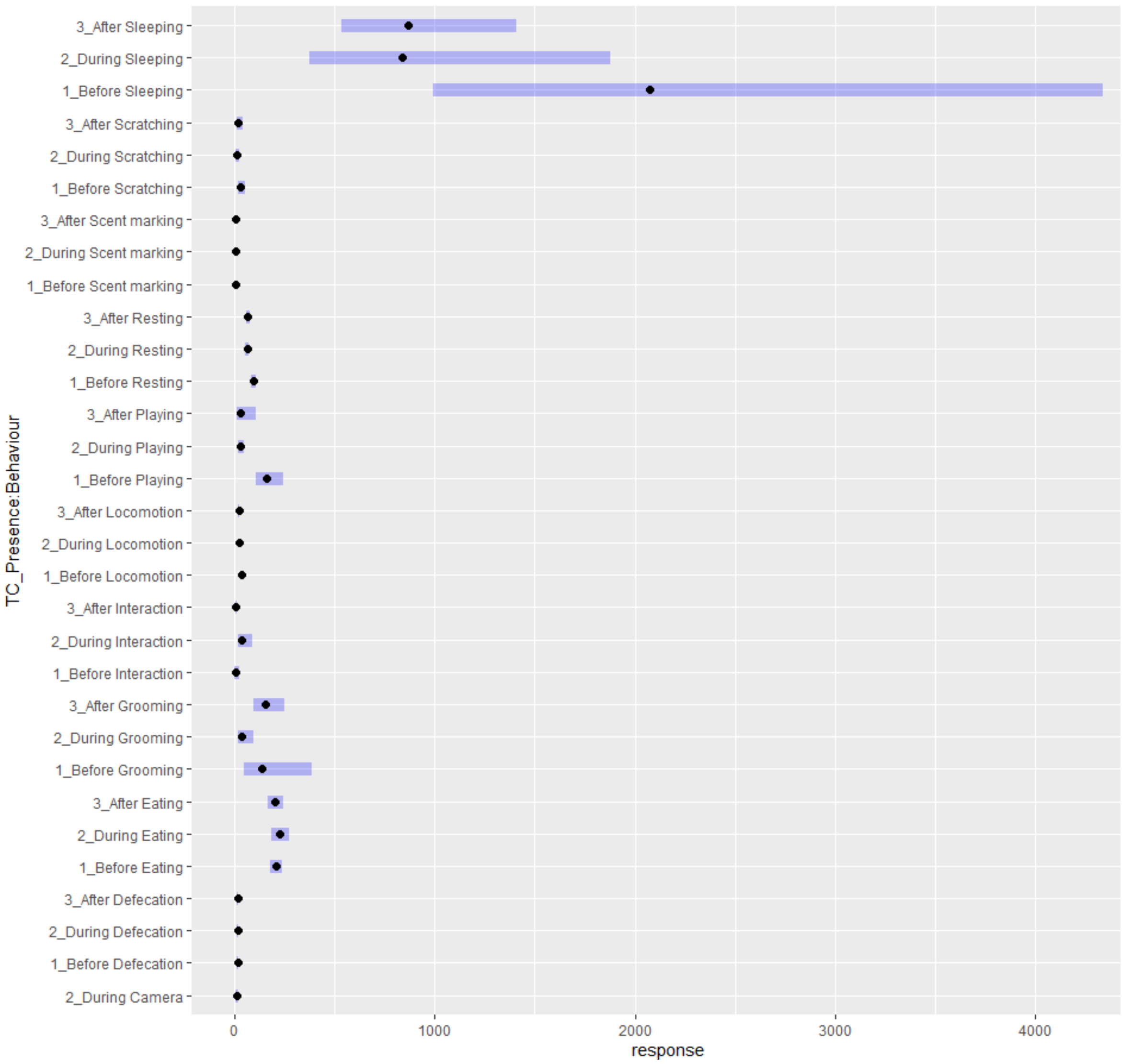

Figure 27: Emmeans plot output (+ 95 CI) from R showing responses in relation to the behaviour/trail camera presence interaction for Blackeye footage at Auckland Zoo.

5.1.2 Hamilton zoo

Observational data

For length of time as a dependent variable, AIC was again used to compare the different model types with the negative binomial GLMER deemed to have the best fit (negative binomial: AIC= 10307.16, Gaussian: AIC= 10638.35, Poisson: AIC= 89017.98). The negative binomial model with an interaction term between trail camera presence and behaviour had the best fit. Qqnorm testing showed a less than ideal fit (see Appendix C, figure C. 2c), but as the binomial distribution showed the best model fit in terms of AIC and no outlying data points were identified, I continued with this model.

The drop1 feature was used to test significant terms in the model. The interaction term between behaviour and trail camera presence was significant (χ^2= 1739.64, DF= 23, P= <0.001), as was temperature (χ^2= 914.94, DF= 1, P= <0.001) and date (χ^2= 921.62, DF= 12, P= <0.05) (Table 3).

Observational data also showed sleeping to be the most common behaviour at Hamilton Zoo (Fig. 28, followed by; locomotion, grooming, eating, and resting. Sleeping declined from 74% in the *before* period, to just 59% in the '*during* period' and increased slightly to 63% in the *after* period.

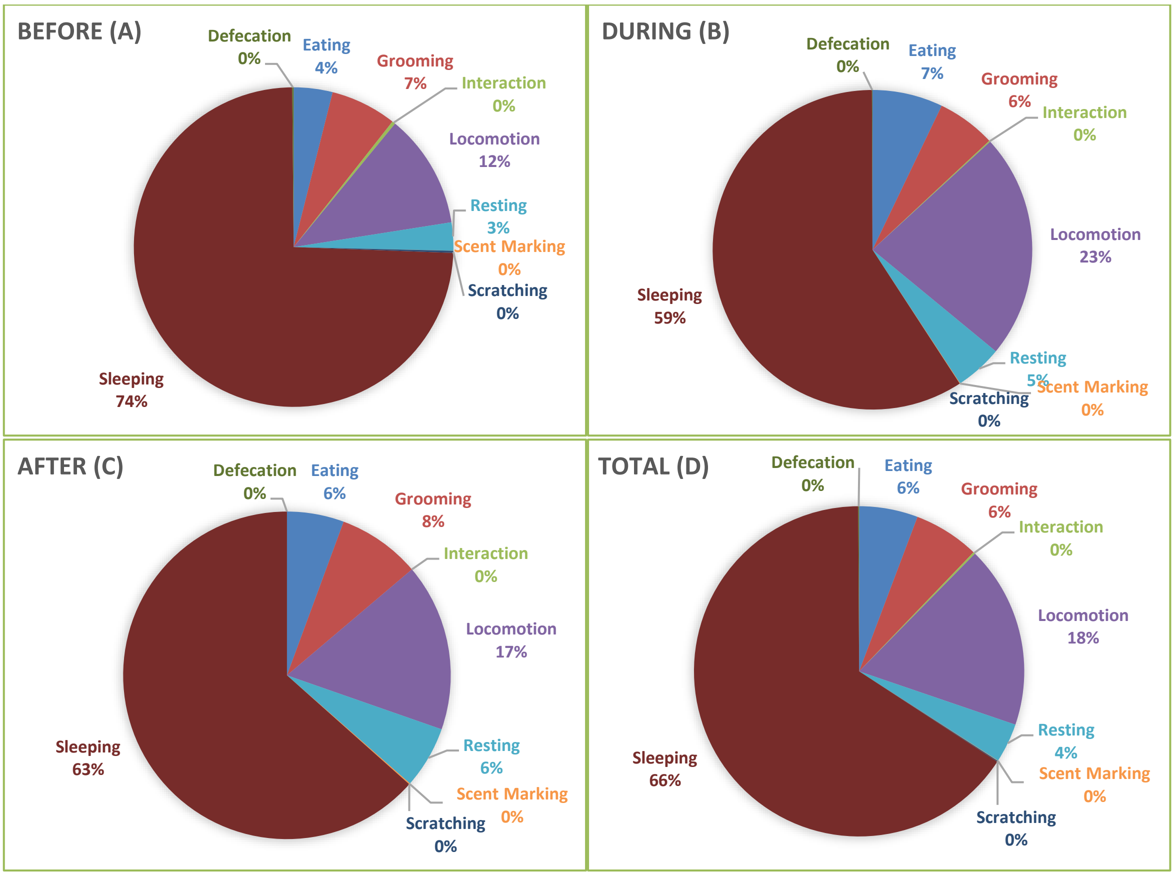

Figure 28: Percentage of time spent doing all behaviours recorded by observations (This is not a full activity budget, due to observations being ~3 hours a day during open hours). A- *'Before'* 29/04/2019 to 6/05/2019. B- *'During'*, once trail cameras were put into the enclosure, 07/05/2019 to 13/05/2019. C- *'After'* 14/05/2019 to 15/05/2019. D- *'Total'* is all observations, 29/04/2019 to 15/05/2019.

Emmeans testing showed some overlaps and some differences in behaviours over the study period (Fig. 29). Scratching was not observed *during* or *after.* Grooming and eating show a larger range in response in the *after* trail camera period but still overlap, giving a non-significant result. When pairwise comparisons of behaviours between periods *before*, *during* and *after* were compared, there were no significant differences in responses at the behaviour level (Table. 4).

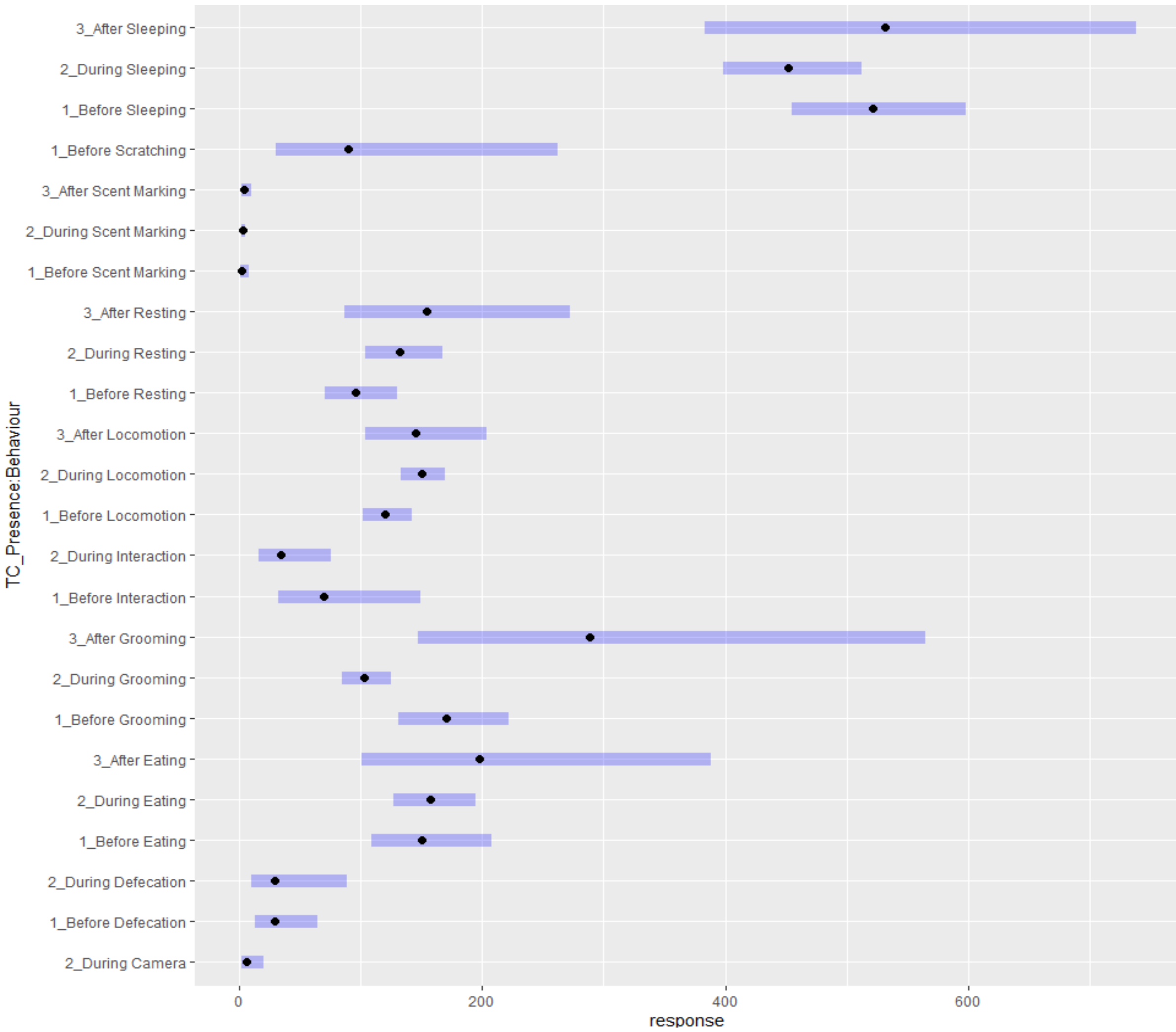

Figure 29: Emmeans plot output (+95 CI) from R, showing responses in relation to the behaviour/trail camera presence interaction for observational data at Hamitlon Zoo.

Behaviour length of time was significantly affected by the temperature at Hamilton Zoo (χ^2= 914.94, DF= 1, P= <0.001) (Fig. 30). All behaviours and lengths of behaviour were carried out at all temperatures. The temperature range was more similar to their natural range than the previous zoos.

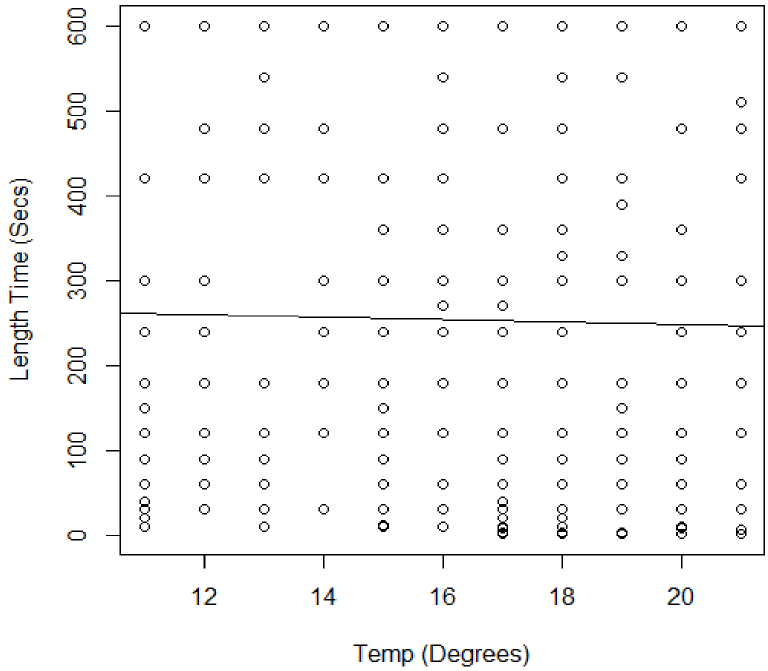

Figure 30: The duration of behaviours was not influenced by increasing temperature.

Blackeye camera footage

A GLM model, with length of time as the dependent variable, was tested with a Gaussian (AIC= 45552.80), Poisson (AIC= 105163.72) and negative binomial (AIC=32590.93) error distributions to assess the best fit. The negative binomial model with an interaction term between trail camera presence and behaviour had the best fit. Qqnorm testing showed a less than ideal fit (see Appendix C, figure C. 2d), but as the binomial distribution showed the best model fit in terms of AIC and no outlying data points were identified, I continued with this model.

The drop1 function was used once again to test for significant terms in the model. The results were similar to Auckland Zoo's Blackeye footage. The interaction term between behaviour and trail camera presence was significant (χ^2= 8826.2, DF= 25, P= <0.001). Date and position in the enclosure were also tested, and both terms were also significant (Date: χ^2= 4503.5, DF= 15, P= <0.001) (Position: χ^2= 4637.6, DF= 8, P= <0.001) (Table 3).

Like the Auckland Zoo Blackeye camera footage (Fig. 26), Hamilton Zoo footage also showed locomotion to be the most common behaviour (Fig. 31). Resting, eating, and defecation were the next most common behaviours. Locomotion was fairly stable in the *before* and *during* period but rose in the *after* period.

