Mammalian Pests in the Waikato Region:

A Site-Occupancy Analysis of Main Habitats

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Abstract

This project aimed to use camera traps to study the distribution of seven important mammalian pests across the three main vegetation types of the Waikato Region and to see if this method is a more informative alternative to other passive detection methods. For this study, the species of interest are the common brushtail possum (*Trichosurus vulpecula*), the European hedgehog (*Erinaceus europaeus*), ship rat (*Rattus rattus*), house mouse (*Mus musculus*), stoat (*Mustela erminea*), ferret *(Mustela putorius*), and weasel (*Mustela nivalis*).

The objectives of this study were to 1) calculate the distribution of each mammalian pest within the three main vegetation types of the Waikato Region 2) to determine site occupancy i.e. patchiness of species distribution within these habitats, and the probability of detection where they are present and 3) to evaluate whether the above parameters are influenced by the seasons and/or interactions between the species.

To meet these objectives, I measured five parameters related to site occupancy and activity levels for each species, and use the results to present an estimate of the proportion of the Waikato Region occupied by each species.

These analyses suggest that suggest that species distributions are very much dependent on habitat, but a large portion of all species was accounted for by pastoral areas. Even when species are not particularly abundant on pasture, it makes up more than half of the Waikato, and as such is potentially a source for reinvasions of controlled areas when not cleared in concert with the surrounding areas.

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Chapter One

Introduction

1.1 Overview

In this chapter, I briefly review the literature on the history and biology of introduced mammals in New Zealand. While 35 exotic mammals have established in New Zealand, I will focus on seven small pest species and their social, environmental, and economic effects. The species of interest are the common brushtail possum (*Trichosurus vulpecula*), the European hedgehog (*Erinaceus europaeus*), ship rat (*Rattus rattus*), house mouse (*Mus musculus*), stoat (*Mustela erminea*), ferret *(Mustela putorius*), and weasel (*Mustela nivalis*).

The review will also summarise common methods of monitoring these species and some of the limits and assumptions that are associated with these methods. I will discuss the use of cameras to monitor populations of small mammals and the advantages and disadvantages of this technique. I will describe the major vegetation types of the Waikato Region, how these have changed in recent history and current knowledge of how these different habitats are utilised by the seven species.

Finally, I provide a brief summary of my hypotheses, aims and objectives, and the expected outcomes of this project.

1.2 Literature Review

Prior to human colonisation, New Zealand fauna included only 12 species of native mammals: eight pinnipeds, three bats and one vagrant little red flying fox (King, 2005a). Along with humans, who arrived in New Zealand in three waves, 54 mammalian species were introduced to its shores (King, 2005a). Fortunately for the native species, about a third of these did not establish sustainable populations, and only 35 species survived long-term (King, 2005a). Those that became established can be grouped into seven categories according to the reason they were introduced (Table 1-1). Some species were introduced for several reasons and were counted twice in the table. One such example is *Felis catus*, the domestic cat, introduced both as a pet and for pest control (King, 2005a).

Table 1-1 Number of mammalian species introduced to New Zealand and the reason for their introduction (adapted from Table 2B in King (2005a)).

Reason	Sport	Escapees	Utility	Biological Control	Economic	Stowaway	Pet
No. of Species	16	8	6	5	4	4	2

To collect the material for this review, I searched Web of Science and Google Scholar using the search string “introduce* AND mammal* AND Zealand” and reviewed the abstracts from the results for relevant papers. To ensure comprehensive coverage of the literature, results in Web of Science were first sorted by relevance and then times cited. Subsequent search strings included “mammal* AND colonise* AND zealand”, “mammal AND distribution AND habitat” and “distribution AND abundance AND camera”. As part of this review is on the history of introductions and methods of animal detection that have been in use for a long time, I set no timeframe limitations on the search, other than that imposed by the database itself. For Web of Science, this timeframe was 1965 – 2017. Finally, I scanned the references of all located papers for any other relevant source that might have been missed during the above-mentioned process.

1.2.1 History of colonisation

The first humans to colonise New Zealand were the Polynesians, during the 13th century (Anderson, 2000; Wilmshurst & Higham, 2004). While it has been suggested that the first introduced mammals, the kiore or pacific rat (*Rattus exulans*), arrived almost 1000 years earlier (Holdaway, 1996), more recent studies have shown that this suggestion was based on an error in dating the rat bones (Anderson, 2000; Wilmshurst & Higham, 2004). Instead, the arrival of the kiore, along with the kuri, the Polynesian dog, is closely linked to that of the Polynesians, perhaps deliberately introduced to the mainland as a supplementary food source (Roberts, 1991), although several islands that were settled by Maori show no evidence of kiore (Atkinson & Towns, 2005).

As the first rodent to invade New Zealand, the kiore faced very little competition and was able to spread across most if not all of New Zealand, filling a large number of niches previously occupied by birds, reptiles and insects. Only after the introduction of other rodent species did the distribution of kiore decline, to the point where there are only a few extant populations left and most of these are on offshore islands (Atkinson, 1973; Roberts, 1991; Ruscoe, 2004).

The next wave of human arrivals was led by Captain Cook in 1769, and then by the crews of European sealing and whaling ships, who harvested their quarry for about 30 years from 1792 and then departed. These ships were the likely mechanism for the invasion of New Zealand by the Norway rat (*Rattus norvegicus*) and the house mouse (*Mus musculus*), followed later by the ship rat (*Rattus rattus*) (King, 2005a). These species were not deliberately introduced, rather they came as stowaways on the ships (Table 1-1).

The final wave of human arrivals, the organised European settlers, started arriving in New Zealand in the 1840s, with the intention of staying permanently. Only after they were settled were the vast majority of non-native species introduced to New Zealand (King, 2005a). the last of these was the chamois (*Rupicapra rupicapra*) introduced in 1907 (King, 2005a). Some of these species then rapidly dispersed throughout the country, others remained local, but all except two of the 35 surviving mammal species originally from Europe (King, 2005a).

Five species, along with ship rats and house mice mentioned above, are the focus of this review and the rest of my thesis, but whereas the rodents were stowaways on the ships of the visitors, these five were deliberately introduced for a variety of reasons.

The Australian brushtail possum, one of the five ‘Economic’ species in Table 1-1 above, was introduced to establish a fur trade, starting in 1858 (King, 2005a). This was a very successful industry at first, worth NZ$23 Million by 1980 (Wodzicki & Wright, 1984).While possum fur is still used in clothing today, increasing worldwide opposition has reduced the demand significantly (SAFE, 2017).

Five species were introduced as biological control agents (Table 1-1). Three of these were mustelids, introduced to New Zealand in the late 1800's as a biological control for rabbits, whose populations had quickly become an uncontrollable threat to pastoral agriculture. They were the weasel, the stoat or ermine and the ferret, although stoats are now the most common (King, 2005a).

The fourth species introduced as a biological control agent was the European hedgehog, the only representative of the order Insectivora to be introduced to New Zealand. Introduced to control populations of insects and various garden pests, the first record of their presence was in 1870, when a pair was presented to the Canterbury Acclimatisation Society (Jones & Sanders, 2005).

The fifth species introduced for pest control, at least partly, is the domestic cat. Ironically, all the mammals introduced as biological control agents for other pest species have, in turn, become some of the most destructive pests themselves, incurring significant ecological and economic costs to New Zealand

1.2.2 Effect of introduced mammals

Ecological Costs

Prior to human arrival, New Zealand's native fauna was dominated by birds that filled many niches normally filled by mammals in other parts of the world, from herbivores to hunters. Any anti-predator behaviour displayed by native fauna had evolved to protect against avian predators (Dowding & Murphy, 2001). For example, Dowding and Murphy (2001) outlined several traits of New Zealand shorebirds that provide protection against avian predators:

1) "Eggs and chicks of all species are cryptic and small chicks crouch and remain motionless when danger threatens.
2) Some species, such as shore plover and Chatham Island snipe, nest out of sight in holes or under vegetation.
3) Most species have a well-developed distraction and injury-feigning displays." (Dowding and Murphy 2001, p. 57)

While these strategies may be effective against predominantly visual hunters, they would be less effective against mammalian predators using other senses when hunting for prey. Olfactory cues are important to mammals, and these will not be fooled by motionless prey; on the contrary, this habit might just make it easier for mammalian predators to catch them. In addition, many island birds also have general characteristics that make them more attractive and easier prey, including large size, reduced or complete loss of flying ability, lower reproductive rates, ground nesting and behavioural naivety towards mammalian predators (Dowding & Murphy, 2001).

Rats and mice eat a wide range of invertebrates, but the biggest problem with mice is that they may, in certain circumstances, support population of larger predators such as stoats. This is clearly shown in the years following mast events, where eruptions of mouse populations are invariably followed by increases in stoat numbers (King 1983; Fitzgerald *et al.* 1996). Multiple reviews on the current knowledge of the effects of rodents on New Zealand environments (Innes, 2005b; O'Donnell *et al.*, 2015; O'Donnell *et al.*, 2017) found that mice and rats are an important predator of the endangered rock wren and the southern New Zealand dotterel (O'Donnell *et al*. 2017). Innes (2005b) notes that the spread of ship rats through New Zealand coincides with the decline or disappearance of at least nine bird species. These rodents also eat large numbers of invertebrates such as weta and *Powelliphanta* snails, especially in non-mast years, as well as completely consuming all eggs of inanga from spawning sites (O'Donnell *et al.*, 2017).

Possums eat a wide range of native flora, which can result in drastic changes in the composition of indigenous forests where they are present (Wodzicki & Wright, 1984). Selective feeding can completely remove preferred plant species from the forests, and canopy defoliation can lead to further, less obvious problems (Cowan, 2005). Increased exposure to the elements can cause significant changes to the environment, leading to more changes in species composition and increased soil erosion (Cowan, 2005). Possums are known to eat small quantities of invertebrates such as *Powelliphanta* snails as well as prey on birds, such as kea, but also eggs, including eggs of kiwi (Brown *et al.*, 1993; Elliott & Kemp, 2004; McLennan *et al.*, 1996; O'Donnell *et al.*, 2017).

Innes *et al.* (2010) found that possums and rats have a significant impact on native bird populations. As omnivores, they eat both birds and their food source.

While stoats were initially introduced to control the spread of rabbits, they also prey on a variety of other animals including birds, rodents, invertebrates and even possums (Dowding & Murphy, 1994). Destruction of the sheep's grazing led to a reduction in productivity due to malnutrition, and, as the 'natural enemies of the rabbit' but (unlike foxes) too small to threaten lambs, mustelids were thought to be the answer. While helpful, rabbit populations were ultimately too large, and the control effort unsuccessful (King, 2017b).

Control of stoat populations has been shown to increase the reproductive success of mohua (Dilks *et al.*, 2003; Odonnell *et al.*, 1996), kaka (Dilks *et al.*, 2003) and bellbirds (Kelly *et al.*, 2005). Studies on stoat diet in alpine regions found they are an important predator of the endangered takahe, rock wren, and Hutton's shearwater (O'Donnell *et al.*, 2017). Along with dogs, ferrets were the main predators of adult brown kiwi in lowland forests, while stoats and cats were the main threat to the young (McLennan *et al.*, 1996). Stoats have also been shown to prey on kea in Nelson Lakes National park and in South Westland (Elliott & Kemp, 2004; McLennan *et al.*, 1996).

In addition to the damage caused to native fauna and flora by rodents, possums, and mustelids, these pests also pose a threat to the New Zealand economy. Both possums and ferrets are carriers of bovine tuberculosis (Byrom *et al.*, 2015; Byrom *et al.*, 2016). As bovine tuberculosis threatens market access for New Zealand's $16.5 billion dairy, beef and venison industry, these species are a major risk (Jones *et al.*, 2012; MAF, 2017).

Hedgehog diet varies with habitat, but include many invertebrates as well as frogs and even lizards (Jones *et al.*, 2013; Spitzen-van der Sluijs *et al.*, 2009). While hedgehogs were historically thought to pose little threat to birds (Wodzicki & Wright, 1984), more recent studies have shown that ground-nesting birds, as well as their eggs, are often destroyed by hedgehogs (O'Donnell *et al.*, 2015).

The naivety of New Zealand's native fauna towards these introduced mammals has made them easy prey. Another factor has played a large role in making mammalian predators so destructive to native species compared to their homelands. Compared to Australia, where populations of brushtail possums have been greatly reduced through habitat clearing and predation, possums are nationally or locally abundant in New Zealand, with a rapid increase in numbers and distribution since their introduction (King, 2005a). One of the reasons for this difference is the lack of their native predators. Another reason for their numbers in New Zealand is the abundance of food plants lacking toxic defences, especially in areas with a mix of forest and pasture (King, 2005a). Similarly, hedgehogs are well adapted to New Zealand conditions. A lack of parasites, a result of the long voyage from Europe, mild winters and a longer breeding season are some of the reasons for the hedgehog's success in New Zealand (King, 2005a).

As of 2016, 71 of New Zealand's remaining 426 bird taxa are listed as Threatened by the Department of Conservation, with a 107 listed as At Risk (Robertson *et al.*, 2016).

Economic Costs

Calculating the economic impact of pest species is difficult and often contentious (Clout, 2014). Possums alone costs farmers about $35 million, and the government spends about $110 million per year on possum control (PredatorFreeNZ, 2016). The overall cost of pest species to New Zealand has been calculated as $3424 million per annum, of which $2454 million were production losses and $970 million were defensive expenditures (Clout, 2014).

1.2.3 Waikato Vegetation and Small Mammal Distribution

Waikato Region habitat types

Prior to European settlement and the accompanying land-use changes, the vegetation of the Waikato region consisted of indigenous forest, scrub and tussock fields and a number of large wetlands (Leathwick *et al.*, 1995). Clarkson *et al.* (2007) provided a detailed description of the vegetation associated with the different landforms in the region.

Forests dominated by tawa (*Beilschmiedia tawa*), with occasional rimu (*Dacrydium cupressinum*), miro (Prumnopitys ferruginea), kahikatea (*Dacrycarpus dacrydioides*), totara (*Podocarpus totara*), and northern rata (*Metrosideros robusta*) emergent, covered the low rolling hills in the region, including the foothills of the mountain ranges up to 100 meters in elevation. Kauri (*Agathis australis*) and hard beech (*Fuscospora truncata*) forest was restricted to the hills and foothills of the Northern parts of the region, and pukatea (*Laurelia novae-zelandiae*) and kahikatea forest dominated the more poorly drained footslopes.

Vegetation on alluvial plains consisted of two main forest types. Mixed conifer-broadleaf forests with species such as totara, rimu, tawa and rewarewa (*Knightia excelsa*) covered the ridges, while semi-swamp forest dominated by kahikatea covered the depressions.

Forest consisting of totara, matai (*Prumnopitys taxifolia*) and kowhai (*Sophora microphylla*) covered the narrow terraces adjacent to the Waikato River as well as gully slopes, while kahikatea, pukatea and swamp maire (*Syzygium maire*) forest respectively dominated gully floors.

Peatland vegetation consisted mostly of submerged and marginal herbaceous vegetation in the peat lakes, and swamp forest and scrubland on the margins. The vegetation of peat bogs consisted mostly of low growing shrubs and sedges, while jointed ‘rushes’ dominated peat domes (Clarkson *et al.*, 2007).

Since 1840, much of the indigenous forest has been cleared and swampland drained, to open land for agriculture as well as for the growing towns and cities. As of 2012, 52% of the vegetation in the Waikato is classed as high production grassland, 19% is still indigenous forest and a further 11% consists of exotic forest such as pine plantations. Together these make up 82% of the vegetation in the Waikato region, with the remainder being mainly manuka & kanuka, broadleaved indigenous forest, cropland and harvested forest (LCDB v4.1 2012).

Habitat use by small mammals

Although the majority of native vegetation in the Waikato has been converted to other uses, there are still remnants of most native vegetation types scattered throughout the region. The question then becomes whether the vegetation type significantly affects the distribution and abundance of pest species. If there are differences, then it might be more effective to target certain vegetation types to maximise the potential impact of control operations.

(King *et al.*, 1996a; King *et al.*, 1996b) studied the distribution of small mammals in relation to habitat in Pureora Forest Park, looking at logged and unlogged indigenous forest and exotic plantations of various ages. They found that mice were most abundant in young plantation forest, with the lowest abundance found to be unlogged indigenous forest (King *et al.*, 1996b).

Conversely, King *et al.* (1996c) found that ship rats were most abundant in indigenous forest, regardless of logging history, and absent from the young plantation forest. A review in King (2005a) also found that ship rats were most abundant in mature lowland podocarp-broadleaf forest. The distribution of ship rats was limited to native and secondary forest dominated by *Podocarpus* and *Junipers* trees. Pye *et al.* (1999) studied the distribution of ship rats on the sub-antarctic Macquarie Island, the southernmost limit to their distribution. They found that the rats preferred the tussock grassland habitat over herbfield or feldmark, with their distribution closely mirroring that of the tussock. Rats dig and construct nests under the tussock, which provides year-round shelter and food, as well as a warmer and more stable thermal environment than outside (Pye *et al.*, 1999).

Possums also show habitat preferences (Gormley *et al.*, 2015). In a study on the cost-effectiveness of reducing sampling effort, Gormley *et al.* (2015) determined that possums occupy significantly more sites in forested habitats compared to non-forested.

In the study by King *et al.* (1996a), mustelid distribution was shown to vary between habitat types. Stoats were most abundant in the older exotic plantations, while weasels were most abundant in the young plantation and along road edges in indigenous forest. Ferrets were most common in unlogged indigenous forest. King (2005a) also states that stoats are comparatively more common in grassland habitats than weasels, with the reverse being true for forested habitats.

King *et al.* (1996c) found more hedgehogs than expected in unlogged indigenous forest and in the older plantation forest. A study by Haigh *et al.* (2012) on Irish hedgehogs determined that in a mixed agricultural landscape, hedgehogs preferred to forage in the open on arable land. While they had no forest areas for comparison, they found that the main driver of foraging location was the density of invertebrates that the hedgehogs prey on.

1.2.4 Monitoring of pest mammals in New Zealand

Historical Methods

Proper management of animal populations, whether for conservation or eradication purposes, requires a knowledge of their distribution and abundance (Keeping & Pelletier, 2014; Pickerell *et al.*, 2014; Rowcliffe *et al.*, 2008). It is often necessary to know not only where a target species can be found, but also how many of them there are. While there are several ways to go about collecting this information, some methods are better than others, and the effectiveness of the method depends on the target animal (Pickerell *et al.*, 2014).

One method is direct observation of the target species. Unfortunately, this is time-consuming, and may not work for all species. For example, an observer may not be able to accurately measure species that are nocturnal, or one that displays cryptic behaviour, so for these animals another sampling method may be more effective. Different observers might also detect the target species with varying accuracy, which will significantly impact results.

To determine actual density of a target species, the Mark-Recapture method may be used (Lecren, 1965). While the technology has changed significantly over the decades, the underlying principles are still the same. This method requires capturing a known number of individuals, and marking them before releasing them back into the population. When another sample is taken later, the total population can be calculated using $N = M*T/R$ where M is the number initially marked, T is the total individuals in the second sample and R is the number of marked recaptures (Lecren, 1965). One of the disadvantages of the mark-recapture method is the high labour costs involved. For each session, traps should be set for at least five nights, and a robust design should include at least three sessions

(Lettink & Armstrong, 2003). In addition, sampling session should be close enough together that immigration and emigration are unlikely (Lettink & Armstrong, 2003). While this method would work well for confined areas, assuming the above directions are followed, the cost associated with this method makes it impractical for nation-wide monitoring operations. A more important problem is the assumption that marked and unmarked animals will be equally liable to capture during the second session. If animals become trap shy after the first session, this condition will be violated.

Indirect measurements such as chew cards or tracking tunnels are a good way to indicate the presence or absence of some species such as rodents and possums (Pickerell *et al.*, 2014), and can even be used to create a relative density index. While these methods do not allow for individual recognition, it is assumed that a higher activity level is linked to higher densities, and this can be used to compare the relative abundance of a target species between sites (Pickerell *et al.*, 2014). As in the study by Gormley *et al.* (2015), using these methods it is possible to state that the target species is more abundant in 'habitat a' than in 'habitat b'. Unfortunately, there is often not enough data available to clearly define the relationship between these density indexes and the true abundance of the target species.

Another limitation of using indirect sampling methods such as tracking tunnels is the difficulty in distinguishing between the marks left by closely related species. Pickerell *et al.* (2014) used nine commonly-available techniques to detect the presence of mammalian predators in non-forested habitats, including a variety of tracking tunnels, hair tubes, wax tags, kill traps and manual searches, and found that the success of each method is highly species specific. Large tracking tunnels were best for detecting hedgehogs, wax tags were best for possums, and tracking tunnels and hair tubes were best suited to feral cats. Tracking tunnels were the only method that recorded all eight of the species present across their study area, but as found by (O'Donnell *et al.*, 2017), they were unable to distinguish between Norway and ship rats, and could not assign all mustelid tracks to a particular species with any certainty.

Much more accurate information can be obtained regarding distribution of the target species across the sampling sites, complete with confidence limits, when sampling stations are checked daily.

MacKenzie *et al.* (2002) developed a method of using binary presence-absence data to estimate site occupancy rates when the probabilities of detection were less than one. By using a sampling method that records multiple visits to each site, e.g., a camera location, detection probabilities can be estimated and occupancy rates i.e. the proportion of sites occupied, can be predicted and compared between study areas even when a species may not be detected at all sites.

Just because a species is not detected at a particular site on a given day is not proof of absence. Using the detection history of multiple sites across multiple sampling sessions, it is possible to calculate the likelihood that at least one individual of a given species is present. This likelihood can be defined as $P\ (h = 10101) = \Psi.(1 - p_1)p_2(1 - p_3)p_4(1 - p_5)$ where Ψ is the probability a species is present and p is the probability that, given that it is present, it will be detected on each day. This framework can also be modified to account for covariates. These may include attributes of the sites that may influence the probability a species is present, such as habitat type, or even daily variables such as weather conditions affecting the probability that a species may be detected on any given session.

Use of camera traps to monitor small mammals

More recently, technological improvements have allowed for the use of cameras to determine the presence of a target animal. At its most basic, a set of fixed cameras, triggered by motion sensors, take pictures of a passing animal. As with other passive detection methods, such as tracking tunnels, the number of photographs taken at a specific location gives an indication of animal abundance. If the target animals have markings that allow for individual recognition, this method can also be used to accurately determine the density of the target species. For these reasons, use of camera traps is a better alternative than other passive detection methods.

Camera trapping incurs low labour costs, is non-invasive, and can be used to monitor highly cryptic species and in difficult terrain where other field methods are likely to fail (Rowcliffe *et al.*, 2008).

Using a technique called site-occupancy analysis, the captured images can be turned into presence-absence data. Site-occupancy performs two functions 1) to determine the proportion of study sites occupied by the target species and 2) the probability that a site is occupied even if nothing was detected on a given day.

While using camera traps to determine the presence or absence of a species is relatively straightforward, turning these data into estimates of abundance is more complex. This is especially true for those species where recognition of specific individuals is impossible. Rowcliffe *et al.* (2008) created the Random Encounter Model for use in these cases. By using information such as movement speed and home range sizes for the target animals, as well as angle of detection for the cameras used, this model can estimate population sizes for these animals. Rowcliffe *et al.* (2008) emphasised three key assumptions for this model: (i) animals conform adequately to the model used to describe the detection process; (ii) photographs represent independent contacts between animal and camera; and (iii) the population is closed. For the Random Encounter Model to return accurate density estimates, care must be taken to ensure the camera traps are placed randomly with respect to the animal’s movement and that cameras are placed so that the same individual animals is unlikely to be recorded by multiple stations. Rowcliffe *et al.* (2013) later clarified that while animals do not move randomly, camera placement should be i.e. not clumped on wildlife tracks or near water holes.

Pickerell *et al.* (2014) did not use camera traps, but it is likely that if they had, these would have been the clear winner in their comparison. The problems they identified with the tracking tunnels would not have been a factor with using cameras. As there is no need for the animal to interact with the trap, it will be much less species-specific, and as photos are taken of the individuals, species identification would have been much more accurate.

With the Mark-Recapture method, or in fact any method that traps or kills individuals, there is the risk that a portion of the population become trap shy, which will impact the data collected from successive seasons. This is unlikely to be a problem with camera traps.

As with the data from other passive detection methods that record observations across multiple successive days, camera data can be transformed into presence-absence data and run through the framework outlined by MacKenzie *et al.* (2002) and later developed into a program called PRESENCE.

In addition to presence-absence data, much more information can be gleaned from said images, such as the number of discrete visits, as well as the timing of these visits. In some cases, it might even have been possible to identify individual animals.

1.3 Background to My Approach

1.3.1 Aims

The aims of this project are two-fold. First, to use camera traps to study the distribution of seven important mammalian pests across the three main vegetation types of the Waikato Region and to see if this method is a more informative alternative to other passive detection methods. Second, to use the data collected to provide information on which habitats are most important when targeting different pest species.

1.3.2 Objectives

1) To calculate the distribution of each mammalian pest within the three main vegetation types of the Waikato Region.
2) To determine site occupancy i.e. patchiness of species distribution within these habitats, and the probability of detection where they are present.
3) To evaluate whether the above parameters are influenced by the seasons and/or interactions between the species.

1.4 Hypotheses

I have developed five null hypotheses for testing to meet the objectives listed in 1.3.2 above. These hypotheses are formally listed in 1.4.1 below. They provide the formal tests necessary to meet my objectives.

I also had two questions regarding the sensitivity of the results obtained from the camera trapping, listed as research questions in 1.4.2.

1.4.1 Null hypotheses

1) That similar habitats of the same type have similar species composition.
2) That there are no detectable differences in species distribution between different habitat types.
3) That species distribution within habitats are uniform, and there are no significant differences in detection at different points within each habitat.
4) That there are no changes in the detectability of a particular species at a given camera site within the sampling period.
5) Species distribution and abundance are not affected by the seasons.

1.4.2 Research Questions

1) Can camera traps be used to determine differences in the levels and/ or periods of activity of small mammals, when not individually identifiable?
2) Can camera traps be used to study the effect of the presence of other species on target species distribution and abundance?

1.5 Expected Outcomes

I expect that this study will provide information on the use of different habitat types by a range of small mammalian pest species.

I expect this study will provide valuable information on the co-existence of different species across a number of habitat types.

I expect this study will provide more information regarding seasonal changes for a number of species under different habitat conditions.

I expect this study will provide valuable information regarding areas and/or habitat types to be a priority target for pest control projects.

I expect this study to provide an indication of the total proportion of the Waikato Region that are occupied by each target species.

I expect this study will show if using camera traps is a viable method to monitor small mammal populations on the way to a pest-free New Zealand.

Chapter Two

Methods and Materials

2.1 Overview

In this chapter I start with a brief explanation of the development of my chosen methods. In the second part of this chapter I provide a detailed description of the process of selecting camera sites and of the study areas, their location and main features.

In the third part I then provide a detailed description of the materials used and how they were set up across the study areas to collect the data required on species abundance and distribution.

The final section of this chapter provides a comprehensive account of how the data collected for each species were catalogued, sorted and analysed.

2.2 Development of Null Hypotheses

The first two hypotheses relate to my first objective: to calculate the distributions of each mammalian pest species with regards to the main vegetation types of the Waikato Region. The first of these simply examine the data collected from the camera traps to determine if the species detected in each area are comparable with the replicate area of the same habitat type. The second tests for differences between habitat types. Are there differences in the numbers and composition of species observed in different habitats, or can all species be found in all habitats?

The third and fourth hypotheses relate to my second objective: to determine site occupancy, i.e. patchiness of distribution within these habitats, and the probability of detection if they are present. As the array of study sites can observe only a small proportion of each habitat type, assumptions will have to be made regarding the relevancy of the results to the wider Waikato Region and beyond. It is therefore important to know whether the distribution of the target species is consistent throughout a particular habitat, or whether species presence is determined by more factors than just general habitat type. This is tested for by my third hypothesis. The fourth hypothesis tests whether there are changes in the detectability of small mammals at a given trap site within each season. Does detectability change over time; are there differences in detectability for the different target species? While camera traps are less labour intensive than many other monitoring methods, they still need to be left on station for long enough that all target species can be detected if they are indeed present. To make camera trapping as effective and efficient as possible, cameras need to be on station for the least amount of time possible. This will allow more study areas to be sampled within a given season.

The final hypothesis tests whether any of the measured parameters of composition, distribution, abundance, and detectability vary significantly with the seasons. Are there significant trends, and are these consistent across species and habitats?

2.3 Method Development

This study aims to investigate the distribution and numbers of each of the seven target species in three of the main habitat types of the Waikato Region. This requires more than just knowing where the species are present within these habitats.

As outlined in Chapter One, cameras collect a large amount of data on animal behaviour beyond simple presence-absence. In addition, camera traps do not require an individual animal to interact with the trap, as is the case with live-capture and kill-traps, resulting in better detection probabilities for cryptic and trap-shy individuals (Rowcliffe *et al.*, 2008). De Bondi *et al.* (2010) showed that camera trapping and live trapping of small mammals in Australia produced similar results, but that camera trapping was much more cost-effective. In addition, the cameras were more effective in recording the presence of three of my target species that were included in the Australian study. The other four are either not present in Australia at all, or were not detected by either method.

During their study, De Bondi *et al.* (2010) found that seven days were sufficient to detect all but one of the thirteen species visiting their sites, with house mice and ship rats detected in two days and brushtail possums in four. To collect enough data for site-occupancy analysis, and to ensure that all species were detected if present, I decided that my cameras should be set for at least ten days per sampling period. After analysing the results from my first set of sites, I decided that a two week sampling period would fit better. This reasonable minimum also ensured that all sites could be sampled within a given season.

I used lures to attract animals to my camera set-up. While this precludes the calculation of population sizes, for reasons described by (Rowcliffe *et al.*, 2008), there are benefits to this strategy as well. The main assumption used in the calculation of population sizes from camera trap data is that photographs represent independent contacts between animal and camera, and by using lures, this assumption is not met. The benefits of using lures include attracting more individuals to the camera sites, and increased the time they spent in the area, thereby increasing the probability of their being detected. The use of lures was especially important for the mustelid species. With their low population numbers, they would otherwise have shown up in too few occasions to be useful for analysis, or not at all. In addition, having individuals stationary in front of the camera while they are interacting with the lure, allows for better species identification.

As outlined in 2.6, I used four different camera models to collect my data. This is not ideal, as the different models have different specifications (Table 2-1). However, the camera set-up and data analyses were designed to minimise the differences in the number of records from each camera (see 2.9.1

Site-occupancy analysis assumes that sites are independent of each other, and that the same individual is not present at multiple sites. Therefore, I had to space the cameras far enough apart to reduce the probability of failing to meet this assumption, while still allowing for adequate coverage of the habitat. This becomes problematic when dealing with multiple species, as home range sizes vary significantly. Even within species, home range size varies with sex, habitat, and population density.

Clout and Sarre (1997) found that possums in pine forests had a home range of 0.2 – 1.4 ha, with little difference between sexes. In contrast, (Whyte *et al.*, 2013) found that possum home rage size across mixed forest and pasture areas ranged from 1.8 ha at a high density to 12.0 ha at low density for males, and 1.2 to 7.7 ha for females.

Rats in tawa-dominated indigenous forest had home ranges of 1.1 ha for males and about a third of that for females (Hooker & Innes, 1995). In beech forest, home ranges were much larger, reaching 7.5 – 11.4 ha for males and 0.27 – 0.89 ha for females (Pryde *et al.*, 2005).

It would be impossible to optimise the camera layout equally for all species and habitats, so I have chosen to optimise for ship rats, as they are by far the most common of the target species, and the only species present at all sites. Hence, the cameras were spaced 500m apart.

Figure 2-1 Location of the Waikato region that is the focus of this study.

The Waikato Region is the fourth largest local authority region in the country. It covers most of the central North Island (approximately 25,000 km^2, or 2.5 million hectares), and it has 1,138 km of coastline. The region stretches from the Bombay Hills and Port Waikato in the north, south to Mokau on the west coast, across to the slopes of Mt Ruapehu and the Kaimai Range, and northeast to the Coromandel Peninsula (Figure 2-1).

While the majority of the vegetation in the Waikato Region is high production pasture, there are still many other vegetation types scattered throughout the region. Due to the time and resource constraints on this study, it would have been impossible to sample either all of the vegetation types in the region, or large proportion of the total area. I therefore had to prioritise not only the vegetation types to target for this study, but also select which of the sites of those particular types to use.

To determine which habitats that I should focus on for this study, I used the New Zealand Land Cover Database (LCDB). The LCDB is a multi-temporal, thematic classification of New Zealand's land cover. It defines 33 land cover classes for mainland New Zealand. The data set is designed to complement in theme, scale and accuracy, the 1: 50,000 topographic database published by Land Information New Zealand. LCDB is suitable for use in national and regional state-of-environment monitoring, forest and scrubland inventory, biodiversity assessment, trend analysis and infrastructure planning. A summary of the extent of land covered by each class as of 2015, along with the definitions for each class will be included in the appendices following this text, and is available as an attachment to this dataset in the LRIS portal (lris.scinfo.org.nz) and on the LCDB project site (www.lcdb.scinfo.org.nz). LCDB v4.1 was released in July 2015 and includes corrections to all time steps 1996/97, 2001/02, 2008/09 and 2012/13.

2.4 Selection of Study Areas

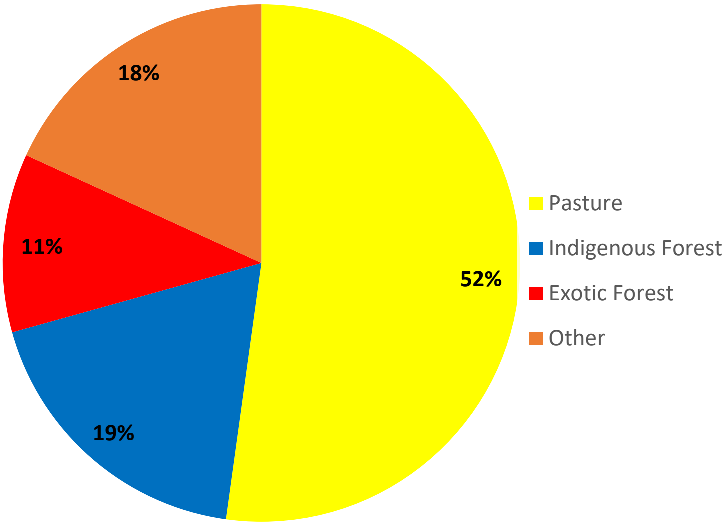


Figure 2-2 Breakdown of the vegetation types of the Waikato region showing the three largest vegetation types.

According to the LCDB, 82% of the vegetation in the Waikato region is composed of only three vegetation types: 52% is classed as high production grassland, 19% is still indigenous forest, and a further 11% consists of exotic forest such as pine plantations (Figure 2-2).

Once I identified the main vegetation types, I grouped all fragments by size. I then selected sampling sites with help from Environment Waikato to ensure that they suitably represent each habitat type in the region. To provide increased accuracy during the analysis and interpretation of the results, I selected two sites of each habitat type for monitoring. In addition, I selected a small fragment of native bush to investigate any possible difference in species composition between large tracts of protected indigenous forest and the much smaller forest fragments commonly found on Waikato farmland (Figure 2-3).

2.5 Study Areas Descriptions

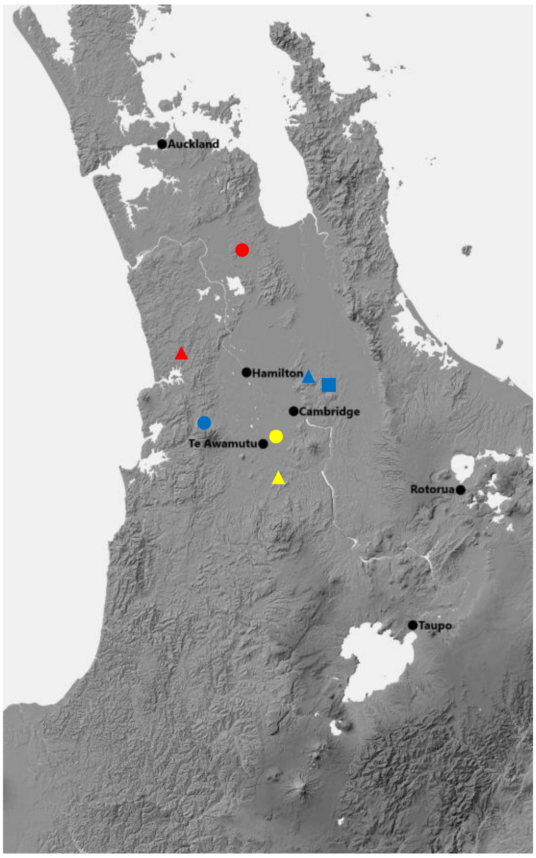


Figure 2-3 Map of the Waikato Region showing the main population centres and study sites. Pasture areas are depicted in yellow, indigenous forest in blue, and pine forest in red.

2.5.1 Pasture North

This area samples two dairy farms north-west of Te Awamutu, and consists of entirely flat land divided by drainage channels. Very few trees or shrubs are present, mostly limited to the northern border of the farms. During the autumn and summer seasons, two cameras were located close to maize stands.

2.5.2 Pasture South

This area samples another dairy farm, about 25 km South of Pasture North. Consisting of low, rolling hills, this site features no drainage channels, but with more trees and shrubs, and two gullies run through the site.

2.5.3 Pirongia Forest Park

This area samples part of Pirongia Forest Park, a 13,500 ha podocarp forest 25 km east of Te Awamutu. The cameras were set up just off the Bell track, on the north-western slope of Mount Pirongia, between 120 and 520 metres in elevation. This is the only area where the cameras were not placed in a grid layout, due the steepness and inaccessibility of the terrain.

2.5.4 Te Tapui Scenic Reserve

This area samples the northern section of the 2310 ha Te Tapui Scenic Reserve, approximately 40 km north-east of Te Awamutu. The cameras were set up in a grid centred on the track to the summit. Cameras were placed between 160 and 440 meters in elevation, starting 600 meters from the edge of the forest, with the last cameras just past the summit.

2.5.5 Te Miro Forest Fragment

This area is a small forest fragment just east of the Te Tapui Reserve, selected to compare with the larger indigenous forest areas. Surrounded by farmland, the forest fragment is only 5 ha and contained only five cameras, spaced 100 metres apart along the centre of the fragment. This fragment has been studied before (labelled Fragment 2 in (King *et al.*, 2014; King *et al.*, 2011)), so there is a large amount or prior information about the rats living there.

2.5.6 Brooklands Forest Estate

This area is located 50 km North-West of Te Awamutu, in a 1200 ha *Pinus radiata* plantation, planted 2001. Twice yearly pest control is conducted here, in autumn and spring, using both cyanide and 1080.

2.5.7 Maramarua Forest

This area is located 80 km North of Te Awamutu within a 1200 ha *Pinus radiata* plantation, planted in 2001. The last pest control operation was an aerial drop of 1080 in 2014.

2.6 Cameras

I used thirty-two cameras, split into two groups of sixteen to allow for the monitoring of two areas simultaneously. The specifications of the cameras used are compared in Table 2-1.

Table 2-1 Camera specifications

	Browning Strike Force HD	Bushnell Trophy Cam HD	Bushnell Trophy Cam	Trail
Number available	22	4	4	2
IR flash range	17 m	18 m	15 m	20 m
Detection range	30 m	18 m	15 m	20 m
Trigger speed	0.67 sec	0.20 sec	1.00 sec	1.00 sec
Image resolution	10 MP	8 MP	5 MP	12 MP
Firing speeds	2-8 @ 2 secs	1-3 @ 1 sec	1-3 @ 1 sec	1-3 @ 1 sec
Rapid Fire	1-8 @0.3 secs			
Recovery time	1.5 secs			
Viewing angle	55 degrees	45 degrees	50 degrees	55 degrees

While the use of a single camera model would have been preferred, I decided that ten additional cameras would be more useful, provided they were properly calibrated. The need for calibration between cameras was found after the first sampling session, when images from the four Bushnell Trophy Cam HD cameras taken at short distance and at night were completely unusable. After the cameras were fully calibrated I could find no appreciable difference between them in the results obtained. Using the additional cameras allowed me to increase my study area by almost 50%.

One of the main differences between camera models was the interval between images captured in a rapid-fire configuration. While this could, in some circumstances, have a significant impact on the results obtained, for the purposes of this study, this was not a significant issue (See 2.9.1).

After the first session in autumn of 2016, I decided to lengthen the recording sessions from 10 to 14 days, to ensure all species present were detected.

2.6.1 Camera Setup

Figure 2-4 Camera set-up in pine forest and pasture

At each study area, up to sixteen cameras were set up in a grid layout with a five hundred meter spacing between adjacent cameras. Ideally, cameras were set out in a four by four grid, but this was not possible at every site. At each camera site, cameras were secured to a suitable tree or fencepost, approximately one hundred and thirty centimetres above the ground. Cameras were placed horizontally facing the ground, focussed on approximately 0.5 m^2 visible at the foot of the tree or fencepost.

The exception was in the Te Miro forest fragment, which had room for only five cameras spaced one hundred meters apart.

Each camera was set to capture images at an 8 MP resolution when triggered by motion around the lures. The 4 Bushnell Trophy Cam cameras were set to their highest setting of 5 MP. Cameras were set to trigger three times in rapid succession with a cooldown of thirty seconds before it could be triggered again. All cameras were set to their maximum trigger sensitivity and flash strength, except the four Bushnell Trophy Cam HD cameras where the flash was set to the minimum strength.

2.7 Lures

I used two lures to attract target species to the camera traps, both supplied by the Goodnature Company, Wellington.

Rodent Detector Cards are normally used in combination with the Goodnature A24 rat traps to detect the presence of rodents prior to selecting trap locations. They contain a long-lasting non-toxic lure adjacent to a scratch sensitive surface, from which several species can be identified from tooth marks. While the cards were not used for this purpose, it is possible to use them to determine whether rats, mice, possums or hedgehogs were present in the area surrounding the detector card.

The second lure used was the Goodnature stoat lure, another long-lasting non-toxic lure composed primarily of rabbit meat. These lures are formulated to last up to a month, to be safe around pets and birds and to be water resistant and stable across a range of different climatic conditions. While this lure is primarily focused on attracting stoats, it will also attract weasels and ferrets, as well as rats.

Between the two Goodnature lures used in this study, all the target species should be reliably attracted to the camera traps if they are present at the study site.

The two lures were placed at the bottom of the tree or fencepost. First, the Goodnature Rodent Detection Card was attached to the tree approximately ten centimetres above ground level, as per Goodnature recommendations. Second, approximately two grams of Goodnature stoat lure was applied directly to the tree just above the card, using a teaspoon to smear the material into a circle three to five centimetres across.

2.8 Data Collection

Data for this study were collected over twelve months from March 2016 to February 2017, with a total of four sessions for each study area. Each of the four sets of records was collected to correspond to the seasons, with the first set collected between March and June (autumn), the second set from June to August (winter), the third set from September to November (spring) and the final set from December to February (summer). Data were collected from two areas at a time to ensure that all study areas were surveyed once within each season, as well as to allow for some time between the final sampling of one season and the first sampling of the following season.

Cameras were set up as above and left in place for two weeks at a time to ensure that the cameras recorded all target species, if they were present in the area. At the end of the sampling period, the cameras were removed, images downloaded and batteries replaced before the cameras were moved to the next study areas.

2.9 Data Analysis

2.9.1 Excel Species Databases

I sorted the images by season, camera site and camera, and inspected them to determine the species recorded. For each image, I recorded the camera number, date, time, and species detected in a Microsoft Excel Workbook, with separate workbooks for each session. Within each workbook, I set up six sheets for each camera at that site, summarising the information:

1. Summary – a summary of the totals for all species recorded on all cameras. Uses formula = Table1[[#Totals],[Possum]].
2. Images Summary – the number of images for each target species sorted by date.
   Uses formula =COUNTIFS('Cam 1'!$H:$H,1,'Cam 1'!$B:$B,C$1).
3. Presence or Absence – a binary representation of Images Summary where any detections are represented by ‘1’ and no detections represented by ‘0’. Cases where no data were available either way were denoted by a ‘-’. Uses formula =COUNTIF('Images Summary'!C2,">0") which displays a 1 when the same cell on the previous sheet has a value greater than 0.
4. Activity Visits – the number of images for each target species sorted by date, and limited to images taken at least 15 minutes after the one before.
   Uses the formula =SUMIFS('Cam 1'!$H:$H,'Cam 1'!$H:$H,1,'Cam 1'!$B:$B,'Activity Visits'!C$1,'Cam 1'!$G:$G,">0.01042").
5. Images Hourly - the number of images for each target species sorted by hour it was taken.
   Uses the formula =COUNTIFS('Cam 1'!$H:$H,1,'Cam 1'!$C:$C,C$1).
6. Activity Visits Hourly - the number of images for each target species sorted by hour it was taken, limited to images taken at least 15 minutes after the one before.
   Uses the formula =SUMIFS('Cam 1'!$H:$H,'Cam 1'!$H:$H,1,'Cam 1'!$C:$C,'Activity Visits Hourly'!C$1,'Cam 1'!$G:$G,">0.01042").

Pre-analysis sorting of images was set up in such a way as to record the presence of a species only once per trigger, regardless of whether it was present in one, two or all three images taken at each trigger event. Combined with the lures that encourage each individual to remain stationary in front of the cameras, this is the reason that the slight differences between cameras in trigger speed were of no consequence.

2.9.2 PRESENCE and Site Occupancy

The binary presence-absence data constructed for each species as outlined above were then used to determine site occupancy using the analysis program PRESENCE.

Types of models

Throughout the rest of this thesis, I will be using the notation of MacKenzie *et al.* (2002) when naming different models. In addition, study area denotes the different habitats studied, while site refers to the location of each camera within the study areas. The probability that a site is occupied by at least one (unidentified) individual of a given species is represented by 'Ψ', while the likelihood that that species is detected on a given day, given that it is present, is represented by a lowercase 'p'. p_i is used to denote the probability of detecting the species in the i^{th} survey. An uppercase 'P' is used to denote the probability that a species is detected over the entire study period.

When naming a model, the parameters used to estimate each variable are inserted into brackets following the variable. A full stop indicates a constant, t indicates time and T indicates a trend. The name of the covariate may also be included. For example, $\Psi(.)p(.)$ would be a model with constant occupancy and constant detectability; $\Psi(gully)p(rain)$ indicates a model where occupation varies depending on the characteristics of the site (i.e. is it a gully or not), and detectability is dependent on whether or not it rained on that particular day.

MacKenzie *et al.* (2002) present a model for estimating the site occupancy probability for a target species where detection probability is less than one i.e. there is no guarantee that it will be detected even when present. They use a probabilistic argument to describe the observed detection history for a site over a series of surveys. For example, the probability of observing the history 1001 (denoting the species was detected in the first and fourth surveys of the site) is:

$\Psi \times p_1(1-p_2)(1-p_3)p_4$.

The probability of never detecting the species at a site (0000) would therefore be,

$\Psi \times (1-p_1)(1-p_2)(1-p_3)(1-p_4) + (1-\Psi)$,

which represents the possibilities that either the species was there, but was never detected, or the species was genuinely absent from the camera site ($1-\Psi$). By combining these probabilistic statements for all N sites, maximum likelihood estimates of the model parameters can be obtained.

The model framework of MacKenzie *et al.* (2002) allows for missing observations: occasions when a site was not surveyed. Missing observations usually resulted from faulty cameras where no data were collected at all. This does not include occasions where no data were collected but the camera was definitely working. In effect, a missing observation supplies no information about the detection or non-detection of the species, which is exactly how the model treats such values. Two key assumptions of single-season models are that all parameters are constant across sites and that occupancy state of the sites does not change for the duration of the survey.

The model also enables parameters to be functions of covariates. For example, the probability of occupancy may be a function of habitat i.e. is there water nearby, or is understory vegetation present? Detection probability is a function of environmental conditions, such as whether it rained or not. The model therefore allows relationships between occupancy state and site characteristics to be investigated.

The multiple-season model (MacKenzie *et al.*, 2003) extends the single-season model by introducing two additional parameters, ε_t and γ_t. These parameters are, respectively, the probability a species becomes locally extinct or colonizes a site between seasons t and t+1.

For example, if the detection history 101 000 was observed over two consecutive seasons at the same site (denoting that the species was detected in the first and third survey of the site in the first season; not detected otherwise), the probability of this occurring could be expressed as:

$\Psi \times p_{1,1}(1-p_{1,2})p_{1,3} \times ((1-\varepsilon_1)\ (1-p_{2,1})\ (1-p_{2,2})\ (1-p_{2,3}) + \varepsilon_1)$.

In this case, the species may either still be present in the second season but avoiding detection, or it may have gone extinct.

Within each of these model types, there is a variety of models that can be used, depending on the parameters of the study and the data available. For example, the multi-method model (Nichols *et al.*, 2008) extends the single-season model by allowing different detection probabilities for different methods of observation.

The spatial dependence model assumes that sampling stations are not independent, such as when sampling is done along a track, where the stations closer together will be more similar than those further apart. Another model is the false-positive detection model (Miller *et al.*, 2011), which relaxes the assumption that a species will not be detected if it is not present. Neither of these models fit the data for this study.

The two-species model (MacKenzie *et al.*, 2004) extends the single-season model in another way by allowing the computation of occupancy parameters of two species along with conditional probabilities of occupancy when the other species is present or detected.

I tested the multi-season model, but this did not provide the information I needed. Instead, I used the basic single-season to calculate probability of occupancy for each of my camera sites. Within each model, I also tested for different variations in occupancy and detectability.

For each species, I then selected the model with the lowest AIC score to create a graphical representation of species distribution, as it is the one most likely to represent reality accurately. Where the ΔAIC value of multiple models was less than two, these models were deemed significant, even if they were not the best model.

The advantages of Site-Occupancy Analysis with PRESENCE software were:

- Does not require individual counts, only species presence;
- Can estimate site-occupancy of sites despite gaps in the data series;
- Correlated with abundance, so can be used to monitor population trends;
- Analysis of occupancy and detectability covariates is an integral part of the model;
- Allows for statistical analysis of how target species are influenced by the presence of other species at each site;
- Allows for analysis across multiple seasons, including the possibility of extinction and/or colonisation.

The limitations of Site-Occupancy Analysis and PRESENCE software were:

- All parameters must be constant across sites or modelled with covariates, because un-modelled heterogeneity in detection probabilities will cause occupancy to be underestimated;
- Model assumes sites are independent, so it requires careful consideration of site placement.

2.9.3 Activity Levels and Active Period

For each species, activity was graphically represented per study area per season. The first of these graphs shows the total number of visits recorded at each site. The second shows the total number of visits each species made to the cameras during each hour of the day. In both cases, separate visits are defined as separated by at least 15 minutes, and expressed per 100 camera nights.

Chapter Three

Distribution and Activity Levels of Brushtail Possums in Three Waikato Vegetation Types

3.1 Overview

In this chapter I will be testing my five hypotheses as they relate to brushtail possums in the Waikato Region. I will compare five different parameters of the possum populations at my study areas and how they vary with respect to habitat type (pasture, indigenous forest, and pine forest) and season.

In section 3.2 I investigate their distribution within each study area as detected by the cameras, as well as the site occupancy and probability of detection in each area as calculated by PRESENCE.

In section 3.3 I use the data collected from the time-stamped images to display the period of activity within each habitat. In addition, I investigate the number of visits, plotted against time, and provide an overall visit count for each area and season.

I will then discuss my results and whether or not it supports my hypotheses, concluding with an evaluation of my hypotheses and research questions as they relate to possums.

3.2 Distribution and Site Occupancy

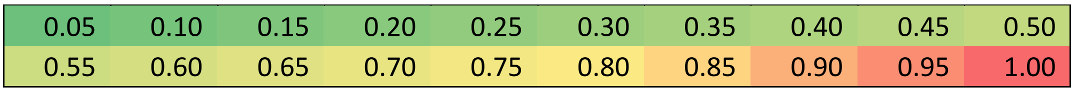
3.2.1 Results

Site Occupancy

For each study area and season, a separate analysis of site occupancy was run using PRESENCE, and the results are reported in the tables below. Each cell contains two values, with the upper value being the calculated estimate for site occupancy Ψ, and the bottom value being the naïve occupancy, i.e. the raw proportion of sites where possums were detected by the cameras. The difference between them illustrates how unreliable simple observation can be in estimating the real distributions of animals.

Each table also contain a visual representation of possum distribution, with the ¤ symbol showing where possums were positively identified. The colour of each cell represents the likelihood that possums are present at the site even if none was not detected. Solid green represents a probability of 0, while red indicates a probability of 1 (Table 3-1).

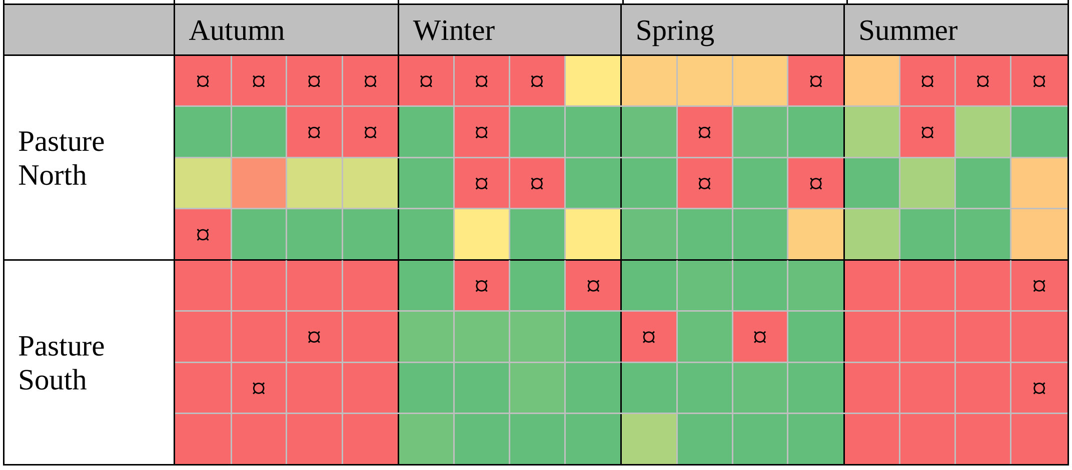
Table 3-1 Key to tables depicting site occupancy at each of the study areas. The different colours represent the estimated probabilities that a site is occupied, even if no possums were detected.



0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00

Table 3-2 Site occupancy estimates of the two pasture study areas.

	Autumn	Winter	Spring	Summer
Pasture North	0.55 0.58	0.46 0.46	0.40 0.33	0.41 0.31
Pasture South	1.00 0.13	0.15 0.14	0.15 0.17	1.00 0.15



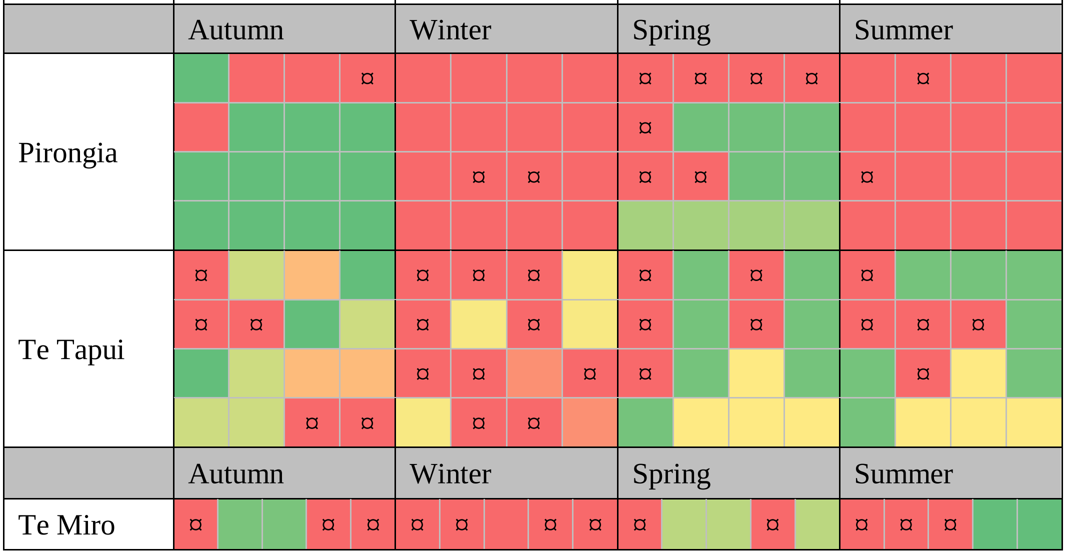
	Autumn				Winter				Spring				Summer			
Pasture North	¤	¤	¤	¤	¤	¤	¤					¤		¤	¤	¤
			¤	¤		¤				¤				¤		
						¤	¤			¤		¤				
	¤															
Pasture South						¤		¤								¤
			¤						¤		¤					
		¤														¤

Estimated occupancy probabilities were more consistent at Pasture North than Pasture South (Table 3-2). Occupancy at Pasture North trended downwards from autumn to spring, with summer being lower still, although not as significantly. A visual representation of where possums where recorded shows that while the site occupancy values stayed reasonably constant, the sites where they were recorded did not.

The occupancy estimates for Pasture South were highest for the autumn and summer months, when Ψ estimated complete coverage, compared the other seasons. Surprisingly, while the estimated occupancy was much higher, the naïve occupancy rates were much more consistent, and among the lowest of all my study areas.

Table 3-3 Site occupancy estimates of the three indigenous forest areas.

	Autumn	Winter	Spring	Summer
Pirongia	0.25 0.07	1.00 0.15	0.57 0.58	1.00 0.15
Te Tapui	0.53 0.38	0.84 0.71	0.45 0.42	0.45 0.42
Te Miro	0.64 0.60	1.00 1.00	0.63 0.40	0.60 0.60



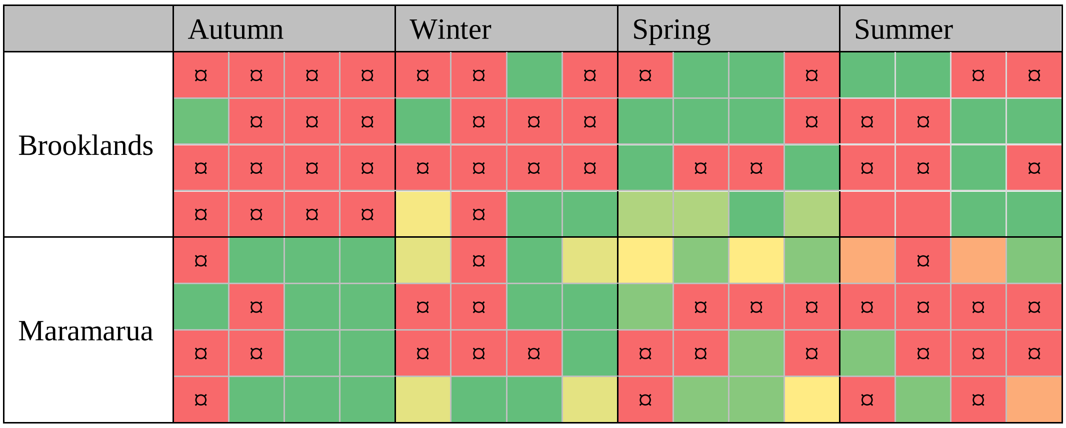
	Autumn				Winter				Spring				Summer			
Pirongia				¤					¤	¤	¤	¤		¤		
									¤							
						¤	¤		¤	¤			¤			
Te Tapui	¤				¤	¤	¤		¤		¤		¤			
	¤	¤			¤		¤		¤		¤		¤	¤	¤	
					¤	¤		¤	¤					¤		
			¤	¤		¤	¤									

	Autumn					Winter					Spring					Summer				
Te Miro	¤			¤	¤	¤	¤		¤	¤	¤			¤		¤	¤	¤		

Pirongia was like the Pasture South area in that possum occupancy was estimated by the model to be complete during two seasons while the naïve occupancy rate was only 0.15. Te Tapui and Te Miro were quite similar in their occupancy rates. Both areas found occupancy to be highest in the winter, by both measures. Once again, spring and summer values were not significantly different. A visual representation confirms that while possums occupied some sites at all seasons, possums also visited most other sites intermittently (Table 3-3).

Table 3-4 Site occupancy estimates of the two pine forest study areas.

	Autumn	Winter	Spring	Summer
Brooklands	0.94 0.94	0.73 0.73	0.38 0.38	0.50 0.56
Maramarua	0.32 0.31	0.50 0.50	0.61 0.54	0.80 0.77



	Autumn				Winter				Spring				Summer			
Brooklands	¤	¤	¤	¤	¤	¤		¤	¤			¤			¤	¤
		¤	¤	¤		¤	¤	¤				¤	¤	¤		
	¤	¤	¤	¤	¤	¤	¤	¤		¤	¤		¤	¤		¤
	¤	¤	¤	¤		¤										
Maramarua	¤					¤								¤		
		¤			¤	¤				¤	¤	¤	¤	¤	¤	¤
	¤	¤			¤	¤	¤		¤	¤		¤		¤	¤	¤
	¤								¤				¤		¤	

Occupancy at Brooklands declined across the seasons. The biggest difference was that where possums are usually scarcer in summer than in spring, here they were significantly more often found in that season. Maramarua was the only area where possum occupancy increased steadily across the study period, but only one or two sites had possums year-round (Table 3-4).

Detectability

Several models were run on PRESENCE to determine the probability of possums being detected given that they were present at the different areas and seasons. Each of the following tables shows the most likely model for each area, along with the probability of possums being detected (P) over the sampling period. Where rain was a co-variate for detection over the sampling period, two probabilities were given for that season. The first probability is for days without rain, while the one in brackets is for days where rain was recorded.

Table 3-5 Results from PRESENCE analysis of pasture study areas showing the best models and P values for each season.

Pasture Areas	Autumn	Winter	Spring	Summer
North	Ψ(bush)p(.) P=0.43	Ψ(.)p(.) P=0.48	Ψ(drain)p(.) P=0.26	Ψ(drain)p(.) P=0.12
South	Ψ(.)p(.) P=0.01	Ψ(bush)p(.) P=0.12	Ψ(bush)p(.) P=0.21	Ψ(.)p(rain) P=0 (0.04)

Detection probabilities for possums were higher at the northern area than at the southern area across all seasons. Possums were more detectable in the winter and spring compared to autumn and summer. No particular model was best for all seasons. All but one had a constant probability of detection, and rain increased the probability of detection only at Pasture South (Table 3-5).

Table 3-6 Results from PRESENCE analysis of indigenous forest study areas showing the best models and P values for each season.

Indigenous Forest	Autumn	Winter	Spring	Summer
Pirongia	Ψ(gully)p. P=0.02	Ψ(.)p(.) P=0.01	Ψ(gully)p(rain) P=0.22 (0.09)	Ψ(.)p(.) P=0.01
Te Tapui	Ψ(gully)p. P=0.10	Ψ(.)p(.) P=0.13	Ψ(.)p(.) P=0.17	Ψ(.)p(.) P=0.17
Te Miro	Ψ(.)p(.) P=0.18	Ψ(.)p(rain) P=0.00 (1.00)	Ψ(.)p(rain) P=0.00 (0.11)	Ψ(.)p(.) P=0.50

Possums were much less likely to be detected in the Pirongia indigenous forest area than at Te Tapui, in all seasons except in spring. Detection probability was constant in three quarters of the models, including (by contrast with pasture) the winter and spring months. The only detections at Te Miro were made on rainy days, but not at Pirongia, which had a much higher detection probability on days with no rain. Overall, indigenous forest areas had the lowest detection probability of all the study areas (Table 3-6).

Table 3-7 Results from PRESENCE analysis of pine forest study areas showing the best models and P values for each season.

Pine forests	Autumn	Winter	Spring	Summer
Brooklands	Ψ(.)p(.) P=0.33	Ψ(.)p(rain) P=0.52 (0.37)	Ψ(.)p(.) P=0.40	Ψ(gully)p(.) P=0.27
Maramarua	Ψ(.)p(.) P=0.24	Ψ(.)p(.) P=0.33	Ψ(.)p(.) P=0.15	Ψ(.)p(.) P=0.21

Possums were more likely to be detected at my pine forest areas than in other habitats. All pine forest areas but one had a constant probability of detection, and only once did rain have a noticeable effect on detection probabilities. At Brooklands, rain decreased the probability of detection, although detectability across all seasons were still higher than for Maramarua. Brooklands was also the only area where the probability of possums being detected was higher than 0.50 (Table 3-7).

3.3 Active Period and Activity Levels

3.3.1 Results

Active Period

At the northern pasture area, almost ten times the number of possum visits were recorded compared with the southern area. Even so, the main period of activity was very similar, between 7.00 pm and 4.00 am, with a peak at 1.00 am. Visits at Pasture North were evenly spread across the night. In general, summer activity seemed to start later than the other months (Figure 3-4).

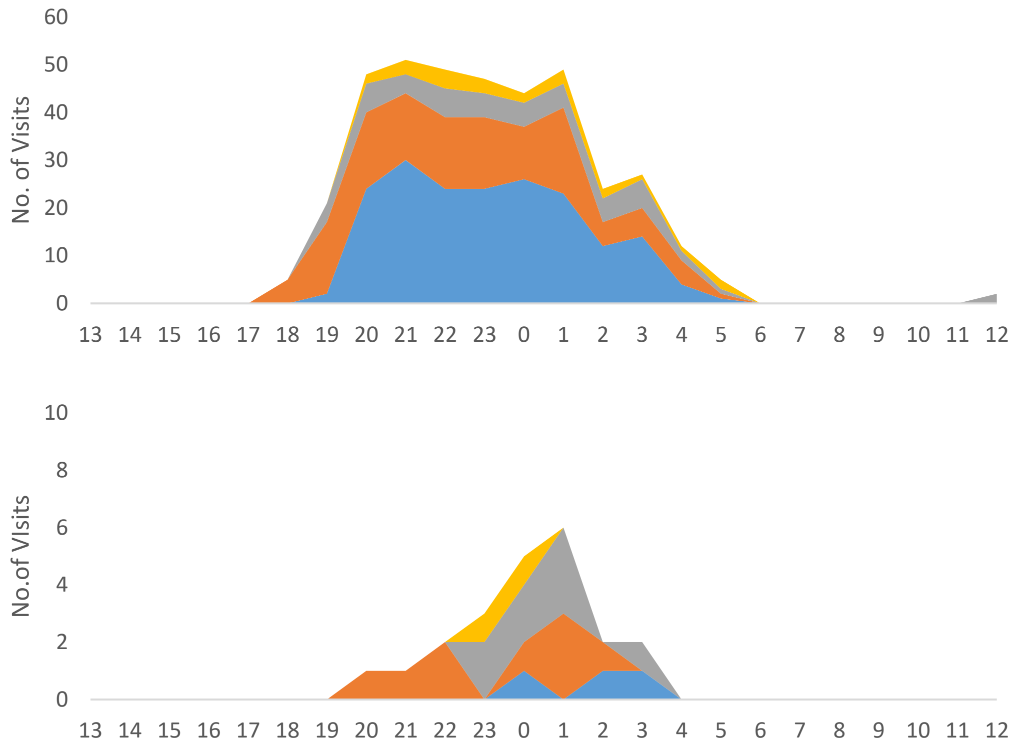


Figure 3-1 Number of possum visits recorded at Pasture North (top) and Pasture South (bottom) in each season plotted against time of day. Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

Possum visits to my three indigenous forest areas, Pirongia, Te Tapui and Te Miro, were similar overall, although Pirongia had about half the visits of the other two. A higher proportion of visits was made earlier in the afternoon and later in the mornings. While the lower visit counts make calculating exact activity periods difficult, visits peak three times at each of the sites, and at approximately the same times. In general, summer activity seemed to start later than the other months (Figure 3-5).

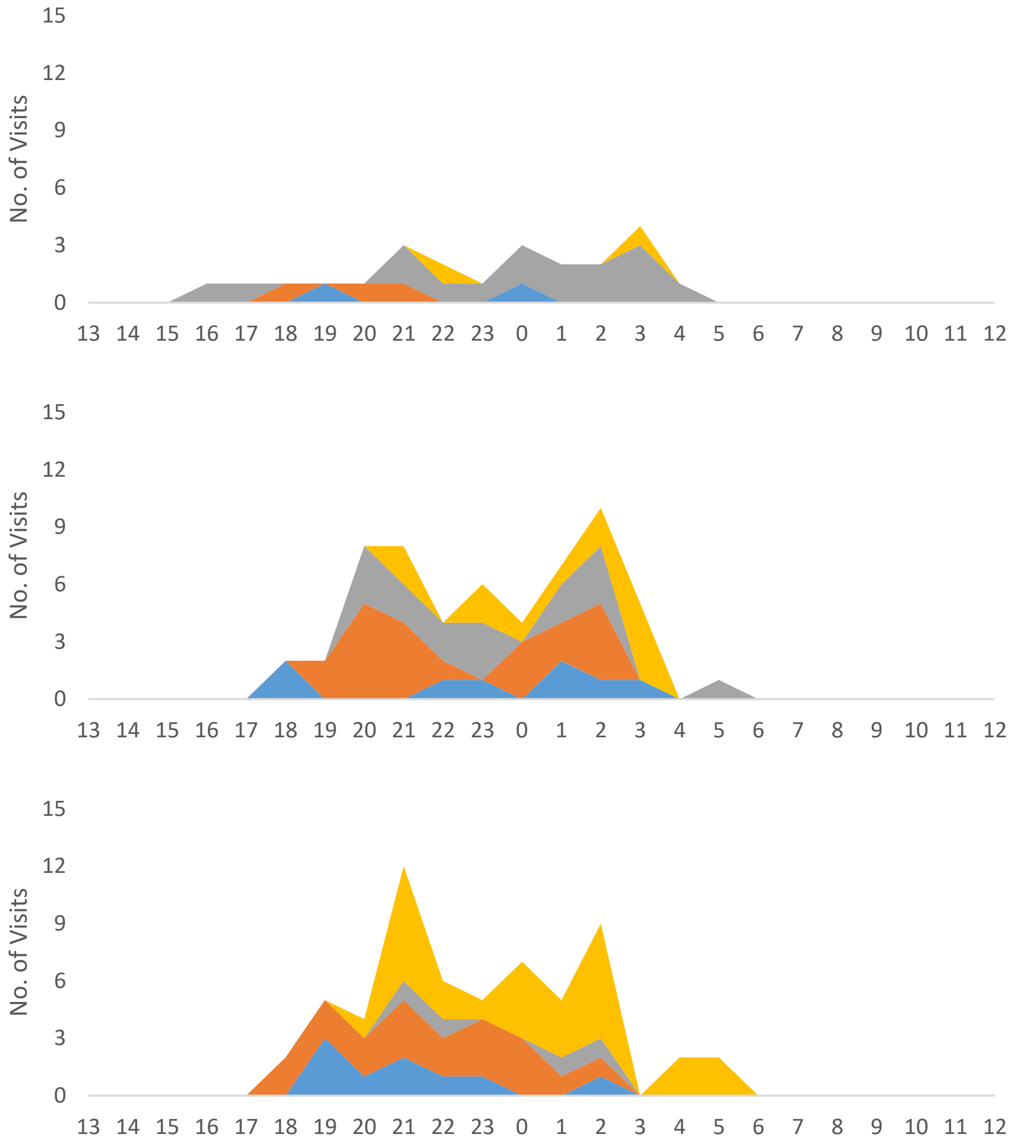


Figure 3-2 Number of possum visits recorded at Pirongia (top), Te Tapui (middle) and Te Miro (bottom) in each season plotted against time of day. Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

Brooklands recorded approximately double the number of visits of Maramarua, but at similar times of day. The pattern is similar to that of the indigenous areas, but without the activity spike around midnight. In general, summer activity seemed to start later than the other months (Figure 3-3).