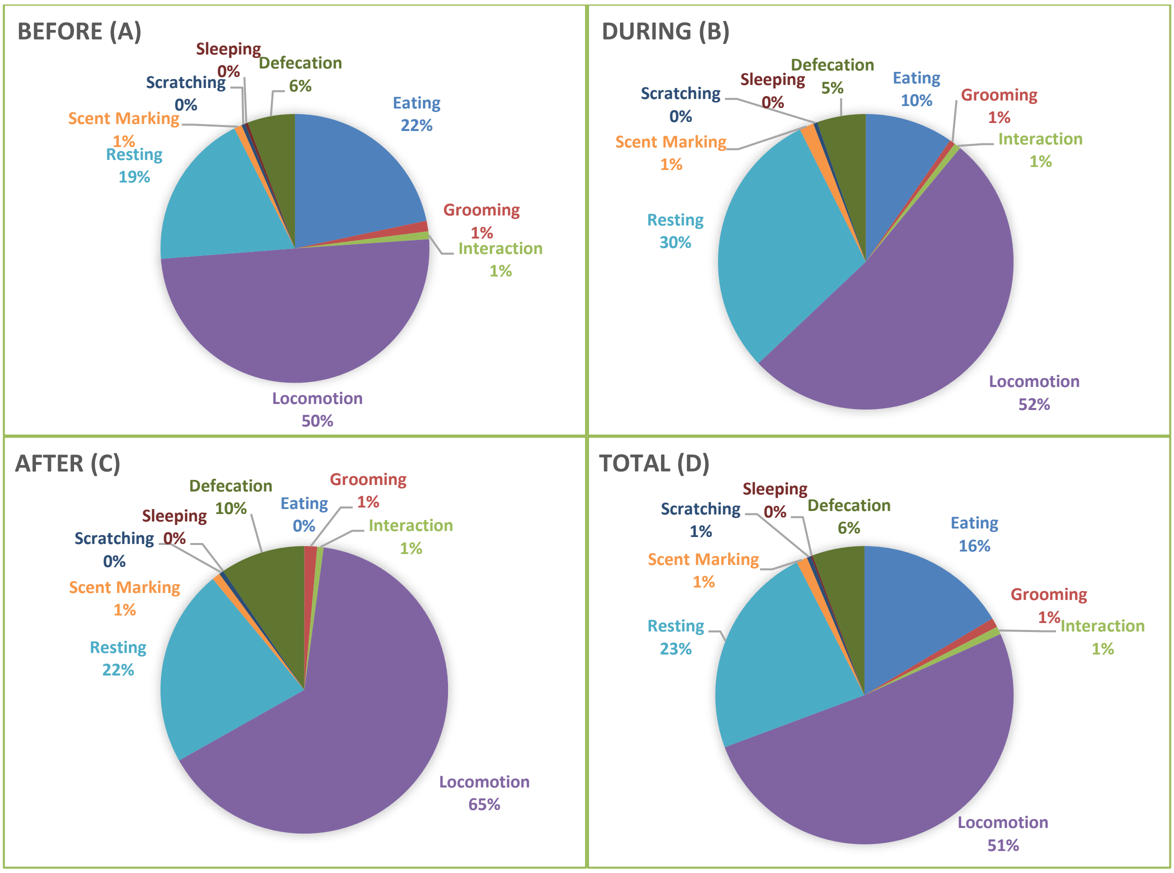

Figure 31: Percentage of time spent doing all behaviours as recorded by the Blackeye camera. A- *'Before'* 29/04/2019 to 6/05/2019. B- *'During'*, once trail cameras were put into the enclosure, 07/05/2019 to 13/05/2019. C- *'After'* 14/05/2019 to 15/05/2019. D- *'Total'* is all observations, 29/04/2019 to 15/05/2019. Sniffing was absorbed into scent marking for these graphs.

Emmeans testing (Fig. 32) showed some overlaps and some differences in behaviour over the study. Behaviours like sleeping and playing show a massive difference because these behaviours were not recorded *during* or *after* trail cameras. The pairwise comparison tests of main effects show that the differences occurred between *before* and *during* ($P = <0.001$), and *before* and *after* ($P = <0.001$). *After* and *during* were considered to be non-significant ($P = 0.146$). When pairwise comparisons of behaviours between periods of *before, during* and *after* were compared, there were some differences in locomotion (*before-during* $P = <0.001$, *before-after* $P = <0.001$) (Table. 4).

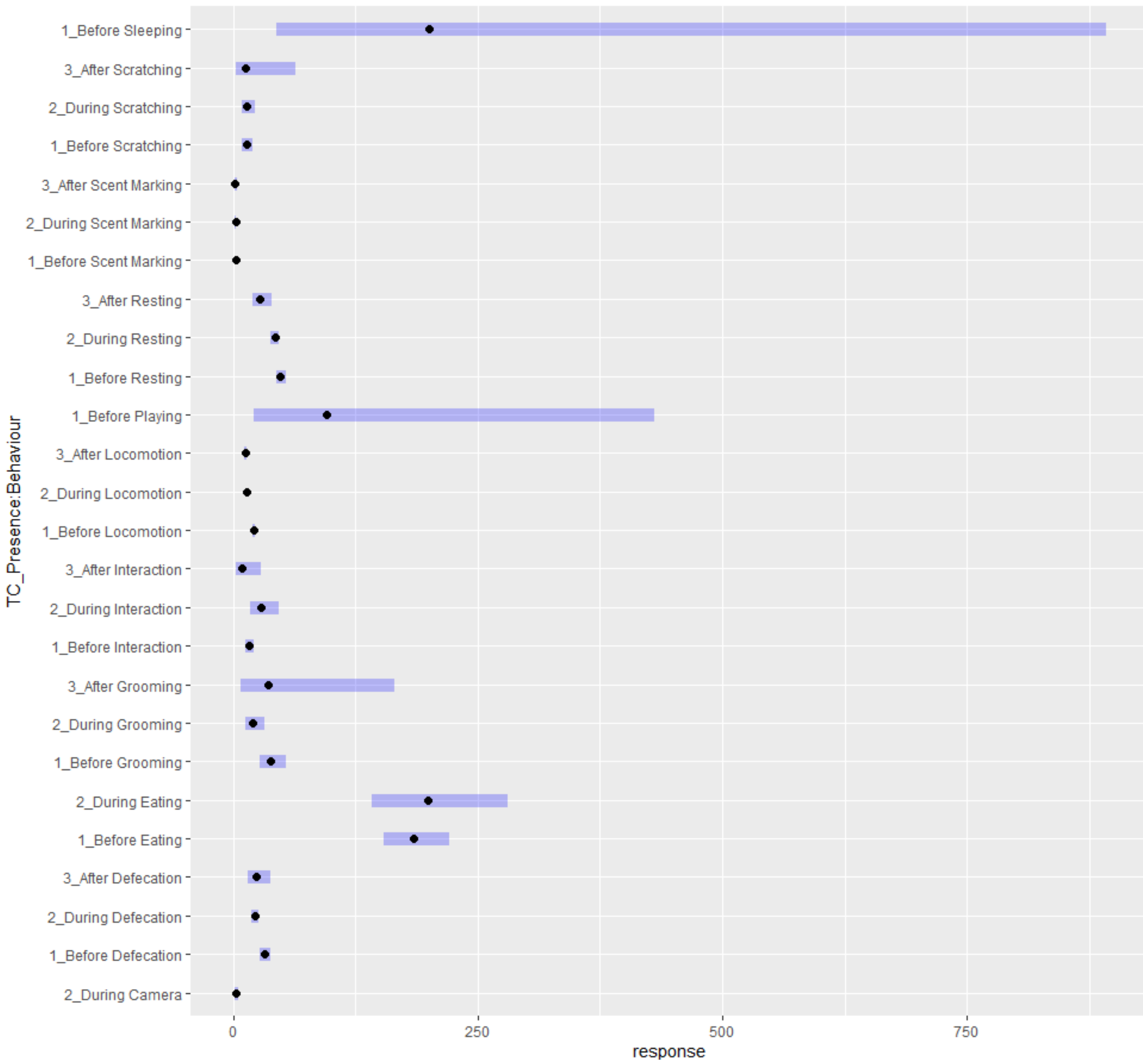

Figure 32: Emmeans plot output (+ 95 CI) from R showing responses in relation to the behaviour/trail camera presence interaction for Blackeye footage at Hamilton Zoo.

5.1.3 Currumbin Wildlife Sanctuary

Observational data

Length of behaviours was bimodally distributed (see Appendix C, figure C. 3). Sleeping mostly lasted between 250-600 seconds (4-10 mins). Sleeping and resting had the biggest value range and contributed to the bimodal distribution.

With the data being bimodal we then tested the model fit using a GLM with a negative binomial against Gaussian and Poisson error distributions. AIC was used to compare the different model types (negative binomial: AIC= 4847.606, Gaussian: AIC= 5430.309, Poisson: AIC= 35988.14). The negative binomial model with an interaction term between trail camera presence and behaviour had the best fit.

Residuals compared to fitted (see Appendix C, figure C. 4) showed a straight line, meaning the model was a good fit for the data. The residuals compared to leverage plot showed no significant data points having leverage on the model, and so all original data points could be kept for the analysis.

When the interaction term between behaviour and trail camera presence was tested, it was significant (χ^2= 1055.32, DF= 23, P= <0.001) Temperature and position in the enclosure were also significant. (Temperature: χ^2= 483.11, DF= 1, P= <0.01) (Position: χ^2= 501.90, DF= 6, P= <0.001). However, Position was deemed a confounding variable, covarying with the type of behaviour (e.g. sleeping was always performed on the front platform) (Table 3).

Sleeping was the most common and lengthy behaviour across all observational periods (Fig. 33), followed by resting, locomotion, time spent in den out of sight, grooming and eating. Behaviours varied over these periods.

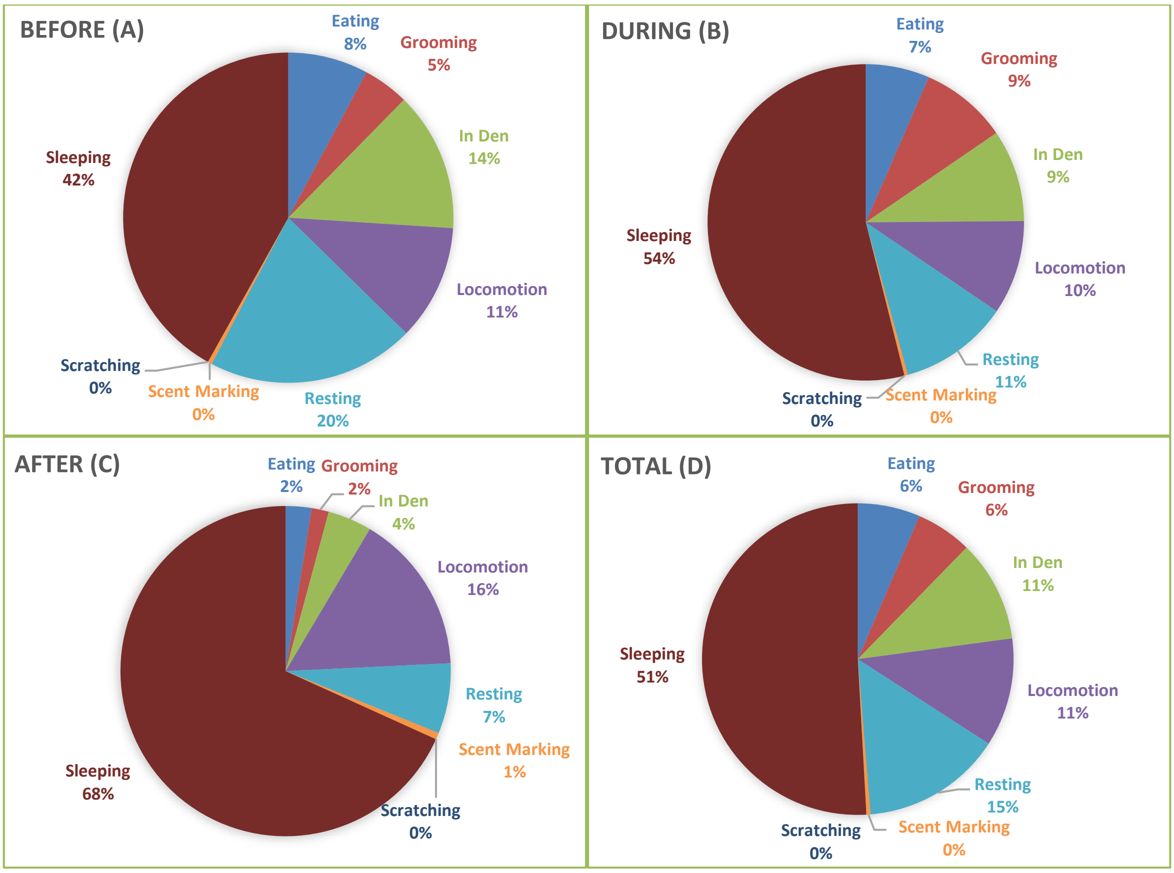

Figure 33: Percentage of time spent doing all behaviours recorded by observations (This is not a full activity budget, due to observations being ~3hours a day during open hours). A- *'Before'* 03/12/2019 to 06/12/2019. B- *'During'*, once trail cameras were put into the enclosure, 07/12/2019 to 10/12/2019. C- *'After'* 11/12/2019 to 12/12/2019. D- *'Total'* is all observations, 03/12/2019 to 12/12/2019.

Emmeans testing showed some changes in the length of behaviours over the study period (Fig. 34). Time spent in the den seems like it sould be significantly different in the *before* period from emmeans tesiting and eating in *after*. The pairwise comparison tests of the main effect 'trail camera presence' shows that the differences occurred between *before and during* (P= <0.05), and *during and after* (P= <0.01). *Before and after* were non-significant (P= 0.146). When pairwise comparisons of behaviours between periods of *before*, *during* and *after* were compared, there were no significant differences in responses at the behaviour level (Table 4).

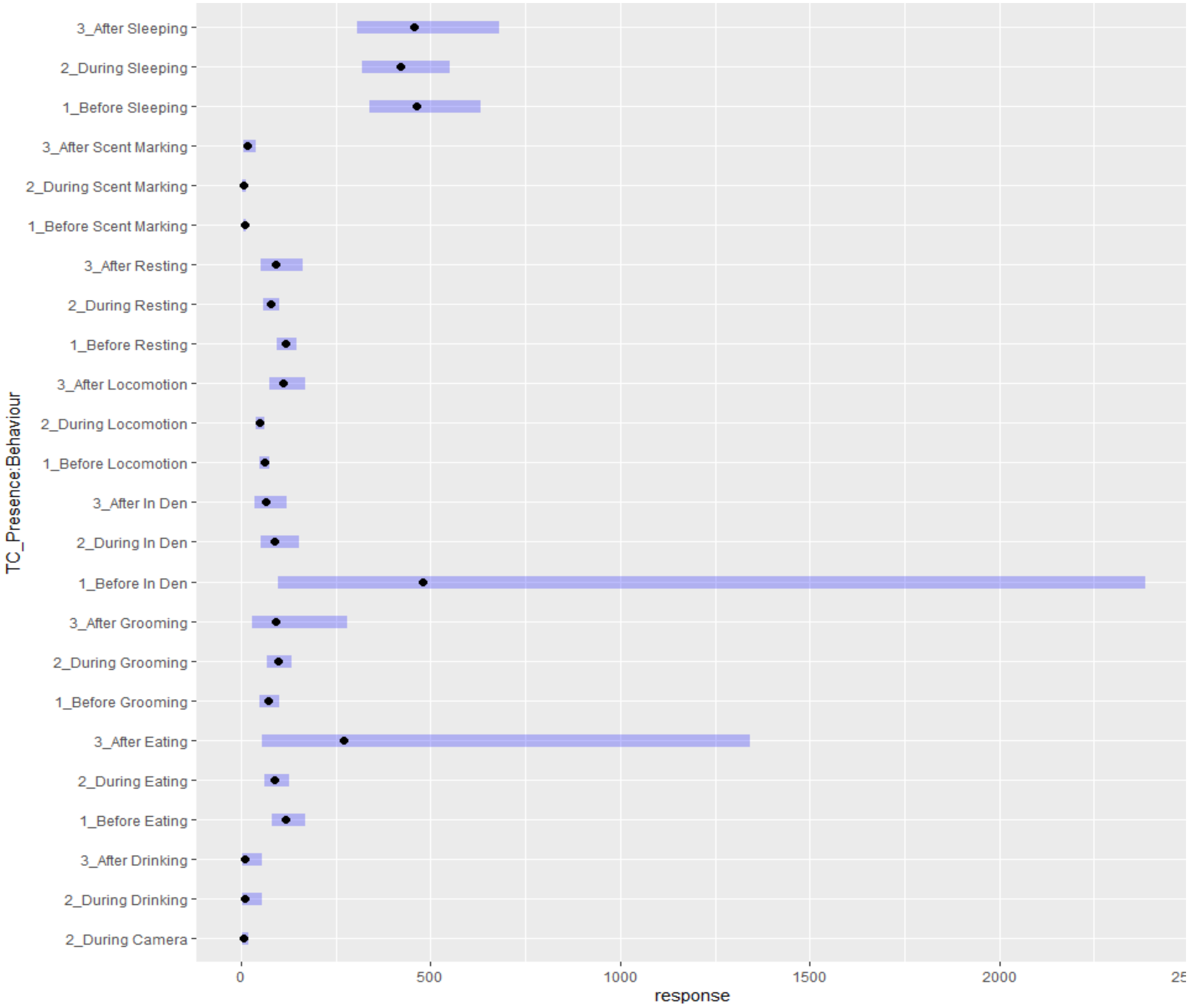

Figure 34: Emmeans plot output (+ 95 CI) from R showing responses in relation to the behaviour/trail camera presence interaction for observational data at Currumbin Wildlife Sanctuary.

Long-lasting behaviours, such as sleeping, occur at all temperatures, but shorter duration behaviours, such as locomotion, do not occur as frequently at temperatures over 29˚C (Fig. 35).

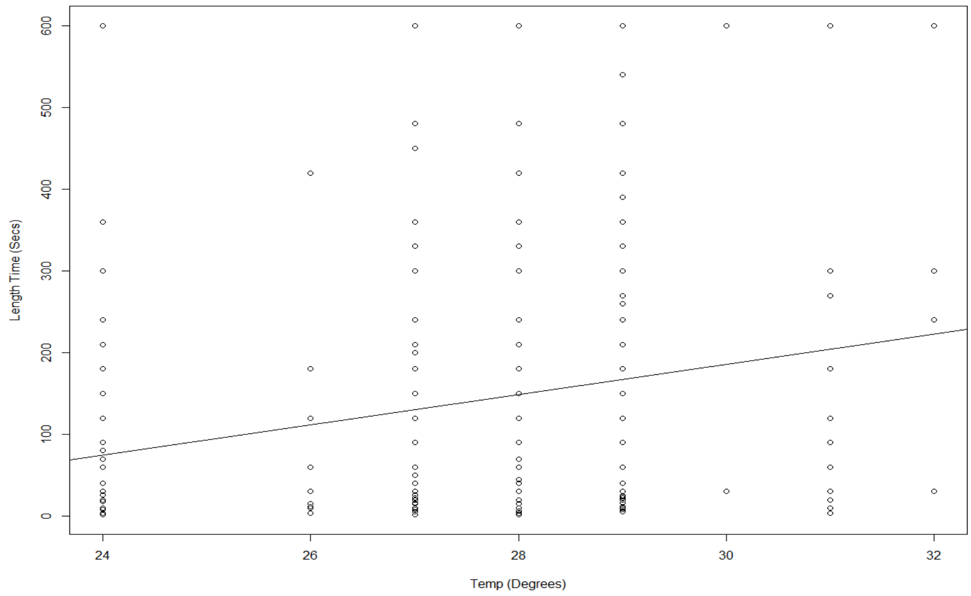

Figure 35: The duration of behaviours was positively influenced by increasing temperature.

Blackeye camera footage

A GLM model was tested with a Gaussian (AIC= 41352.83), Poisson (AIC= 396629.64) and negative binomial (AIC= 25763.94) error distributions to assess the best fit. The negative binomial model with an interaction term between trail camera presence and behaviour had the best fit.

Initial investigation of model fit showed a significant outlying point with leverage (see Appendix C, figure C. 5). Upon further investigation, it was deemed four points had significant leverage on the model. I removed all four points and ran the residual plots a second time (see Appendix C, figure C. 6). No new points had any significant leverage.

Testing of the model with the drop1 function showed the interaction term between behaviour and trail camera presence to be significant (χ^2= 11964.0 DF= 20, P= <0.001). All fixed terms were added to the model and tested in this same way. The date was the only term tested that was significant (χ^2= 3024.9, DF= 7, P= <0.001). The date was likely confounded by trail camera presence (Table 3).

The Blackeye camera footage also found sleeping to be the most common behaviour (Fig. 36), followed by resting, locomotion, grooming, eating and scent marking. These behaviours also changed over observational periods, but less than observational data (Fig. 33).

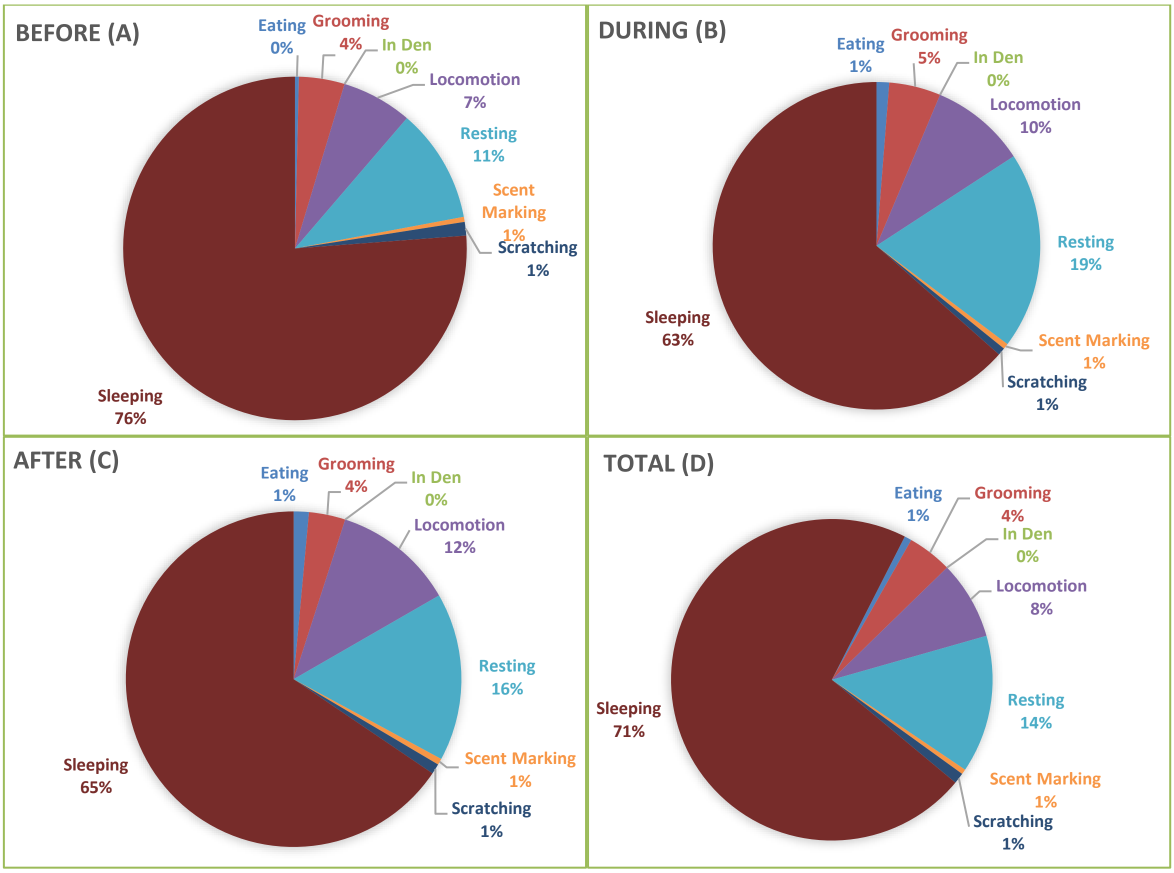

Figure 36: Percentage of time spent doing all behaviours as recorded by the Blackeye camera. A- *'Before'* 03/12/2019 to 06/12/2019. B- *'During'*, once trail cameras were put into the enclosure, 07/12/2019 to 10/12/2019. C- *'After'* 11/12/2019 to 12/12/2019. D- *'Total'* is all observations, 03/12/2019 to 12/12/2019.

Emmeans testing showed overlaps in the length of behaviours over observational periods (Fig. 37). At a glance, grooming in *after* appears to be the only stand out change in behaviour, but when pairwise comparisons of behaviours between periods of *before*, *during* and *after* were compared, there were no significant differences in responses at the behaviour level (Table 4).

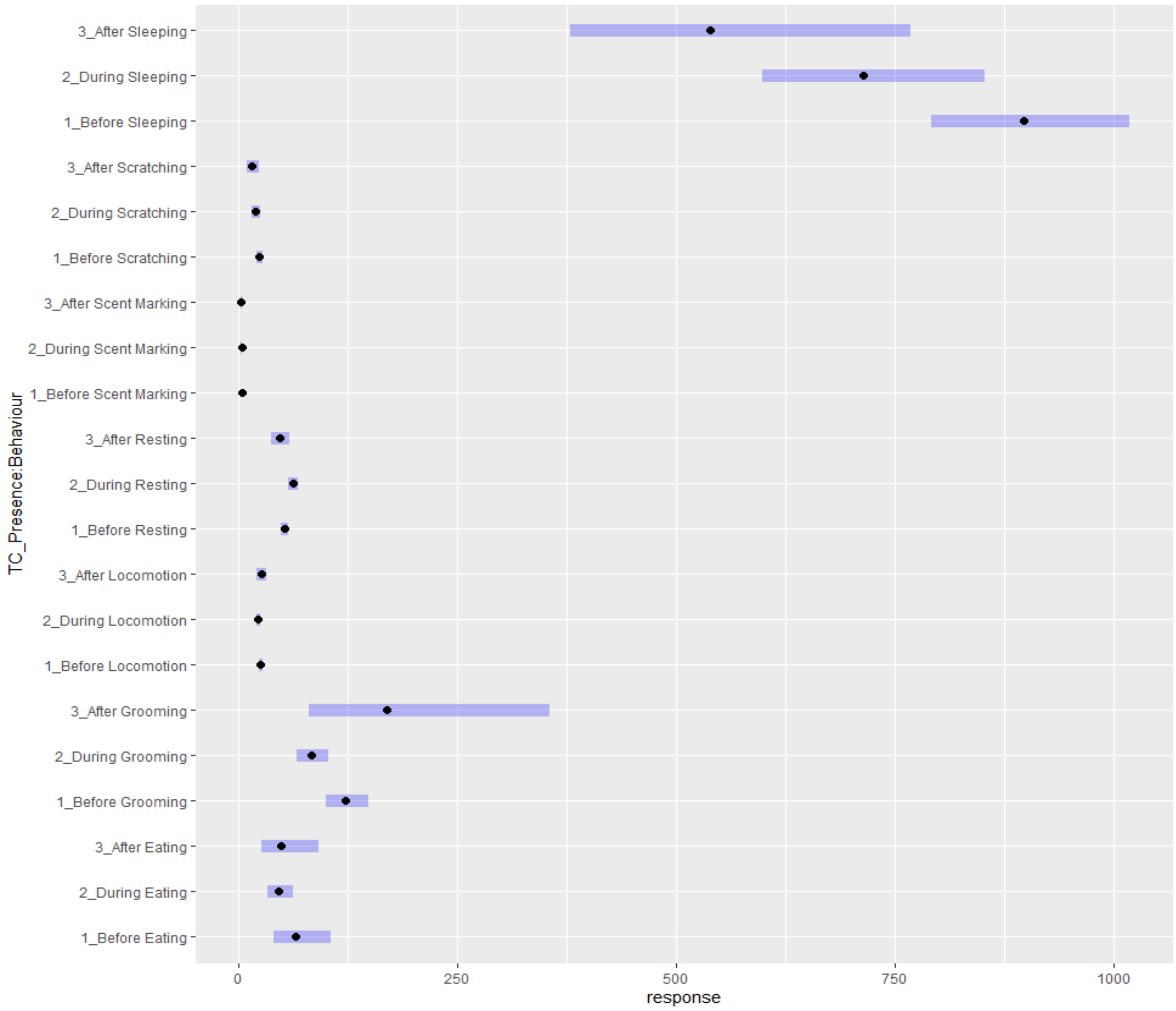

Figure 37: Emmeans plot output (+ 95 CI) from R showing responses in relation to the behaviour/trail camera presence interaction for Blackeye footage at Currumbin Wildlife Sanctuary.

5.1.4 Summary data

Summarises of significant factors affecting behaviours show that temperature, date and position in the enclosure could impact the length of time spent performing behaviours as well as trail camera presence (Table 3).

Table 3: Significant factors affecting time spent performing behaviours

Zoo and observation method	Significant interactions	P-value
Auckland Zoo, observations	Temperature, date	P= <0.001, P= <0.001
Auckland Zoo, Blackeye	None	N/A
Hamilton Zoo, observations	Temperature, date	P= <0.001, P= 0.05
Hamilton Zoo, Blackeye	Date, position	P= <0.001, P= <0.001
Currumbin, observations	Temperature, position	P= 0.01, P= <0.001
Currumbin, Blackeye	Date	P= <0.001

Summary of the pairwise analysis shows locomotion to be the most likely affected behaviour by trail camera presence (Table 4).

Table 4: Significant pairwise comparison tests, showing where the differences in behaviours occurred

Zoo	Time periods compared	Behaviour	P-value
Auckland Zoo	*Before-during*	Locomotion	<0.001
Auckland Zoo	*Before-after*	Locomotion	<0.001
Auckland Zoo	*Before-during*	Playing	<0.001
Auckland Zoo	*Before-during*	Resting	0.002
Auckland Zoo	*Before-after*	Resting	0.02
Hamilton Zoo	*Before-during*	All	<0.001
Hamilton Zoo	*Before-after*	All	<0.001
Hamilton Zoo	*Before-during*	Locomotion	<0.001
Hamilton Zoo	*Before-after*	Locomotion	<0.001
Currumbin Wildlife Sanctuary	*Before-during*	All	0.05
Currumbin Wildlife Sanctuary	*Before-after*	All	0.01

5.2 Discussion

This chapter aimed to answer the question, 'do trail cameras affect captive red panda's behaviour?' I assessed this by observing 'normal' behaviour for a week with personal observations and a camera just outside of the enclosure, recording continuously. With the information gathered on areas frequented and how pandas moved through the enclosure, trail cameras were then placed inside the enclosure, in different locations. Observations continued while trail cameras were in place. They were removed after a pre-determined time and observations continued to assess for any ongoing behavioural changes. I found that trail cameras did, indeed change captive red panda behaviour, as they became more active during this period. However, factors such as temperature also affected how active red panda were.

I began the analysis by summarising the data (using pie charts), to get an overall picture of how the proportion of time spent performing behaviours may have changed (or not) over the study. When comparing pie charts from the zoos, Auckland Zoo, observational data (Fig. 21) shows sleeping increased with trail camera presence, and locomotion declined. Hamilton Zoo observational data (Fig. 26) shows the opposite, sleeping declined with trail camera presence and locomotion increased. Currumbin Wildlife Sanctuary observational data (Fig. 31) showed a steady increase in sleeping over the study period, with locomotion remaining similar. Since observational data could only be collected between 7 am and 5 pm, it seems that trail cameras affected how active Pasang was during visiting hours.

The Blackeye cameras at Auckland Zoo and Hamilton Zoo were placed to overlook the area where the pandas spent most of their active time, as they slept in large, bushy trees, not easily viewed with a camera. Auckland Zoo's (Fig. 24) Blackeye footage showed very little sleeping until it increased significantly in the *after* period, but this is due to the cub Tashi and his mother, Khela, spending more time out of the den as he got older. There are only slight changes in eating, resting and locomotion.

Hamilton Zoo (Fig. 29) showed a large increase in locomotion in the *after*-trail camera period, resting was higher in the *during* period and eating seemed to vary dramatically from 22% (*before*) to 10% (*during*) to 0% (*after*). The *after* footage was only of two days compared to the week, for *before* and *during*, which may have influenced Hamilton Zoo results. If *during* is compared to the average total time spent doing behaviours, then it looks as though behaviour is unaffected by trail cameras at Auckland Zoo and Hamilton Zoo. Blackeye footage pie charts were a little more difficult to compare, as only Currumbin Wildlife Sanctuary had a setup that allowed for sleeping to be observed continuously. Therefore, looking first at the Currumbin summary (Fig. 34) for the Blackeye camera footage, it showed that behaviours were variable over the study period. Sleeping was higher in the *before* period (76%) and declined after trail cameras were added (63%). Locomotion slightly increases (from 7% to 10%) and so too does resting (from 11-19%).