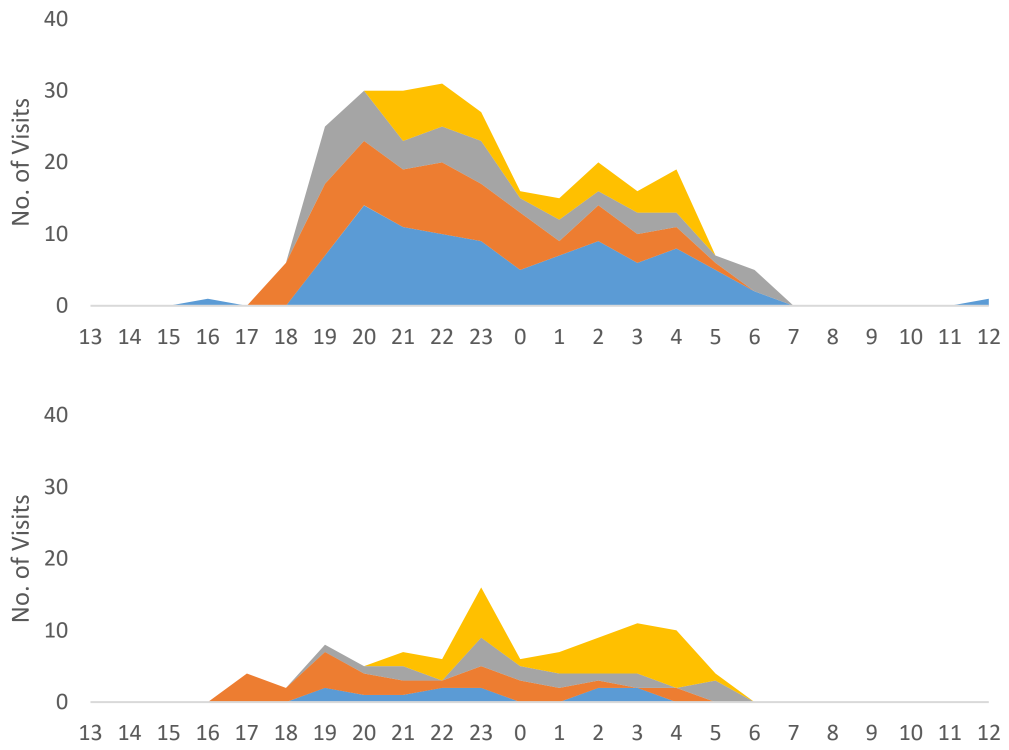


Figure 3-3 Number of possum visits recorded at Brooklands (top) and Maramarua (bottom) in each season plotted against time of day. Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

Activity Levels

This section summarises the number of possum visits recorded by the cameras for each site and season. For each study area, two data points were calculated. V/100 TN is the number of possum visits to all the cameras, standardised for 100 nights. MV/D is the maximum number of visits recorded by one camera on one day.

Table 3-8 Visit summaries for each season at each study area. V/100 TN is a measure of the number of visits recorded per 100 trap nights, while MV/D indicates the maximum visit count for a single camera on any one day.

	Autumn	Winter	Spring	Summer
Pasture North				
V/100 TN	82.14	66.48	22.62	12.09
MV/D	11	8	6	5
Pasture South				
V/100 TN	1.34	3.57	4.17	1.10
MV/D	2	2	2	1
Pirongia				
V/100 TN	0.51	1.65	8.93	1.10
MV/D	1	2	2	1
Te Tapui				
V/100 TN	4.40	9.69	10.12	7.14
MV/D	1	2	2	1

Te Miro				
V/100 TN	12.85	24.26	5.71	54.3
MV/D	2	2	2	3
Brooklands				
V/100 TN	41.07	34.76	16.48	17.86
MV/D	4	4	4	2
Maramarua				
V/100 TN	8.93	16.67	9.89	19.23
MV/D	2	3	2	2

Most possum visits were recorded at Pasture North and Brooklands, and least at Pasture South and Pirongia (Table 3-8). For most sites, possums were recorded more often in spring or summer. Surprisingly, the two sites with the most possum records did not follow this pattern, and is the only sites where possum visits decreased steadily over the year, from autumn to the following summer.

Daily visits

The highest number of daily visits was recorded at Pasture North, where possums were present in autumn and winter from day one. The first possum of spring was recorded on the third day, and in summer possums showed up only from day five. For all but the last three days, the number of possums recorded were highest in autumn, trending downwards over the year. Pasture South had significantly fewer possum visits over the two-week study period. While possums were recorded in all seasons, there was no discernible trend, and only in spring were possums recorded past the first week (Figure 3-4).

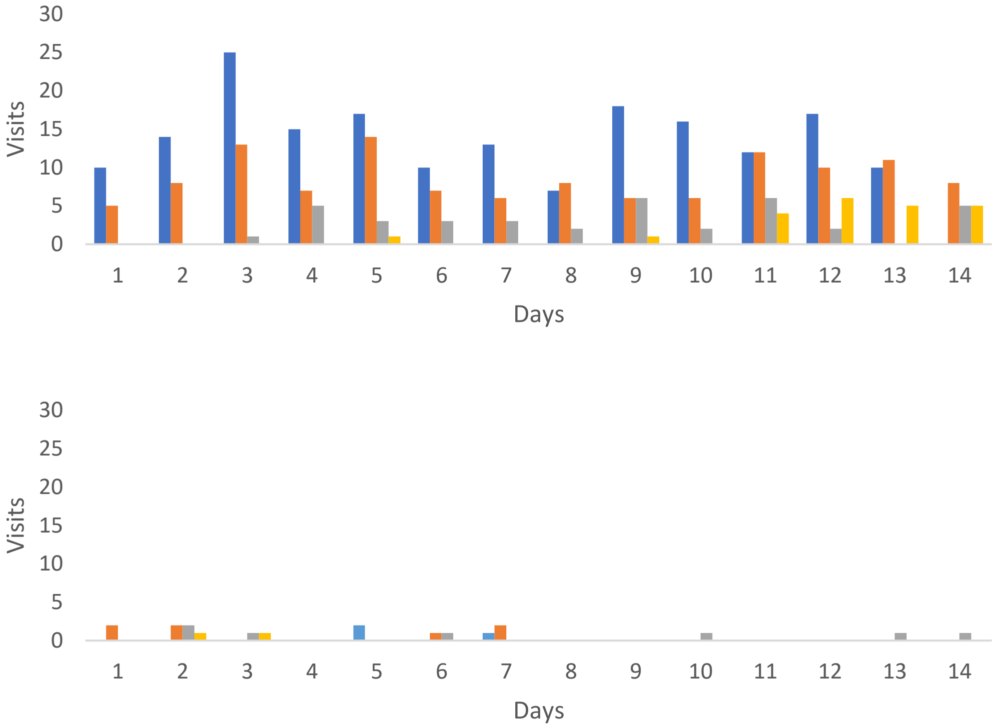


Figure 3-4 Number of possum visits recorded each day of the study period at Pasture North (top) and Pasture South (bottom). Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

Pirongia also displayed no discernible trend over the study period, although possums were recorded in all seasons. As in the pasture areas, most records were in the first week, except for autumn, where the sole possum record was in the 13th day of the study. While the maximum visit count for Te Tapui was similar to that of Pirongia, possum visits across all seasons were much more regular. However, there was still no real trend in the records, either over time or between seasons. The maximum daily visit counts at Te Miro were similar to the other indigenous forest areas, although the pattern was closer to that of Te Tapui than Pirongia. Across all seasons, possums were recorded at least once in the first week. In contrast to the other indigenous forest areas, possums were recorded least often in the spring, and most often in the summer months. This is especially surprising for Te Tapui as they were often monitored at the same time (Figure 3-5).

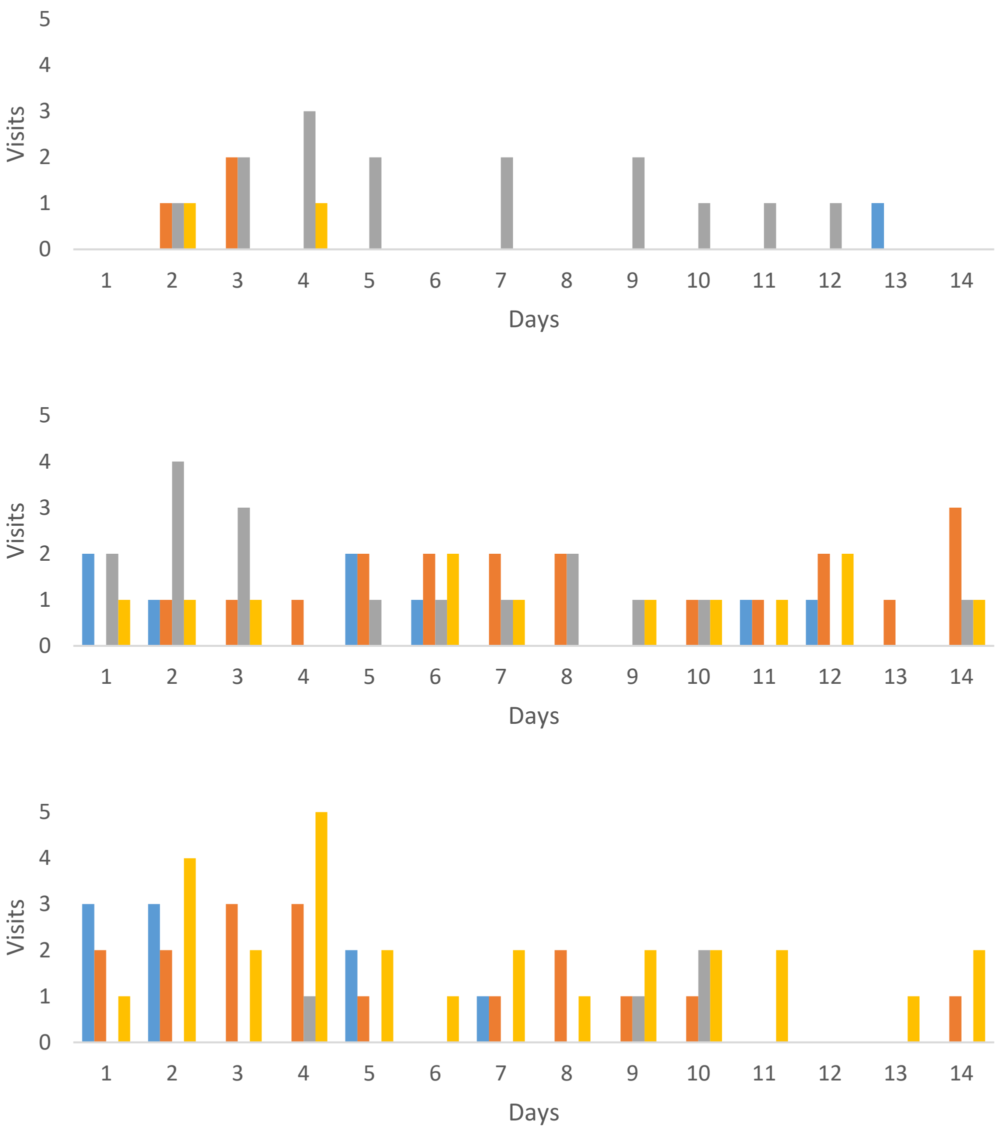


Figure 3-5 Number of possum visits recorded each day of the study period at Pirongia (top), Te Tapui (middle) and Te Miro (bottom). Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

Brooklands had the highest visitation count of all the study areas after Pasture North. Like Pasture North, there was a downward trend in possum visits over the year, although not quite as clear. One difference from the pasture area is that possums in summer and spring were recorded much sooner in the two-week study period. Maramarua was visited had about half as often as Brooklands. The downward trend over the year is not visible, but summer recorded the most visits. One similarity to Brooklands is that possums in all four seasons were recorded within the first 24 hours (Figure 3-6).

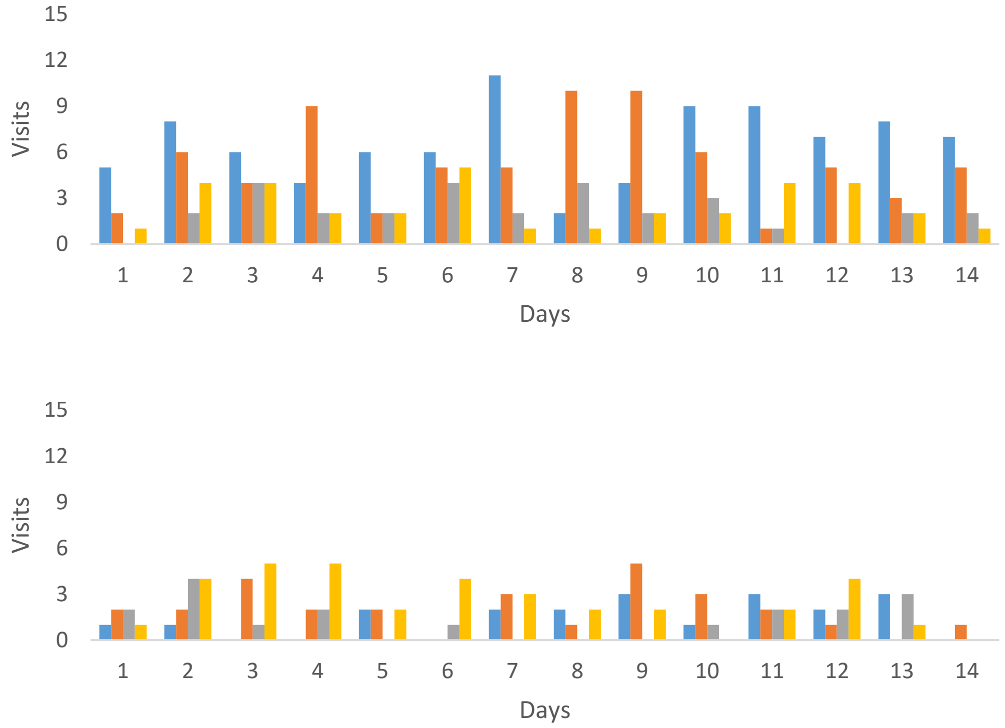


Figure 3-6 Number of possum visits recorded each day of the study period at Brooklands (top) and Maramarua (bottom). Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

3.4 Discussion

The purpose of this chapter is to study possum distribution and detection probabilities as they relate to varying habitats and seasons. In addition, this chapter aimed to answer whether camera traps can be used to determine differences in the levels and/ or periods of activity of possums.

In this section I discuss the results obtained and whether this confirms or refutes my hypotheses. I also answer the question of whether cameras can be used to monitor activity levels in possums. For a detailed discussion of how my results relate to the literature, see Chapter 9.

This analysis tested five hypotheses and accepted none in their original form.

3.4.1 Evaluation of Hypotheses

First hypothesis: that similar habitats of the same type have similar species composition.

Analysis of the occupancy data in 3.2.1 show that possums were present at each replicate of all three habitat types, and therefore this hypothesis could be accepted in its current state.

Comparing the probabilities of detection of the two pasture areas show significant differences. Given that I am comparing the same species at similar habitats, I would assume these to be similar and if population numbers were equal, detection probabilities should also be similar. That they are not, leads me to suspect the low probability for Pasture South is a real result of very low population numbers, a conclusion which is supported by the daily visit counts and the visits per 100 trap nights. So, for the detection probabilities to be this different, there must be a significant difference in population.

The same difference could also be observed for Te Tapui and Pirongia. While Te Tapui had consistently high estimates for site occupancy, Pirongia had possum numbers low enough to be virtually undetectable across most seasons. It is thus very likely that possums could be present at some areas, and entirely absent at other locations with the same habitat types.

It would therefore be more accurate to accept this hypothesis in a modified form: that similar habitats of the same type *are likely to have* similar species composition *but local variation is significant*.

Second hypothesis: that there are no detectable differences in species distribution between different habitat types.

All three habitat types showed significant differences in possum distribution. The pine forest areas were the only ones where possum site occupancy was consistently high, and pasture areas had the lowest occupancy overall. In fact, not only are possum distributions between habitats significantly different, there were often significant differences between areas with a similar habitat, as evidenced by comparing my pasture and indigenous forest areas.

Possums are known to be present in a large variety of habitat types, because some form of cover and a variety in food sources are the only requirements for possums to be present (Cowan 2005). Therefore, the true differences in possum populations between habitat types may be reflected in abundance rather than simple presence or absence.

This hypothesis can therefore only be accepted in a modified form: that there are *significant differences in species distribution within and between* different habitat types.

Third hypothesis: that species distribution within habitats are uniform, and there are no significant differences in probability of detection at different points within each habitat.

The PRESENCE analysis of site occupancy within each habitat found significant patchiness in where possums were detected. In addition, the areas in which possums were detected did not stay constant throughout the year. As possums were still seen even when present in very low numbers, this suggests that possums really were absent at the locations where they were not detected, rather than that they were missed by the camera. This then suggests that the distribution of possums within these areas was not uniform.

Possums often have large home ranges, and move around within these to take advantage of seasonally available foods (Cowan 2005). This might account for the seasonal differences observed in the analysis of site occupancy.

It is important to note that the differences between the different models tested in PRESENCE were often quite fine, so the results displayed here are only an indication to provide a way of comparing the different areas. The full model lists with their associated AIC scores and likelihood values are provided in the Appendices.

While the best model incorporated habitat features such as gullies or bush, these may not have been that significant overall, especially as the best models were not consistent across the seasons with respect to the habitat feature modelled.

PRESENCE requires at least ten data points to validly apply a model, so where possum occupancy was not very high, PRESENCE had difficulty in fitting the data to a model. Take Pasture South for example: across all seasons, possums were detected at only two sites. The difference lies in the number of visits recorded during each season. Possums were recorded slightly more than once per 100 trap nights during autumn and summer, which led PRESENCE to estimate complete coverage of the area. In contrast, possums were recorded approximately four times for the same period in winter and spring, and this was sufficient to produce more accurate estimates of site occupancy.

This hypothesis can therefore be accepted only in a modified form: that species distribution within habitats were not uniform, and there were no significant differences in detection probability at different points within each habitat.

Fourth hypothesis: that there are no changes in the detectability of given species of small mammals at a given camera site within a trapping session.

For most areas and seasons, the best models were those that incorporated a constant detection probability over the study session. Rainfall was the only other co-variate that seemed to affect detection, but only in a few cases, and the differences between these models and others with a constant probability of detection were minimal.

Literature on possums in New Zealand shows that heavy rain can delay possum emergence from their dens (Cowan 2005). A possible limitation of my model may be that I incorporated only whether it rained or not, and not the severity or timing of the rain. This may be why rain appeared in the best models only a few times.

I did not find rain to be a significant factor in detecting possums, but further study with more cameras over a longer period may well come to a different conclusion.

This hypothesis can therefore be accepted only in a modified form: that there *may or may not* be changes in the detectability of possums at a given camera site within a trapping session.

Fifth hypothesis: species distribution and abundance are not affected by the seasons.

There were significant differences in both the detectability and site occupancy of possums across the different seasons, although not with any consistent trends. In some cases, there was a downward trend across the seasons, in others the trend was reversed, or there was no visible trend. We know that most possums breed in autumn, with a smaller breeding season in the spring, particularly if the autumn breeding was early in the season (Cowan 2005). and while I noted more young in the spring and summer images, this trend was not visible as greater numbers in the analyses.

Brooklands was the only area where autumn and spring pest control was ongoing. While the spring sampling session definitely removed some possums, judging by the large number of dead possums found, and the significant drops in both distribution and the number of visits noted in spring, the same was not observed in the autumn.

This hypothesis can therefore be rejected: species distribution and abundance *are* affected by the seasons.

3.4.2 Evaluation of Research Questions

Can camera traps be used to determine differences in the levels and/ or periods of activity possums, when not individually identifiable?

Figure 3-7 Possum at Brooklands

Analysis of the time-stamped images does allow for a study of differences in the levels and/or periods of activity of possums on my study areas, with clear periods of peak activity and the number of visits to each camera. These confirm that possums are almost exclusively nocturnal, making only a few visits during the day. Current knowledge of possum behaviour predicts that they are most active between 11.00 pm and 2.30 am, somewhat consistent with my data, but I also found another peak of activity around 8.00 pm.

Seasonal changes in activity are also evident, starting earlier in the day in winter and latest in summer, when days are longer. Summer visits also ended later in the day, which does not fit this pattern.

3.5 Conclusions

My analyses reject the hypotheses that there are no differences in species distribution and detectability between different habitat types, and that seasons have no effect on these parameters of possum populations. I must also reject the hypothesis that possum detectability was constant over the study period.

Cameras provide a viable method of studying possum populations, and while a two-week study period is sufficient, more cameras are needed to improve the accuracy of results for site-occupancy analysis, especially where the proportion of sites occupied are low.

Chapter Four

Distribution and Activity Levels of Hedgehogs in Three Waikato Vegetation Types

4.1 Overview

In this chapter I will be testing for my five hypotheses as they relate to European hedgehogs in the Waikato Region. I will compare five different parameters of the hedgehog populations at my study areas and how they vary with respect to habitat type (pasture, indigenous forest, and pine forest) and season.

In section 4.2 I investigate their distribution within each study area as detected by the cameras as well as the site occupancy and probability of detection in each area as calculated by PRESENCE.

In section 4.3 I use the data collected from the time-stamped images to display the period of activity within each habitat. In addition, I investigate the number of camera visits, plotted against time, and provide an overall visit count for each area and season.

I will then discuss my results and whether or not they support my hypotheses, concluding with an evaluation of my hypotheses and research questions as they relate to hedgehogs.

4.2 Distribution and Site Occupancy

4.2.1 Results

Site Occupancy

For each area and season in the two replicate study areas, a separate analysis of site occupancy was run using PRESENCE, and the results are reported in the tables below. Each cell contains two values, with the upper value being the calculated estimate for site occupancy Ψ, and the lower value being the naïve occupancy, i.e. the raw proportion of areas where hedgehogs were detected by the cameras. The difference between them illustrates how unreliable simple observation can be in estimating the real distributions of animals.

Each table also contain a visual representation of hedgehog distribution, with the ¤ symbol showing where hedgehogs were positively identified. The colour of each cell represents the likelihood that hedgehogs are present at the site even if it was not detected. Solid green represents a probability of 0, while red indicates a probability of 1 (Table 4-1).

Table 4-1 Key to tables depicting site occupancy at each of the study areas. The different colours represent the estimated probabilities that a site is occupied, even if no hedgehogs were detected.

0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00

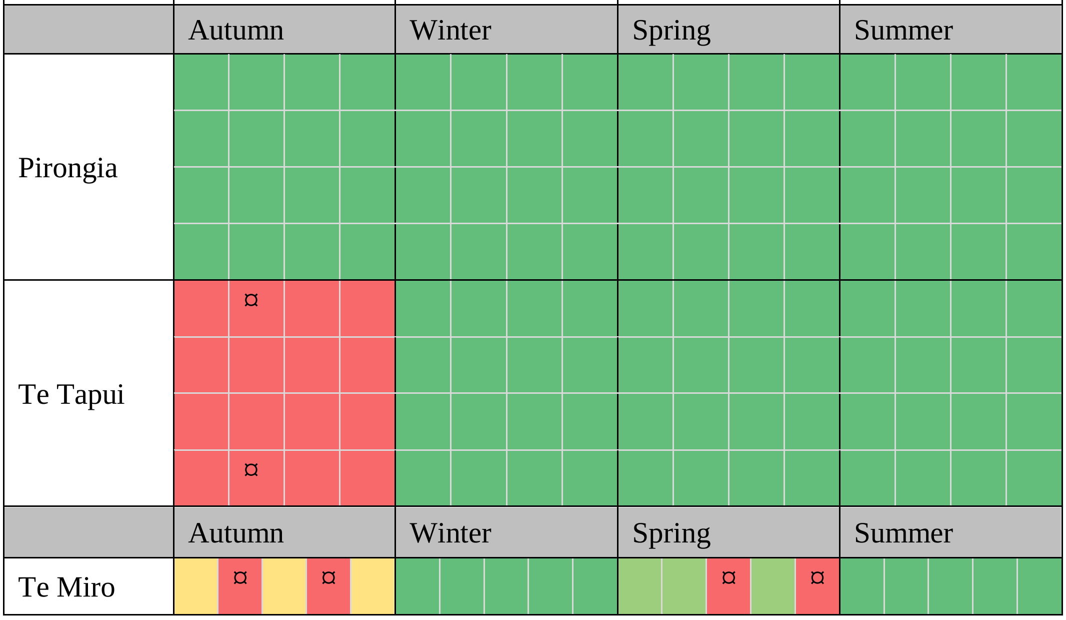
Table 4-2 Site occupancy estimates of the two pasture study areas.

	Autumn				Winter				Spring				Summer			
Pasture North	0.87 0.83				0.72 0.54				0.71 0.75				0.45 0.31			
Pasture South	0.71 0.69				0.43 0.43				0.60 0.58				0.57 0.54			
	Autumn				Winter				Spring				Summer			
Pasture North	¤	¤	🟩	¤	¤	¤	🟩	🟥	🟨	🟨	🟨	¤	🟨	¤	🟩	¤
	¤	¤	¤	¤	🟩	🟩	🟥	🟩	🟩	¤	¤	¤	🟩	¤	🟩	🟩
	🟧	🟧	🟧	🟧	¤	¤	🟩	¤	¤	¤	¤	🟩	🟩	¤	🟩	🟨
	¤	¤	¤	🟩	¤	🟨	¤	🟥	🟩	¤	¤	🟨	🟩	🟩	🟩	🟨
Pasture South	¤	¤	¤	¤	¤	¤	🟩	¤	🟩	¤	🟩	¤	¤	🟩	🟩	🟩
	¤	🟩	🟩	¤	¤	🟩	🟩	¤	¤	🟩	🟩	¤	¤	¤	🟩	¤
	¤	¤	🟩	¤	¤	🟩	🟩	🟩	¤	¤	¤	🟩	¤	🟩	🟩	¤
	🟩	🟩	¤	¤	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	¤	🟨	🟨

Overall, Pasture North had the highest proportion of the sites occupied of all my study areas. Both areas showed the same trend of highest occupancy in the autumn and spring, with winter and summer being lower. This trend was not as visible in the estimated total occupancies. A visual representation of site occupancy shows that those cameras where hedgehogs were not detected in the autumn, usually did not detect hedgehogs in the other seasons either (Table 4-2).

Table 4-3 Site occupancy estimates of the three indigenous forest areas.

	Autumn	Winter	Spring	Summer
Pirongia	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00
Te Tapui	1.00 0.15	0.00 0.00	0.00 0.00	0.00 0.00
Te Miro	0.65 0.40	0.00 0.00	0.48 0.40	0.00 0.00



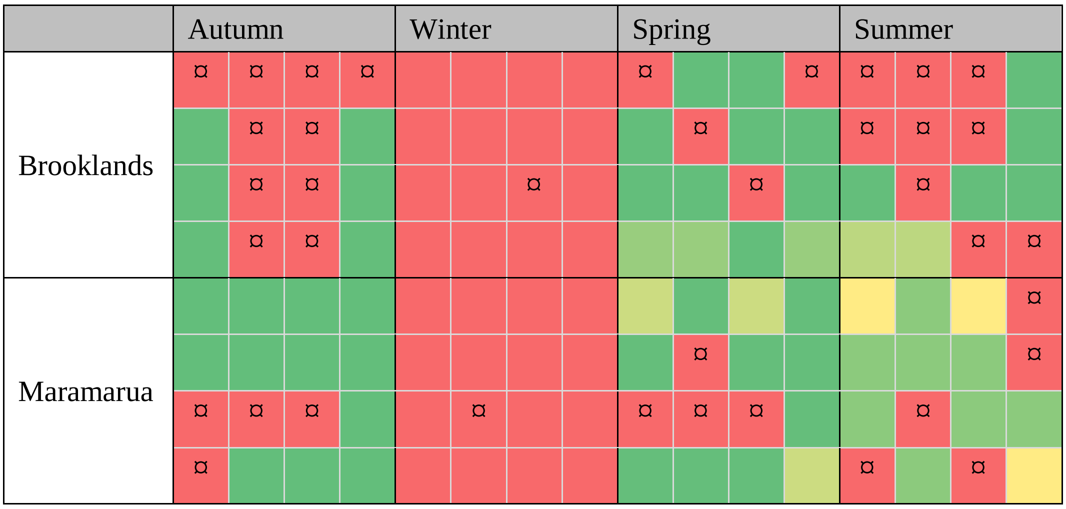
	Autumn				Winter				Spring				Summer			
Pirongia	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Te Tapui	🟥	🟥 ¤	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	🟥	🟥 ¤	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

	Autumn					Winter					Spring					Summer				
Te Miro	🟨	🟥 ¤	🟨	🟥 ¤	🟨	🟩	🟩	🟩	🟩	🟩	🟢	🟢	🟥 ¤	🟢	🟥 ¤	🟩	🟩	🟩	🟩	🟩

Hedgehogs were never detected in indigenous forest at Pirongia, and only twice at Te Tapui, both in the autumn. So few records made PRESENCE wrongly estimate that they were there throughout the area in autumn. At Te Miro, in both autumn and spring, hedgehogs were also detected at only two sites, although different for each season. As the cameras recorded a larger number of detections there, PRESENCE could estimate a more realistic representation of hedgehog distribution across the Te Miro area. The trend observed for hedgehogs at Te Miro is identical to that at the pasture areas, and has similar occupancy estimates (Table 4-3).

Table 4-4 Site occupancy estimates of the two pine forest study areas.

	Autumn	Winter	Spring	Summer
Brooklands	0.63 0.63	1.00 0.07	0.31 0.31	0.63 0.64
Maramarua	0.25 0.25	1.00 0.08	0.32 0.31	0.46 0.38



	Autumn				Winter				Spring				Summer			
Brooklands	🟥 ¤	🟥 ¤	🟥 ¤	🟥 ¤	🟥	🟥	🟥	🟥	🟥 ¤	🟩	🟩	🟥 ¤	🟥 ¤	🟥 ¤	🟥 ¤	🟩
	🟩	🟥 ¤	🟥 ¤	🟩	🟥	🟥	🟥	🟥	🟩	🟥 ¤	🟩	🟩	🟥 ¤	🟥 ¤	🟥 ¤	🟩
	🟩	🟥 ¤	🟥 ¤	🟩	🟥	🟥	🟥 ¤	🟥	🟩	🟩	🟥 ¤	🟩	🟩	🟥 ¤	🟩	🟩
	🟩	🟥 ¤	🟥 ¤	🟩	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟥 ¤	🟥 ¤
Maramarua	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟩	🟨	🟩	🟨	🟥 ¤
	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟩	🟥 ¤	🟩	🟩	🟩	🟩	🟩	🟥 ¤
	🟥 ¤	🟥 ¤	🟥 ¤	🟩	🟥	🟥 ¤	🟥	🟥	🟥 ¤	🟥 ¤	🟥 ¤	🟩	🟩	🟥 ¤	🟩	🟩
	🟥 ¤	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟩	🟥 ¤	🟩	🟥 ¤	🟨

Hedgehogs occupied a significant number of sites in both pine forest areas for all seasons except winter. Site occupancy was low in the summer but a large proportion of sites were occupied. Once again, this apparent contradiction arises because a complete occupancy during winter is the result of PRESENCE's inability to accurately model occupancy from only one instance of detection at each area. A visual representation of site occupancy shows that those cameras where hedgehogs were not detected in the autumn, usually did not detect hedgehogs in the other seasons either (Table 4-4).

Detectability

Several models were run in PRESENCE to determine the probability of hedgehogs being detected given that they were present it the different areas and seasons. Each of the following tables shows the most likely model for each area, along with the probability of hedgehogs being detected (p) over the sampling period. Where rain was a co-variate for detection over the sampling period, two probabilities were given for that season. The first probability is for days without rain, while the one in brackets is for days when rain was recorded.

Table 4-5 Results from PRESENCE analysis of pasture study areas showing the best models and P values for each season.

Pasture Areas	Autumn	Winter	Spring	Summer
North	Ψ(.)p(.) 0.21	Ψ(bush)p(.) 0.10	Ψ(drain)p(.) 0.27	Ψ(drain)p(rain) 0.03 (0.16)
South	Ψ(bush)p(rain) 0.12 (0.35)	Ψ(.)p(.) 0.30	Ψ(.)p(.) 0.24	Ψ(.)p(.) 0.54

Hedgehogs were more likely to be detected it the pasture areas than either of the forest types. Of the two pasture areas, hedgehogs were more likely to be detected at Pasture South, where detection probabilities were higher at all seasons except spring. While Pasture North had a higher detection probability in spring, this was not a significant difference. No particular model was best for all seasons, with no one co-variate constant across all seasons (Table 4-5).

While rain showed as a co-variate in the models for one season at each area, these models were not significantly different from models featuring a constant detection probability (ΔAIC < 2.00). In both cases the detection probability increased when it was raining.

The probability that hedgehogs would be detected at Pasture North in the summer approached 0, particularly when it was not raining, whereas Pasture South summer had the highest probability of detection of any season. At Pasture South, the winter and summer months had the highest probabilities of detection, but the lowest proportion of areas occupied.

Table 4-6 Results from PRESENCE analysis of indigenous forest study areas showing the best models and P values for each season.

	Autumn	Winter	Spring	Summer
Pirongia	N/A N/A	N/A N/A	N/A N/A	N/A N/A
Te Tapui	$\Psi(.)p(.)$ 0.01	N/A N/A	N/A N/A	N/A N/A
Te Miro	$\Psi(.)p(.)$ 0.07	N/A N/A	$\Psi(.)p(.)$ 0.12	N/A N/A

Hedgehogs were rarely detected in any of the indigenous forest areas. Pirongia showed no evidence of hedgehogs, and the detection probability for autumn at Te Tapui, approached 0. The only significant detection probabilities were at Te Miro, and then only for two of the four seasons (Table 4-6Table 4-7).