When assessing the significance of factors upon the length of behaviour, with the drop1 test, it was shown that the trail camera presence had a significant effect (P= <0.001) on the length of time spent doing normal behaviours. Behaviours such as locomotion, resting and sleeping were most affected. Red panda spent more time being active with trail cameras in their environment. This was shown with both observational data and Blackeye footage for all three zoos. A study focusing more on their scent-marking behaviours around this would likely show that they spent more time scent-marking with trail camera presence, but my data was not collected in a way that could reliably give an answer to this question. Extra territorial patrols and scent-marking could indicate an increased level of stress.

Pairwise comparisons were useful for finding out where the significant changes in behaviours occurred (Table 4). Auckland Zoo had significant changes in locomotion, resting and playing when the trail cameras were in the enclosure. Locomotion and resting did not return to *before* trail camera averages in the *after* period. Hamilton Zoo's red panda's locomotion was also affected by trail camera presence both *during* and *after* trail cameras. Hamilton Zoo and Currumbin Wildlife Sanctuary both had significant pairwise comparison results when all behaviours were combined and tested. *Before* compared to *during* and *after* were significant for these zoos.

Temperature also had a significant effect on the panda's behaviour, according to observational data. This could not be reliably collected from the Blackeye camera as it did not have the same internal feature that the trail cameras have. Poor planning also meant that I did not set up an external temperature probe next to the Blackeye. At Currumbin Wildlife Sanctuary, there were fewer short behaviours (e.g., locomotion) as temperatures (above 29˚C) increased (Fig. 33). Pasang slept and rested on the front platform more often (anecdotally, with his tongue out). Loeffler (2011) states that "red panda are well adapted to coping with low ambient temperatures but have no mechanisms with which to tolerate heat. Protection of red panda from temperatures above 27˚C is critical." The

AZA red panda care manual (2012) also states that heat stress in red panda is intensified by high humidity. Air-conditioned indoor areas or nest boxes are recommended in these conditions. Misters are noted as being a way to provide cooled areas for red panda, which Currumbin Wildlife Sanctuary turned on daily (AZA, 2012: Roberts and Gittleman, 1984). Auckland Zoo (Fig. 23) and Hamilton Zoo (Fig. 28) also had significant temperature interaction but were not as obvious to the observer, as even the highest temperature there was not as high as the lowest temperature at Currumbin Wildlife Sanctuary. Heat stress can increase the levels of stereotyping seen in captive red panda (Khan et al., 2017). Stereotypies may include pacing, tongue flicking and position circling (Khan et al., 2017). Pasang at Currumbin Wildlife Sanctuary was seen tongue flicking in the hottest periods. Captive boars (*Sus scrofa*) activity patterns had a significant correlation with the average temperature, with the highest percentage of activity occurring at the lower temperatures in a study by Blasetti et al. (1988).

Some other factors were also significant on the length of time spent performing a behaviour (Table 3). The date was one that came up fairly frequently as being significant. This is likely tied into trail camera presence and/or temperature as a factor. Position in the enclosure was significant at Hamilton Zoo with the Blackeye dataset and Currumbin Wildlife Sanctuary observations. I did not record position for Auckland Zoo observations. The position is also tied to another significant factor, behaviour. For example, Pasang only slept on the front platform at Currumbin Wildlife Sanctuary.

These results show some kind of effect on red panda when trail cameras are present in their enclosure. The trail camera did not appear to induce obvious stress behaviours or avoidance of areas with cameras, but results do show a change in how captive red panda spent their time. So, while trail cameras provide a unique opportunity to study animal behaviour without observer interference, we should always assume some kind of effect on animals, as they are a novel object in their environment (Schneider et al., 2018: Cutler and Swann, 1999). Observers are prone to biases, such as spending too much time on a focal animal or influence of prior knowledge (Nowak et al., 2014). Whereas, trail camera data can be interrupted by multiple people, coming to the same conclusion. These methods have differing limitations, but as long as the person using them is aware, they can be mitigated, or included in the results.

Species, in other studies, show various reactions to trail cameras. After five trap nights, tigers became trap shy, avoiding trail cameras in-situ, likely due to flash (Wegge et al., 2004). Capture rates of tiger decreased by more than 50% after five nights. Mills et al. (2018) had some species showing an immediate reduction in activity, lasting 1-2 days before levelling off. Female jaguars were the most likely to avoid trail cameras, a learned neophobia over six months (Srbek-Araujo, 2018). This causes sex biases problems in data. Coyotes, appear to avoid all humans in their territories, thus avoiding trail cameras by tracking the humans placing them (Sequin et al., 2003). Of the other species looked into, Kinkajou (*Potos flavus*) are the most closely related to red panda. Their response to trail cameras was extreme. Where white flash was used, they avoided those tree walkways completely (IR trail cameras were not trailed) (Schipper, 2007). All of these studies could not consider trail cameras to be non-invasive.

No trail camera remains undetected by wildlife, even those with no glow IR (Rovero et al., 2013). Trail cameras cannot be considered truly non-invasive if animals are readily showing a change in behaviour around them (Meek et al., 2014). If repeat visits to a site are necessary, then the use of trail cameras may introduce bias on the data and detection probabilities (Meek et al., 2014). As long as we take these shortcomings into consideration, then trail cameras continue to be one of the best ways to monitor wildlife without direct human disturbance.

Chapter 6

General conclusions

This study had three main questions to answer:

1. What is a typical red panda time budget? Are these consistent across zoos and different management types?

2. Do different observational methods provide a similar picture of red panda behaviour?

3. Are trail cameras a genuinely passive form of monitoring captive wild animals? Or does the behaviour of captive red panda change with exposure to this novel stimulus?

The first two questions were answered in chapter four, where I found that the typical red panda day involves a lot of sleeping and resting, followed by locomotion. There were differences in time budgets across zoos, but this was attributed to temperature rather than management styles. The two observational methods showed differences in behaviours recorded. Personal observations showed sleeping and resting to be more frequent that the Blackeye footage. This is likely due to the fact that personal observations were only carried out during the day and red panda being crepuscular. The third question was answered in chapter five, where I discovered that trail cameras did have some effect on captive red panda behaviour. Red panda were more active during these trials.

When examining the red panda time budget more closely, sleeping and resting were the most common behaviours but I also found that second most common behaviour seen was locomotion (walking, climbing, running etc). Locomotion took up 13-22% of their daily behaviours (Fig. 13). Perhaps unsurprisingly, in this study, red panda were less active than reports from other studies on wild red panda, probably due to less time spent foraging.

Peaks in activity were associated with keeper activity, bringing food. However, there are also peaks later in the afternoon and early morning, which cannot be explained by keeper activity. These afternoon and early morning peaks are probably more closely aligned to their natural activity patterns, which are slightly extended or altered by keeper hours. Mallapur and Chellam (2002) studied leopards (*Panthera pardus*) in Indian zoos and found that their peaks in activity and resting were associated with their natural crepuscular pattern rather than keeper timings. Interestingly, stereotypical behaviours such as pacing was associated with keeper activities such as cleaning and feeding (Mallapur and Chellam, 2002).

Auckland Zoo and Hamilton Zoo had similar management styles and temperature ranges. Bamboo was always on offer at all zoos, but other food sources were provided at different times. This is probably the biggest contributing factor for Currumbin Wildlife Sanctuary's red panda activity budgets being slightly different to the other zoos for observations. The massive difference in Blackeye footage budgets comes from the Blackeye camera position, as at Currumbin, the camera encompassed the entirety of the enclosure, whereas, at Auckland and Hamilton Zoos, I had to pick an area to focus on. The area I chose for both of these zoos comprised of the largest open area I could focus on, which usually also encompassed some feeding and latrine sites.

If direct observations taken during the day are compared to continuous 24/7 observations, then we perceive different activity budgets for captive red panda. Care must be taken to mitigate this bias for crepuscular and nocturnal animals.

Results from chapter five showed a change in behaviour at all zoos *during* trail camera periods. Analysis of both observational types showed significant effects on length of time preforming normal behaviours. Locomotion, resting and sleeping had the most changes between periods. Red panda spent less time sleeping and resting, and more time moving around their enclosures with exposure to trail cameras.

Factors other than prescence of trail cameras were examined to determine if these to had an effect on captive red panda behaviour. Temperature was only reliably collected during personal observations but had a significant effect on movement. Red panda were less active when temperatures where higher. Other studies (Loeffler, 2011 and Khan et al., 2017) have shown that red panda do not cope with high temperatures as well as low ones. Higher temperatures can lead to an increase in resting behaviours and stereotypies. Date was also another significant factor, but likely to be to tied into trail camera prescence to be considered a significant factor of its own. Position in enclosure where behaviours were preformed was also considered significant for the Hamilton Zoo Blakeye footage and Currumbin Wildlife Sanctuary observation datasets. Knowledge of how other factors may have contributed to changes in behaviour around trail cameras, helps to identify the significane of those changes. If changes in behaviour around trail cameras, were more than the changes from 'normal' environmental factors, then it is likely that trail cameras would be considered invasive.

Scent-marking was not collected in a way that could be analyised reliably to answer whether or not they scented more or less during trail camera periods. However, I would hypothsise that scent-marking did increase. If I had structured my observations to include where captive red panda were moving then I could have examined if extra territorial patrols, or movement past cameras increased *during* trail camera exposure. I could have also assume that stress levels had increased.

At the beginning stages of this study, I hoped to investigate which aspects of trail cameras attracted or repelled red panda, e.g., lights, noise, novelty of the object. If they showed an obvious response, and there was enough time. Alas, I didn't get either. It was not until the data was assessed that I realised there was a significant effect on how active they were. I would propose further studies to increase the sample size beyond three zoos (although each zoo represents an extra logistic challenge). An external thermometer that records temperatures at regular intervals should be added to complement continuous footage as temperature seems to be an obvious factor for movement as well. Further study on the impact of temperature on red panda activity may help to increase the knowledge around their husbandry manual (AZA Small Carnivore TAG, 2012).

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Appendix A

Research proposals

A.1 Auckland Zoo

Instructions: The applicant is to complete all boxes shaded in blue, and upon completion e-mail 1 copy to the Research Coordinator (richard.jakob-hoff@aucklandzoo.co.nz) and mail a signed hard copy to: Richard Jakob-Hoff, Auckland Zoological Park, Private Bag 78700, Grey Lynn, Auckland, 1245. Please mark the envelope with "RESEARCH APPLICATION" in the top left-hand corner.

1. PROJECT TITLE

The title should include the name of the species of animal(s) to be studied	
Title:	Impacts and outcomes of using infra-red camera traps on captive red panda (Alirius fulgens) behaviour

2 APPLICANT'S DETAILS

Name of Applicant:	Kathryn Bugler
Postal Address:	71 Farrington avenue Bishopdale Christchurch
Telephone:	022 341 7926
Email:	Kat.bugler@lincolnuni.ac.nz
Institution:	Lincoln University

Please include names, addresses, institutions and roles of other participants (if applicable):	
Participant:	
Participant:	
Participant:	

3 PROJECT SUPERVISORS

Name:	Adrian Paterson and James Ross
Position:	Head of Ecology, Senior lecturer
Telephone:	03 34230750 03 34230752
Fax:	
Email:	Adrian.paterson@lincoln.ac.nz James.ross@lincoln.ac.nz

Institution:	Lincoln University

4 ZOO STAFF CONTACTS

FIRST CONTACT:	
Name:	Lauren Booth 027 705 7272
Position:	Team Leader, Carnivores
SECOND CONTACT:	
Name:	Warren Spencer 027 439 6135
Position:	Curator of Mammals

5 INVOLVEMENT OF OTHER INSTITUTIONS

Name(s) of any institutions involved not mentioned above (if applicable):	
Institution:	Wellington Zoo
Institution:	Hamilton Zoo
Institution:	

6 APPLICANT'S AND SUPERVISOR'S CERTIFICATION

I/we have read and agree to abide by the Zoo's Code of Conduct for Researchers. I/we apply for approval to conduct the research project described herein. I seek approval to commence the project on:	
Date:	February/2019
And terminate it no later than:	
Date:	October/2019

Applicant:		**Supervisor:**	
Signed:		Signed:	
Full Name:	Kathryn Bugler	Full Name:	Adrian Mark Paterson
Date:	20/11/2018	Date:	21/11/2018

7 LAYPERSON'S SUMMARY

In non-technical language, briefly summarise the objectives of this study, and the method(s) to be used:	
Summary:	Camera traps have recently become common when studying cryptic species in the wild. They began to appear in papers from about 1989-1991 and became common place after 2008 (Meek et al, 2015). Camera traps have different types of activation which include; time, mechanical mechanisms and breaking of an active or passive beam, which is usually infra-red (Meek et al, 2015). Red pandas are a cryptic and globally-threatened species. Red panda live in areas of difficult terrain and little is known about their behaviour. To date camera traps have only been used to monitor red panda in one study by S. Lama (2018, Unpublished data) in Nepal and we do not know whether camera traps affect red panda behaviour. In this study, I will assess the efficacy of passive IR camera traps as a neutral tool for recording red panda behaviour.
Method(s):	Cameras will be placed outside the enclosure to assess 'normal' red panda behaviour for 5-7 days. Then camera traps will be placed in one frequented and one less frequented areas for 5-7 days to assess how red pandas may react to their presence. Camera traps will then be removed from inside enclosures, while outside cameras will monitor their return to normal for 5-7 days.

8 RESEARCH QUESTION(S) AND HYPOTHESIS(ES)

I will be asking if camera traps are a truly passive form of monitoring wild animals? I hypothesize that red panda will investigate cameras, as Krebs et al. (2017) found that red panda in their study spent longer than average looking at cameras when keepers were about to arrive for feeding. I predict that captive red panda will not be repelled by camera traps and that behaviour will remain unaffected or they will spend extra time, initially, investigating cameras. Any wiring or shutter tones would likely be drowned out by constant zoo background noise and will most likely be ignored by red panda. Flash types would most likely effect red panda behaviour in-situ, as Kinkajous (*Potos flavus*) have been reported to avoid treetop routes where white flash cameras have triggered and tiger capture rates decreased in Nepal when white flash was used (Meek et al, 2014). However, because white flash is not commonly used anymore, we will not test these and therefore before should not be wholly affected.

9 PROJECT JUSTIFICATION

What are the benefits of this project to the care and/ or conservation of the animal(s) involved:
This project may influence the way we view camera traps if they cause bias to a cryptic species in monitoring studies. Camera traps are viewed as passive and if they change behaviour then this view may need to change. On the other hand, if behaviour is not affected, then the study will help us to understand what types of behaviours and how much we can monitor with camera traps.
How will the results of this work be used:
The results of this study will be used for my thesis and to publish a scientific paper.

10 METHODOLOGY AND PROJECT TIMETABLE

Explain in detail, the procedures to be used in the study and include a timetable for the project (add extra pages if required):
Within the context of zoo research, time spent within the zoo can range from 15-21 days as each section of research is 5-7 days. Before, during and after treatment.

Before: 5-7 days of observations with one- two camera/s outside of the enclosure to assess normal behaviours
During: 5-7 days with two camera traps inside enclosures, as well as, the outside enclosure camera.
After: 5-7 days with the two inside enclosure camera traps removed and observing with the outside enclosure camera when normal behaviour returns (if behaviour changes).
If you have multiple enclosures for red panda then this timing would be per enclosure, if deemed possible.

Equipment and setup

At least two different types of cameras will be used in this study, following trials beforehand. Outside of the enclosure measuring reactions to the inside enclosure cameras will be the Kinopta, Blackeye 2W. Inside of the enclosures will be standard camera traps made by Bushnell. Newer model cameras (Trophy cam HD aggressor, model number: 45156) with no glow infra-red at high frequencies (920nm). Older cameras with lower frequencies will be used if there is extra time. At this stage white flash cameras will not be tested, as they are less likely to be used in the wild for studying cryptic species. Trigger speeds make noise as well as any on-going whirring that may be out of human perception. Wild animals do not tend to race past cameras at high speeds and therefore, trigger rates do not need to be incredibly quick to capture animals (Glen et al, 2013).

Stock photo of a Bushnell trophy cam aggressor, attached to a tree with a strap

Stock photo of a Kinopta Blackeye, which can be setup on a tripod or strapped to a pole or tree

Methods

This study will have a BACI (before-and-after control impact) design. Monitoring of individuals before cameras are installed will take place. Jule et al. (2009) studied red pandas in captivity to formulate a behavioural study curve (ethogram). Twenty hours was enough time to produce reliable and accurate estimations for discovering new behaviours. After 30 hours of study results did not significantly change detection of new behaviours. However, because this study is not about discovering new behaviours a much smaller observation time is appropriate. Each red panda will be observed for at least 3 hours (by sight) during high-activity bouts (feeding times and natural high-activity times such as dawn and dusk) to categorise normal behaviours (such as sleeping, feeding and play) and movements. This may require multiple days at each enclosure to ascertain panda behaviour over multiple conditions. Any behavioural observations should be long enough to obtain the duration and frequency of a behaviour, but not so long that the observer becomes fatigued (Jule et al, 2009). The Blackeye camera will also be outside the enclosure recording movements missed by observing during the day This monitoring will also allow me to find out the pandas most frequented routes for camera placement. Differences between days would be noted such as weather and other environmental factors, keepers, food availability, enrichment present/absent, panda composition, time of year and visitor numbers.

Cameras will then be installed within the enclosure at two locations, one frequented area and one less frequented area. Camera position in the enclosure will be identified after initial observations, to determine the best height and placement. A camera outside the enclosure will also be setup to monitor interactions with the camera itself and capture reactions. This footage can also be used to compare what kinds of behaviours/ information camera traps can gather or miss. Outside enclosure cameras will be installed for 5-7 days prior to inside enclosure camera traps. Once cameras traps are installed, monitoring will commence for another 5-7 number of days. Behaviours will be monitored for changes. The camera traps inside enclosures will then be removed and pandas monitored for return to ‘normal’ behaviours for a further 5-7 days.

Figure two shows a decision tree for how red panda may react (or not) to cameras and the way I will decide from there about how to continue with this study. If behaviour is affected by the camera’s presence, they may be repelled or attracted by the cameras. Once this is ascertained then I can begin to understand why. If red panda behaviour is affected by cameras and time allows, I will introduce different types of camera to enclosures. These cameras will be adjusted from the “normal” camera trap i.e., empty camera box, camera without box, camera turned off (no noise or light), camera without IR lighting and a random novel item. If behaviour is un-affected, then original cameras will stay in place and a comparison between internal camera

traps and ongoing video cameras outside enclosures will be carried out. Cameras may also tell us things about the behaviour outside zoo times that keepers and visitors do not experience.

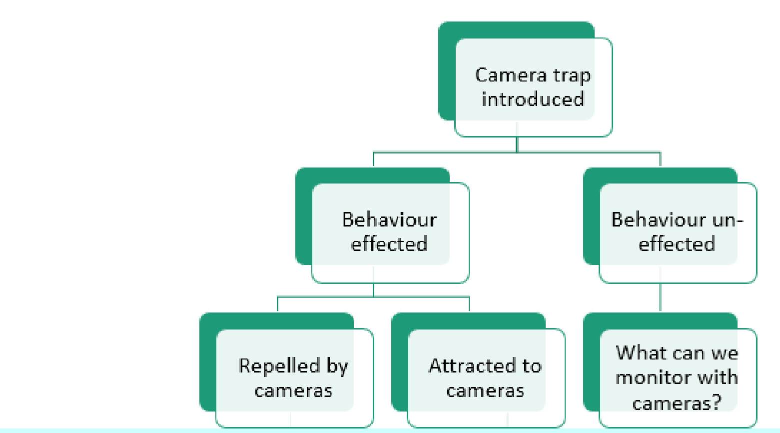


Figure two: Decision tree for behavioural changes in captive red panda.

11 RESOURCES REQUIRED

What assistance, equipment and facilities will you require from the Zoo:
Just access to the red panda enclosures to change camera trap batteries and SD cards when needed.

A.2 Hamilton Zoo

Hamilton Zoo
Research Proposal Instructions

The applicant is to complete all boxes shaded in green, and upon completion e-mail a signed copy to the Professional Development Team Leader (Jesse.Golden@hcc.govt.nz).

1 RESEARCH CATEGORY

Please select one of the following five options:	
☐*Category 1: Non-Animal Related* ☐*Category 2: Opportunistic* ☒*Category 3: Observational*	☐*Category 4: Manipulative (Behavioural)* ☐*Category 5: Manipulation (Physical)*

2 PROJECT TITLE

The title should include the name of the species of animal(s) to be studied	
Title:	***Impacts and outcomes of using infra-red camera traps on captive red panda (Alirius fulgens) behaviour***

3 APPLICANT'S DETAILS

Name of Applicant:	***Kathryn Bugler***
Postal Address:	***71 Farrington avenue Bishopdale Christchurch New Zealand***
Telephone:	***0223417926***
Email:	***Kat.bugler@lincolnuni.ac.nz***
Institution:	***Lincoln University***

Please include names, addresses, institutions and roles of other participants (if applicable):

Participant:	
Participant:	***James Ross*** ***Co-supervisor*** ***Lincoln University***

4 PROJECT SUPERVISORS (IF APPLICABLE)

ame:	***Adrian Paterson, James Ross***
Position:	***Head of Ecology, Senior Lecturer***
Telephone:	***03 342 30750***
Email:	*Adrian.paterson@lincoln.ac.nz James.ross@lincoln.ac.nz*
Institution:	***Lincoln university***

5 INVOLVEMENT OF OTHER INSTITUTIONS

Name(s) of any institutions involved not mentioned above (if applicable):	
Institution:	
Institution:	

6 OTHER APPROVALS (If research category is 4 or 5)

Has this project been referred to the Animal Ethics Committee (AEC) Or any other institution:	***Yes No*** ***If Yes, please provide details of, including result of your application (please attach any relevant correspondence from the AEC):*** ***Was told it did not need approval because it does not involve manipulations due to camera traps being considered a passive intervention.***
Have you received all necessary permits and approvals from relevant agencies (e.g. DOC, ERMA):	***Yes No*** ***If Yes, please attach copies of relevant permits and approvals (please note: Hamilton Zoo cannot approve your application until all necessary permits and approvals are received).***

7 OVERALL PROJECT DETAILS

7.1 LAYPERSON'S SUMMARY

In non-technical language, briefly summarise the reasons for doing this study, the project's objectives and the method(s) to be used. Please include references.:	
Species:	***Red panda (Alirius fulgens)***
Summary: ***(250-word limit)***	*('overview' taken from my proposal to the university)* *Camera traps have become common when studying cryptic species in the wild. They began to appear in papers from about 1989-1991 and became common place after 2008 (Meek et al, 2015). Camera traps have different types of activation which include; time, mechanical mechanisms and breaking of an active or passive beam, which is usually infra-red (Meek et al,*

	2015). Red pandas are a cryptic and globally-threatened species. Red panda live in areas of difficult terrain and little is known about their behaviour. To date, camera traps have only been used to monitor red panda in one study by S. Lama (2018, Unpublished data) in Nepal and we do not know whether camera traps affect red panda behaviour. In this study, I will assess the efficacy of passive IR camera traps as a neutral tool for recording red panda behaviour.
Objectives:	***To assess passive infra-red camera traps ability to record red panda behaviour and if it affects their behaviour***
Method(s):	*Captive facilities over New Zealand and potentially Australia.* *Two passive IR camera traps (Bushnell, trophy cam aggressor) to be setup inside enclosures as well as one camera (Kinopta, Blackeye 2W) outside the enclosure to capture ongoing footage of red panda reactions.* *The camera outside the enclosure will be setup for 5-7 days to assess 'normal' behaviour, then cameras inside the enclosure setup for 5-7 days with outside camera monitoring their behaviour. Finally, the cameras inside of the enclosure will be removed and a further 5-7 days of monitoring to see how quickly behaviours return if they are affected.*

7.2 ETHICAL CONCERNS

Describe any ethical concerns associated with this project and how you plan to address them:
No ethical concerns

7.3 PROJECT RATIONALE AND OUTCOMES

How does your project fit into the Zoo's purpose to 'provide world class visitor experience that inspires conservation action':
I would love to create some signage that could be placed outside the enclosure for visitors to read about the study that is happening and why it is important to monitor threatened wildlife, as well as, why red panda are threatened.
What are the benefits of this project to the husbandry and/ or conservation of the animal(s) involved:
If the species is native to New Zealand, please attach any relevant correspondence from DOC. *This project will help change the way we view camera traps if they cause bias to a cryptic species in monitoring studies. Camera traps are viewed as passive and if they change behaviour then this view may need to change. On the other hand, if behaviour is not affected, then the study will help us to understand what types of behaviours and how much we can monitor with camera traps.*
How will the results of this work be used?
This is for my master's thesis, if all goes to plan I would like a published paper from the work as well.

7.4 PROJECT TIMETABLE

Explain in detail, a timeline for the project. This must include the procedures to be used in the study and the project's commencement and termination:
Within the context of zoo research, time spent within the zoo can range from 15-21 days as each section of research is 5-7 days. Before, during and after treatment. *Before: 5-7 days of observations with one camera outside of the enclosure to assess normal behaviours* *During: 5-7 days with two camera traps inside enclosures, as well as, the outside enclosure camera.* *After: 5-7 days with the two inside enclosure camera traps removed and observing with the outside enclosure camera when normal behaviour returns (if behaviour changes).* *If you have multiple enclosures for red panda then this timing would be per enclosure, if deemed possible.* *Given that Hamilton zoo is the preferred zoo to begin studies (I did some Unitec placement hours with you and feel most comfortable within your zoo) we would like to start as soon as possible but I am aware of the heat and crowds summer brings, which in itself changes red panda behaviour.*

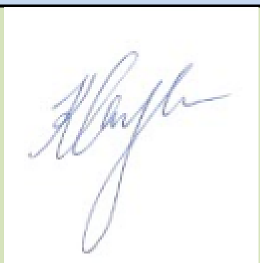
8 RESOURCES REQUIRED

What assistance will you require from the Zoo staff:
Minimal, advice on where red panda frequent for camera placement
Can these tasks be incorporated into the staff member's daily routine:
YES/NO **If No, please indicate how much non-routine time is required of Zoo staff:**
What resources do you expect the Zoo to provide for this study?
None
What resources are provided by the researcher?
Cameras, batteries, SD cards, tripod, signage

9 HEALTH AND SAFETY IMPLICATIONS

Describe the health and safety hazards to animals, staff, researchers or members of the public which MAY occur as a direct result of the implementation of this project:
Neophobic response by the red panda to cameras. Staff should have no additional health and safety concerns. The public should not be affected either
What measures will be taken to eliminate, minimise or isolate the health and safety hazards described above:
N/A

I have read and agree to abide by the Zoo's Instructions for Researchers and this application has the full support of the supervisor:

Applicant:		**Supervisor: (if applicable)**	
Signed:		**Signed:**	
Full Name:	**Kathryn Bugler**	**Full Name:**	**Dr James Ross**
Date:	**31/10/2018**	**Date:**	**1 /11/2018**

Below section is for Zoo staff only

Date Received:		**Project No.:**	
Date Discussed:		**Addendum:**	**Yes/No**
Team Leader Professional Development		**Zoo Curator**	
Signed:		**Signed:**	
Full Name:		**Full Name:**	
Date:	/ / 20____	**Date:**	/ / 20____
Zoo Leadership Representative		**Zoo Director**	

Signed:		***Signed:***	
Full Name:		***Full Name:***	
Date:	***/ / 20____***	***Date:***	***/ / 20____***

13 APPROVAL AND RECORDS

On receipt of the full and complete research proposal the zoo curator shall put it forward for discussion in a Zoo management team meeting.
If approved by the zoo director, the zoo curator or delegate shall arrange a meeting with the researcher to discuss and finalise logistics.
A copy of the research proposal, any supporting documents and publications shall be kept by the zoo records officer indefinitely.
Upon completion of project researchers may be asked to report research methods and outcomes to zoo staff and stakeholders in a presentation.

A.3 Currumbin Wildlife Sanctuary

RESEARCH PROJECT REQUEST FORM

Currumbin Wildlife Sanctuary receives many requests for assistance and data for valuable research projects. Thank you for taking the time to fill out this form so that we can assess if we are able to help with your project.

Name of project: Impacts and outcomes of using infra-red camera traps on captive red panda (Alirius fulgens) behaviour
Applicant's name: Kathryn Bugler
Affiliation (university/research group): Lincoln University
Email: kat.bugler@lincolnuni.ac.nz
Phone: +64223417926
Supervisor's name: Adrian Patterson and James Ross
Email: Adrian.patterson@lincoln.ac.nz, James.ross@lincoln.ac.nz
Phone: +6434230750 (Adrian)
Brief description of project: (please attach extra sheet if you require more room for details) Using infra-red camera traps, I will assess whether their presence affects captive red panda's behaviour. I will have the outside camera running for all 12 days as well as doing observations twice a day for 1.5hr. After 5 days of initial baseline behaviour is observed, I will place three Bushnell camera traps inside the enclosure. The cameras inside the enclosure will be placed in two well used areas (walkways, latrine sites) and one in a less used area. I will discuss options with keepers. I will bring extra cameras if the keepers have other areas they'd like looked at (Hamilton zoo asked for all feeding sites and their off-display house to have cameras for interest sake). The camera traps will stay in for 5 days and then for the last 2 days the cameras will come out of the enclosure and the outside camera will stay. Before, during and after footage will be compared to assess if there are any differences. If no differences in behaviour occur, then footage between cameras inside and outside the enclosure will be compared. This will determine the types of behaviour that camera traps can record.
What is the expected date range of your project? 2-13th December 2019
Will you provide or cover costs for all disposables required for this project?

○ Yes
Will you cover any of the expenses we may incur when assisting with the project? E.g. anaesthesia ○ Yes
Will there be any requirement for CWS staff to be involved in this project? Yes If yes, what level of involvement? Just to let me inside the enclosure for camera trap placement and checking of batteries and SD cards every other day (takes 5 minutes). Easy to work around keeper schedules.
Would Currumbin Wildlife Sanctuary be acknowledged for supporting your project? ○ Yes ○ If yes, how? In acknowledgement section of thesis and any scientific papers published
Will the results of your findings be published? ○ Yes ○ If yes, where? Yet to be determined, but is it hoped they will be published
Comments/Supporting information I have already carried out studies in Auckland zoo and Hamilton zoo. The cameras so far seem to be as passive as first hoped. No major changes have occurred. Further statistical analysis needs to be carried out for subtle effects. If it also helps, I studied captive wildlife management in 2012 at Unitec and volunteered at Willowbank here in Christchurch for several years. I know how to behave around captive animals, I'm not just your average master's student!

Appendix B

Camera settings

Table B. 1: Camera trap settings used for Bushnell trophy cam aggressor (model number: 119874).

Parameter	Setting
Preset	Advance
Mode	Camera
Image size	4k
Image format	Full screen
Capture number	1-3 photos
LED control	High
Video size	1920x1080
Video length	10s
Interval	10s
Sensor level	Auto
Night vision shutter	Auto
Camera mode	24 hrs
Format	Execute, yes
Time stamp	On
Field scan	Off
Coordinate input	Off
Video sound	On

Table B. 2: Camera trap settings used for Browning dark ops sub micro series (Model number: BTC-6).

Parameter	Setting
Capture mode	Trail cam/video mode
Photo quality	Ultra
Video resolution	Ultra, 1280x720
Video length	10s
Photo delay	10s
Multi shot modes	Off
Temperature unit	Celsius
Info strip	On
Motion test	Off
Motion detection	60ft
Battery type	Alkaline
Trigger speed	Fast

Table B. 3: Settings used for Kinopta Blackeye BE2-W.