Table 4-7 Results from PRESENCE analysis of pine forest study areas showing the best models and P values for each season.

	Autumn	Winter	Spring	Summer
Brooklands	Ψ(.)p(.) 0.29	Ψ(.)p(.) <0.01	Ψ(.)p(rain) 0.23 (0.23)	Ψ(open)p(.) 0.28
Maramarua	Ψ(.)p(.) <0.01	Ψ(.)p(.) <0.01	Ψ(.)p(.) 0.23	Ψ(.)p(.) 0.12

Hedgehogs were more likely to be detected in the Brooklands pine forest area than at Maramarua, where the probability of detection was almost 0 in both autumn and winter. Even so the probability that hedgehogs would be detected at Brooklands was also very low in the winter. While rain showed as a co-variate in the models for one season at Brooklands, this model was not significantly different from models featuring a constant detection probability (ΔAIC < 2.00) (Table 4-7).

In contrast to the pasture areas, the detection probabilities on days with and without rain were identical. Modelling sites with no ground layer vegetation found the best fit for Brooklands in the summer, but once again this was not significantly different from models with a constant probability that all sites are occupied.

4.3 Active Period and Activity Levels

4.3.1 Results

Active Period

In the following graphs, the number of hedgehog visits recorded by the cameras for each season were plotted against the time of day.

For my Pasture North and South areas, the number of hedgehogs that visited the cameras were somewhat different, with about 44% more visits recorded at Pasture South. Even so, the main period of activity at both was between 5.00 pm and 7.00 am; hedgehogs were rarely active during the day. The number of visits recorded per hour did not stay constant over the night. Rather, it formed three main peaks of activity, visible at both areas, particularly during spring (Figure 4-1).

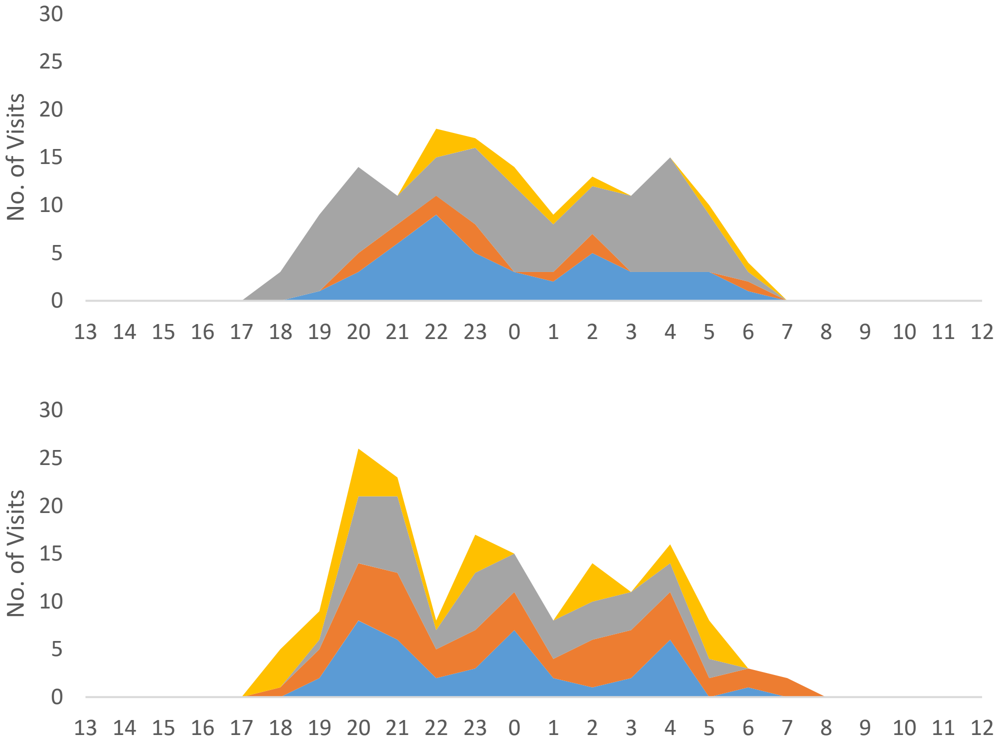


Figure 4-1 Number of hedgehog visits recorded at Pasture North (top) and Pasture South (bottom) in each season plotted against time of day. Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

Te Tapui and Te Miro both recorded a few hedgehog visits, although not enough to identify any patterns. The only visits were in autumn and spring, and within the times recorded at the pasture areas (Figure 4-2).

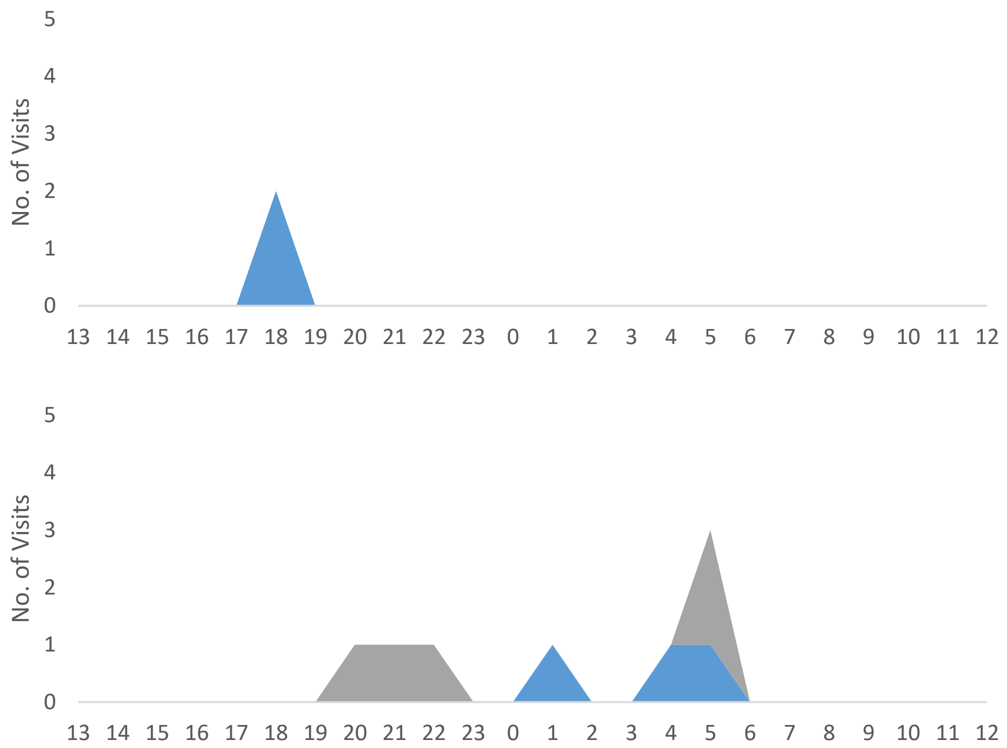


Figure 4-2 Number of hedgehog visits recorded at Te Tapui (top) and Te Miro (bottom) in each season plotted against time of day. Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

Both pine forest areas recorded hedgehog visits across all seasons, but only barely in winter. While the proportions of visits recorded at the different seasons were similar, Brooklands recorded about six times more visits than Maramarua. Once again, the time period was similar to that of the pasture areas, and the number of visits were not constant throughout the night. However, whereas the pasture areas had three distinct periods of activity, activity in the two pine forests peaked twice, on either side of midnight (Figure 4-3).

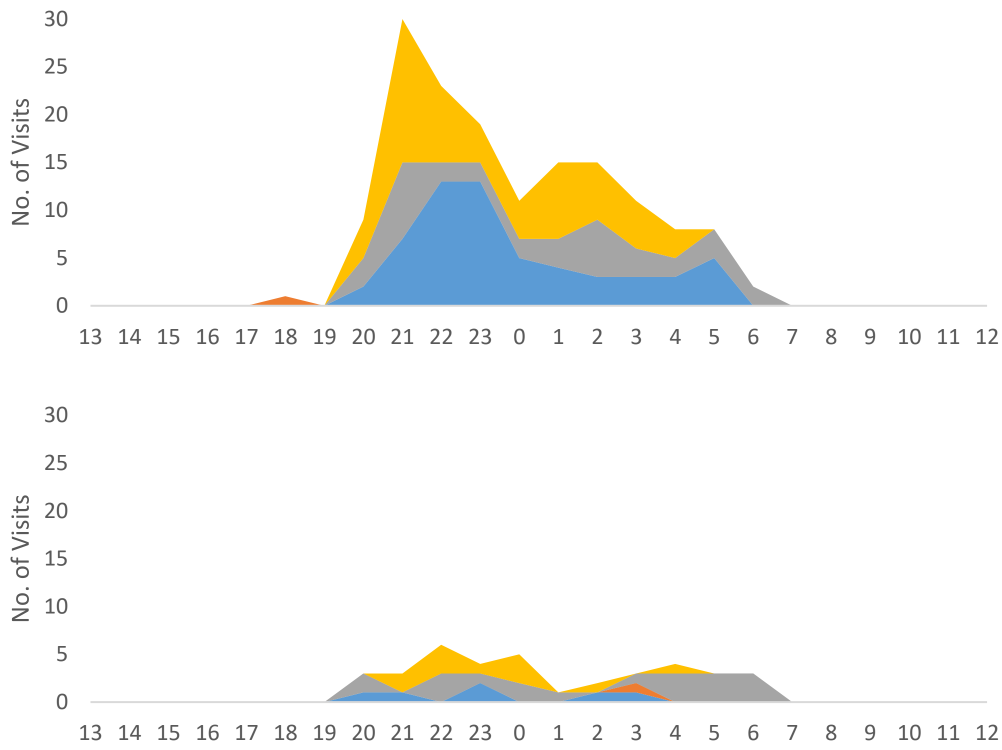


Figure 4-3 Number of hedgehog visits recorded at Brooklands (top) and Maramarua (bottom) in each season plotted against time of day. Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

Activity Levels

This section summarises the number of hedgehog visits recorded by the cameras for each area and season. For each area, two data points were calculated. V/100 TN is the number of hedgehog visits to all the cameras in the area standardised for 100 nights. MV/D is the maximum number of visits recorded by one camera on one day.

Table 4-8 Visit summaries for each season at each study area. V/100 TN is a measure of the number of visits recorded per 100 camera nights, while MV/D indicates the maximum visit count for a single camera on any one day.

	Autumn	Winter	Spring	Summer
Pasture North				
V/100 TN	16.07	7.14	34.52	5.49
MV/D	2	2	6	3
Pasture South				
V/100 TN	16.52	19.9	19.64	10.99
MV/D	2	8	3	2
Te Tapui				
V/100 TN	1.10	0.00	0.00	0.00
MV/D	1	0	0	0
Te Miro				
V/100 TN	4.29	0.00	7.14	0.00
MV/D	1	0	2	0

Brooklands				
V/100 TN	23.21	0.48	13.19	29.59
MV/D	3	1	4	3
Maramarua				
V/100 TN	7.14	0.60	8.24	6.04
MV/D	2	1	2	2

Across all sites, hedgehogs were generally recorded most often in autumn and spring. Only at Pasture South was hedgehogs recorded at a similar rate in winter. This is probably a case of individual behaviour affecting the general result: winter had the least number of sites occupied, but almost half of the winter visits over 100 trap nights was made to one camera in a single day (Table 4-8).

Hedgehog records in indigenous forest areas were too few to allow any analysis of visitation rates. Te Miro recorded the most visits of all indigenous forest areas, but less than any other area. Even so, visits still followed the established pattern.

Visitation rates over time

Each of the following graphs depicts the number of hedgehog visits recorded during each day of the two-week study period.

Hedgehogs were recorded at Pasture North within the first 24 hours for all seasons but spring. In spring, hedgehogs were only recorded from the third day onwards, but were then seen every day. There was no discernible trend in hedgehog records over the study period, with different seasons peaking at different times. Summer had the least number of visits recorded, and this is reflected in the number of days they were recorded. Visits for Pasture South was highest in the winter, but most of these were limited to only one day. On most other days, winter visits were much lower, being equal or fewer than the other seasons. In all seasons, hedgehogs were detected from day one, and on most days throughout the study period (Figure 4-4).

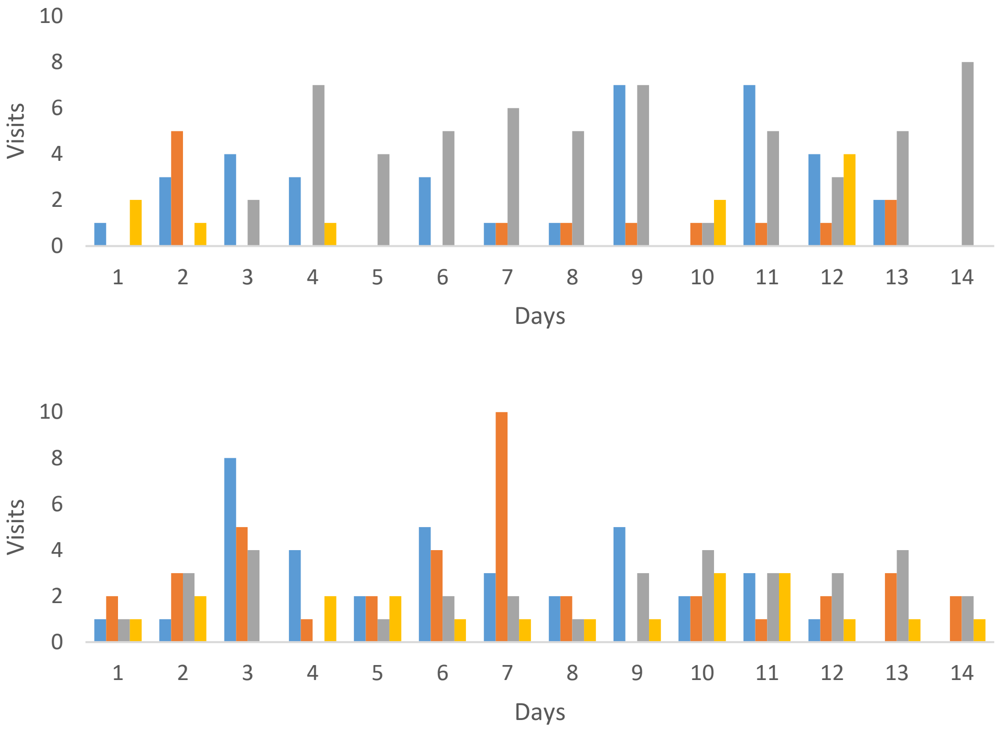


Figure 4-4 Number of hedgehog visits recorded each day of the study period at Pasture North (top) and Pasture South (bottom). Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

Te Miro recorded the most visits of all indigenous forest area, spread throughout the study period. Most days recorded only one visit, except on day three, when two visits were recorded, both at the same site (Figure 4-5).

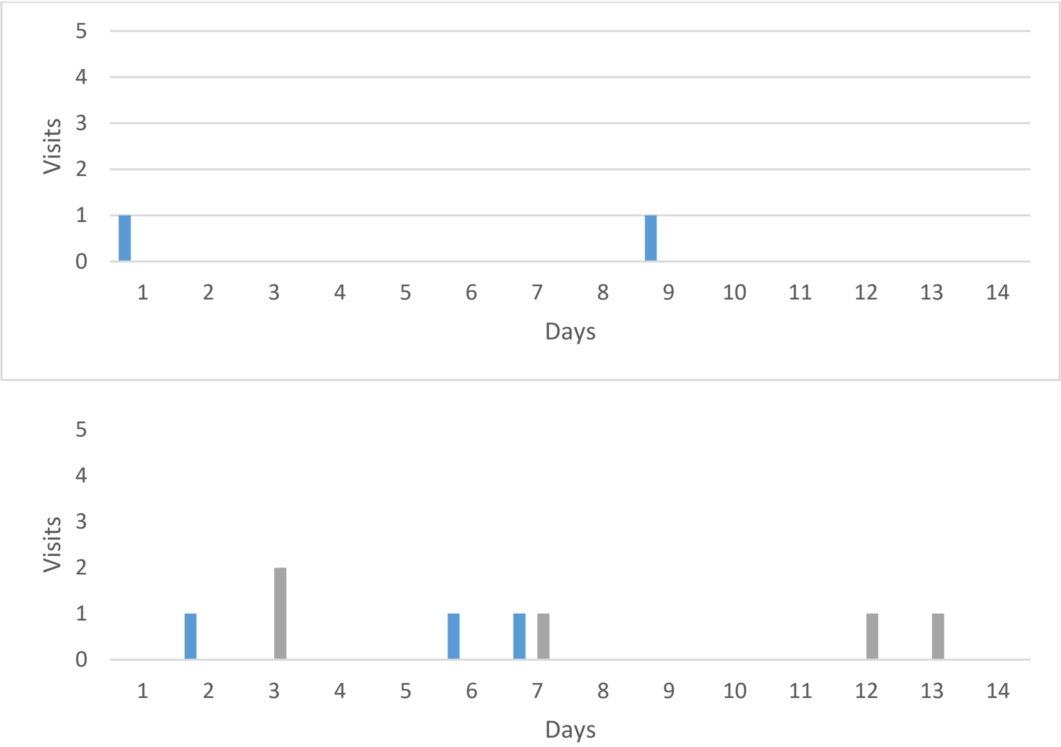


Figure 4-5 Number of hedgehog visits recorded each day of the study period at Te Tapui (top) and Te Miro (bottom). Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

Brooklands had one of the highest and most consistent hedgehog visitation rates of all areas. Except in winter, hedgehog visits in Brooklands were recorded from day one. In summer, hedgehogs were seen on all days, and on most days in spring and autumn. The only winter visit was recorded on day four. Hedgehog visits in Maramarua were much less frequent than at Brooklands. The number of visits and the days they were recorded were not as consistent, with more days when no hedgehogs were seen at all. Even so, hedgehogs were detected within the first two days in all seasons except winter (Figure 4-6).

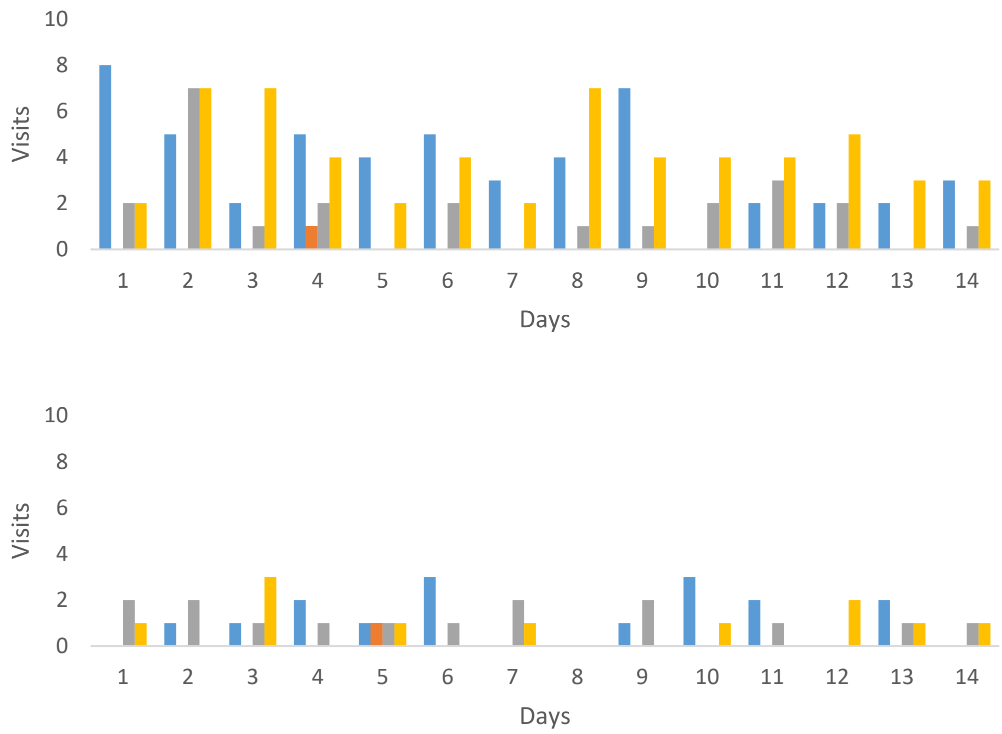


Figure 4-6 Number of hedgehog visits recorded each day of the study period at Brooklands (top) and Maramarua (bottom). Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

4.4 Discussion

The purpose of this chapter is to study hedgehog distribution and detection probabilities as they relate to varying habitats and seasons. In addition, this chapter aimed to answer the question of whether camera traps can be used to determine differences in the levels and/ or periods of activity of hedgehogs.

In this section I discuss the results obtained and whether this confirms or refutes my hypotheses. I also answer the question of whether cameras can be used to monitor activity levels in hedgehogs. For a detailed discussion and how my results relate to the literature, see Chapter 9.

This analysis tested five hypotheses and accepted none in their original form.

4.4.1 Evaluation of Hypotheses

First hypothesis: that similar habitats of the same type have similar species composition.

Analysis of the occupancy data in 4.2.1 show that hedgehogs were present at both replicates of the pasture and pine forest areas. However, they were not detected at Pirongia at all, and at Te Tapui, only in the autumn. Te Miro was the only indigenous forest area where hedgehogs were consistently detected, and this is probably because it was a forest fragment surrounded by farmland, and only about 100 meters at its widest point.

In addition, while the detection probabilities for the two pasture areas were similar, those for the two pine forest areas were not. As I am comparing the same species in the same habitat type, I expected these to be similar. The same pattern can be seen in the number of visits recorded in the two pine forest areas. The fact that they are so different may indicate a significant difference in population size at these two areas.

It would, therefore, be more accurate to accept this hypothesis in a modified form: that similar habitats of the same type *are likely to have* similar species composition *but local variation is significant*.

Second hypothesis: that there are no detectable differences in species distribution between different habitat types.

Hedgehogs were present in all three habitat types. There was, however significant differences in the proportions of each habitat that were occupied by hedgehogs. Pasture areas had the highest occupancy, with > 0.50 site occupancy estimated for three out of four seasons at each area. In contrast, only one season each for Te Tapui and Te Miro had an estimated occupancy > 0.50. Site occupancy at the pine forest areas were not as consistent, but lower than in the pasture areas.

So, while hedgehogs were present in all habitat types, there were significant differences both between and with different habitats, and this hypothesis can only be accepted in a modified form: that there are *significant differences in species distribution within and between* different habitat types.

Third hypothesis: that species distribution within habitats are uniform, and there are no significant differences in probability of detection at different points within each habitat.

The PRESENCE analysis of site occupancy within each habitat found significant patchiness in the local distributions of hedgehogs. In addition, the sites at which hedgehogs were detected did not stay constant throughout the year.

Hedgehogs were still detected in both pasture and pine forest areas even when present in very low numbers, suggesting that hedgehogs really were absent at the locations where they were not detected, rather than that they were missed by the cameras. This then suggests that the distribution of hedgehogs within these areas was not uniform.

Hedgehogs were detected at Te Miro in the autumn and spring, probably individuals that wandered in from the surrounding farmland, but not in winter. The records are too few to support a viable interpretation.

It is important to note that the differences between the different models tested in PRESENCE were often quite fine, so the results displayed here are only an indication to provide a way of comparing the different areas. The full model lists with their associated AIC scores and likelihood values are provided in the Appendices.

This means that while the best model in a few cases incorporated habitat features such as bush or drains, these may not have been that significant overall, especially as the best models were not consistent across the seasons with respect to the habitat feature modelled.

This hypothesis can therefore only be accepted in a modified form: that species distribution within habitats were not uniform, and there *were* significant differences in detection probability at different points within each habitat.

Fourth hypothesis: that there are no changes in the detectability of given species of small mammals at a given camera site within a trapping session.

For most areas and seasons, the best models were those that incorporated a constant detection probability over the study session. Only the pasture and pine forest areas showed rainfall to be a co-variate that affected detection, but only in a few cases.

While the difference between these models and others with a constant probability of detection were minimal, the same was true in reverse. Even for seasons when the best model featured a constant p value, models that incorporated rain was not significantly different (ΔAIC < 2.00).

Rain did not influence detection at all areas and in all seasons. However, for those where rain was a co-variate in the best model, it usually increased the probability that hedgehogs would be detected.

This hypothesis can therefore be accepted only in a modified form: that there *may or may not* be changes in the detectability of given species of small mammals at a given camera site within a session.

Fifth hypothesis: species distribution and abundance are not affected by the seasons.

There were significant differences in both the detectability and site occupancy of hedgehogs across the different seasons. In most cases, occupancy peaked in the autumn and spring, with significantly fewer hedgehogs detected in the winter and summer.

In several cases, winter detections were non-existent or insignificant. This could be due to hibernation (Jones & Sanders, 2005), as the high visit numbers in spring makes excessive winter mortality unlikely. On the other hand, hedgehogs fresh out of hibernation might be especially attracted to food baits.

Ironically, the two areas where the most hedgehogs were seen, Pasture North and Brooklands, were the two areas that did not conform to that trend.

This hypothesis can therefore be rejected: species distribution and occupancy *are* affected by the seasons.

4.4.2 Evaluation of Research Questions

Can camera traps be used to determine differences in the levels and/ or periods of activity of hedgehogs, when not individually identifiable?

Figure 4-7 Hedgehog at Brooklands

Analysis of the time-stamped images does allow for a study of differences in the levels and/ or periods of activity of hedgehogs on my study areas, with clear periods of peak activity and the number of visits to each camera. The records confirm that hedgehogs are almost exclusively nocturnal, only rarely seen during the day. Current knowledge of hedgehog behaviour predicts that they are most active between 8.00 pm and 5.00 am, with peak activity at 2 and 8 hours after sunset. This fits surprisingly well with my data, although I also found another peak of activity around midnight, particularly on the pasture areas.

Seasonal changes in activity are not as evident, but the low hedgehog occupancy at half of my study areas makes spotting trends difficult.

4.5 Conclusions

My analyses reject the hypotheses that there are no differences in hedgehog distribution and detectability between different habitat types, and that seasons have no effect on these parameters of hedgehog populations. I must also reject the hypothesis that hedgehog detectability was constant over the study period.

Cameras provide a viable method of studying hedgehog populations, and while a two-week study period is sufficient, more cameras are needed to improve the accuracy of results for site-occupancy analysis, especially where the proportion of sites occupied are low.

Chapter Five

Distribution and Activity Levels of Rats in Three Waikato Vegetation Types

5.1 Overview

In this chapter, I will be testing for my five hypotheses as they relate to rats in the Waikato Region. I will compare five different parameters of the rat populations in my study areas and how they vary with respect to habitat type (pasture, indigenous forest, and pine forest) and season.

In section 5.2 I investigate their distribution within each study area as detected by the cameras as well as the site occupancy and probability of detection in each area as calculated by PRESENCE.

In section 5.3 I use the data collected from the time-stamped images to display the periods of activity within each habitat. In addition, I investigate the number of visits plotted against time, and provide an overall visit count for each area and season.

I will then discuss my results and whether or not it supports my hypotheses, concluding with an evaluation of my hypotheses and research questions as they relate to ship rats.

5.2 Distribution and Site Occupancy

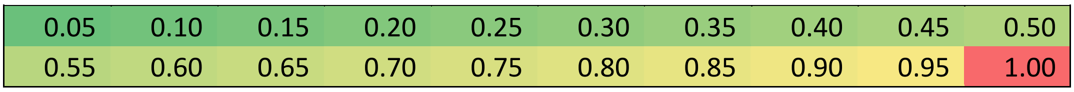
5.2.1 Results

Site Occupancy

For each area and season, a separate analysis of site occupancy was run using PRESENCE, and the results are reported in the tables below. Each cell contains two values, with the upper value being the calculated estimate for site occupancy Ψ, and the bottom value being the naïve occupancy, i.e. the raw proportion of sites where rats were detected by the cameras. The difference between them illustrates how unreliable simple observation can be in estimating the real distributions of animals.

Each table also contains a visual representation of rat distribution, with the ¤ symbol showing where rats were positively identified. The colour of each cell represents the likelihood that rats are present at the site even if it was not detected. Solid green represents a probability of 0, while red indicates a probability of 1 (Table 5-1).

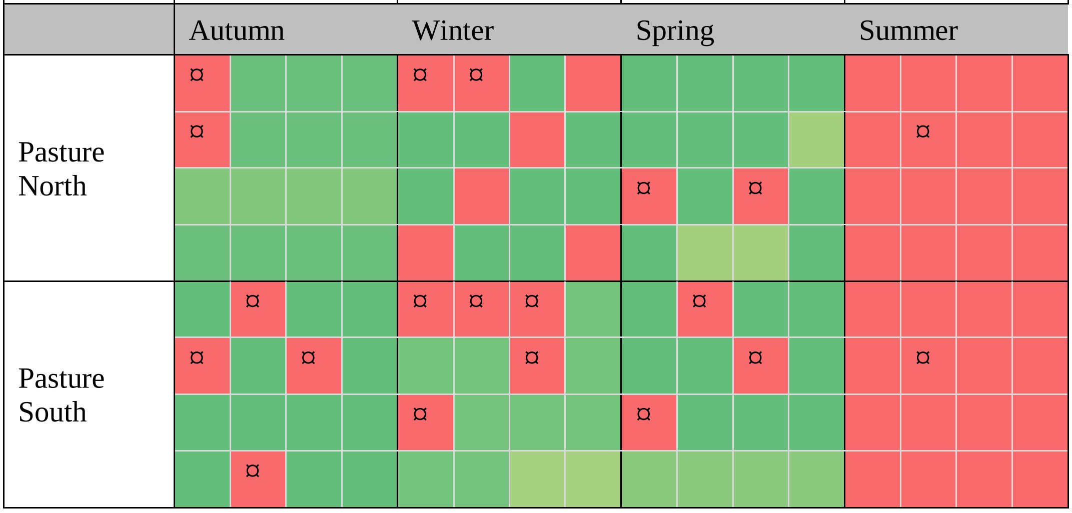
Table 5-1 Key to tables depicting site occupancy at each of the study areas. The different colours represent the listed probabilities that a site is occupied, even if no rats were detected.



0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00

Table 5-2 Site occupancy estimates for rats in the two pasture study areas.

	Autumn	Winter	Spring	Summer
Pasture North	0.20 0.17	0.44 0.15	0.20 0.17	1.00 0.08
Pasture South	0.25 0.25	0.43 0.36	0.25 0.25	1.00 0.07



	Autumn				Winter				Spring				Summer			
Pasture North	¤				¤	¤										
	¤													¤		
									¤		¤					
Pasture South		¤			¤	¤	¤			¤						
	¤		¤				¤				¤			¤		
					¤				¤							
		¤														

Estimated occupancy was lowest overall for the pasture areas compared to the other habitats. For both areas, winter and summer had the highest estimated occupancy, although naïve occupancy was lowest in the summer. While estimated occupancy was similar for the two areas, naïve occupancy was significantly higher for the pasture south area (Table 5-2).

A visual representation of site occupancy at each area show that the sites where rats were positively identified were not consistent across the seasons, particularly for the northern area. While the same was true for the southern area, there were some overlap from one season to the next.

Table 5-3 Site occupancy estimates for rats in the three indigenous forest areas.

	Autumn	Winter	Spring	Summer
Pirongia	1.00 1.00	1.00 1.00	0.92 0.92	0.85 0.85
Te Tapui	1.00 1.00	1.00 1.00	0.92 0.92	1.00 1.00
Te Miro	1.00 1.00	1.00 1.00	0.80 0.80	0.80 0.80

	Autumn				Winter				Spring				Summer			
Pirongia	¤	¤	¤	¤	¤	¤	¤	¤	¤	¤	¤	¤	🟩	¤	¤	¤
	¤	¤	¤	¤	¤	¤	¤	¤	¤	¤	¤	🟩	¤	¤	¤	¤
	¤	¤	¤	¤	¤	¤	¤	¤	¤	¤	¤	¤	¤	¤	🟩	¤
	¤	¤	🟥	🟥	¤	🟥	🟥	🟥	🟨	🟨	🟨	🟨	¤	🟨	🟨	🟨
Te Tapui	¤	¤	🟥	¤	¤	¤	¤	¤	¤	🟩	¤	¤	¤	¤	¤	¤
	¤	¤	¤	¤	¤	¤	¤	¤	¤	¤	¤	¤	¤	¤	¤	¤
	¤	¤	🟥	🟥	¤	¤	🟥	¤	¤	¤	🟨	¤	¤	¤	🟥	¤
	¤	¤	¤	¤	¤	¤	¤	🟥	¤	🟨	🟨	🟨	¤	🟥	🟥	🟥

	Autumn					Winter					Spring					Summer				
Te Miro	¤	¤	¤	¤	¤	¤	¤	¤	¤	¤	¤	🟩	¤	¤	¤	¤	¤	¤	¤	🟩

Overall, the estimated site occupancy of indigenous forest by rats was the highest of all habitat types. In all cases, autumn and winter had the highest occupancy, with spring and summer somewhat lower. The exception is Te Tapui, which also had a 1.00 occupancy estimate for summer (Table 5-3).

A visual representation show that rats were positively identified in most areas. In fact, for autumn and winter across all study areas, rats were detected at all sites where data was available. For spring and summer at all indigenous forest areas, the yellow sites correspond to those sites where information was unavailable, while the green sites were those where data was available, but no rats detected.

Table 5-4 Site occupancy estimates of the two pine forest study areas.

	Autumn				Winter				Spring				Summer			
Brooklands	0.26 0.19				0.49 0.47				0.49 0.38				0.38 0.14			
Maramarua	0.88 0.88				0.83 0.83				0.85 0.85				0.85 0.85			
	Autumn				Winter				Spring				Summer			
Brooklands	🟩	🟩	🟩	🟥¤	🟩	🟩	🟥¤	🟩	🟩	🟥¤	🟩	🟩	🟩	🟩	🟥	🟥¤
	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥¤	🟩	🟩	🟩	🟥¤	🟩	🟩	🟩	🟩
	🟩	🟩	🟩	🟩	🟥¤	🟩	🟩	🟥¤	🟥¤	🟩	🟩	🟥¤	🟥¤	🟩	🟩	🟥
	🟥¤	🟩	🟩	🟥¤	🟨	🟥¤	🟥¤	🟥¤	🟩	🟩	🟥¤	🟩	🟥	🟥	🟩	🟩
Maramarua	🟥¤	🟥¤	🟥¤	🟥¤	🟨	🟥¤	🟥¤	🟨	🟨	🟥¤	🟨	🟩	🟨	🟥¤	🟨	🟥¤
	🟥¤	🟥¤	🟥¤	🟩	🟥¤	🟥¤	🟥¤	🟥¤	🟥¤	🟥¤	🟥¤	🟥¤	🟥¤	🟥¤	🟥¤	🟥¤
	🟥¤	🟩	🟥¤	🟥¤	🟩	🟩	🟥¤	🟥¤	🟥¤	🟩	🟥¤	🟥¤	🟩	🟥¤	🟥¤	🟥¤
	🟥¤	🟥¤	🟥¤	🟥¤	🟨	🟥¤	🟥¤	🟨	🟥¤	🟥¤	🟥¤	🟨	🟥¤	🟥¤	🟩	🟨

Pine forest was the only habitat where there were significant differences between the different areas. Brooklands had an estimated occupancy approximately half that of Maramarua, and was significantly lower in autumn than the other seasons (Table 5-4).