Parameter	Setting
Set time	Sync now
Operating mode	Normal
Photo rate	2fps

Appendix C

Results

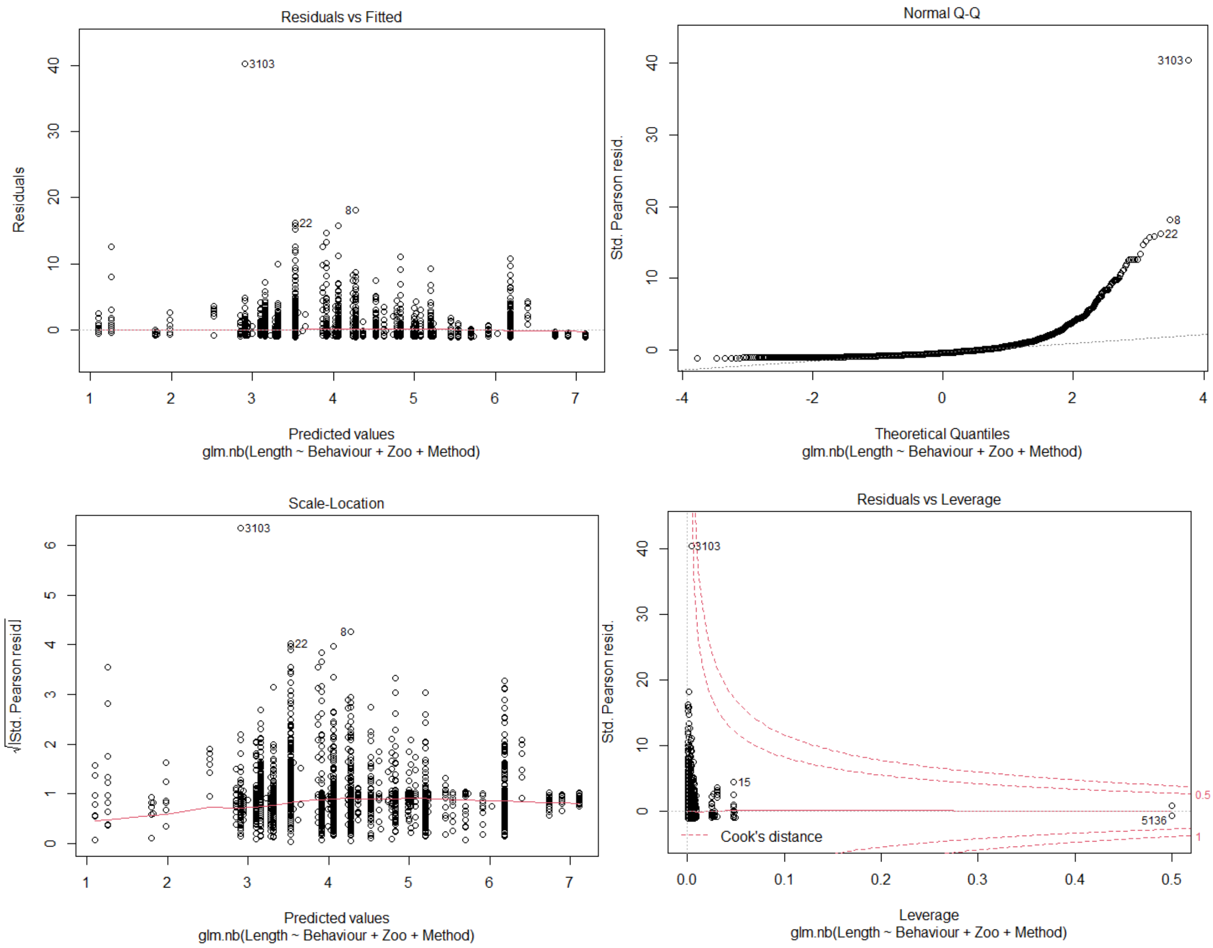


Figure C. 1: Plots from R to show how residuals fit the model for the all zoos combine *before* trail camera data. One data point was removed due to leverage.

Table C. 1: Time and date that the Blackeye camera cut out and lost footage or was taken away to extract files from.

Zoo	**Cut-out time and date**
Auckland Zoo	26/03/2019 00:06 to 28/03/2019 16:40
	30/03/2019 02:00 to 03/04/2019 11:00
	05/04/2019 09:00 to 08/04/2019 13:30
	11/04/2019 01:00
Hamilton Zoo	02/05/2019 12:54 to 03/05/2019 12:10
	06/05/2019 04:50 to 07/05/2019 09:00
	07/05/2019 10:00 to 14:00
	09/05/2019 12:00 to 14:00
	10/05/2019 10:00 to 11/05/2019 12:00
	13/05/2019 11:15 to 15:20

	15/05/2019 01:00
Currumbin Wildlife Sanctuary	09/12/2019 14:30 to 15:49
	10/12/2019 13:11 to 11/12/2019 17:47
	12/12/2019 15:54

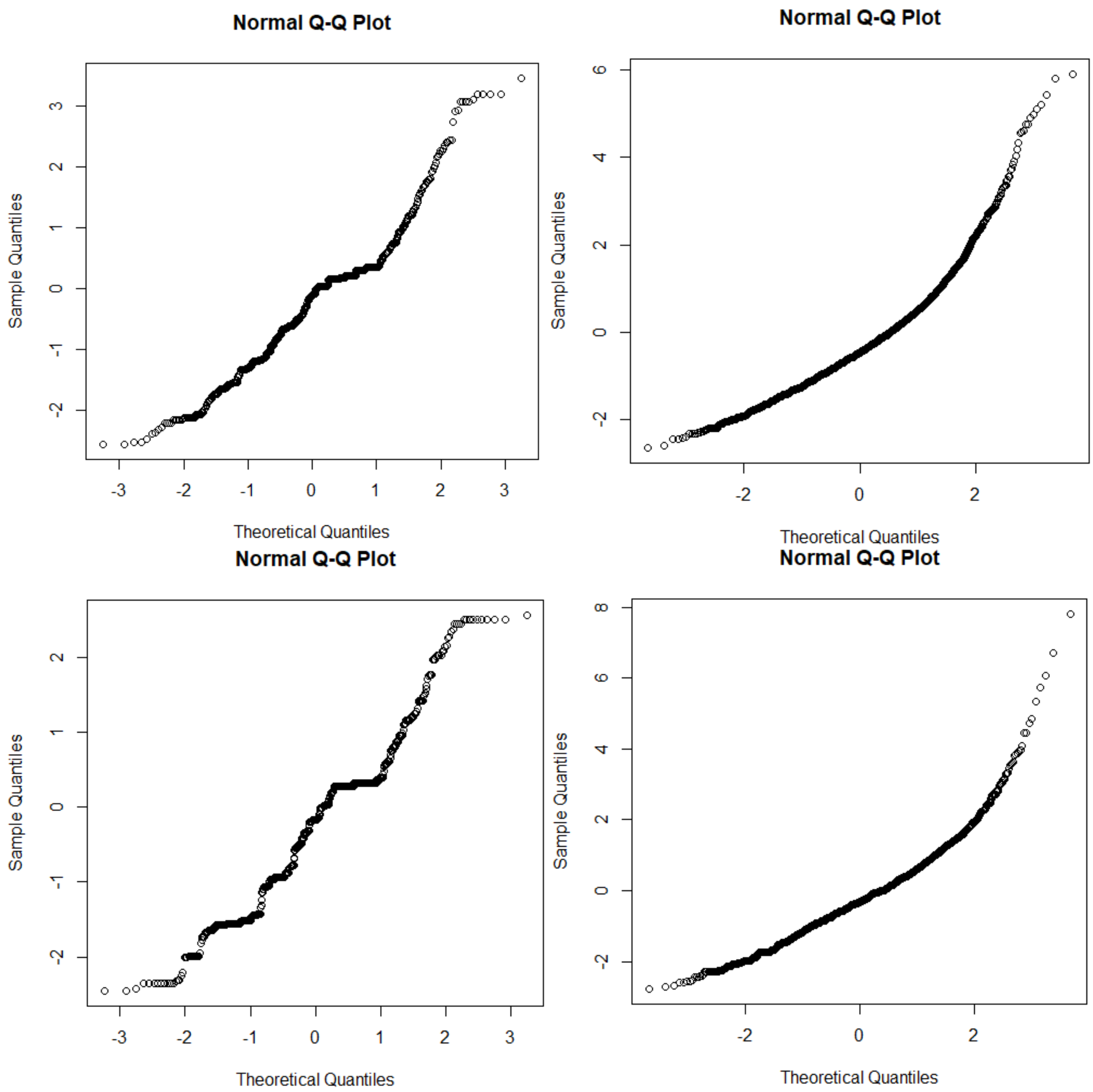


Figure C. 2 : Qqnorm outputs from R, showing how residuals fit the model for Auckland Zoo observations (a), Auckland Zoo Blackeye footage (b), Hamilton Zoo observations (c) and Hamilton Zoo Blackeye footage (d).

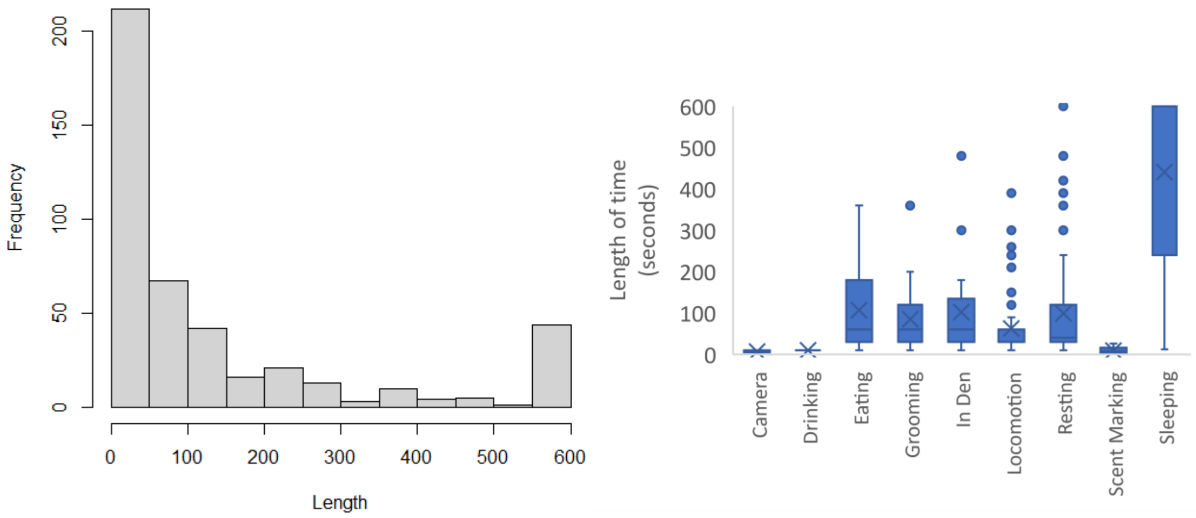


Figure C. 3: Currumbin Wildlife Sanctuary observations. A- Histogram of the length of behaviours in seconds, showing bimodal distribution. B- Boxplot showing the spread of the length of behaviours. Both from observations at Currumbin Wildlife Sanctuary.

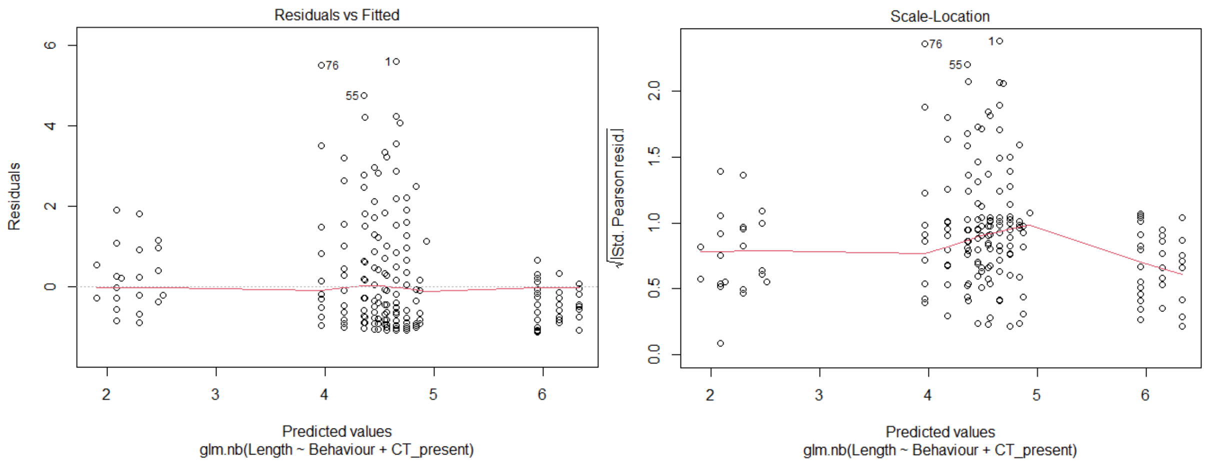


Figure C. 4: Plots from R to show how residuals fit the model for Currumbin Wildlife Sanctuary observations. "A" shows non-normality as we know, and used a negative binomial distribution. No points in the prdicted values graph (not shown) were considered to have to

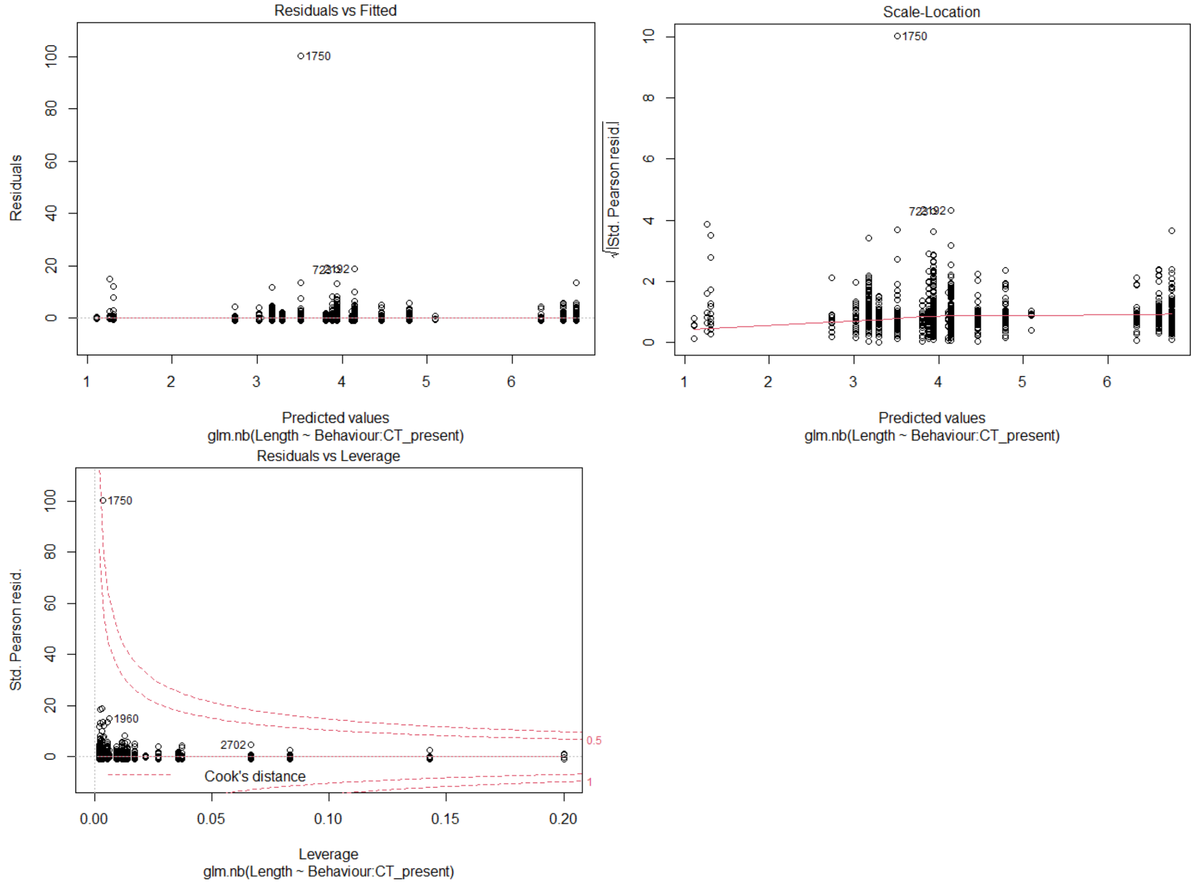


Figure C. 5: Model fit outputs from R for Currumbin Wildlife Sanctuary Blackeye footage. “C” - some cited data points may hold too much leverage on the model.