A visual representation of site occupancy at these sites showed that while not perfect, there was significant overlap in the sites where rats were detected from one season to the next. Analysis of site occupancy for Brooklands in the summer is the only season where PRESENCE estimated the probability of some sites to be occupied as 1.00 when no rat was detected there (red squares containing no symbol).

Detectability

Several models were run on PRESENCE to determine the mean probability of rats being detected given that they were present at the different areas and seasons. Each of the following tables shows the most likely model for each area, along with the probability of rats being detected (P) at the study area. Where rain was a co-variate for detection over the sampling period, two probabilities were given for that season. The first probability is for days without rain, while the one in brackets is for days where rain was recorded.

Table 5-5 Results from PRESENCE analysis of pasture study areas showing the best models and P values for each season.

Pasture areas	Autumn	Winter	Spring	Summer
North	Ψ(.)p(.) P=0.12	Ψ(bush)p(.) P=0.03	Ψ(drain)p(.) P=0.07	Ψ(.)p(.) P=<0.01
South	Ψ(bush)p(rain) P=0.53	Ψ(.)p(.) P=0.12	Ψ(.)p(.) P=0.31	Ψ(.)p(rain) P=0 (0.02)

In general, rats were least likely to be detected on pasture areas than in any other habitat. Of these, rats were less likely to be detected at the northern pasture area, with a lower P value across all seasons. Both areas had highest P values for autumn and spring, with autumn being highest overall (Table 5-5).

For the pasture areas, no model best fit the data consistently across all seasons. For Pasture North, no model that incorporated rain as a covariate provided best fit to the data. However, for all seasons, the equivalent model with rain as a parameter was not sufficiently different to be discounted entirely.

For Pasture South, only in autumn was rain was a significant co-variate in the models. While it best fit the data for summer as well, it was not significantly different from other models that incorporated constant detection over time.

Table 5-6 Results from PRESENCE analysis of indigenous forest study areas showing the best models and P values for each season.

Indigenous Forest	Autumn	Winter	Spring	Summer
Pirongia	Ψ(.)p(.) P=0.56	Ψ(.)p(rain) P=0.48 (0.48)	Ψ(.)p(.) P=0.58	Ψ(.)p(.) P=0.56
Te Tapui	Ψ(.)p (.) P=0.62	Ψ(.)p(rain) P=0.44 (0.64)	Ψ(.)p(.) P=0.49	Ψ(.)p(.) P=0.42
Te Miro	Ψ(.)p(.) P=0.76	Ψ(.)p(.) P= 0.87	Ψ(.)p(.) P=0.88	Ψ(.)p(.) P=0.77

Rats were most likely to be detected in indigenous forest areas than any other habitat. In general, the trend in detection followed that of the pasture areas where rats were most likely to be detected in the autumn and spring. However, the differences between seasons were not quite as evident (Table 5-6).

Across all areas and seasons, the best models incorporated a constant probability of occupancy at each site, and rain featured in models only for winter. At Te Miro, rain did not feature in the best model for any season. Surprisingly, rain increased P at Te Tapui, but not at Pirongia.

Table 5-7 Results from PRESENCE analysis of pine forest study areas showing the best models and P values for each season.

Pine forests	Autumn	Winter	Spring	Summer
Brooklands	Ψ(.)p(.) P=0.08	Ψ(gully)p(rain) P=0.14 (0.33)	Ψ(.)p(rain) P=0.06	Ψ(gully)p(.) P=0.04
Maramarua	Ψ(.)p(.) P=0.45	Ψ(.)p(.) P=0.40	Ψ(.)p(.) P=0.38	Ψ(.)p(.) P=0.55

P values for pine forest areas were very different for the two areas, with rats much more likely to be detected at Maramarua than Brooklands. Another difference from the other habitats is that P values did not peak in autumn and spring; rather they were much more consistent over the year (Table 5-7).

Although rain did not feature in the best models across all Brooklands seasons, it was still significant. Rain data were not available for Maramarua. While the best models incorporated a constant probability of occupancy, models including the effects of gullies were still significant ($\Delta AIC < 2.00$).

5.3 Active Period and Activity Levels

5.3.1 Results

Active Period

Rats were more active at Pasture South than Pasture North. More visits were recorded there, and rats were also generally active later in the day. The exception was in spring, where a handful of visits were recorded in the northern area well after sunrise. Rats were seen most often in the hours before midnight, peaking around 11.00 pm, and summer visits started later than the other seasons. Rats were active longest in the spring. Rats were also significantly more active in autumn, particularly at the southern area (Figure 5-1).

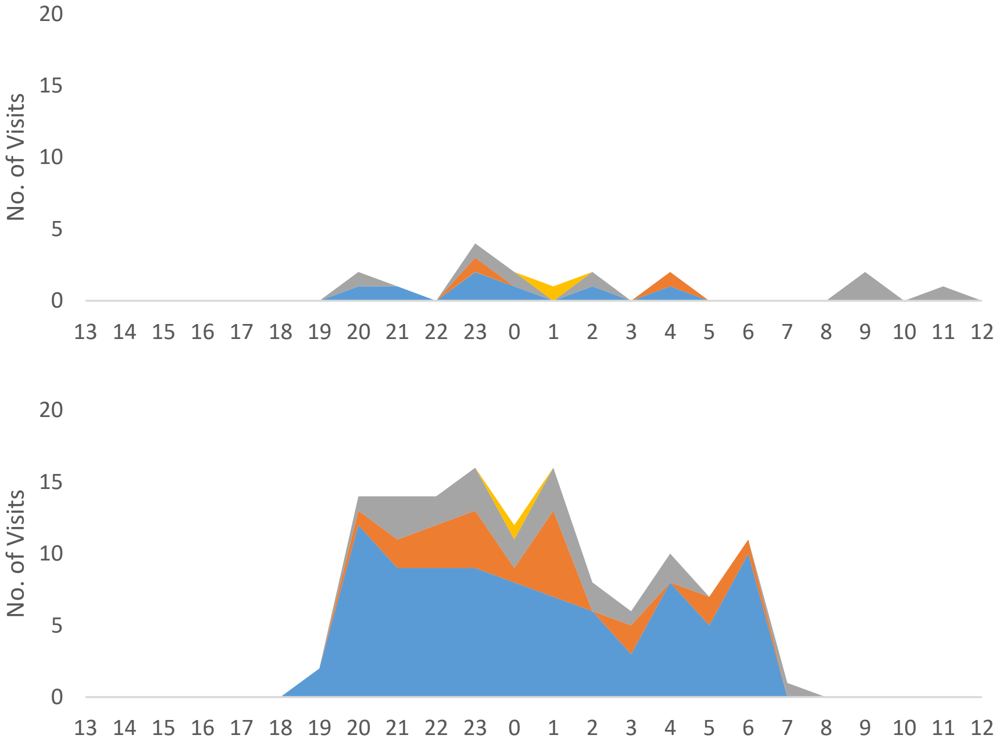


Figure 5-1 Number of rat visits recorded at Pasture North (top) and Pasture South (bottom) in each season plotted against time of day. Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

Rats were recorded most often in the indigenous forest areas. Pirongia recorded the most visits, and visits started earlier in the day and lasted longer. Both Pirongia and Te Tapui recorded a large spike in the number of visits around 8.00 pm, whereas Te Miro was much more consistent. The number of visits at Te Miro were surprisingly high. While they were approximately half that of the other areas, Te Miro covered less than 10% of the area of the others (Figure 5-2).

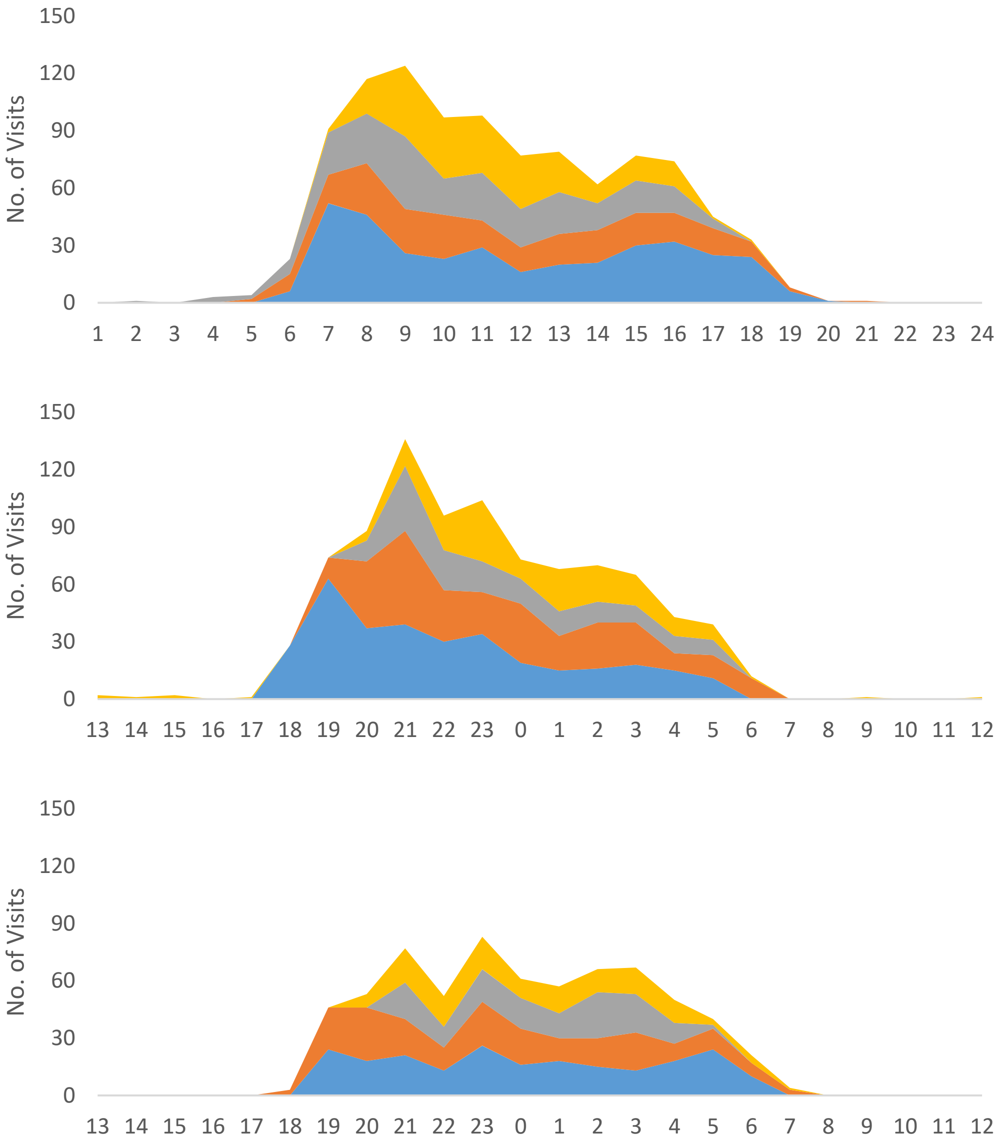


Figure 5-2 Number of rat visits recorded at Pirongia (top), Te Tapui (middle) and Te Miro (bottom) in each season plotted against time of day. Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

There was a large difference in the number of visits between the two pine forest areas, with Maramarua recording approximately three times as many visits during the most active part of the night. Even so, the overall period of activity was similar, and both areas recorded a peak in visit count around midnight. Surprisingly, while autumn made up a large portion of the visits for all other areas, there were almost no visits recorded at Brooklands in this season. Similarly, rats were much less active in summer compared to the other areas (Figure 5-3).

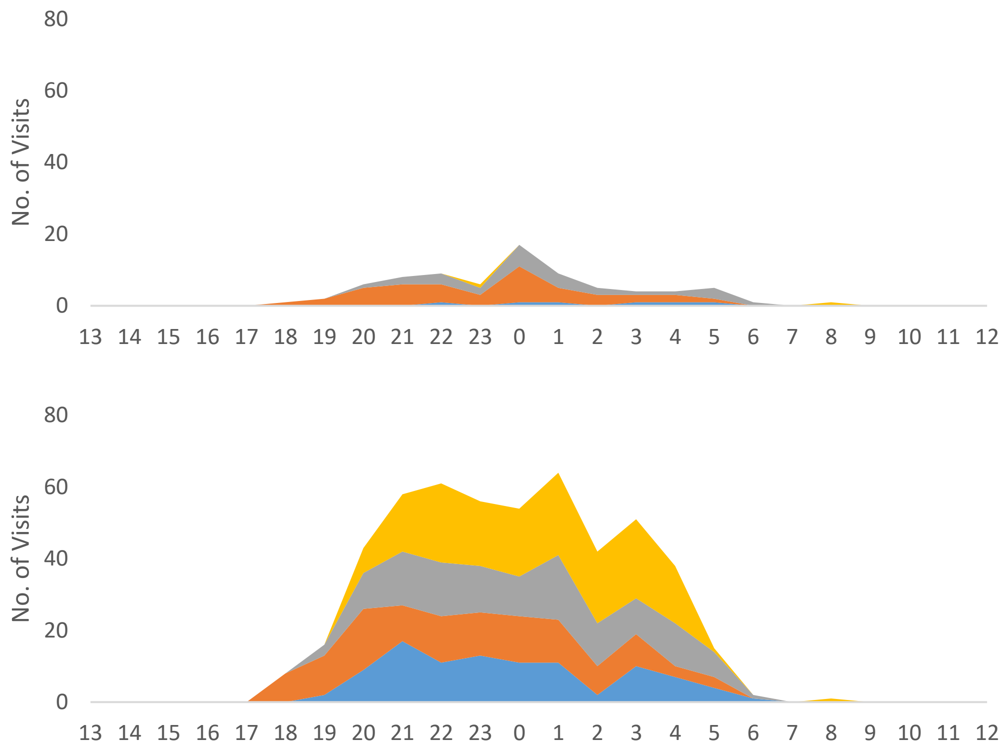


Figure 5-3 Number of rat visits recorded at Brooklands (top) and Maramarua (bottom) in each season plotted against time of day. Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

Activity Levels

This section summarises the total numbers of rat visits recorded by the cameras for each area and season. For each area, two data points were calculated. V/100 TN is the number of rat visits to all the cameras on the area standardised for 100 nights. MV/D is the maximum number of visits recorded by one camera on one day.

Table 5-8 Visit summaries for each season at each study area. V/100 TN is a measure of the number of visits recorded per 100 trap nights, while MV/D indicates the maximum visit count for a single camera on any one day.

	Autumn	Winter	Spring	Summer
Pasture North				
V/100 TN	3.13	1.10	0.60	0.55
MV/D	3	1	1	1
Pasture South				
V/100 TN	37.05	6.63	11.31	0.55
MV/D	8	3	4	1

Pirongia				
V/100 TN	156.63	122.53	133.33	113.19
MV/D	10	12	11	9
Te Tapui				
V/100 TN	140.11	117.35	72.02	94.05
MV/D	8	8	11	9
Te Miro				
V/100 TN	298.57	268.57	185.71	285.71
MV/D	11	9	8	9
Brooklands				
V/100 TN	2.23	19.52	10.99	1.02
MV/D	1	5	3	1
Maramarua				
V/100 TN	66.07	70.83	62.09	90.11
MV/D	7	12	8	10

Some of the lowest visitation rates of all areas were recorded at Pasture North. At all pasture and indigenous forest areas, the most visits were recorded in autumn. Both the pasture and pine forest sites showed significant differences between replicates in the visits recorded (Table 5-8). Indigenous forest had the highest visitation rates, with the visits recorded at Te Miro double that of the other areas.

Daily visits

Visits at Pasture North were few and intermittent. In fact, no season recorded visits on more than four days, and in summer rats were recorded only on one day, ten days after the start of the study period. Most visits were recorded at the end of the first week. Visits were recorded much more consistently at Pasture South. In particular, rats were recorded on every day in autumn. All seasons recorded rats in the first week, but rats were still only recorded once in summer. Like Pasture North, most visits were recorded at the end of the first week (Figure 5-4).

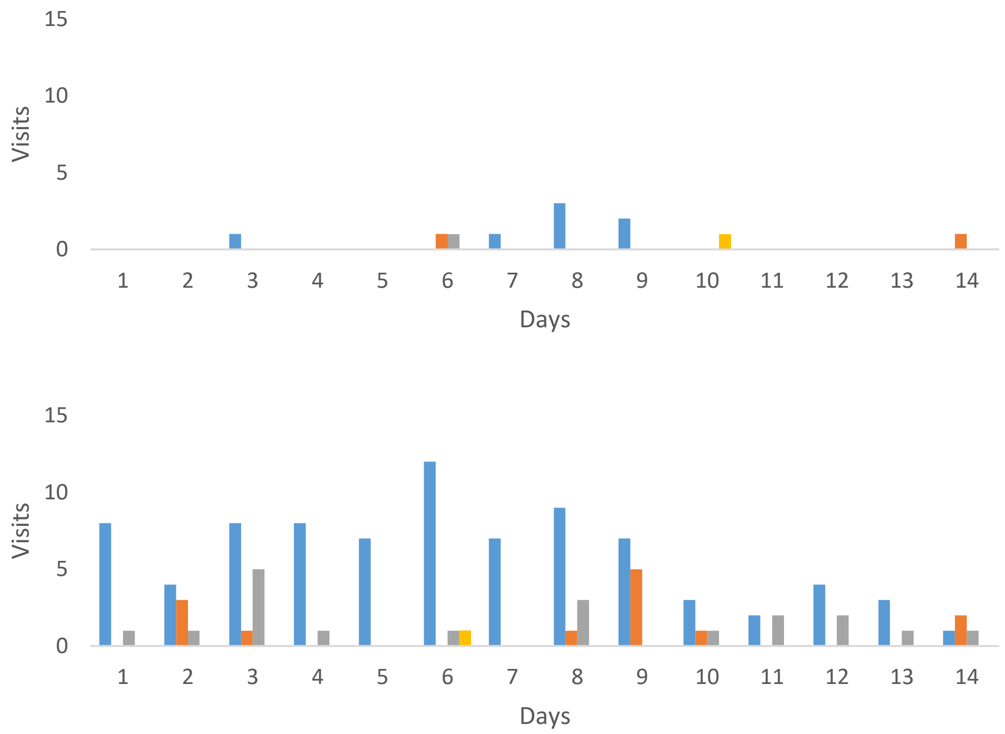


Figure 5-4 Number of rat visits recorded each day of the study period at Pasture North (top) and Pasture South (bottom). Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

With the large number of rats recorded at the indigenous forest areas, a clear pattern emerges for when rats visited the camera locations. Pirongia had the most rat visits, recorded on all days for all seasons. In particular, visits peaked in day two, trailing off but still present at day fourteen. Autumn consistently recorded the most visits. Te Tapui showed the same trend as Pirongia, although with lower visit counts, it was not as pronounced. Visits were recorded on all days for all seasons. In particular, visits peaked in day two, trailing off but still present at day fourteen. No season consistently recorded the most visits. Te Miro showed the same trend as Pirongia, although with lower visit counts, it was not as pronounced. Visits were recorded on all days for all seasons. In particular, visits peaked in day two, trailing off but still present at day fourteen. The daily visit counts were not that different from Te Tapui. No season consistently recorded the most visits (Figure 5-5).

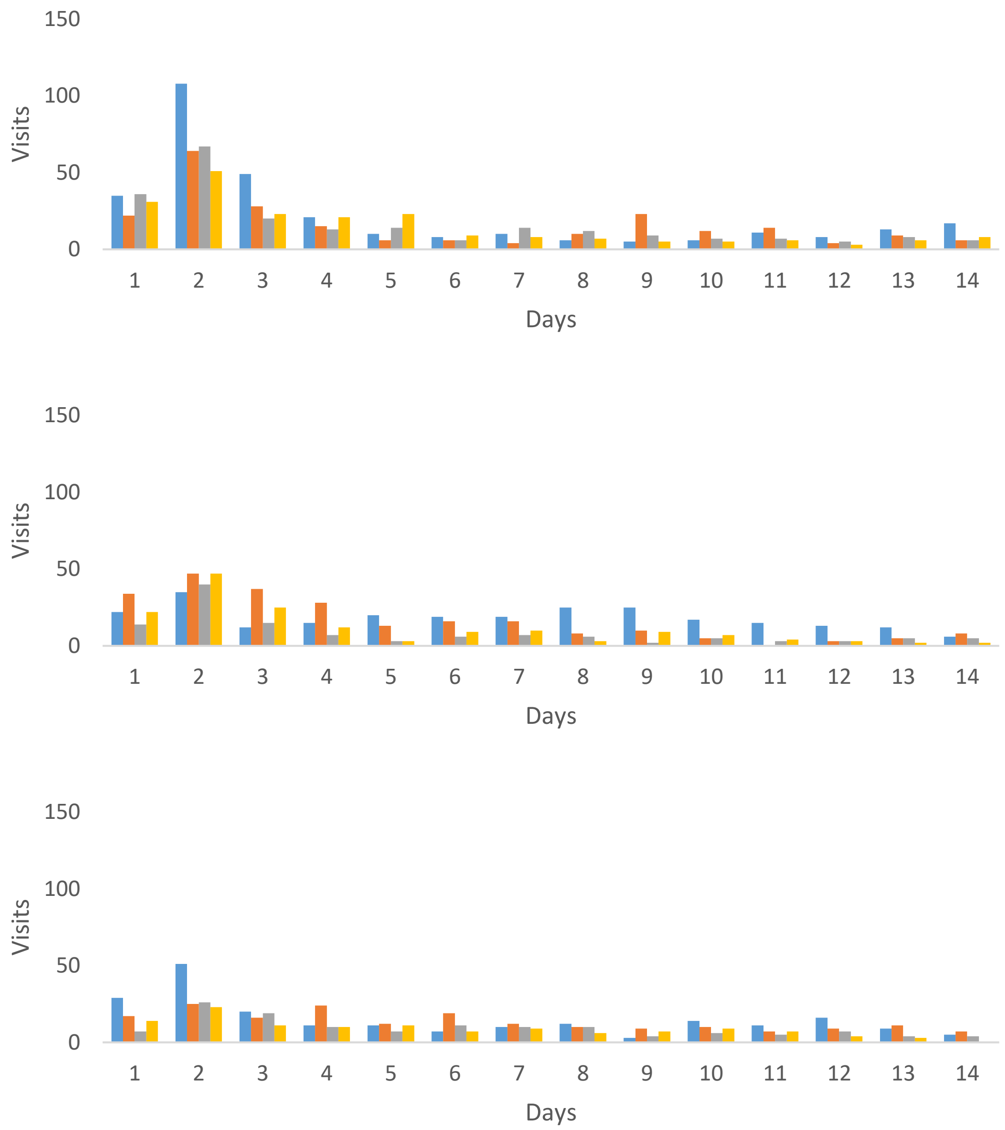


Figure 5-5 Number of rat visits recorded each day of the study period at Pirongia (top), Te Tapui (middle) and Te Miro (bottom). Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

Brooklands had a very low daily visit count. Except for a few days, the most visits were recorded in winter, and rats were recorded only on two days in the summer. While the majority of the visits were recorded in the first week, the overall lower visit counts meant that no real pattern was evident. Maramarua showed the same trend as the indigenous forest areas, and even with lower visit counts, it was quite pronounced. Visits were recorded on all days for all seasons. In particular, visits peaked in day two, trailing off but still present at day fourteen. No season consistently recorded the most visits (Figure 5-6).

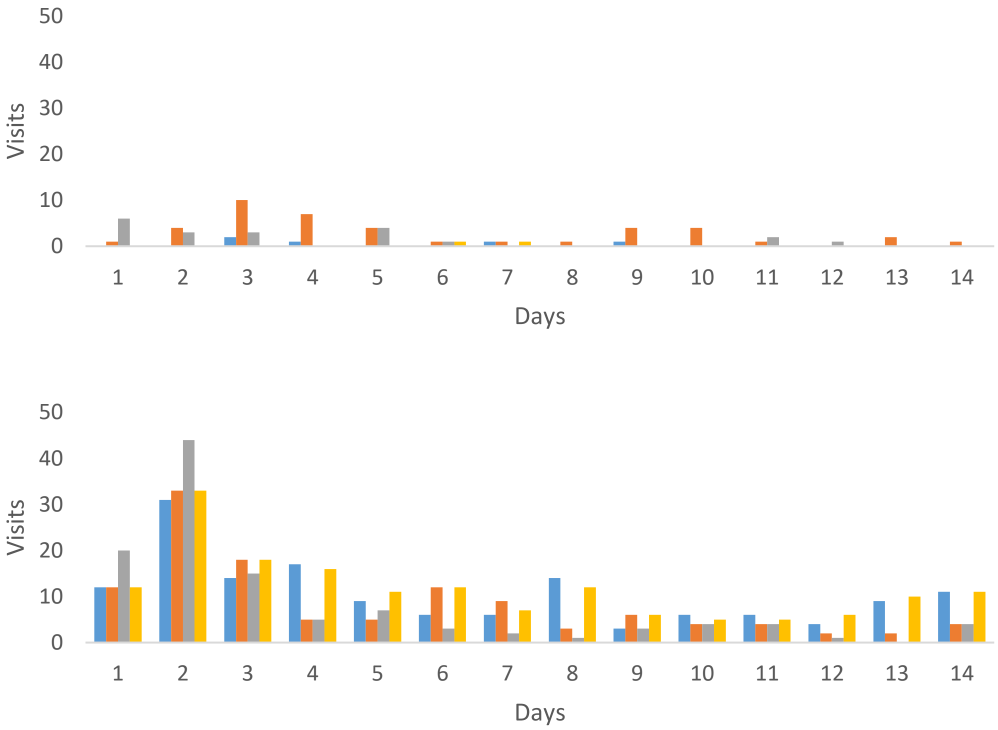


Figure 5-6 Number of rat visits recorded each day of the study period at Brooklands (top) and Maramarua (bottom). Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

5.4 Discussion

The purpose of this chapter is to study rat distribution and detection probabilities as they relate to varying habitats and seasons. In addition, this chapter aimed to answer whether camera traps can be used to determine differences in the levels and/ or periods of activity of rats.

In this section I discuss the results obtained and whether this confirms or refutes my hypotheses. I also answer the question of whether cameras can be used to monitor activity levels in rats. For a detailed discussion and how my results relate to the literature, see Chapter 9.

This analysis tested five hypotheses and accepted none in their original form.

5.4.1 Evaluation of Hypotheses

First hypothesis: that similar habitats of the same type have similar species composition.

Analysis of the occupancy data in 5.2.1 show that rats were detected at each area of all three habitat types. In addition, both the pasture and indigenous forest areas had similar occupancies for each replicate. While the pine forest areas did not follow this pattern, it may be that external factors beyond habitat type influenced results here. Both these areas consist of *Pinus radiata* planted in 2001. The biggest difference between these areas were in the pest control history. Brooklands has ongoing biannual pest control, while the last pest control operation at Maramarua was in 2014.

Brooklands had a much lower estimated occupancy for all seasons than had Maramarua. While I noticed some dead rats during my spring sampling session, a seasonal effect is not obvious from my data. However, it is likely that the biannual pest control has resulted in lower population numbers than would normally be expected at a pine forest area.

It would therefore be more accurate to accept this hypothesis in a modified form: that similar habitats of the same type *are likely to have* similar species composition.

Second hypothesis: that there are no detectable differences in species distribution between different habitat types.

All three habitat types recorded rats as being present, but with differences. Except for Brooklands, all forests had more than 80% of sites recorded as occupied by rats, and this often increased to 100% depending on the season. As mentioned, constant pest control is the likely reason that Brooklands is so different.

In addition, while both forest types had very high occupancy rates, the number of visits recorded at these areas were quite different, with indigenous forest recording approximately double the number of visits of the pine forest areas. Pasture areas on the other hand, were very different, with less than 50% occupancy, and only about a tenth of the visits recorded at the indigenous forest areas.

So, while rats were present in all habitat types, and similar habitats produced similar results, there were significant differences between different habitats. Particularly those with different vegetation types i.e. pasture vs. trees. From these results, I would expect other habitats such as manuka/kanuka stands to be different again. Therefore, this hypothesis can be rejected. Rather, there are *significant differences in species distribution between* different habitat types.

Third hypothesis: that species distribution within habitats are uniform, and there are no significant differences in probability of detection at different points within each habitat.

The PRESENCE analysis of site occupancy within each habitat found that for forested habitats this seemed to be mostly true. While the data for one or two seasons fit better to models that include habitat features as a co-variate, the vast majority found that a constant Ψ fit the data best.

However, rat distribution across the pasture areas were very patchy, and often were recorded on only two or three cameras.

It is important to note that the differences between the different models tested in PRESENCE were often quite fine, so the results displayed here are only an indication to provide a way of comparing the different areas. The full model lists with their associated AIC scores and likelihood values are provided in the Appendices.

This means that while the best model in a few cases incorporated habitat features such as bush or drains, these may not have been that significant overall, especially as the best models were not consistent across the seasons with respect to the habitat feature modelled.

This hypothesis can therefore be accepted only in a modified form: that species distribution within habitats *are not* always uniform, but there *are no* significant differences in detection probability at different points within each habitat.

Fourth hypothesis: that there are no changes in the detectability of given species of small mammals at a given trap site within a trapping session.

For most areas and seasons, the best models were those that incorporated a constant detection probability over the study session. Rainfall was the only other co-variate that seemed to affect detection, but only in a few cases, and the differences between these models and others with a constant probability of detection were minimal. The opposite was also true. In particular, for Pasture North and Brooklands, rain was a significant co-variate across all seasons, even if it was not featured in the best model.

Overall, I did not find rain to be a significant factor in the probability of detecting rats, but further study with more cameras over a longer period may well come to a different conclusion. When rain was modelled, it either had no effect on detection or increased, it never decreased.

This hypothesis can therefore be accepted only in a modified form: that there *may or may not* be changes in the detectability of rats at a given trap site within a trapping session.

Fifth hypothesis: species distribution and abundance are not affected by the seasons.

There were significant differences in both the detectability and site occupancy of rats across the seasons, particularly at the pasture areas. Even at the forested areas, while distribution was not affected as much, the levels of activity were very much seasonally dependent.

Rats have been found to breed between September and April, which could explain why most areas, and the indigenous forest areas in particular, had high visit counts for the autumn season; i.e., at the end of the breeding season before winter mortality sets in.

This hypothesis can therefore be rejected: species distribution and abundance *are* affected by the seasons.

5.4.2 Evaluation of Research Questions

Can camera traps be used to determine differences in the levels and/ or periods of activity of rats, when not individually identifiable?

Figure 5-7 Rats at Pirongia.

Analysis of the time-stamped images does allow for a study of differences in the levels and/ or periods of activity of rats on my study areas, with clear periods of peak activity and the number of visits to each camera. These confirm that rats are active from dusk till dawn, making only a few visits during the day.

5.5 Conclusions

My analyses reject the hypotheses that there are no differences in species distribution and detectability between different habitat types, and that seasons have no effect on these parameters of rat populations. I must also reject the hypothesis that rat detectability was constant over the study period.

Cameras provide a viable method of studying rat populations, and while a two-week study period is sufficient, more cameras are needed to improve the accuracy of results for site-occupancy analysis, especially where the proportion of sites occupied are low.

Chapter Six

Distribution and Activity Levels of Mice in Three Waikato Vegetation Types

6.1 Overview

In this chapter I will be testing for my five hypotheses as they relate to wild house mice in the Waikato Region. I will compare five different parameters of the mouse populations at my study areas and how they vary with respect to habitat type (pasture, indigenous forest, and pine forest) and season.

In section 6.2 I investigate their distribution within each study area as detected by the cameras, as well as the site occupancy and probability of detection in each area as calculated by PRESENCE.

In section 6.3 I use the data collected from the time-stamped images to display the period of activity within each habitat. In addition, I investigate the number of visits plotted against time, and provide an overall visit count for each area and season.

I will then discuss my results and whether or not it supports my hypotheses, concluding with an evaluation of my hypotheses and research questions as they relate to mice.

6.2 Distribution and Site Occupancy

6.2.1 Results

Site Occupancy

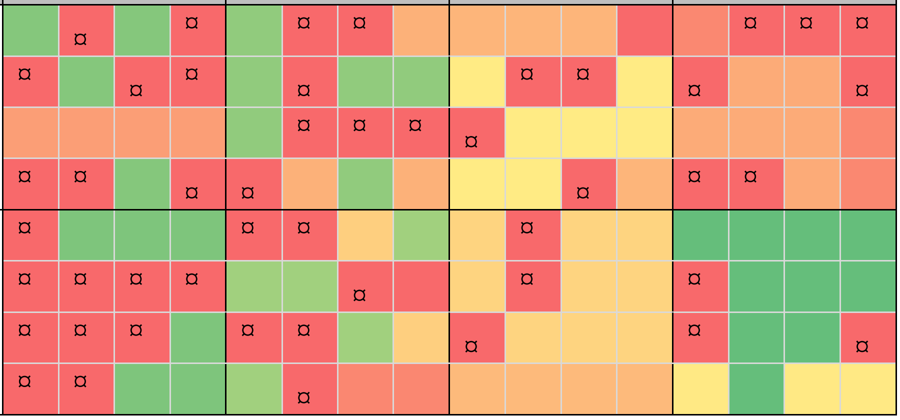
For each area and season, an analysis of site occupancy was run using PRESENCE, and the results are reported in the tables below. Each cell contains two values, with the upper value being the calculated estimate for mean site occupancy Ψ, and the bottom value being the naïve occupancy, i.e. the raw proportion of sites where mice were detected by the cameras. The difference between them illustrates how unreliable simple observation can be in estimating the real distributions of animals. Each table also contains a visual representation of mouse distribution, with the ¤ symbol showing where mice were positively identified. The colour of each cell represents the likelihood that mice are present at the site even if it was not detected. Solid green represents a probability of 0, while red indicates a probability of 1 (Table 6-1).

Table 6-1 Key to tables depicting site occupancy at each of the study areas. The different colours represent the listed probabilities that a site is occupied, even if no mice were detected.

0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00

Table 6-2 Site occupancy estimates for mice on the two pasture study areas.

Pastures	Autumn				Winter				Spring				Summer			
Pasture North	0.68 0.67				0.57 0.54				0.54 0.42				0.82 0.54			
Pasture South	0.64 0.63				0.59 0.50				0.52 0.25				0.23 0.23			
	Autumn				Winter				Spring				Summer			
Pasture North		¤		¤		¤	¤							¤	¤	¤
	¤		¤	¤		¤				¤	¤		¤			¤
						¤	¤	¤	¤							
	¤	¤		¤	¤						¤		¤	¤		
Pasture South	¤				¤	¤				¤						
	¤	¤	¤	¤			¤			¤			¤			
	¤	¤	¤		¤	¤			¤				¤			¤
	¤	¤				¤										

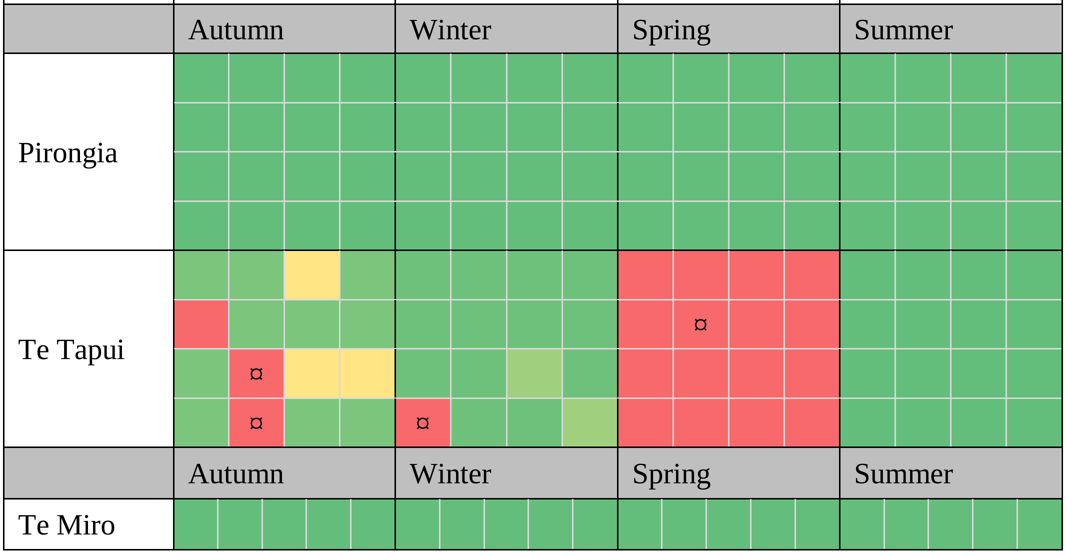


Site occupancy over the seasons was most consistent for the two pasture areas. They were also the only areas where mice were detected year-round. Site occupancy values for both areas were very similar, except in summer. While site occupancy was highest for the northern area in the summer, for the southern area it was lowest (Table 6-2).

Occupancy decreased over the seasons, but only for Pasture South.
A visual representation of site occupancy at each area show that mice were not consistently seen at the same sites across the seasons, particularly in the northern area. While the same was true for the southern area, there were some overlap from one season to the next.

Table 6-3 Site occupancy estimates of the three indigenous forest areas.

Indigenous forests	Autumn	Winter	Spring	Summer
Pirongia	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00
Te Tapui	0.28 0.23	0.09 0.07	1.00 0.08	0.00 0.00
Te Miro	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00



	Autumn				Winter				Spring				Summer			
Pirongia	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Te Tapui	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟩
	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥 ¤	🟥	🟥	🟩	🟩	🟩	🟩
	🟩	🟥 ¤	🟨	🟨	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟩
	🟩	🟥 ¤	🟩	🟩	🟥 ¤	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟩

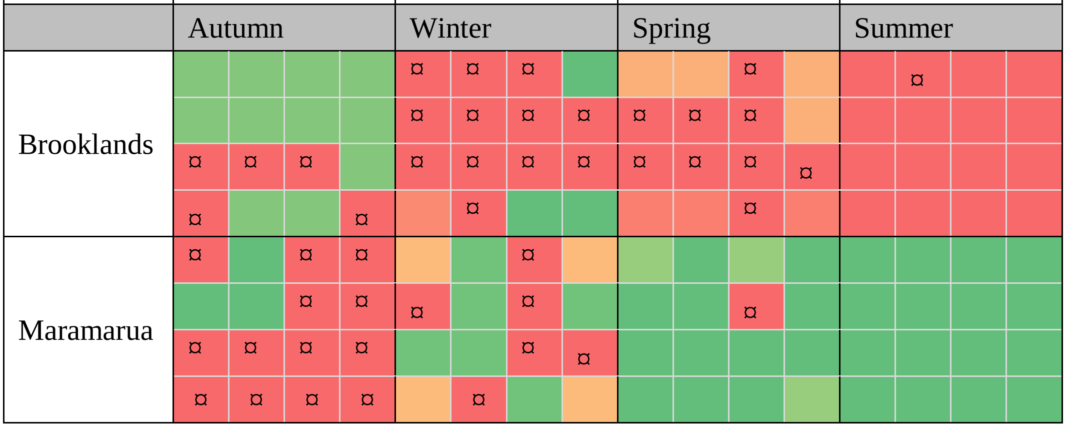
	Autumn					Winter					Spring					Summer				
Te Miro	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

Overall, the estimated site occupancy of mice in indigenous forests was the lowest of all habitat types. Only Te Tapui recorded any mice, and even there, none were recorded in the summer. The highest naïve occupancy was recorded in autumn, and this is consistent with the pasture results (Table 6-3).

A visual representation shows that mice were positively identified in very few areas, and these did not stay constant. Both winter and spring only recorded mice at one site, but the seasons were modelled very differently.

Table 6-4 Site occupancy estimates of the two pine forest study areas.

Pine forests	Autumn	Winter	Spring	Summer
Brooklands	0.35 0.31	0.80 0.80	0.87 0.69	1.00 0.07
Maramarua	0.81 0.81	0.51 0.50	0.08 0.08	0.00 0.00



	Autumn				Winter				Spring				Summer			
Brooklands					¤	¤	¤				¤			¤		
					¤	¤	¤	¤	¤	¤	¤					
	¤	¤	¤		¤	¤	¤	¤	¤	¤	¤	¤				
	¤			¤		¤					¤					
Maramarua	¤		¤	¤			¤									
			¤	¤	¤		¤				¤					
	¤	¤	¤	¤			¤	¤								
	¤	¤	¤	¤		¤										

The pine forest areas also showed significant local differences. Mice were recorded at Brooklands in all seasons, with the highest site occupancy recorded in spring. In contrast, no mice were recorded at Maramarua in summer, and only at one site in spring. There were also significant seasonal differences, with the highest site occupancy recorded at Brooklands in spring, and at Maramarua in autumn (Table 6-4).

A visual representation of site occupancy at these areas showed that there was some overlap in where mice were recorded in the different seasons. Brooklands summer and Maramarua winter both only showed mice at one site, but the seasons were modelled very differently

Detectability

Several models were run on PRESENCE to determine the probability of mice being detected given that they were present in the different areas and seasons. Each of the following tables shows the most likely model for each area, along with the probability of mice being detected (P) over the sampling period. Where rain was a co-variate for detection over the sampling period, two P values were given for that season. The first probability is for days without rain, while the one in brackets is for days where rain was recorded.

Table 6-5 Results from PRESENCE analysis of pasture study areas showing the best models and P values for each season.

Pasture areas	Autumn	Winter	Spring	Summer
North	Ψ(.)p(.) P=0.24	Ψ(.)p(rain) P=0.05 (0.26)	Ψ(.)p(.) P=0.10	Ψ(.)p(.) P=0.07
South	Ψ(.)p(.) P=0.24	Ψ(bush)p(.) P=0.15	Ψ(.)p(.) P=0.05	Ψ(.)p(.) P=0.28

The probability that a pasture area is occupied was best modelled with a constant Ψ and p, except in winter. In the northern area, rain was an important covariate, and significantly improved the probability of detecting mice. In the southern area, winter was the only season when the presence of trees nearby was a covariate in the best model (Table 6-5).

P values for both areas followed the same pattern as the overall site occupancy. They decreased over the seasons in the northern area, and also in the southern area except in the summer.

Table 6-6 Results from PRESENCE analysis of indigenous forest study areas showing the best models and P values for each season.

Indigenous Forest	Autumn	Winter	Spring	Summer
Pirongia	N/A	N/A	N/A	N/A
Te Tapui	Ψ(.)p(.) P=0.15	Ψ(.)p(.) P=0.12	Ψ(.)p(.) P=0.01	N/A
Te Miro	N/A	N/A	N/A	N/A

Te Tapui data best fit models with constant Ψ and probability of detection over time. P also consistently decreased over the seasons, with no mice detected in the summer (Table 6-6).

Table 6-7 Results from PRESENCE analysis of pine forest study areas showing the best models and P values for each season.

Pine forests	Autumn	Winter	Spring	Summer
Brooklands	Ψ(.)p(.) P=0.16	Ψ(.)p(.) P=0.48	Ψ(.)p(.) P=0.11	Ψ(.)p(rain) P=0.00 (0.01)
Maramarua	Ψ(gully)p(.) P=0.58	Ψ(.)p(.) P=0.25	Ψ(.)p(.) P=0.57	N/A

Mice were more likely to be detected in pine forest than in any other habitat. P values for pine forest areas were very different for the two areas, with mice much more likely to be detected at Maramarua than Brooklands. Another difference from the other habitats is that P values did not peak in autumn and spring; rather they were much more consistent over the year (Table 6-7).

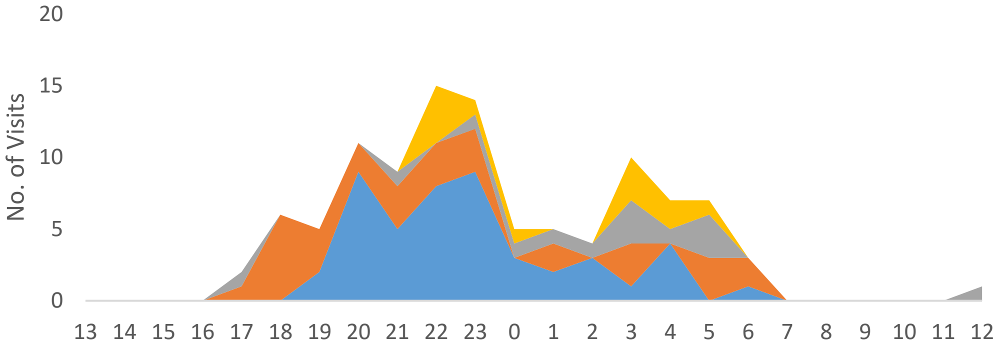
Although rain did not feature in the best models across all Brooklands seasons, it was still significant. Rain data was not available for Maramarua. While the best models incorporated a constant probability of occupancy, models with gullies were not sufficiently different to be discounted.

6.3 Active Period and Activity Levels

6.3.1 Results

Active Period

The active period of mice was similar in the two pasture areas. At both, activity reached a peak between 8.00 pm and 11.00 pm, with much less activity recorded after midnight. There was a slight difference in the hours when mice were active at these two areas. Mouse activity started earlier at the northern area, but also finished earlier in the morning. Only at the northern area were a few mice active at mid-day. Mice were recorded in all seasons, but least often in spring. Summer activity started later and finished earlier. Mice were active earliest in the winter (Figure 6-1).



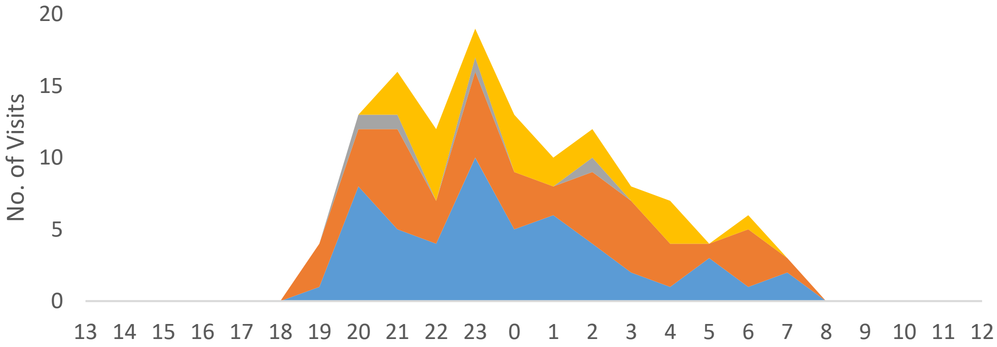


Figure 6-1 Number of mouse visits recorded at Pasture North (top) and Pasture South (bottom) in each season plotted against time of day. Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

Mouse activity in indigenous forest was recorded only at Te Tapui. No activity was recorded in summer. Mice were active at a similar time in indigenous forest as at the other areas, although the low number of records makes defining an active period difficult. In general, activity peaked twice, after sunset and before sunrise. Mice were active earliest in the winter (Figure 6-2).

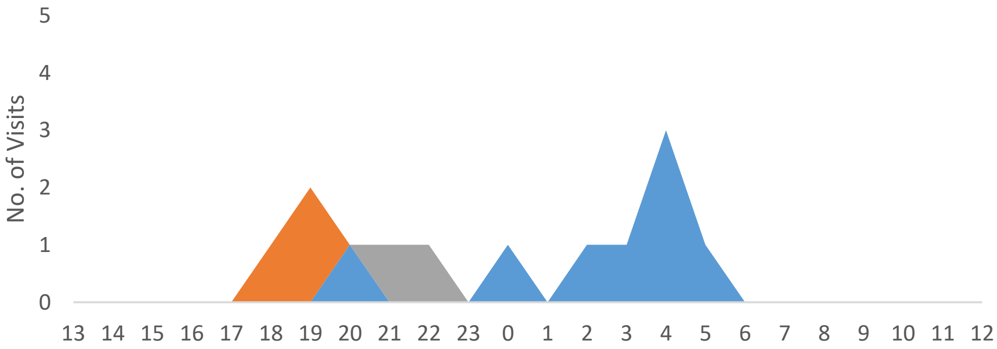


Figure 6-2 Number of mouse visits recorded at Te Tapui in each season plotted against time of day. Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

Mice were more active at Brooklands than at Maramarua in all seasons but autumn. Activity at the two pine forest areas started at a similar time, but mice at Maramarua were still active well after sunrise. At both areas, activity peaked around 8.00 pm, and bottomed out around 1.00 am (Figure 6-3).

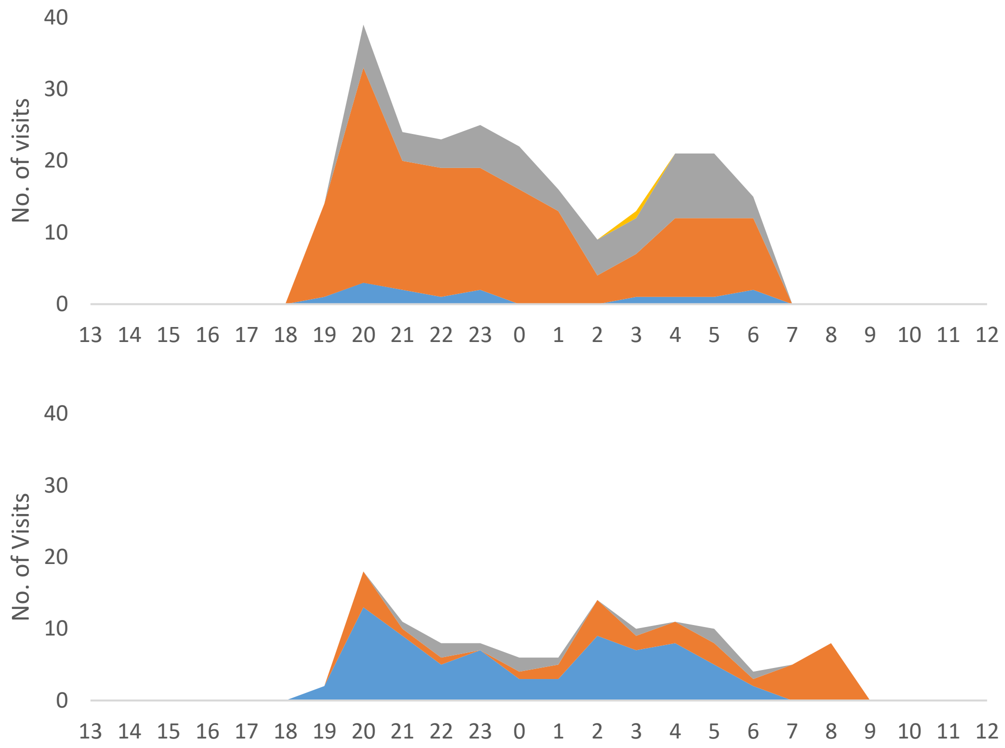


Figure 6-3 Number of mouse visits recorded at Brooklands (top) and Maramarua (bottom) in each season plotted against time of day. Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

Activity Levels

This section summarises the mouse visits recorded by the cameras for each area and season. For each area, two data points were calculated. V/100 TN is the number of mouse visits to all the cameras in the area standardised for 100 nights. MV/D is the maximum number of visits recorded by one camera on one day.

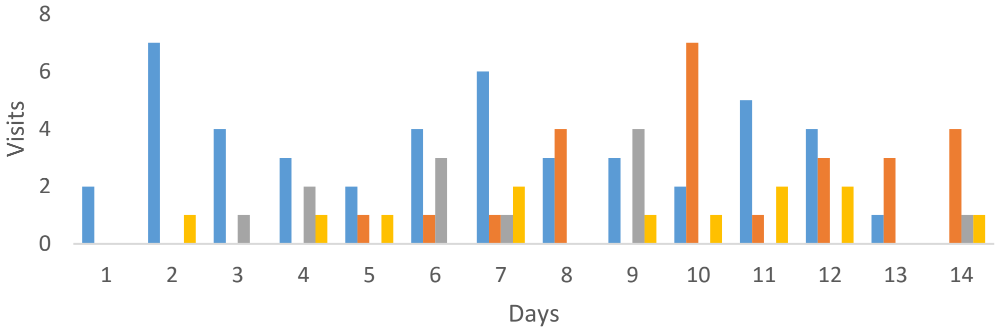
Table 6-8 Visit summaries for each season at each study area. V/100 TN is a measure of the number of visits recorded per 100 trap nights, while MV/D indicates the maximum visit count for a single camera on any one day.

	Autumn	Winter	Spring	Summer
Pasture North				
V/100 TN	20.54	13.74	7.14	6.59
MV/D	5	4	2	2
Pasture South				
V/100 TN	22.32	9.18	2.38	11.54
MV/D	4	2	1	5
Te Tapui				
V/100 TN	4.40	1.53	1.19	0.00
MV/D	2	2	2	0
Brooklands				
V/100 TN	7.14	78.57	29.67	0.51
MV/D	2	9	7	1
Maramarua				
V/100 TN	80.36	20.83	4.95	0
MV/D	7	5	2	0

Most mice were recorded at the pasture and pine forest areas. While the pasture replicates were somewhat similar, those of the pine forest areas were not. For most areas, mice were recorded more often in autumn and winter, and least in summer (Table 6-8).

Daily visits

At Pasture North, mice were detected at in all seasons within the first week. Winter recorded one of the highest daily visit counts of any season, even though visits only started on day five. Visit counts at Pasture South were similar to those of the northern area at all seasons but spring, which had many fewer visits. Even so, all seasons recorded visits within the first two days (Figure 6-4).



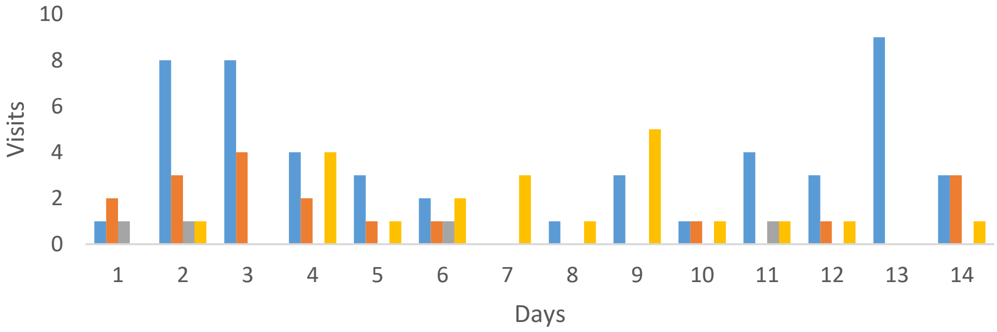


Figure 6-4 Number of mouse visits recorded each day of the study period at Pasture North (top) and Pasture South (bottom). Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

Te Tapui not only had the fewest mice detected, but also the most infrequent detections of all areas. In spring, mice were detected only on day one, and in winter only for two days, starting seven days into the study period (Figure 6-5).

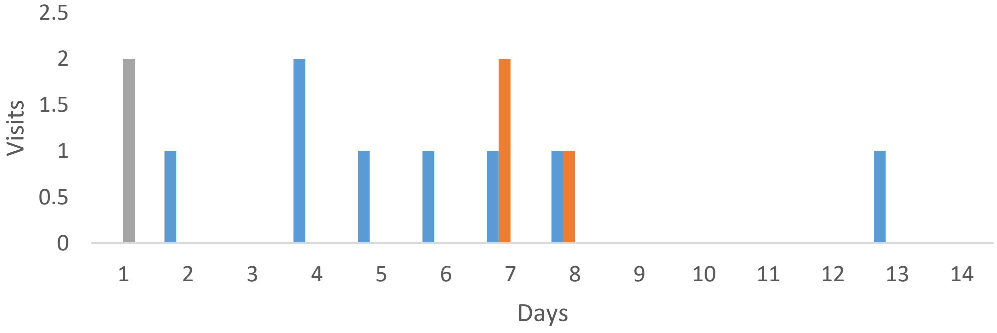


Figure 6-5 Number of mouse visits recorded each day of the study period at Te Tapui. Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

At Brooklands, mice were detected only on one day in summer, and this on day ten of the study period. During the other seasons, mice were detected on most if not all days. In contrast to all other areas, here mice were detected most consistently and frequently in winter. At Maramarua, mice were detected much more often in autumn than any other season. Even so, in all seasons but summer, mice were detected on most, if not all, days (Figure 6-6).

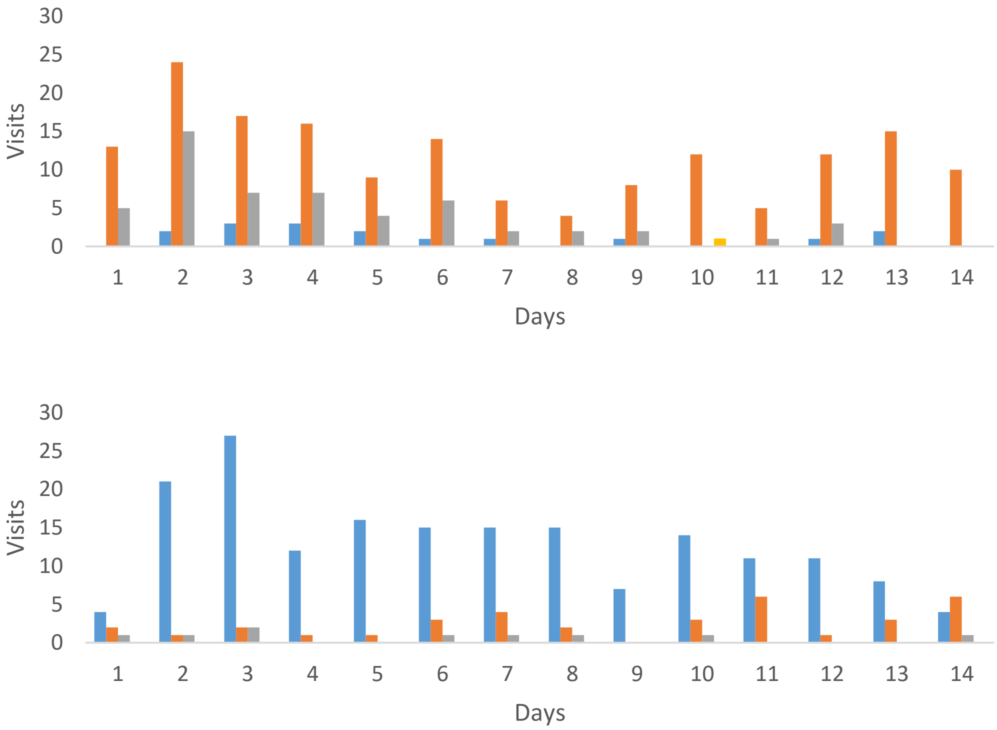


Figure 6-6 Number of mouse visits recorded each day of the study period at Brooklands (top) and Maramarua (bottom). Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

6.4 Discussion

The purpose of this chapter is to study mice distribution and detection probabilities as they relate to varying habitats and seasons. In addition, this chapter aimed to answer whether camera traps can be used to determine differences in the levels and/ or periods of activity of mice.

In this section I discuss the results obtained and whether this confirms or refutes my hypotheses. I also answer the question of whether cameras can be used to monitor activity levels in possums. For a detailed discussion and how my results relate to the literature, see Chapter 9.

This analysis tested five hypotheses and accepted none in their original form.

6.4.1 Evaluation of Hypotheses

First hypothesis: that similar habitats of the same type have similar species composition.

Analysis of the occupancy data in 6.2.1 show that there were significant differences in distribution of mice between different areas of the same habitat. While mice were present at all pasture and pine forest areas, they were detected at only one of the three indigenous forest areas. Additionally, mice were barely detected at Maramarua in the spring, and not at all in the summer.

It would therefore be more accurate to accept this hypothesis in a modified form: that similar habitats of the same type *may or may not have* similar species composition.

Second hypothesis: that there are no detectable differences in species distribution between different habitat types.

Mice were present in all three habitat types, but with differences. Pasture was the only habitat type where site occupancy was high at all areas. Pine forest areas did not record high occupancy as consistently, but had a much greater number of visits. The indigenous forest areas had both the lowest occupancy overall, as well as the least number of visits recorded. These differences will be discussed further in Chapter 9.

So, while mice were present in at least one area of all habitat types, there were significant differences between different habitats. Therefore, this hypothesis can only be rejected: that there are *significant differences in species distribution between* different habitat types.

Third hypothesis: that species distribution within habitats are uniform, and there are no significant differences in probability of detection at different points within each habitat.

The PRESENCE analysis of site occupancy within each habitat found that mice were not spread evenly across any habitat, although the pine forest areas had the highest naïve occupancy rates. For the pasture and indigenous forest areas, distribution was very patchy, and the sites occupied changed with the seasons.

While the data for one or two seasons fit better to models that include habitat features as a co-variate, the vast majority found that a constant Ψ fitted the data best.

It is important to note that the differences between the different models tested in PRESENCE were often quite fine, so the results displayed here are only an indication to provide a way of comparing the different areas. The full model lists with their associated AIC scores and likelihood values are provided in the Appendices.

This means that while very few of the best models incorporated habitat features such as bush or gully, these may not have been completely insignificant, especially at areas where they did show up in the best model at least once. In no case did the best model have a ΔAIC score > 2.00 compared to all other models, which means that some of these features may still play a role in the distribution of mice across the area.

This hypothesis can therefore be accepted only in a modified form: that species distribution within habitats *are not* always uniform, but there *are no* significant differences in detection probability at different points within each habitat.

Fourth hypothesis: that there are no changes in the detectability of mice at a given trap site within a trapping session.

For all but two seasons, the best models were those that incorporated a constant detection probability over the study session. Rainfall was the only other co-variate that seemed to affect detection, but the differences between these models and others with a constant probability of detection were minimal. The opposite was also true. Rain was a co-variate in at least one of the top models across all areas and seasons, and in several instances, it was a co-variate in the second most likely model.

Overall, I could not definitively prove whether rain was a significant factor in detecting mice or not, but further study with more cameras over a longer period may well come to a different conclusion. It is interesting that when rain was modelled, P was always higher.

This hypothesis can therefore only be accepted in a modified form: that there *may or may not* be changes in the detectability of given species of mice at a given trap site within a trapping session.

Fifth hypothesis: species distribution and abundance are not affected by the seasons.

There were significant differences in both the detectability and site occupancy values for mice across the seasons, particularly in the forested areas. Even at the pasture areas, while distribution was more constant, the levels of activity were very much seasonally dependent. Possible explanations for these differences will be discussed further in Chapter 9.

This hypothesis can, therefore, be rejected: species distribution and abundance *are* affected by the seasons.

6.4.2 Evaluation of Research Questions

Can camera traps be used to determine differences in the levels and/ or periods of activity of small mammals, when not individually identifiable?

Figure 6-7 Mouse at Pasture North

Analysis of the time-stamped images does allow for a study of differences in the levels and/ or periods of activity of mice on my study areas, with clear periods of peak activity and the number of visits to each camera. These confirm that mice are active from late afternoon to early morning, making only a few visits during the day.

In most areas, mice were detected in the first week of the study. At the latest, for Pasture South in the summer, mice were detected on day ten of 14. At all other times but one, mice were detected within the first three days. This suggests that mice really were absent at the areas mentioned above, and a longer study period is unlikely to find them.

6.5 Conclusions

My analyses reject the hypotheses that there are no differences in distribution and detectability of mice between different habitat types, and that seasons have no effect on these parameters of mouse populations. I must also reject the hypothesis that mouse detectability was constant over the study period.

Cameras provide a viable method of studying mice populations, and while a two-week study period is sufficient to detected mice at most areas, more cameras are needed to improve the accuracy of results for site-occupancy analysis, especially where the proportion of sites occupied are low.

Chapter Seven

Distribution and Activity Levels of Mustelids in Three Waikato Vegetation Types

7.1 Overview

In this chapter, I will be testing my five hypotheses as they relate to mustelids in the Waikato Region. I will compare five different parameters of the mustelid populations at my study areas and how they vary with respect to habitat type (pasture, indigenous forest, and pine forest) and season.

In section 7.2 I investigate their distribution within each study area as detected by the cameras, as well as the site occupancy and probability of detection in each area as calculated by PRESENCE.

In section 7.3 I use the data collected from the time-stamped images to display the periods of activity within each habitat. In addition, I investigate the number of visits, plotted against time, and provide an overall visit count for each area and season.

I will then discuss my results and whether it supports my hypotheses, concluding with an evaluation of my hypotheses and research questions as they relate to mustelids.

7.2 Distribution and Site Occupancy

7.2.1 Results

Species Composition

Table 7-1 Distribution of three mustelid species (weasels, stoats and ferrets) across the study areas. For each season, a dot represents simple presence, indicated by at least one sighting.

	Autumn	Winter	Spring	Summer
Pasture North				
Weasel	•	•	•	
Stoat		•	•	
Ferret		•	•	
Pasture South				
Weasel	•		•	•
Stoat		•		•
Ferret				
Pirongia				
Weasel				
Stoat		•	•	•
Ferret				
Te Tapui				
Weasel				
Stoat	•	•	•	•
Ferret		•		
Te Miro				
Weasel				
Stoat		•		•
Ferret				
Brooklands				
Weasel				
Stoat		•		
Ferret				
Maramarua				
Weasel	•	•		•
Stoat	•	•		•
Ferret	•			

The three species of mustelids were recorded unevenly across the seven study areas. No weasels were recorded at the indigenous forest areas, and ferrets were present only in some areas of each habitat (Table 7-1). Because separate records for each species are insufficient for proper analysis, all visits were grouped together under mustelids for the rest of the analyses.

Site Occupancy

For each area and season, a separate analysis of site occupancy was run using PRESENCE, and the results are reported in the tables below. Each cell contains two values, with the upper value being the calculated estimate for site occupancy Ψ, and the bottom value being the naïve occupancy, i.e. the raw proportion of sites where mustelids were detected by the cameras. The difference between them illustrates how unreliable simple observation can be in estimating the real distributions of animals.

Each table also contain a visual representation of mustelid distribution, with the ¤ symbol showing where mustelids were positively identified. The colour of each cell represents the likelihood that mustelids are present at the site even if it was not detected. Solid green represents a probability of 0, while red indicates a probability of 1 (Table 7-2).

Table 7-2 Key to tables depicting site occupancy at each of the study areas. The different colours represent the listed probabilities that a site is occupied, even if no mustelids were detected.

0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00

Table 7-3 Site occupancy estimates of the two pasture study areas.

	Autumn	Winter	Spring	Summer
Pasture North	1.00 0.17	0.62 0.17	1.00 0.42	0.00 0.00
Pasture South	0.00 0.00	1.00 0.07	1.00 0.17	1.00 0.23

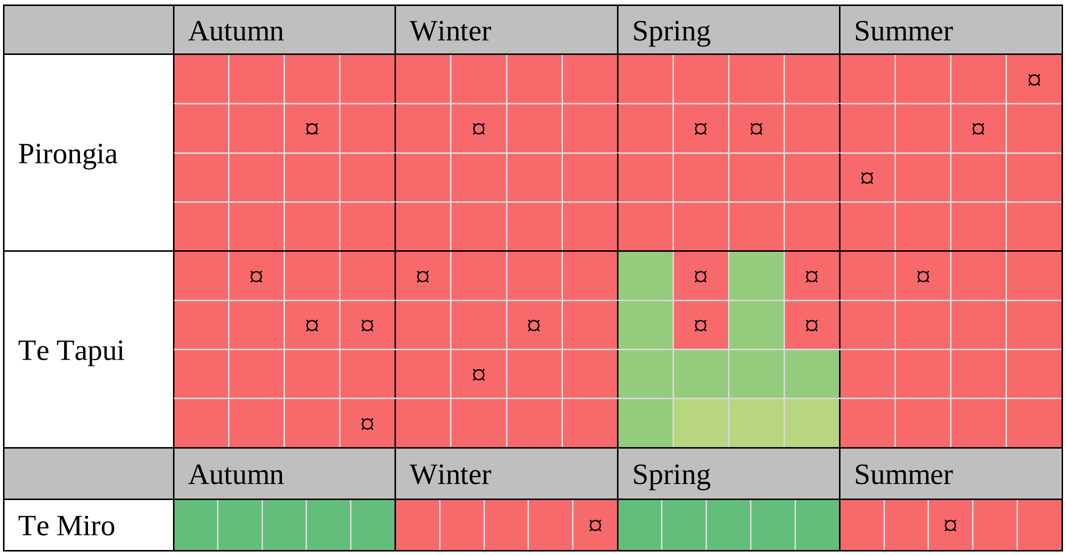
	Autumn				Winter				Spring				Summer			
Pasture North	🟥	🟥	🟥	🟥 ¤	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟩
	🟥	🟥	🟥	🟥 ¤	🟥	🟥 ¤	🟥	🟩	🟥 ¤	🟥 ¤	🟥 ¤	🟥 ¤	🟩	🟩	🟩	🟩
	🟥	🟥	🟥	🟥	🟩	🟥 ¤	🟩	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟩
	🟥	🟥	🟥	🟥	🟥 ¤	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟩
Pasture South	🟩	🟩	🟩	🟩	🟥	🟥 ¤	🟥	🟥	🟥	🟥	🟥 ¤	🟥	🟥	🟥 ¤	🟥 ¤	🟥
	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥 ¤	🟥	🟥	🟥	🟥	🟥
	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥 ¤	🟥	🟥

Naïve site occupancy values on the two pasture areas were very low, and not consistent over the seasons. At both, occupancy increased over the year of observations, even though no mustelid were seen in the northern area in the fourth season (summer). While naïve occupancy for the northern area was identical in autumn and spring, the estimated overall occupancy was very different (Table 7-3).

A visual representation of site occupancy at each pasture area shows that the sites where mustelids where positively identified were not consistent across the seasons, particularly for the northern area. While the same was true for the southern area, there were some overlap from one season to the next.

Table 7-4 Site occupancy estimates of the three indigenous forest areas.