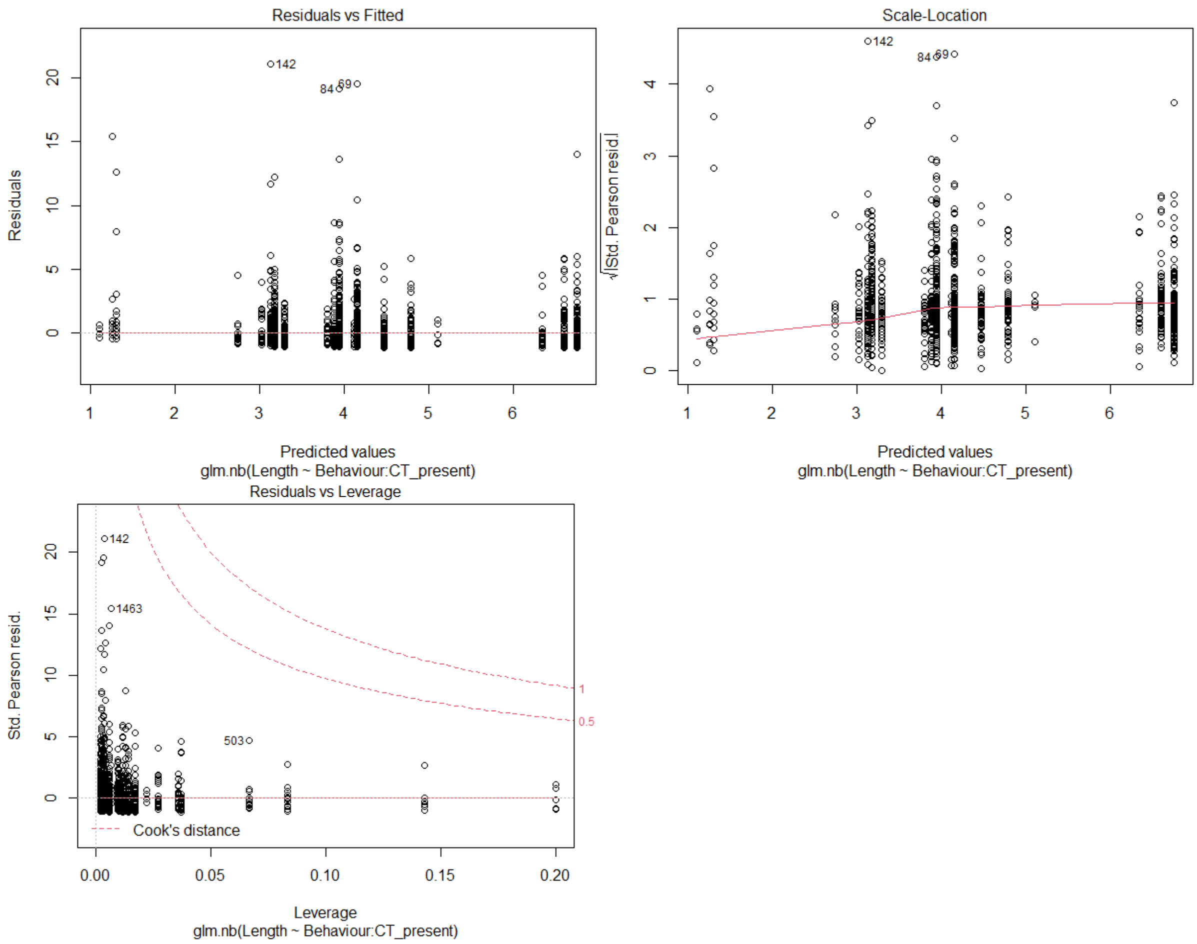


Figure C. 6: Model fit outputs from R for Currumbin Wildlife Sanctuary Blackeye footage. No further points in the bottom left graph were considered to have too much leverage so the new data set could be used.

Appendix D

OSPRI Management report

I helped mostly with a literature review and some statistical analysis.

DEPARTMENT OF PEST-MANAGEMENT AND CONSERVATION
FACULTY OF AGRICULTURE AND LIFE SCIENCES

Detecting possums at very low densities following control.

Associate Professor Dr James Ross

Due date: 30/06/2010

Lincoln University
Te Whare Wānaka o Aoraki
AOTEAROA • NEW ZEALAND

New Zealand's specialist
land-based university

OSPRI New Zealand Limited
Interim Report

Project Code and Title	Detecting possums at very low densities following control.
Research Leader	Associate Professor James Ross
Authors	Kathryn Bugler, James Ross
Interim Report 1	
Proposed Completion Date: 30/06/2020	Actual Completion Date: 30/12/2020
Value of Milestone: $84,496	

D.1 Introduction

The purpose of this interim report is to report on the underlined research objectives below. Due to problems with both field sites at Bottle Rock and the Kaitake Ranges, we are currently unable to report back on the other three research objectives. Lack of progress at the field sites was caused by two issues. First, Zero Invasive Predators decided to scale back at Bottle Rock and they have ceased their intensive monitoring and control work. Second, the Kaitake Ranges work was delayed as DoC were unable to completely remove all possums after "dual-application" aerial 1080 control and they are now installing raised, automated leg-hold traps to remove the survivors. It is now planned that the remaining field work will be start in August (T Sjoberg pers comm, DoC, 2020) with the final report to be written up by 30/12/2020.

<u>**Objectives of research project**</u>

Stage 1 Objectives:

The objectives of the Stage 1 research are to:

- Determine if monitoring devices at a grid spacing of 1/50 ha are sensitive enough to detect individual possums remaining after eradication
- <u>Field test a new thermal camera that identifies and stores animal interactions on board</u>
- Assess the cost-effectiveness of the new camera monitoring system compared with current detection tools used by OSRPI Stage 2 Objectives:

The objectives of the Stage 2 research are to:

- <u>Assess the sensitivity of the new thermal camera and calibrate it with current detection tools at an OSPRI surveillance site</u>
- Field-test the reliability of the cellular connection

D.2 Background and Justification for the Research

D.2.1 Possums

Brushtail possums (*Trichosurus vulpecula*) are a 2-4 kg arboreal, marsupials that are native to Australia (Cowan 1992). While mostly folivores, possums are also opportunistic feeders (Efford et al. 2000). They were first introduced to New Zealand in 1858 to establish a fur trade (Nugent et al. 2015). Today possums are classified as a pest species with many studies finding possums responsible for competition and death of native bird species such as adult kiwi and eggs (McLennan et al. 1996), nesting adult kaka, their eggs and nestlings (Powlesland et al. 1999; Moorhouse et al. 2003).

Possums also threaten our important beef and dairy industries by being the primary host for bovine tuberculosis (TB; Efford et al. 2000). Ferrets may also be a secondary host of TB, as they can scavenge on infected possum carcasses (OSPRI 2016). While most possums die of TB within six months of contracting it, killing the host seems to be the only way to reduce TB infection rates (Nugent et al. 2015). In areas where possums are heavily controlled, TB is generally not found (OSPRI nd-a). Over 120,000 possums have been necropsied in the last decade, of these only 0.04% tested positive for TB (OSPRI nd-a). In 2016, 1,364 possums were recovered from Mt Cargill, and just six (0.43%) tested positive for the same strain of TB that was affecting the farms cattle. With this low prevalence, ongoing and sustained control is required to completely remove any remaining infected animals.

D.2.2 Possum control methods and monitoring

When possum control is carried out, signs of biodiversity benefits are usually seen in the following spring and summer, when birds breed and the flora recovers (OSPRI 2018). As of 1996, more than 1 million hectares received some form of possum control (Cowan et al. 1996); however, by 2015 this had increased to 8 million hectares (Nugent et al. 2015). Possums are mainly controlled through ground-based trapping or poisoning; however, aerial poison drops are applied in areas with difficult and/or inaccessible terrain (OSPRI 2018). Kills over 90% are not unusual (Ross et al. 2010); however, populations can quickly recover with enhanced recruitment and rapid immigration (Cowan et al. 1997; Warburton & Thomson 2002). Most adult possums remain loyal to their territories due to social pressures (Efford et al. 2000); however, 25% of radio-tagged juveniles can travel more than 2km from natal areas (Cowan et al. 1997). Therefore, monitoring in control areas and adjacent buffer zones is required for ongoing surveillance and management (Whyte et al. 2013).

D.2.3 Monitoring – Leg-hold traps

The National Trap Catch Protocol remains the standard for possum monitoring. Most operators use #1 double-coil spring, leg-hold traps to assess residual trap catch indices following control (RTCI; OSPRI 2017; Powlesland et al. 1999; Veltman & Pinder 2001; Forsyth et al. 2005; Sweetapple & Nugent 2009). The RTCI was adopted in 1996 to ensure standardisation of possum control (Forsyth et al. 2005) and managers generally consider control successful when RTCI is < 2% (i.e., < 2 possums caught per 100 trap/nights). Numbers of trap lines are determined by the size of the control area with location randomised except in farmland, where suitable habitat is often patchy (Forsyth et al. 2005). Knowing the ecology of possums in all habitat types is important as it varies throughout the year (Glen et al. 2012). For example, RTCI is often lower in winter than in summer or early autumn (Nugent et al. 2010). Studies have also found that raising leg-hold traps in trees (to avoid non-target by catch) lowers RTCI estimates (Thomas & Brown 2000; Nugent et al. 2010). Additionally, the timing of post-control monitoring can also affect RTCI. For example, if it is carried out immediately, then the RTCI may be underestimated, as there may be a link between possums who avoid initial control and monitoring trapping (Nugent et al. 2010).

D.2.4 Chew Cards and WaxTags

As possum control has advanced, with >90% kills routinely achieved, it was thought that RTCI estimates were not sensitive enough to detect survivors when possum numbers were extremely low. This led to the development of non-invasive, food-based techniques such as chew cards and WaxTags. Detection devices for small mammals need to be highly sensitive, accurate, have no major biases and are easy to deploy (Sweetapple & Nugent 2011). Given their ease of deployment, chew cards and WaxTags has become increasing used for possum surveillance monitoring (Warburton & Livingstone 2015). Leg-hold traps are more expensive to use because of the daily servicing requirements and have extra weight and bulk during transportation (OSPRI nd-b). For example, it cost $40,000 using chew cards compared with $83,000 using leg-hold traps to monitor the same sized area (Sweetapple and Nugent 2009). Whilst chew cards and WaxTags are considered an improvement for low density monitoring, new monitoring tools need to be continuously investigated (Warburton & Livingstone 2015). For example, a recent study showed that camera traps detected significantly more hedgehogs and rats than food-based tracking tunnels at 40 monitoring sites in an urban city (ratio 1.84:1; Anton et al. 2017). Other studies have shown that camera traps also detect significantly more mammal species when compared to live-capture traps (Meek & Fleming 2014).

D.2.5 Camera traps

Whilst camera traps are thought of as a relatively new technique for surveying wildlife (Caravaggi et al. 2017) their use dates to the 1890s, when George Shiras first developed a wildlife camera using a tripwire. He also created the first white flash (with magnesium powder) for night photography and not surprisingly showed that animals were deterred by the bright flash (Brower 2008). Film based to digital technology only occurred from c. 2007 onwards (Green et al. 2020) and passive sensor, infrared (PIR) cameras now dominate the market, due to companies claiming that animals cannot see the IR flash (Meek et al. 2014). However, some nocturnal animals are sensitive to IR light with anecdotal reports suggesting brushtail possums tend to avoid areas with IR illumination (Meek et al. 2014). Most cameras on the market have a passive detection zone that triggers when there is a difference between the target and background temperatures, with the optimum difference being >2.6°C (Rovero et al. 2013; Welbourne et al. 2016; Green et al. 2020); however, pockets of hot air can also set off PIR cameras causing false triggers (Rovero et al. 2013). Food-based lures may increase detections, due to animals spending more time in front of cameras; however, it was noted that small-fast moving animals do not always set off PIR cameras (Glen et al. 2013). Some researchers have attempted to overcome the problems of PIR detection and use active infra-red, where a beam of IR must be broken to trigger a photo (Kelly & Holub 2008); however, they are harder to setup, have even more false triggers, and if set at the wrong height, will totally miss the target species. In a recent review of PIR cameras Glover-Kapfer et al. (2019) detailed that for PIR cameras to become the mainstream monitoring tool they need to have better sensor detection performance, be more resistance to extreme environmental conditions and a system is needed for automated filtering of blank images (see below).

D.2.6 Artificial intelligence (AI)

Given the problems with false triggers using PIR cameras, researchers often must manually sort through hundreds to thousands of images. Several studies have tried to create artificial intelligence (AI) algorithms to classify these images (Villa et al. 2017; Norouzzadeh et al. 2018; Tabak et al. 2018; Willi et al. 2018; Green et al. 2020); however, such vast differences in the types of photos obtained from camera traps makes computer learning difficult (Villa et al. 2017). Generally, researchers use already classified images from a dataset to train the AI; however, these deep neural AI networks can be overconfident in their predictions (Villa et al. 2017; Norouzzadeh et al. 2018; Willi et al. 2018). For example, in a series of trials using camera images obtained in the Serengetti region, researchers obtained species identification accuracy of between 89-94%; and the AI still failed to remove all blank images (Willi et al. 2018). In a North American study, researchers had 98% accuracy in identifying animals but 75% of these images were empty and still had to be manually classified (Tabak et al. 2018). Currently, AI for PIR cameras is not fully reliable (Green et al. 2020) and many such as ClassifyMe are still in the beta testing phase (Falzon et al. 2019).

D.2.7 Thermal cameras

Researchers have recently looked at using unmanned aerial vehicles (UAV) with thermal cameras to detect and identify free-ranging animals. For example, Gonzalez et al. (2016) used a UAV with thermal cameras to find koalas in Australia. It had 100% accuracy in identifying koalas at 20, 30 and 60 m; however, the forest cover was low and the cameras very expensive. In New Zealand, Landcare Research demonstrated that larger species such as deer, goats, pigs and thar can be detected with lower-cost, less-high-specification cameras, but the accurate detection of small species such as possums and rabbits requires higher resolution (Warburton 2017).

D.2.8 Conclusions

In conclusion, the above research suggests that chew cards and WaxTags are likely more sensitive than leg-hold traps for detecting possums. It is also likely that PIR cameras are more sensitive than chew cards and Waxtags; however, PIR cameras do not always trigger with smaller animals and you need to sort through considerable numbers of false triggers looking for the target species. Thermal cameras have shown some potential; however, the technology is expensive and needs AI identification technology for filtering out false triggers.

In 2018, a new land-based thermal camera was developed by the Cacophony Project. These cameras have cloud-based AI technology which enables them to remotely identify species from video recordings. This information can be stored onboard for collection or transmitted using the cellular network. Essentially this new tool could provide real-time surveillance of possum survivors on a "widely-spaced grid" in remote areas. This could be a major advancement over existing monitoring techniques (including PIR cameras) and was the justification for this research project. The widely-spaced grid concept comes from parallel research conducted by Zero Invasive Predators (ZIP) who developed a "lean" possum detection system at a 400-ha study site (Bottle Rock, Marlborough Sounds) using eight (automated-reporting) raised leg-hold traps (i.e. 1 device per 50 ha see: https://zip.org.nz/findings/2018/5/goodbye-possums).

D.2.9 Research Aims

This interim report provides key research results from the first set of trials run at Lincoln University and nearby Living Springs. As detailed above, this report addresses the following research objectives:

1. Field test a new thermal camera that identifies and stores animal interactions on board.
2. Assess the sensitivity of the new thermal camera and calibrate it with current detection tools at an OSPRI surveillance site.

The bulk of the field work was done by two postgraduate students supervised by Assoc. Professor James Ross. All their research was written up a research placement report and a master's dissertation:

Jansen, M. (2019). *A comparison between a heat and a PIR camera to detect pest animals as part of the Predator Free 2050 programme in New Zealand*. Masters dissertation. Lincoln and HAS universities. 17 p.

Blair, B. (2020*). Investigation of the accuracy of thermal cameras: optimal; distance between lure and camera for identifying possums* (Trichosurus vulpecula). Lincoln University Research Placement. 10 p.

D.3 Methods - Objectives 1 and 2

D.3.1 Pen trials - Lincoln University

The first trial was set up in the 2 ha predator-fenced enclosure (run by ZIP) at Lincoln University (Fig. 1). Both the thermal and the PIR cameras (Bushnell Aggressor model 119874) were placed adjacent to each other (Fig. 2) in three different spots in the enclosure. Each thermal camera was mounted on top of a tripod at 1 m height and the PIR cameras were set at 30-50 cm above the ground

Fig. 1 (above). Predator enclosure at Lincoln University.

Fig. 2 (right). Thermal and PIR camera setup in predator enclosure with small capacity battery.

The PIR cameras were programmed to record a 10-second video on detection of activity with no delay between subsequent videos. One chew card (baited with peanut butter) was placed on a wooden stake (30 cm height) at 10 m distance with another at 20 m, both directly in front of the cameras. From 16-11-2018 until the 19-12-2018, eight possums were individually released into the enclosure, each for three nights.

D.3.2 Field Trials - Living Springs, Canterbury

Comparison between cameras

Living Springs is a 420 ha area of native bush and rural farmland that spans from a crater rim to the foreshore of Lyttleton harbour, Canterbury. Thermal and PIR cameras were set up at five different location from 15-04-2019 until 09-05-2019 (Fig 3.).

Fig. 3. Location of camera sites at Living Springs, Canterbury.

The thermal cameras were placed 2 m from a peanut-butter baited chew card and the PIR cameras were 1.5 m from the chew card (Fig. 4). Each thermal camera was mounted on top of a tripod at 1 m height and the PIR cameras were set at 30-50 cm above the ground. The PIR camera distance of 1.5 m is considered current best practice for small moving animals (Morriss 2017; Gillies 2018). Again, the thermal cameras recorded videos; however, this time the PIR camera traps recorded three rapid images when activated to ensure the SD cards were not exhausted before servicing.

Fig 4. Experimental setup at Living Springs, Canterbury.

This trial ran for 25 nights with five rounds of camera checks. The first two rounds where four nights, round three was seven nights, round four was six nights and round five was four nights. At each service check all devices were checked for battery life with SD memory cards and chew cards replaced (if needed).

D.3.3 Mt Taranaki, New Plymouth

During May and June 2019, DOC aerially applied non-toxic prefeed followed by 1080 cereal baits at 2kg/ha over Mt Taranaki. Each cereal bait was 6 g with a 1080 concentration of 0.015%. Thermal cameras were deployed to monitor survival and possible reinvasion over 9 nights (25-06-19 until 0207-19) at five sites (Fig. 5).

Fig. 5. Location of camera sites at Mt. Taranaki, New Plymouth.

This time the thermal cameras were placed 10 m away from a peanut-butter baited chewcard with the PIR camera 1.5 m away. Each thermal camera was mounted on top of a tripod at 1 m height and the PIR cameras were set at 30-50 cm above the ground. The thermal cameras were placed back at 10 m as earlier trials had shown that the cameras could detect possums at distances exceeding 20 m. At that time, we were still attempting to determine the optional camera distance for possum detection and AI species ID.

Fig 5. Experimental setup at Mt Taranaki, New Plymouth.

Accuracy of the AI species recognition

Following the first trial at Mt Taranaki, we ran a further trial at Living Springs over seven nights (2001-2020 until 27-01-2020). This time the thermal cameras were placed at varying distances from a peanut-butter lured chewcard. Each thermal camera was mounted on top of a tripod at 1 m height (Fig. 5). A tape measure was used to obtain the desired distance from the middle of the chew card to the middle of the tripod. Camera 1 was placed 1 m from the chew card; cameras 2 and 3 were placed 2 m from the chew cards; and cameras 4 and 5 were placed 3.5 m from the chew cards. We ran this trial because of a lack of recordings obtained in the first Mt. Taranaki trial suggested that thermal cameras were struggling at 10 m and a closer distance was likely more optimal for both possum detection and for the AI.

Fig 5. Experimental setup at
Living Springs, Canterbury.

D.3.4 Statistics

Analysis of the ZIP dataset was done using a GLMM with camera type as a fixed effect and possum ID as a random effect. Analysis of the Living Springs dataset was done using a GLMM with camera type and monitoring round as fixed effects, and site as a random effect. Analysis of the AI species recognition data was done using a chi-squared test of independence. All were done using R version 3.5.3 with packages Lme4 version 1.1-23 and Emmeans version 1.4.6.

D.4 Results

D.4.1 Pen trials - Lincoln University

Over 24 nights of recordings the thermal cameras recorded 108 videos, with 18 possum detections. The PIR cameras recorded 4,986 videos, but only five of these were possums. The chew cards had no detections at 10 m and we collected three bitten chew cards at 20 m (Table 1).

The PIR cameras missed 13 (72%) of the thermal camera possum detections; however, there was one recording of a possum on the trial camera which was missed by the thermal camera on 27-112018 most likely due to battery depletion. A summary of videos collected can be viewed in a Utube Video.

Table 1. Numbers of possum detections using thermal cameras, PIR cameras and the chew cards at two different distances from cameras. Number 1 indicates a detection.

Date	Thermal cameras	PIR cameras	Chew cards 10 m	Chew cards 20 m
16-11-2018	1	1	0	0
16-11-2018	1	0	0	0
16-11-2018	1	0	0	0
19-11-2018	1	0	0	0
21-11-2018	1	1	0	0
24-11-2018	1	1	0	0
24-11-2018	1	0	0	0
24-11-2018	1	0	0	1
25-11-2018	1	0	0	0
25-11-2018	1	0	0	0

27-11-2018	0	1	0	0
30-11-2018	1	0	0	0
1-12-2018	1	0	0	0
2-12-2018	1	0	0	0
3-12-2018	1	0	0	1
3-12-2018	1	0	0	0
7-12-2018	1	1	0	1
12-12-2018	1	0	0	0
12-12-2018	1	0	0	0
Total	**18**	**5**	**0**	**3**

Further analysis of the data indicated that the average probability of detecting a possum each night was 46% for the thermal cameras, 21% for the PIR cameras and 13% for chew cards with these differences being statistically significant (χ^2=83.1, df=2, P=0.025; Fig. 6). Chewcards at 10 m were left out of this analysis due to zero detections.

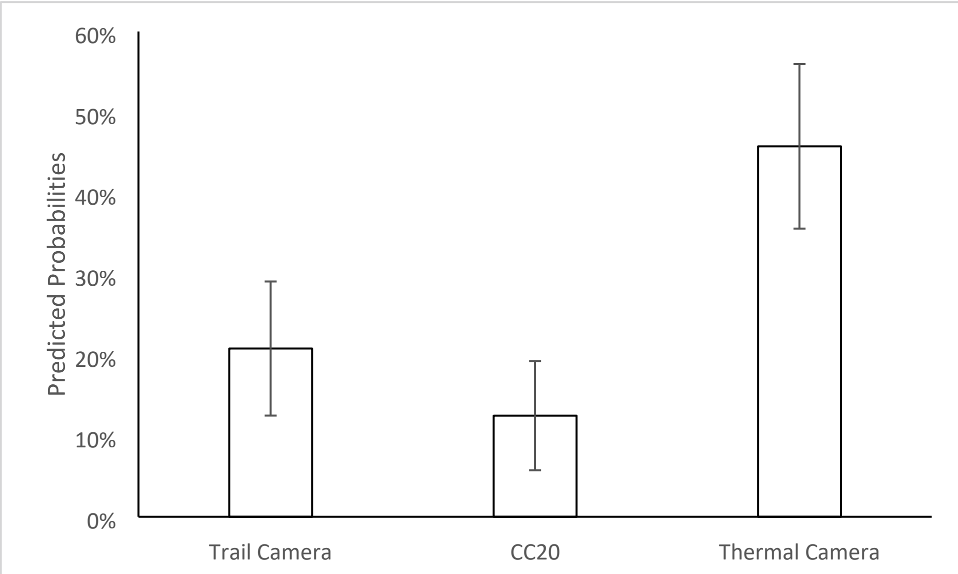


Fig. 6. Predicted probability of detecting a possum on a given night $\pm$ SE.

D.4.2 Living Springs, Canterbury

The thermal cameras recorded 1,376 videos, with 425 videos identified as possums. PIR cameras recorded 12,153 images, with 351 images identified as possums. The PIR cameras missed 74 possums encounters that the thermal camera recorded (Table 2).

Table 2. Numbers of possum detections.

Round	Thermal	PIR	Nights
1	18	3	4
2	97	83	4
3	82	70	7
4	177	149	6
5	51	46	4
Total	**425**	**351**	**25**

Further analysis of the data indicated that the numbers of detections significantly changed over time (χ^2=76.91, df=4, P<0.001; Fig. 7) with the thermal camera having significantly more detections in round 1 (P=0.04; Fig. 7).

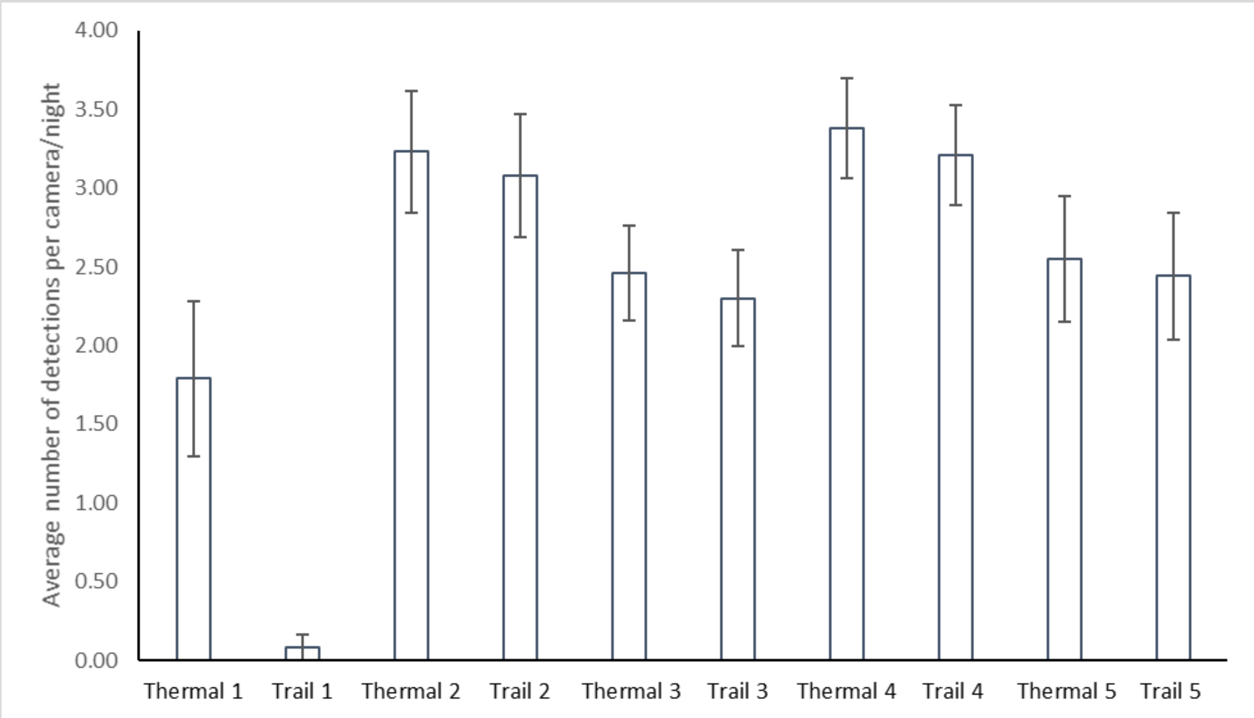


Fig. 7. Pairwise plot of average number of detections (± SE) for Living Springs over five rounds of monitoring.

D.4.3 Mt Taranaki, New Plymouth

The PIR cameras at Mt Taranaki recorded 4,654 images over the nine nights (Table 3). The thermal cameras only recorded three videos and there was concern that the colder temperature at Mt Taranaki combined with the 10 m distance from the chew card was the problem. This led to a rapid test of the cameras at three closer distances at Living Springs – see next section.

Table 3. Numbers of photos recorded by five PIR cameras at Mt Taranaki.

PIR Camera	**1**	**2**	**3**	**4**	**5**	**Total**
Photos	380	984	405	128	2,757	4,654
Possums	34	0	141	6	24	205
% Target	**8.9%**	**0%**	**34.8%**	**4.7%**	**0.9%**	**4.4%**

The time taken to sort through and categorise the photos was estimated at 3.5 hours and the files required 5 GB of data storage. An example of a PIR camera photo (with temperature) is shown in Fig. 8.

Fig. 8. Brushtail possum detected by Bushnell PIR camera 1 at Mt. Taranaki on 29-06-2019.

D.4.4 Accurancy of the AI species recognition

The thermal cameras recorded 787 videos over seven nights, with 51 possum detections. Of these 20 (39%) were correctly identified by the software with the AI performing worse at 1 m distance compared with further 2 m and 3.5 m distances (χ^2=9.38, df=2, P<0.01; Table 3).

Table 3. Numbers of possum detections correctly identified by the AI software.

Distance	**1 m**	**2 m**	**3.5 m**
Detected	3	7	10
Undetected	18	6	7
% Correct	**14.29%**	**53.85%**	**58.82%**

D.5 Discussion

D.5.1 Pen trials – Lincoln University

Differences in device sensitivity were highlighted in this first trial with the PIR cameras missing 72% and the chew cards 83% of thermal camera possum detections. The thermal cameras also had a statistically higher probability of detecting a possum each night; however, we don't know if the possums were active every night as there was substantial rainfall during the trial. At this stage the batteries for the thermal cameras were lasting 5-6 nights; however, the batteries for the PIR cameras were having to be swapped out every seven days due to the large number of videos being recorded (mostly false triggers). The short battery life for the thermal cameras was highlighted as a concern and a new larger capacity option was developed for the later field trials.

The cellular connection was also tested in the captive studies and worked correctly with no loss of data; however, this was also a major drain on the smaller batteries. Accordingly, for the field trials the cameras were programmed to store video onboard and these were then retrieved using the App on a mobile phone. Additionally, given the large numbers of videos being recorded by the PIR cameras, the SD memory cards were being rapidly filled. In response to this problem we changed the settings on the PIR cameras to take a rapid series of 3 photos to reduce storage requirements.

D.5.2 Living Springs

In our first field trial at Living Springs, the trial cameras missed 73 possum detections over 25 nights. The thermal cameras always had more detections; however, possums were picked up earlier by the thermal cameras in round 1. Following round 1, the number of possum detections were similar and it was hypothesised that once the animals had located the chew cards then overall activity increased possibly due to the formulation of scent trials (see Utube video).The PIR cameras had nearly 10times the number of recorded images compared to the thermal cameras and 97% of these were false triggers or non-target species.

The new larger batteries for the thermal cameras were an improvement and were still running after 4-7 nights of use. At this time, we approached Project Cacophony with a goal to develop a battery monitor so we could check remining capacity at each service and this is currently under development. Our current thoughts are that the batteries should last 9-10 days in the field and Project Cacophony is also testing a new solar panel which should further extend battery life.

D.5.3 Mt Taranaki, New Plymouth

In our first trial in New Plymouth we had a programming failure with the thermal cameras. The PIR cameras recorded 205 possum images and the thermals only recorded three videos. The thermal cameras were still running, and our initial hypothesis was that the problem was the much colder temperatures at Mt Taranaki combined with the 10 m distance. Eventually, it was discovered that a software camera update had reset the internal clock and the cameras were not running at night. This has now been rectified and the phone App autocorrects the clock time on connection.

Again, the PIR cameras had a considerable number of false triggers with only 4.4% of the images being possums. Our rough estimate was that was that it took 3.5 hours to categorise these images and we also had our first SD memory card failure, with additional images that could not be recovered. In comparison, it took about 20 minutes to go through the thermal camera videos from the Living Springs field trial, given that the AI correctly identified more than half of the possum encounters and there were many less false triggers (Fig. 9).

2019-05-09

10pm	possum	ospri03	05/09/2019	10:44:35 PM	10:45:58 PM	1
12am	cat	ospri07	05/09/2019	12:41:35 AM	12:41:47 AM	1
	rodent	ospri07	05/09/2019	12:41:57 AM	12:41:38 AM	2
	hedgehog	ospri07	05/09/2019	12:41:44 AM	12:43:59 AM	1
	possum	ospri07	05/09/2019	12:41:30 AM	12:44:15 AM	2
	unknown	ospri07	05/09/2019	12:44:14 AM	12:44:20 AM	1
	possum	ospri10	05/09/2019	12:07:23 AM	12:08:14 AM	1

Fig. 9. Picture of Cacophony browser with AI recognition of animals for one night using five cameras.

D.5.3 Accurancy of the AI species recognition

As detailed above, we decided to run a quick trial looking at the effect of distance from the chew card for both detection and AI species ID. The camera correctly identified 54-58% of possum encounters at 2-3.5 m from the chew card. As such, we currently recommend 2-4 m distance as optimal for possum detection; however, the AI algorithm still needs more video training. To help with this Project Cacophony have developed the "Power Tagger" to increase the number of classified videos for machine learning and significant improvements are expected.

D.6 Conclusions

In conclusion, the goal of this early research was to develop the "optimal" thermal camera setup for later deployment in the Kaitake Ranges. We have already run some small-scale trials in the Kaitake Ranges using the thermal cameras with sound lures. This research is currently being written up as a masters dissertation and will also be reported in the final report. We developed the sound lures with Project Cacophony following a favorable literature review which documented their success in other animal studies.

We currently expect to start the last of the field work in August 2020. Researchers have nearly completed setting up the lean detection grid using 1 raised leg-hold trap/50 ha in the Kaitake Ranges. We will then deploy the thermal cameras on the same grid pattern (with sound lures) to address the remaining three research objectives. We expect that a final report will be written up by 31-12-2020.

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