	Autumn	Winter	Spring	Summer
Pirongia	1.00 0.07	1.00 0.08	1.00 0.17	1.00 0.23
Te Tapui	1.00 0.31	1.00 0.24	0.53 0.33	1.00 0.08
Te Miro	0.00 0.00	1.00 0.20	0.00 0.00	1.00 0.20



	Autumn				Winter				Spring				Summer			
Pirongia	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥 ¤
	🟥	🟥	🟥 ¤	🟥	🟥	🟥 ¤	🟥	🟥	🟥	🟥 ¤	🟥 ¤	🟥	🟥	🟥	🟥 ¤	🟥
	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥 ¤	🟥	🟥	🟥
	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
Te Tapui	🟥	🟥 ¤	🟥	🟥	🟥 ¤	🟥	🟥	🟥	🟩	🟥 ¤	🟩	🟥 ¤	🟥	🟥 ¤	🟥	🟥
	🟥	🟥	🟥 ¤	🟥 ¤	🟥	🟥	🟥 ¤	🟥	🟩	🟥 ¤	🟩	🟥 ¤	🟥	🟥	🟥	🟥
	🟥	🟥	🟥	🟥	🟥	🟥 ¤	🟥	🟥	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥
	🟥	🟥	🟥	🟥 ¤	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥

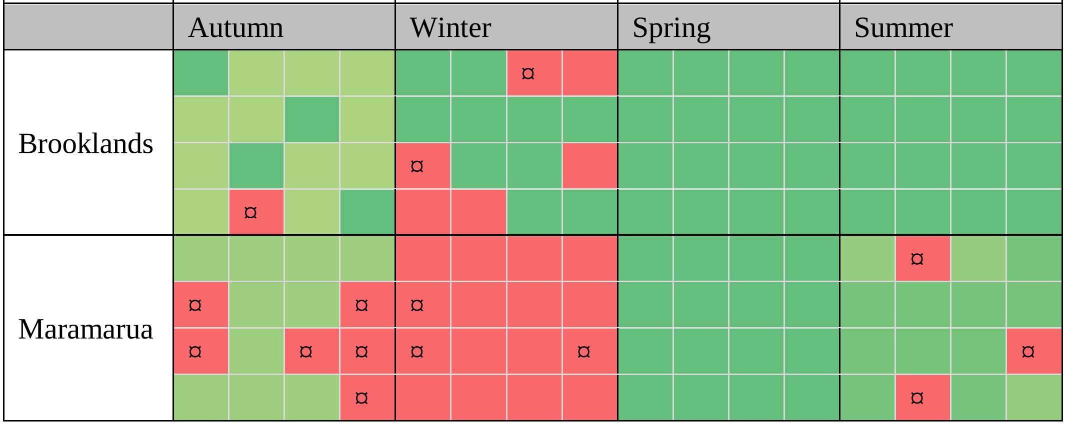
	Autumn					Winter					Spring					Summer				
Te Miro	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟥 ¤	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥 ¤	🟥	🟥

For the larger indigenous forest areas, all sites were estimated to be occupied for all but one season. These were the only areas where mustelids were detected in all seasons. Naïve and estimated occupancy did not display the same seasonal patterns. Each area recorded the highest site occupancy in a different season (Table 7-4).

A visual representation show that mustelids were positively identified in very few areas. Half of the time, mustelids were seen by only one camera. While mustelids were not consistently recorded at the same sites, there were some overlaps between seasons.

Table 7-5 Site occupancy estimates of the two pine forest study areas.

	Autumn	Winter	Spring	Summer
Brooklands	0.38 0.06	0.38 0.13	0.00 0.00	0.00 0.00
Maramarua	0.61 0.38	1.00 0.25	0.00 0.00	0.33 0.23



	Autumn				Winter				Spring				Summer			
Brooklands	🟩	🟩	🟩	🟩	🟩	🟩	🟥 ¤	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	🟩	🟩	🟩	🟩	🟥 ¤	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	🟩	🟥 ¤	🟩	🟩	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Maramarua	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟥 ¤	🟩	🟩
	🟥 ¤	🟩	🟩	🟥 ¤	🟥 ¤	🟥	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	🟥 ¤	🟩	🟥 ¤	🟥 ¤	🟥 ¤	🟥	🟥	🟥 ¤	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥 ¤
	🟩	🟩	🟩	🟥 ¤	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟥 ¤	🟩	🟩

Pine forest areas had the lowest estimated occupancy of all habitats, with only one season estimating complete site occupancy. For both areas, autumn and winter had the highest site occupancy (Table 7-5).

A visual representation of site occupancy at these areas showed that the sites where mustelids were detected was not consistent, although some overlap was observed for Maramarua.

Detectability

Several models were run on PRESENCE to determine the probability of mustelids being detected given that they were present at the different areas and seasons. Each of the following tables shows the most likely model for each area, along with the probability of mustelids being detected (P) over the sampling period. Where rain was a co-variate for detection over the sampling period, two probabilities were given for that season. The first probability is for days without rain, while the one in brackets is for days where rain was recorded.

Table 7-6 Results from PRESENCE analysis of pasture study areas showing the best models and P values for each season.

Pasture areas	Autumn	Winter	Spring	Summer
North	Ψ(.)p(.) P=0.01	Ψ(drain)p(.) P=0.02	Ψ(.)p(.) P=0.03	N/A
South	N/A	Ψ(.)p(rain) P=0.02 (0.00)	Ψ(.)p(.) P=0.01	Ψ(.)p(.) P=0.02

In general, mustelids were least likely to be detected at pasture areas than at any other habitat. In all seasons, P was < 0.05. Drains were a covariate only at Pasture North in the winter, and rain was a co-variate only in the best model for Pasture South in the winter. For all other seasons, constant Ψ and p fit the data best. Rain decreased the probability that mustelids would be detected (Table 7-6).

Table 7-7 Results from PRESENCE analysis of indigenous forest study areas showing the best models and P values for each season.

Indigenous forest	Autumn	Winter	Spring	Summer
Pirongia	Ψ(.)p(.) P=0.01	Ψ(.)p(.) P=0.01	Ψ(.)p(rain) P=0.03 (0.00)	Ψ(.)p(rain) P=0.00 (0.02)
Te Tapui	Ψ(.)p(.) P=0.02	Ψ(.)p(.) P=0.02	Ψ(.)p(.) P=0.07	Ψ(.)p(rain) P=0.04 (0.00)
Te Miro	N/A	Ψ(.)p(.) P=0.01	N/A	Ψ(.)p(.) P=0.01

Mustelids were most likely to be detected at Te Miro, but only in summer. Rain was an important covariate only for Pirongia and Te Tapui, and not in all seasons. In most cases, rain decreased the probability that mustelids would be detected. Across all areas and seasons, the best models incorporated a constant probability of occupancy at each area. For most seasons, P was < 0.05 (Table 7-7).

Table 7-8 Results from PRESENCE analysis of pine forest study areas showing the best models and P values for each season.

Pine forests	Autumn	Winter	Spring	Summer
Brooklands	Ψ(open)p(.) P=0.01	Ψ(gully)p(.) P=0.03	N/A	N/A
Maramarua	Ψ(.)p(.) P=0.07	Ψ(.)p(.) P=0.02	N/A	Ψ(.)p(.) P=0.08

For most seasons, P was < 0.05. While rain data was not available for Maramarua, the best models across all areas and seasons incorporated a constant probability of detection over time. Brooklands data were best explained by habitat co-variates, but this was not consistent over the seasons (Table 7-8).

7.3 Active Period and Activity Levels

7.3.1 Results

Active Period

Mustelid activity on pasture areas were spread throughout the day. Most visits were recorded either during the day or early evening, and only the northern area recorded visits during the evening (Figure 7-1).

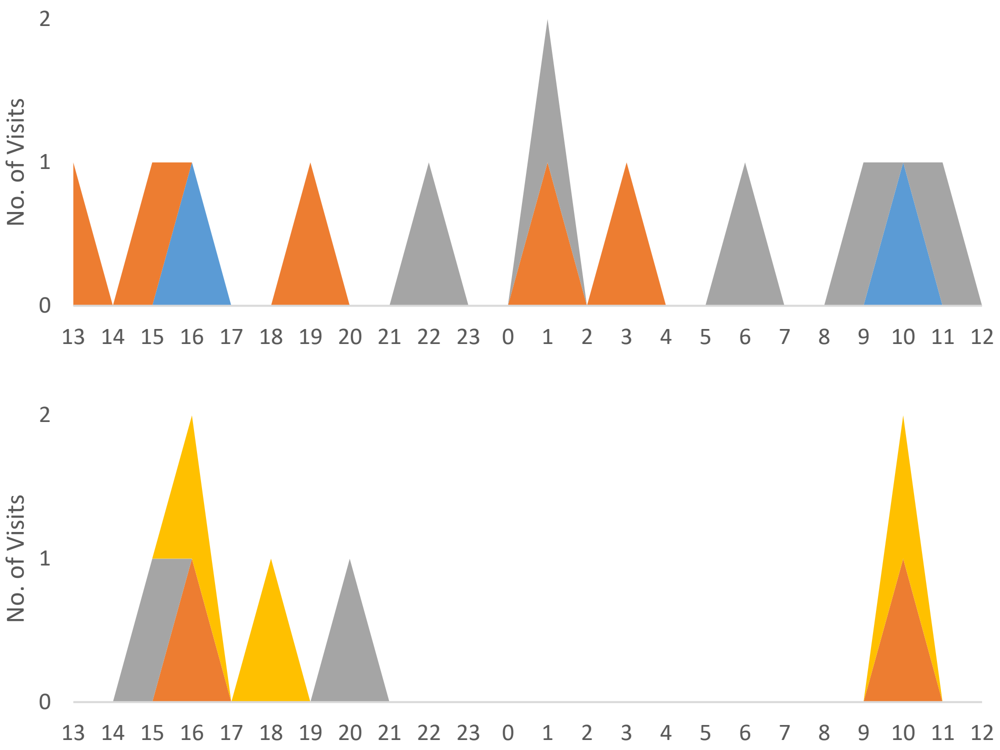


Figure 7-1 Number of mustelid visits recorded at Pasture North (top) and Pasture South (bottom) in each season plotted against time of day. Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

Mustelid visits in the indigenous forest areas, were almost entirely recorded during the day, with the only night-time activity in autumn. Activity peaked at 10.00 am and 2.00 pm. This pattern can also be seen in the other habitats, although it is not as evident there (Figure 7-2).

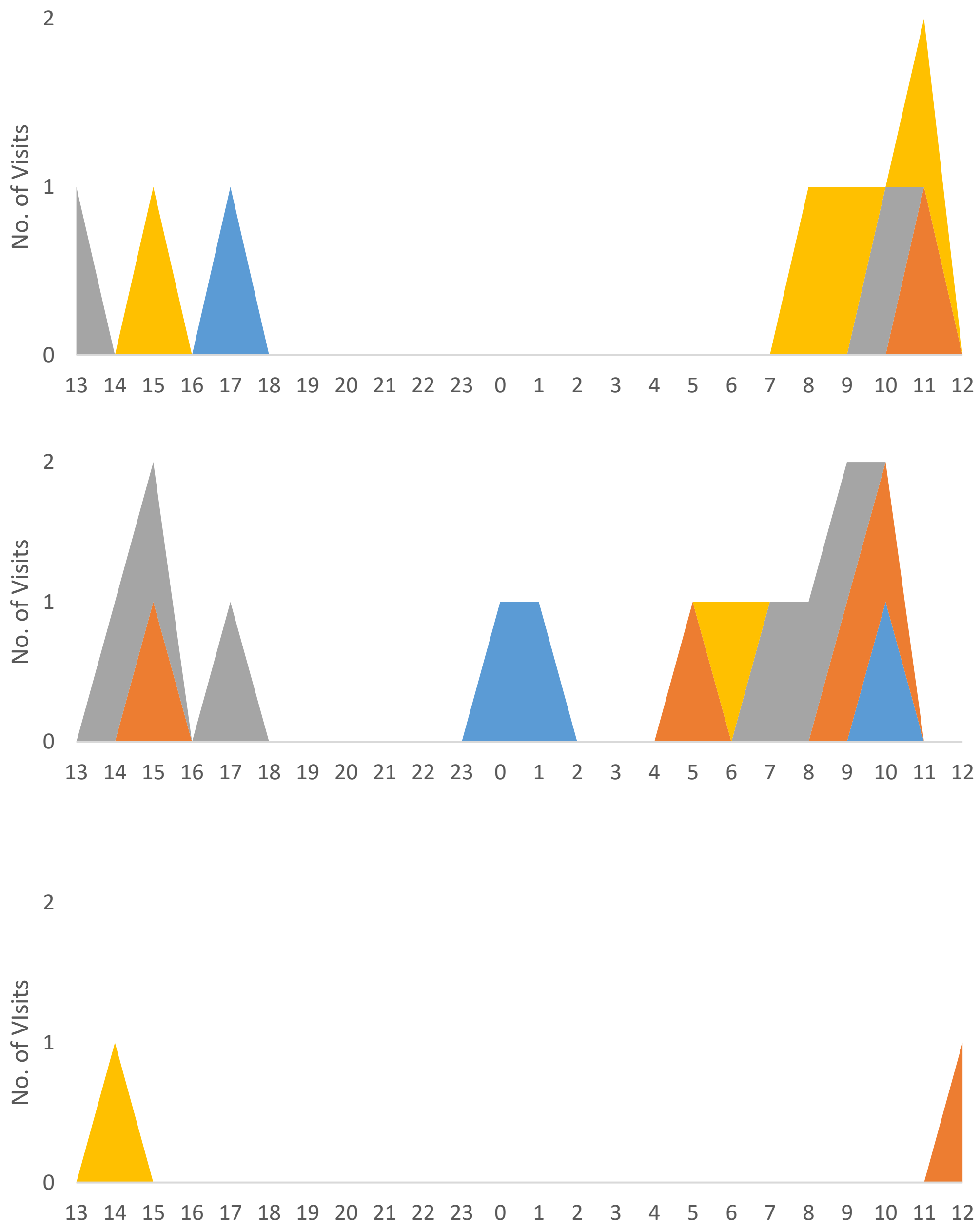


Figure 7-2 Number of mustelid visits recorded at Pirongia (top), Te Tapui (middle) and Te Miro (bottom) in each season plotted against time of day. Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

Mustelid activity in pine forest was similar to that in the indigenous forest areas. Most activity was during the day, with only autumn showing any night-time activity. Pine forest is the only habitat that recorded no visits in spring (Figure 7-3).

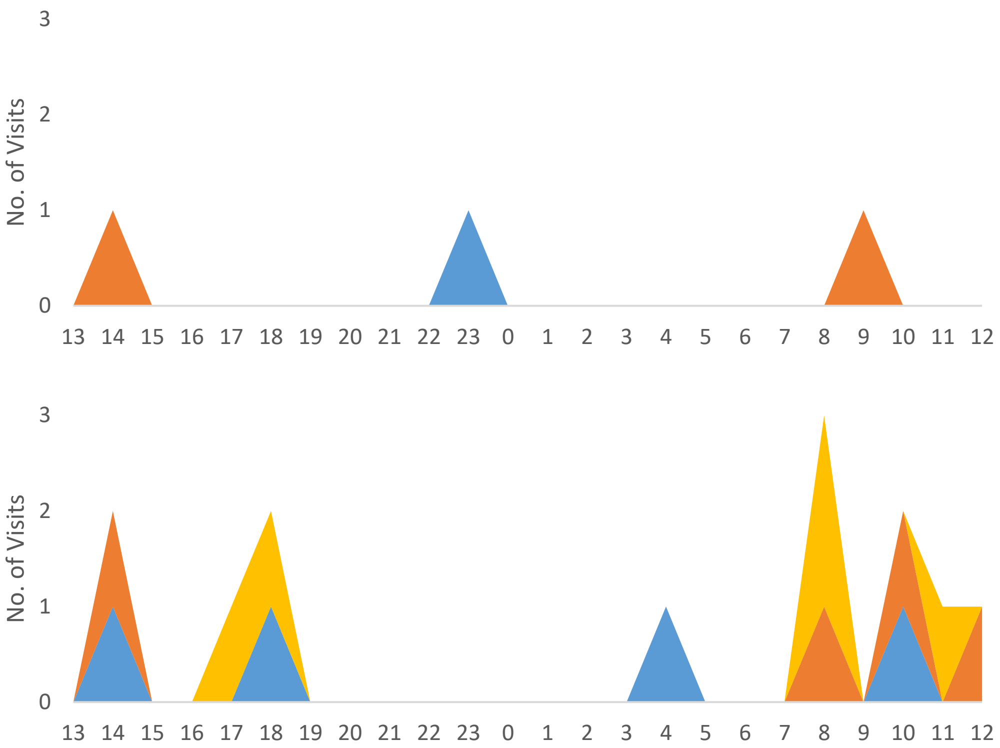


Figure 7-3 Number of mustelid visits recorded at Brooklands (top) and Maramarua (bottom) in each season plotted against time of day. Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

Activity Levels

This section summarises the mustelid visits recorded by the cameras for each area and season. For each area, two data points were calculated. V/100 TN is the number of mustelid visits to all the cameras in the area standardised for 100 nights. MV/D is the maximum number of visits recorded by one camera on one day.

Table 7-9 Visit summaries for each season at each study area. V/100 TN is a measure of the number of visits recorded per 100 trap nights, while MV/D indicates the maximum visit count for a single camera on any one day.

	Autumn	Winter	Spring	Summer
Pasture North				
V/100 TN	0.89	2.75	2.98	0
MV/D	1	2	1	0
Pasture South				
V/100 TN	0.00	0.51	1.19	1.10
MV/D	0	1	1	1
Pirongia				
V/100 TN	0.51	0.55	1.19	2.20
MV/D	1	1	1	2
Te Tapui				
V/100 TN	1.65	1.53	2.98	0.60
MV/D	1	1	1	1
Te Miro				
V/100 TN	0.00	1.43	0.00	1.43
MV/D	0	1	0	1
Brooklands				
V/100 TN	0.45	0.95	0.00	0.00
MV/D	1	1	0	0
Maramarua				
V/100 TN	4.02	1.79	0.00	2.75
MV/D	2	1	0	1

No clear seasonal pattern is evident, with no more than two sites following the same pattern. Pirongia and Te Tapui are the only areas that recorded mustelids year-round. For most areas, mustelids were recorded more often in spring or summer, although winter was the only season when mustelids were recorded at all areas (Table 7-9).

Daily Visits

At Pasture North, mustelids were recorded only once in autumn. In all seasons where mustelids were detected, they were detected in the first week. At Pasture South, mustelids were recorded only three times over all four seasons, and only on one day in summer. In all seasons where mustelids were detected, they were detected in the first week (Figure 7-4).

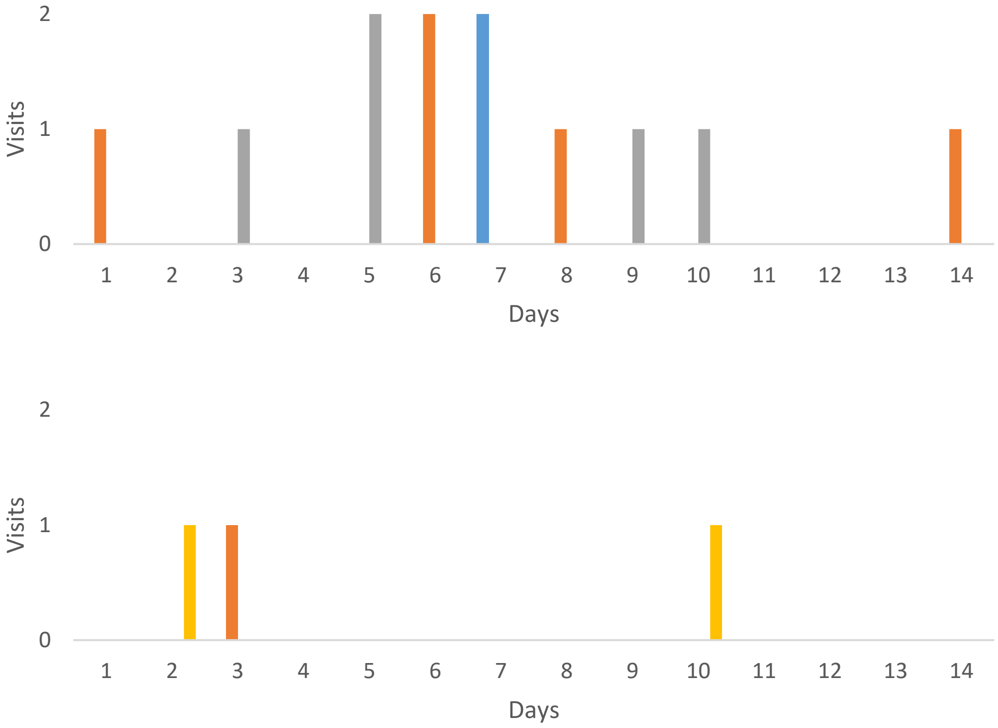


Figure 7-4 Number of mustelid visits recorded each day of the study period at Pasture North (top) and Pasture South (bottom). Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

At Pirongia mustelids were detected on only one day each for autumn and winter. In all seasons where mustelids were detected, they were detected in the first week. At Te Tapui mustelids were only detected on one day in summer. In all seasons where mustelids were detected, they were detected in the first week. Te Miro had the least number of detections, only one each in winter and summer. In all seasons where mustelids were detected, they were detected in the first week (Figure 7-5).

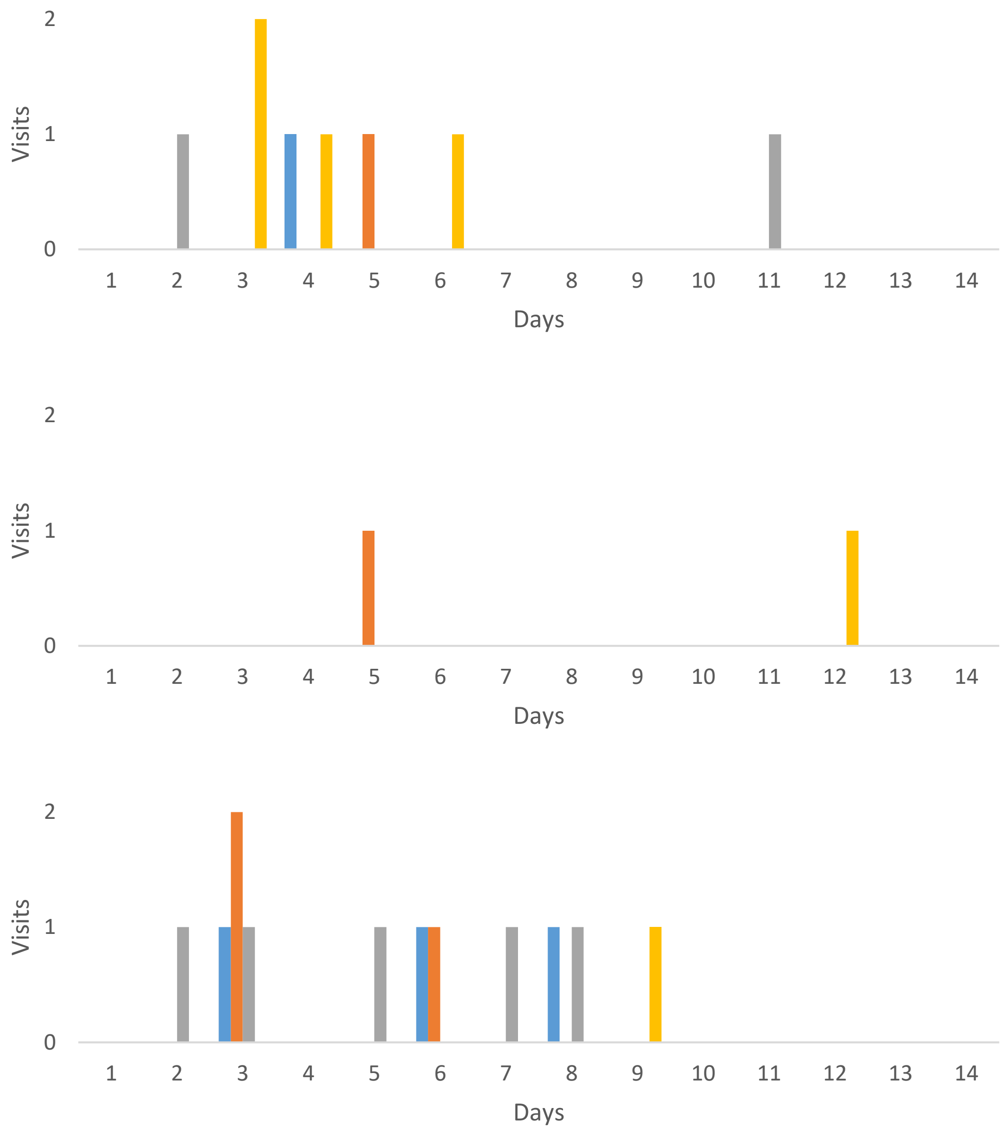


Figure 7-5 Number of mustelid visits recorded each day of the study period at Pirongia (top), Te Tapui (middle) and Te Miro (bottom). Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

Mustelids were not detected at Brooklands until day five, the longest delay of any area. In all seasons where mustelids were detected, they were detected in the first week. Maramarua is the only area where mustelids were detected on multiple days in every season when present. In all seasons where mustelids were detected, they were detected in the first week (Figure 7-6).

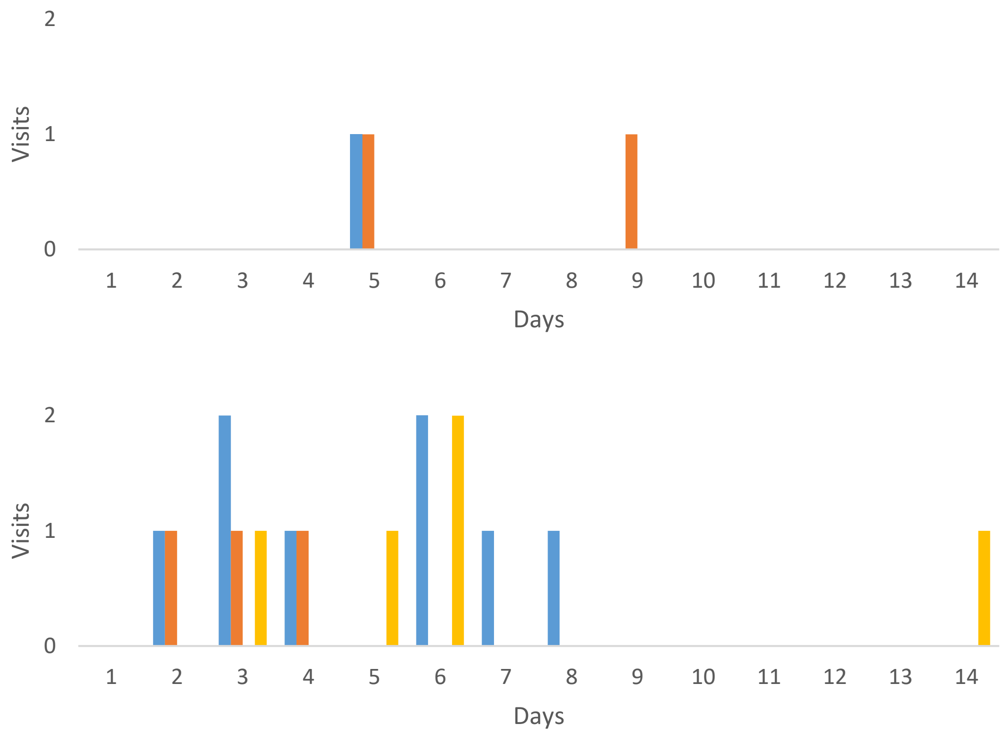


Figure 7-6 Number of mustelid visits recorded each day of the study period at Brooklands (top) and Maramarua (bottom). Seasons are denoted by colour: autumn - blue, winter – orange, spring – grey, summer – yellow.

7.4 Discussion

The purpose of this chapter is to study mustelid distribution and detection probabilities as they relate to varying habitats and seasons. In addition, this chapter aimed to answer whether camera traps can be used to determine differences in the levels and/ or periods of activity of mustelids.

In this section I discuss the results obtained and whether this confirms or refutes my hypotheses. I also answer the question of whether cameras can be used to monitor activity levels in mustelids. For a detailed discussion and how my results relate to the literature, see Chapter 9.

This analysis tested five hypotheses and accepted none in their original form.

7.4.1 Evaluation of Hypotheses

First hypothesis: that similar habitats of the same type have similar species composition.

Analysis of the occupancy data in 7.2.1 shows that one or other of the three species mustelids were detected at each area of all three habitat types. Additionally, across all areas, the probability of detection is very low, and often < 0.01. This means that it is very likely that in those seasons where no mustelids were detected they were simply missed by the camera, rather than not being present at all.

An example of this was the Brooklands area. When setting up the cameras for the winter season, I spotted a stoat running by within 20 metres of where camera four was placed, and yet, this camera did not pick up any mustelids over the next two weeks. Therefore, this hypothesis could be accepted in its current state.

However, when looking at the results from individual mustelid species, it is clear that there are differences even between similar habitats. Stoats were the only mustelid species detected at all areas, the other species were much less common. Ferrets were recorded in only one area of each habitat type.

It would therefore be more accurate to accept this hypothesis in a modified form: that similar habitats of the same type *are likely to have* similar species composition.

Second hypothesis: that there are no detectable differences in species distribution between different habitat types.

All three habitat types recorded mustelids being present. Additionally, visitation rates were quite similar for the different areas. Therefore, this hypothesis could be accepted in its current state.

However, site occupancy values at pine forest areas were much lower than the other habitats. While mustelids as a group were detected in all areas, no weasels were detected at the indigenous forest areas.
So, while one or other of the mustelids was present in all habitat types, and similar habitats had somewhat similar results, there were some differences between different habitats. Therefore, this hypothesis can be accepted only in a modified

form: that there are *significant differences in species distribution between* different habitat types.

Third hypothesis: that species distribution within habitats are uniform, and there are no significant differences in probability of detection at different points within each habitat.

The PRESENCE analysis of site occupancy within each habitat found that pasture and indigenous forest were the habitats that are most likely to have uniform distribution, even though the naïve occupancy does not support this conclusion. This is supported by the large error values for the occupancy calculations, because there was not enough data available to make accurate predictions regarding site occupancy when no mustelids were observed at the areas.

While the data for a few seasons fit better to models that include habitat features as a co-variate, the vast majority found that a constant Ψ fit the data best. It is important to note that the differences between the different models tested in PRESENCE were often quite fine, so the results displayed here are only an indication to provide a way of comparing the different areas. In no cases did the best model have a ΔAIC score > 2.00 compared to all other models, which means that some of these features may still play a role in the distribution of mustelids across the area. The full model lists with their associated AIC scores and likelihood values are provided in the Appendices.

This hypothesis can therefore be accepted only in a modified form: that species distribution within habitats *are not* always uniform, but there *are no* significant differences in detection probability at different points within each habitat.

Fourth hypothesis: that there are no changes in the detectability of given species of small mammals at a given camera site within a trapping session.

For all but four season/area combinations, the best models were those that incorporated a constant detection probability over the study session. Rainfall was the only other co-variate that seemed to affect detection, and the differences between these models and others with a constant probability of detection were minimal. The opposite was also true. Rain was a co-variate in at least one of the top models across most areas and seasons, and in several instances, it was a co-variate in the second most likely model. Only for Pasture North in winter and Te Tapui in autumn was rain not a co-variate of any of the top models.

Overall, I could not definitively prove whether rain was a significant factor in detecting mustelids, or not, but further study with more cameras over a longer period may well come to a different conclusion. When rain was modelled, it did not have a consistent effect on P, probably because of the very low number of detections overall. When mustelids were detected, it was most likely only co-incidence rather than a consequence of the weather.

This hypothesis can therefore only be accepted in a modified form: that there *may or may not* be changes in the detectability of given species of small mammals at a given camera site within a trapping session.

Fifth hypothesis: species distribution and abundance are not affected by the seasons.

There were significant differences in both the distribution and abundance of mustelids across the seasons, particularly at the forest areas. At most areas across all habitats, there was at least one season when no mustelids were detected.

Winter was the only season when mustelids were detected at all areas. At no areas were mustelids detected more than once in all seasons.

This hypothesis can therefore be rejected: species distribution and abundance *are* affected by the seasons.

7.4.2 Evaluation of Research Questions

Can camera traps be used to determine differences in the levels and/ or periods of activity of small mammals, when not individually identifiable?

Figure 7-7 Mustelids at Pasture North. Stoat (top), weasel (middle) and ferret (bottom).

Analysis of the time-stamped images does allow for a study of differences in the levels and/ or periods of activity of mustelids on my study areas. While the low visit counts make detecting a pattern difficult, in general, mustelids were active over the whole day, with no preference for day or night. Ferrets are mostly nocturnal, and nocturnal mustelid detections were most often recorded in places where ferrets were present, but very rarely at others. Stoats, while known be active throughout the day and night (King & Murphy, 2005), were recorded mostly during the day.

7.5 Conclusions

My analyses reject the hypotheses that there are no differences in species distribution and detectability between different habitat types, and that seasons have no effect on these parameters of mustelid populations. I must also reject the hypothesis that mustelid detectability was constant over the study period.

Cameras provide a viable method of studying mustelid populations, and while a two-week study period is sufficient for simple detection, more cameras are needed to improve the accuracy of results for site-occupancy analysis. This is particularly important for mustelids as site occupancy values, and the probabilities of detecting these species, were both much lower than the other species studied.

Chapter Eight

Camera Orientation and Species Detection

8.1 Overview

In this chapter I will be testing for the differences between a horizontal and vertical camera orientation. I will compare five different parameters of five target species present at Te Miro in the summer.

In section 8.2 I discuss the additional methods used to compare vertical and horizontal camera orientation for its effectiveness in detecting my target species.

In section 8.3 I investigate their distribution as detected by each set of cameras as well as the site occupancy and probability of detection in each area as calculated by PRESENCE.

In section 8.4 I use the data collected from the time-stamped images to display the period of activity for each species as detected by each set of cameras. In addition, I investigate the number of visits plotted against time, and provide an overall visit count for each area and season.

I will then discuss my results and what this means for the accuracy of my study design.

8.2 Additional Methods

Camera set-up for this study was based on that of De Bondi *et al.* (2010) which uses cameras placed 130 cm above ground level, looking down on some sort of lure. Close to the end of my data collection, I was made aware of new research (Nichols *et al.*, 2017) that tested the effectiveness of cameras placed vertically against those placed horizontally at ground level. Specifically, Nichols et al. focused on feral cats and mustelids. They found that cameras placed horizontally were more effective, recording both target and non-target species more often.

I tested this approach at Te Miro during my last (summer) sampling season, in February 2017, placing both vertical and horizontal cameras. Two cameras were set up at each of the five monitoring sites used for the previous seasons. One camera was placed 130 cm above the lures, as usual, looking down, while the other was attached to a suitable tree approximately the same distance from the lures.

8.3 Distribution and Site Occupancy

8.3.1 Results

Site Occupancy

For each species and camera orientation, a separate analysis of site occupancy was run using PRESENCE, and the results are reported in the table below. Each cell contains two values, with the upper value being the calculated estimate for site occupancy, and the bottom value being the naïve occupancy, i.e. the raw proportion of sites where the cameras detected a species.

Each table also contain a visual representation of species distribution, with the ¤ symbol showing where each was positively identified. The colour of each cell represents the likelihood that some individual of that species is present at the site even if it was not detected. Solid green represents a probability of 0, while red indicates a probability of 1 (Table 8-1).

Table 8-1 Key to tables depicting site occupancy at each of the study areas. The different colours represent the listed probabilities that a site is occupied, even if no animals were detected.

0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00

Table 8-2 Summer Site occupancy estimates for three species at Te Miro for two different camera orientations.

<table>
<tr><th></th><th colspan="5">Possum</th><th colspan="5">Rat</th><th colspan="5">Mustelid</th></tr>
<tr><td>Vertical</td><td colspan="5">0.40
0.40</td><td colspan="5">0.60
0.60</td><td colspan="5">1.00
0.20</td></tr>
<tr><td>Horizontal</td><td colspan="5">0.40
0.40</td><td colspan="5">0.80
0.80</td><td colspan="5">1.00
0.20</td></tr>
<tr><td></td><td colspan="5">Summer</td><td colspan="5"></td><td colspan="5">Spring</td></tr>
<tr><td>Vertical</td><td>🟥 ¤</td><td>🟥 ¤</td><td>🟩</td><td>🟩</td><td>🟩</td><td>🟥 ¤</td><td>🟥 ¤</td><td>🟩</td><td>🟥 ¤</td><td>🟩</td><td>🟥</td><td>🟥</td><td>🟥 ¤</td><td>🟥</td><td>🟥</td></tr>
<tr><td>Horizontal</td><td>🟩</td><td>🟥 ¤</td><td>🟥 ¤</td><td>🟩</td><td>🟩</td><td>🟥 ¤</td><td>🟥 ¤</td><td>🟥 ¤</td><td>🟥 ¤</td><td>🟩</td><td>🟥</td><td>🟥</td><td>🟥 ¤</td><td>🟥</td><td>🟥</td></tr>
</table>

Both camera orientations detected the same three species at Te Miro. No hedgehogs or mice were detected by either set. Overall, the site occupancies for the three detected species were similar, although rats were detected at more sites by the horizontal cameras. Possums were detected at two sites by each set of cameras, but not the same two sites (Table 8-2).

Detectability

Several models were run on PRESENCE to determine the mean probability of each species being detected given that they were present. The following table shows the most likely model for each species, along with the probability of each being detected (P) at the study area. Where rain was a co-variate for detection over the sampling period, two probabilities were given for that season. The first probability is for days without rain, while the one in brackets is for days where rain was recorded.

Table 8-3 Results from PRESENCE analysis of pasture study areas showing the best models and P values for each species.

	Possum	Rat	Mustelid
Vertical	Ψ(.)p(.) 0.50	Ψ(.)p(.) P=0.79	Ψ(.)p(.) P=0.01
Horizontal	Ψ(.)p(.) 0.0.32	Ψ(.)p(rain) P=0.42 (0.12)	Ψ(.)p(.) P=0.01

In general, the horizontal cameras were less likely to detect either possums or rats, while the P values for mustelids were the same. Rain featured as a co-variate only for rats, and only for the horizontal cameras. Here rain seemed to decrease the probability that rats would be observed, although even without rain P was much lower for horizontal than for the vertical cameras (Table 8-3).

8.4 Active Period and Activity Levels

8.4.1 Results

Active Period

While possums were detected on both sets of cameras, they were more often, and more consistently, detected on the vertical cameras (Figure 8-1).

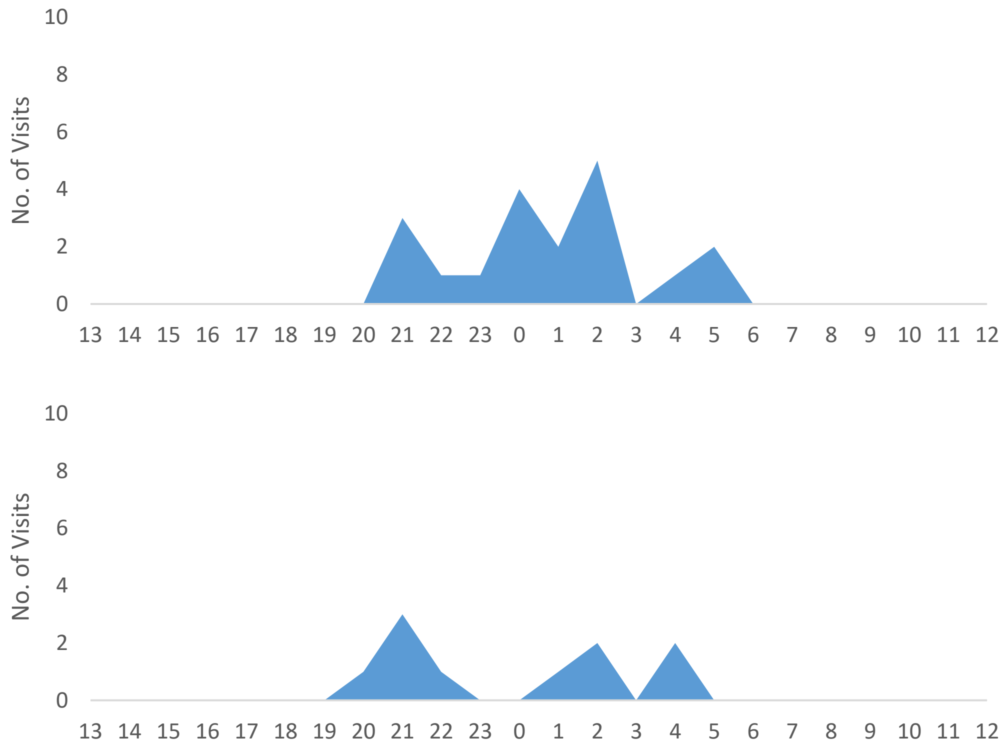


Figure 8-1 Possum visits plotted against time of day as detected by the vertical (top) and horizontal (bottom) cameras.

Rats showed the same pattern as possums. They were detected on both sets of cameras, but were more often, and more consistently, detected on the vertical cameras (Figure 8-2).

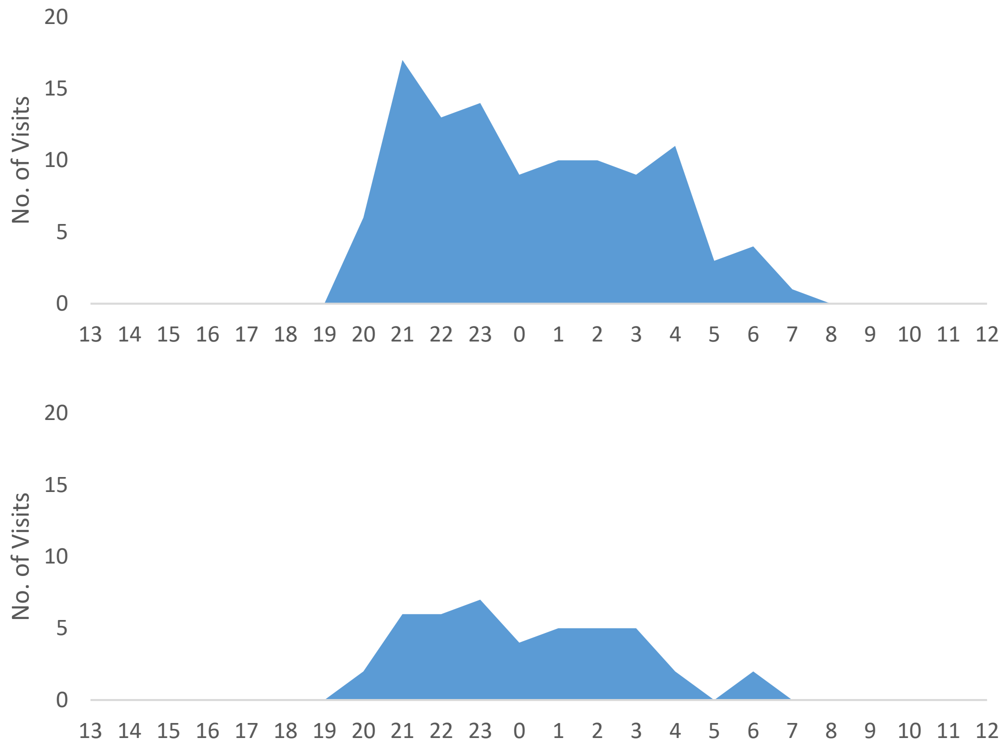


Figure 8-2 Rat visits plotted against time of day as detected by the vertical (top) and horizontal (bottom) cameras.

Mustelids were detected only once by each method, although not at the same time. The vertical camera detected the stoat at 2.00 pm, while the horizontal camera detected a stoat at 1.00 am.

Activity Levels

This section summarises the total numbers of visits recorded by the cameras for each species. For each species, two data points were calculated. V/100 TN is the number of visits to all the cameras on the area standardised for 100 nights. MV/D is the maximum number of visits recorded by one camera on one day.

Table 8-4 Visit summaries for each season at Pasture North. V/100 TN is a measure of the number of visits recorded per 100 trap nights, while MV/D indicates the maximum visit count for a single camera on any one day.

Possums	Possum	Rat	Mustelid
Vertical			
V/100 TN	54.29	285.71	1.43
MV/D	3	9	1
Horizontal			
V/100 TN	28.57	120.0	1.43
MV/D	2	6	1

Both possums and rats were recorded less often on the vertical cameras, and this was evident for both V/100 TN and MV/D. Mustelids showed the same results for both camera orientations, but recorded only one visit on each (Table 8-4).

Daily visits

Possums were detected on both sets of cameras, but they were more often, and more consistently, detected on the vertical cameras (Figure 8-3).

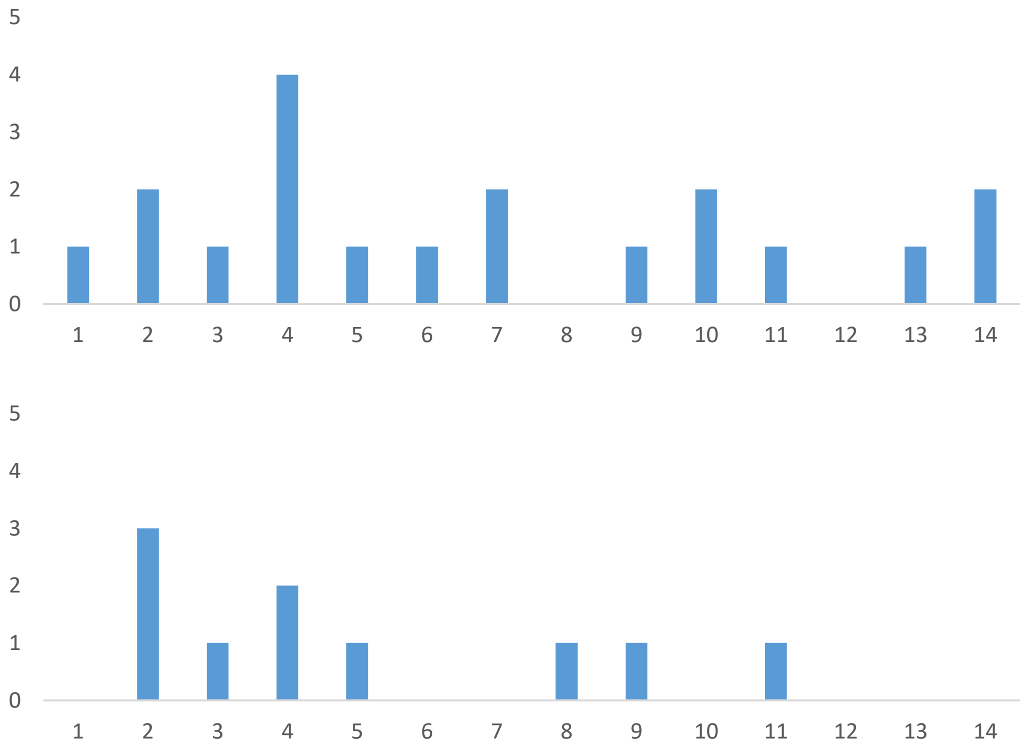


Figure 8-3 Possum visits over the study period as detected by the vertical (top) and horizontal (bottom) cameras.

Rats were also detected more often on the vertical cameras, although the consistency of detections were more similar than that of possums (Figure 8-4).

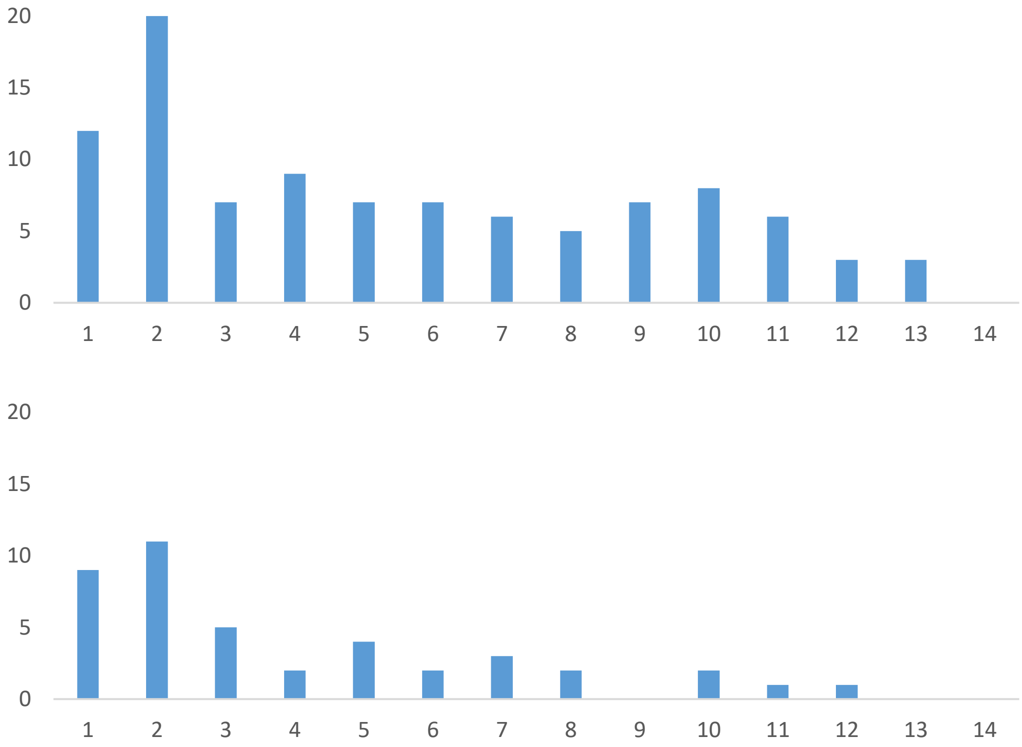


Figure 8-4 Rat visits over the study period as detected by the vertical (top) and horizontal (bottom) cameras.

Mustelids were detected only once by each method, although not on the same day. The vertical camera detected the stoat on day 12, while the horizontal camera detected the stoat on the third day.

For a more in-depth discussion of the Nichols et al. (2017) study and a comparison to my results, see Chapter 9.

8.5 Conclusions

A preliminary examination of the results appeared to show that neither method was better than the other, although a more thorough analysis proved otherwise. Across all parameters measured, the vertical cameras seemed to perform better than the horizontal ones. There was one outlier, rat site occupancy. Rats were detected at one site more by the horizontal cameras, although the number of rats detected was still less overall.

While this was only a small-scale test, it does provide some reassurance that my method was not inferior and my results are valid

Chapter 9

General Discussion and Conclusions

9.1 Overview

In this chapter I discuss the use of cameras to detect and study seven mammalian species across seven study areas.

In section 9.2 I discuss the effectiveness of cameras in collecting the data required to test my hypotheses and answer my research questions.

In sections 9. 3 to 9.6 I discuss my results and whether they confirm or refute my hypotheses as listed in Chapter 1.

In section 9.7 I discuss the evidence for interactions between my target species, and whether these may indicate competition or predator-prey relationships.

Sections 9.8 and 9.9 focus on the consequences of my study for pest monitoring and control of these species, and on future study directions, while 9.10 provides a general conclusion to the study.

9.2 Camera trapping and small mammals

9.2.1 Effectiveness of camera traps

Overall, using cameras to study small mammals in the Waikato Region proved useful and quite effective. While there were some problems associated with using cameras, explained below, they allowed me to collect daily data from seven study areas over four seasons with only two people to assist with fieldwork. Using the cameras allowed me to test five hypotheses and answer two research questions regarding small mammals in the Waikato. This would not have been possible with any other passive detection method. While site-occupancy analysis can be done by daily visits to the monitoring stations, that method would have been impossible with the time and resources available. Even then, I would not have been able to test any of the other hypotheses in any detail. I would also have been unable to study time-specific probabilities of detection over 24 hours a day, or active periods and activity levels.

Camera set-up was based on that of De Bondi *et al.* (2010). As discussed in Chapter 8, Nichols *et al.* (2017) tested the effectiveness of cameras placed vertically against those placed horizontally at ground level. Specifically, Nichols et al. focused on feral cats and mustelids. They found that cameras placed horizontally were more effective, recording both target and non-target species more often.

I tested this approach at Te Miro during my last (summer) sampling season (see Chapter 8). My results did not agree with those of Nichols *et al.* (2017). Rather, my results seem to indicate that vertically placed cameras were just as effective in detecting my target species, if not better.

A possible explanation for this discrepancy with the previous study (Nichols *et al.*, 2017), may lie in the species studied. Only stoats were targeted in both studies. Nichols *et al.* (2017) found that while some encounters were detected by both sets of cameras, in several cases encounters were recorded only on one of the camera sets. For stoats, the horizontal cameras recorded 25 independent visits, while vertical cameras recorded only 20. This means that the horizontal cameras detected stoats < 25% more often when including those detected by both cameras. Each set of cameras detected only one stoat so no direct comparisons are possible either way.

The study by Nichols *et al.* (2017) detected all of my target species, but these were grouped together with other non-target species in their study, so their results for individual species are not available. This makes it difficult to determine whether all of these species were detected more often by the horizontal cameras.

While only a small-scale test with five cameras in each orientation, the larger number of detections for all species other than stoats on the vertical cameras provide some assurance that my study design was effective for the species I targeted.

9.2.2 Problems with using cameras

On several occasions, a few of the cameras did not work correctly, with dates resetting to January 2014 values. In most cases, the data collected were still usable, as there were usually images of me setting up the camera or taking it down, at times I had recorded in my field notes. The times on these images could be compared to those of the other cameras and the incorrect timecodes converted to the correct date and time. Unfortunately, as I was not aware of this problem early on, I neglected to ensure that I always triggered the camera on setup and take-down. This meant that I had to estimate some of these dates as best I could, and while this was still useful for most analyses, it may have compromised the results for the active periods.

Another problem with cameras is the risk that they might be stolen. I lost one camera at Te Tapui to thieves, even though it was well away from the track.

Other than these, mostly minor, inconveniences, cameras worked well to provide the data I needed to study my target species.

9.3 Active Period and Activity Level

The cameras provided an excellent tool to investigate the period when the target animals are most active, except for the occasional malfunction. These errors could usually be compensated for, and in general the cameras supported current knowledge on when these animals are most active, as described in King (2005a) and Tempero *et al.* (2007). As with my results, Tempero *et al.* (2007) found that rats and ferrets were almost exclusively nocturnal, but there were some detection during the day.

While possums and rats were generally detected in large numbers, making it easy to calculate activity periods, mustelids were much less common. Low visit counts made detecting a pattern difficult. Even so, mustelids were found to be active over the whole day, with no preference for day or night. This result is supported by King and Murphy (2005). While I can present only a composite of three mustelid species, ferrets are mostly nocturnal (Clapperton & Byrom, 2005) and nocturnal mustelid detections were most often recorded in places where ferrets were present, but very rarely at others. As Tempero *et al.* (2007) show, cameras are an effective method for collecting this data even at low population numbers.

Cameras are also well suited to provide information on how many visits are made to each bait location per unit time. Given the field records of how far apart these locations were, these data allowed for the calculation of several parameters including visits per trap night and daily presence or absence.

9.4 Species Composition

For each habitat type discussed below, seasonal detection of the target species was summarised in a table. Colour-coding of each cell is to improve the ability of comparing seasonal activity of species in each study area at a glance, and does not reflect site occupancy as in the previous chapters.

🟩 0	🟩 1	🟨 2	🟧 3	🟥 4

Both the colour of the cell and the number recorded in it indicate the number of seasons that each species was detected in each study area. The exact details are reported in the individual chapters for each species.

9.4.1 Pasture

Table 9-1 Number of seasons each target species was detected at the two pasture study areas

Pasture	Possum	Hedgehog	Rat	Mouse	Weasel	Stoat	Ferret
North	4	4	4	3	3	3	2
South	4	4	4	4	2	2	0

Table 9-2 Number of seasons each non-target species was detected at the two pasture study areas

Pasture	Rabbit	Deer	Cat	Pig
North	3	0	3	0
South	3	0	4	0

While possums were detected in both pasture areas, site occupancy, the probability of detection and activity levels were all much higher in the northern area (Table 9-1). This result was quite unexpected, as the southern area is much hillier and with gullies, trees and other vegetation are usually supposed to offer cover for possums. Cowan (2005) and Gormley *et al.* (2015) both found that possums are less likely to be found on pasture than in forest,   on pastures bordering on forest or including forest fragments (Cowan, 2005). In contrast, the northern area is flat terrain with only artificial drainage canals flowing through it, and most of the larger vegetation consists of riparian shrubs.

The results for hedgehogs were similar for the two pasture areas, although there were still differences. A significantly higher proportion of sites was occupied at the southern area in summer, and in them, hedgehogs were more likely to be detected, in both winter and summer. One possible reason for the difference between areas is the higher numbers of mustelids at the northern area, as hedgehogs are known prey of mustelids. (Jones & Sanders, 2005). More likely, the difference might be a result of the distribution of hedgehog prey items (Haigh *et al.*, 2012).

The proportions of sites occupied by rats were very similar for the two pasture areas, across all seasons. However, the number of visits and the probability of detection were both much higher at the southern area.

Like rats, the proportions of sites occupied by mice were very similar for the two pasture areas, except for summer, when site occupancy by mice was much higher at the northern pasture area. However, the summer site occupancy in the northern area was probably overestimated, because fewer visits led to a much lower probability of detection.

Results for mustelids, in general, were similar for the two areas. In particular, the probability that mustelids would be detected in each area if present was almost identical, albeit the lowest of all species at < 0.05 in all cases, even though Pasture North recorded approximately double the visits of the southern area. The most significant difference with the mustelids was that ferrets were detected only at the southern area.

Two non-target species, rabbits and cats were found at both areas (Table 9-2).

9.4.2 Indigenous Forest

Table 9-3 Number of seasons each target species was detected at the three indigenous forest study areas.

Indigenous forests	Possum	Hedgehog	Rat	Mouse	Weasel	Stoat	Ferret
Pirongia	4	0	4	0	0	3	0
Te Tapui	4	1	4	3	0	4	1
Te Miro	4	2	4	0	0	2	0

Table 9-4 Number of seasons each non-target species was detected at the three indigenous forest study areas.

	Rabbit	Deer	Cat	Pig
Pirongia	0	0	0	1
Te Tapui	0	3	2	0
Te Miro	1	0	2	0

Possums and rats were the only species that were detected in all seasons in all indigenous forest areas. Stoats were detected at all areas, but not all seasons. Hedgehogs were never detected at Pirongia, and mice and ferrets were detected only at Te Tapui. Weasels were not detected at any of my indigenous forest areas (Table 9-3).

Four non-target species (rabbits, deer, cats and feral pigs) were also recorded at some of the indigenous forest areas. Cats were detected at Te Tapui and Te Miro, but not Pirongia. Rabbits were found only at Te Miro, deer only at Te Tapui, and pigs only at Pirongia (Table 9-4).

While all areas have a history of pest control, no control had been done recently in the areas where my cameras were located (D. Byers, pers. comm.). Site occupancy, the probability of detection and activity levels were all much higher at Te Tapui and Te Miro, and lower at Pirongia.

Hedgehogs were never detected at Pirongia, and Te Miro was the only area where they were detected with any consistency, in all tested parameters. Differences between Te Miro and the other areas can likely be attributed to the fact that is surrounded by farmland.

Literature on hedgehogs in New Zealand state that the availability of food and dry nest sites determine habitat use (Jones & Sanders, 2005). Hedgehogs are known to favour dairy country, and are present in both pine and indigenous forest areas of Pureora Forest Park (Jones & Sanders, 2005; King *et al.*, 1996c). While my data are somewhat consistent with the literature, they failed to detect hedgehogs at Pirongia. Pirongia falls within the known range of hedgehog distribution in New Zealand (Jones & Sanders, 2005), and has a similar species composition to Te Tapui, with even fewer stoats, which could advantage hedgehogs. Pirongia has an annual rainfall of about 2000 mm, so rainfall is not a limitation either

The data gathered on rats in the indigenous forest areas showed them to be very similar. Site occupancy values for rats were similar in all areas, and in Pirongia and Te Tapui, the probability of detection and the number of visits were also similar. Te Miro was somewhat different, with a higher probability of detection, and lower overall visit count. This is to be expected, as Te Miro is only a forest fragment, small enough that it could fit between two cameras in the other areas. The reduced number of visits could be explained by the fact that it is surrounded by farmland, which has a much lower rat population. The higher probability of detection is most likely due to the fact that there were more cameras at Te Miro than in a similar sized patch of the other areas. While this means that the results are not directly comparable to the other areas, I still thought it worth testing the differences between large forests and a forest fragment.

Mice and rats had nearly reciprocal distributions. Mice were only ever detected at Te Tapui, and then only in very low numbers, on only a few cameras.

Results for mustelids, in general, varied significantly between study areas. Not only did Te Tapui record more stoats, but it was also the only area with more than one mustelid species. While seasonal trends were not consistent between areas over all parameters tested, mustelids were more common at Te Tapui and least at Te Miro. While the comparative abundance of stoats and ferrets support the literature, the results for weasels were not as clear. (King, 2005b; King & Murphy, 2005).

9.4.3 Pine Forest

Table 9-5 Number of seasons each target species was detected at the two pine forest study areas

Pine forests	Possum	Hedgehog	Rat	Mouse	Weasel	Stoat	Ferret
Brooklands	4	4	4	4	0	1	0
Maramarua	4	4	4	3	3	3	1

Table 9-6 Number of seasons each non-target species was detected at the two pine forest study areas

Pine forests	Rabbit	Deer	Cat	Pig
Brooklands	3	4	3	1
Maramarua	1	1	2	0

All of my target species were observed in both the pine forest areas (Table 9-5). Possums, hedgehogs and rats were detected in all seasons at both areas; mice were detected in all seasons at Brooklands, but only in three at the Maramarua. Stoats were the only mustelid detected at both areas, with weasels and ferrets detected only at Maramarua. In general, the composition of target species at the pine forest areas was surprisingly similar to that of the pasture areas, although there were some differences.

Three non-target species rabbits, deer, and cats were all found at both areas, while only Brooklands showed evidence of wild pigs (Table 9-6).

While possums were present in both pine forest areas, there were significantly more possums at Brooklands. This was true for all parameters tested. Site occupancy, the probability of detection and activity levels of possums were all much higher at Brooklands compared to Maramarua. This is particularly surprising, as Brooklands is the only area with ongoing pest control, and many dead possums were found during the spring sampling.

Hedgehog populations at the two pine forest areas were very different. All parameters tested showed more hedgehogs at Brooklands than at Maramarua. These areas are not far enough from each other to have markedly different weather conditions. These were reasonably common at Maramarua, but not at Brooklands. This trend is not definite, but was observed at all habitat types.

The proportions of sites occupied by rats, and the probability that rats would be detected and the number of visits recorded, were very different for the two pine forest areas. Across all parameters, rats were more common at Maramarua compared to Brooklands.

As with the indigenous forest areas, the relationship between rats and mice was reciprocal. In most seasons, mice were more common at Brooklands, and this showed in all parameters tested.

Results for mustelids, in general, were quite different between areas. Not only were more stoats recorded at Maramarua, but it was the only area with more than one mustelid species. Over all parameters tested, mustelids together, and stoats alone, were both more common at Maramarua. Pine forest at Maramarua was the only habitat where the comparative abundance of the different mustelid species follows the trends predicted from the literature (King, 2005b; King & Murphy, 2005). There was insufficient data for Brooklands to draw any conclusions.

9.4.4 Overall species composition

In general, these results are consistent with the literature regarding habitat use by the target species, but my methods allow more detailed documentation. While ferrets are most common in grassland habitats (King, 2017a; King & Murphy, 2005), other studies have also found them to be almost absent form pasture (King, 2017a).

Even so, they were still more common in pasture than in the other habitats. Here my results differ from the findings of King (2017a), which showed that ferrets were more common in forested areas than on pasture. In contrast to the pattern described in (King, 2005a) stoats were the most common mustelid across all habitats. While King and Murphy (2005) stated that weasels are less common in pasture compared to forested habitats, this was not supported by my results. Like King (2017a), weasel were more common in pasture areas, but in contrast to my results, (King, 2017a) found that weasels were more common than even stoats on these habitats. Granted, the pasture areas listed in (King, 2017a) have had significant stoat control, and without this, stoats would likely be much more common.

There were differences between areas with similar habitats in the distributions of both possums and hedgehogs, the reasons for which are discussed in 9.7.

The reciprocal relationship between rats and mice, particularly in the forested areas, is one that has been well studied (Bridgman *et al.*, 2013; Innes *et al.*, 1995; Lidicker, 1976). Ruscoe and Murphy (2005) noted that rats are more often caught in (and removed from) podocarp-hardwood forests, and this often increased the tracking rates of mice. They could not explain this, as mice are usually also removed at the same time. A possible explanation, other than simple population numbers, is that mouse activity levels are suppressed by the presence of rats. Rats are active predators of mice, so where rats are common, mice will be scarce (Bridgman *et al.*, 2013). This supports the idea that mice will be less active to reduce the risk of predation from rats.

This study focused on ship rats, as these were expected to be more common in my study areas (Innes, 2005a, 2005b). While identification was not always possible, not once did I identify any other *Rattus* species.

In general the results for habitat use by rats are consistent with the literature, which notes that rats live in a wide variety of habitats, but are most abundant in lowland podocarp-broadleaved forests (Innes, 2005b). This is true even for forest fragments, such as Te Miro, that has a history of pest control. While setting up cameras at Te Miro, I observed several empty poison bait dispensers attached to trees, indicating pest control in the not too distant past. Even so, the results for rats at Te Miro were not that dissimilar from the larger indigenous forests.

King *et al.* (2011) studied reinvasion of forest fragments by ship rats following eradication. This study is particularly relevant here, as the fragment labelled Fragment 2 in this study is the Te Miro fragment used in my study. In two trapping session spaced approximately 12 weeks apart, they found that rats reinvaded this fragment, increasing to a density about half that before the first trapping. (King *et al.*, 2011) made three important observations regarding rat movement between fragments. 1) the replacement rats were derived from a meta-population stretching across at least 20,000 km^2. 2) gene flow occurred freely between forest fragments, showing that large areas of pasture were not effective barriers, and 3) rats were moving between fragments before the trapping started.

Further, Innes *et al.* (2001) found that rats were more common in indigenous compared to exotic forest, a pattern also observed in my data.

My first hypothesis was that similar habitats of the same type have similar species composition. My results confirmed this hypothesis in general, but there were often differences between areas with similar habitat, for hedgehogs, mice and the mustelid species in particular. Hence it would be more accurate to state that similar habitats of the same type *are likely to have* similar species composition.

My second hypothesis, that there are no detectable differences in species distribution between different habitat types, was not supported by the data. While possums, rats and stoats were present at all study areas, the other species were not. Even for these three, there were differences in population sizes, as indirectly indexed by site occupancy and activity levels. It would be more accurate to state that there *are significant* differences in species distribution between different habitat types, the extent of which depend on the species studied.

9.5 PRESENCE, Models, and Site Occupancy

9.5.1 Pasture

For most seasons, site-occupancy analyses using PRESENCE found that the best models were those that estimated a constant value for the probability that each site is occupied. Possums and hedgehogs were the species for which models most often incorporated habitat co-variates such as bush or gullies, although these were never consistent over the seasons. This result is particularly surprising for mustelids, given that stoats are known to prefer areas with ground cover (King & Murphy, 2005). I would therefore have expected the models to favour habitat co-variates over constant Ψ.

Even so, models including these co-variates were often very similar to the top models, with ΔAIC values < 2.00, suggesting that these features may well play a significant role in which sites are occupied, but that the samples were too small to be sure.

Similarly, most of the best models were those under which the probability of detection over time was constant. Rain was the only other variable that was significant for any species, but models with rain as a co-variate were not significantly different from other models (ΔAIC < 2.00). The mustelids were the only exceptions to the general rule that rain tended to increase the probability of detection for all species.

Site occupancy was not uniform throughout the pasture areas for any species, even assuming constant Ψ. Only mustelids had an apparent uniform distribution across the pasture areas, and with a very low probability of detection across all seasons, this could potentially be an accurate reflection of reality. Uniform distribution was also estimated for both rats and possums in two seasons, likely due to an overestimation of occupancy as a result of a very low probability of detection. In the other seasons, the probabilities that possums and rats would be detected were higher, and occupancy was estimated were much lower.

9.5.2 Indigenous forest

In almost all areas and seasons, an analysis of site occupancy using PRESENCE found that the best models were those that estimated a constant value for the probability that every site is occupied. Possums were the only species for which models incorporated habitat co-variates such as gullies, at least in some seasons. Nonetheless, models with these co-variates were often very similar to the top models, with ΔAIC values < 2.00. This indicates that these features may well play a significant role in which sites are occupied.

Similarly, most of the best models were those in which the probability of an individual being detected over time was constant. Rain was the only variable that was significant for any species. Only for possums and rats was the probability of detection increased by rain, and only in a few cases. Once again, however, models with rain as a co-variate were not significantly different from other models (ΔAIC < 2.00).

Even when a constant Ψ was modelled, site occupancy was not uniform throughout the indigenous forest for any species. While the distributions of mustelids and rats were uniform in most seasons, there were some exceptions. As for the pasture areas mustelids had a very low probability of detection across all seasons, and uniform occupancy could potentially be an accurate reflection of reality. Rats were the exact opposite. The high occupancy result is not a due to insufficient data, but rather to a very high naïve occupancy. While the best models for rats all featured a constant Ψ, there were one or two sites where camera data were available but no rats were found, which might be explained by habitat co-variates I did not test for.

9.5.3 Pine forest

In most cases, an analysis of site occupancy using PRESENCE found that the best models were those that estimated a constant value for Ψ. Even so, all species had at least one season at one of the areas where the best model incorporated habitat co-variates such as open ground or gullies. For seasons where the best model featured a constant Ψ, models with these co-variates were often very similar to the top models, with ΔAIC values < 2.00. This indicates that these features may well play a significant role in which sites are occupied.

Similarly, most of the best models were those where the probability of an individual to be detected over time was constant. Rain was the only other variable that was significant for any species, and then in only a few cases. Once again, however, models with rain as a co-variate were not significantly different from other models (ΔAIC < 2.00). Interestingly, rain either seemed to have no effect or to increase the probability of detection for all species except possums.

Even when a constant Ψ was modelled, site occupancy was not uniform throughout the pine forest for any species. Hedgehogs, mice and mustelids were modelled to have uniform occupancy in some seasons, more likely due to insufficient data than a reflection of reality. At other seasons with higher probabilities of detection for these species, the estimated the occupancy values were much lower.

9.5.4 Overall

Generally, the models that best describe the observed data were those that modelled constant Ψ and p. Even so, models that included co-variates, while less likely, was rarely a significant improvement. This means that all species might be at least somewhat be affected by these co-variates, even if the relationship was not quite strong enough to be picked up by the models. Possums were most often the species where habitat features were incorporated in the best models, and so are the species where distribution are most likely to be affected by these co-variates.

This is particularly interesting as previous knowledge on mustelid behaviour suggest that habitat features that provide cover should impact distribution (Clapperton & Byrom, 2005; King, 2005b; King & Murphy, 2005). From the literature, I would have expected bush and drainage channels on the pasture areas, and gullies in the indigenous forest, to have a significant positive correlation with site occupancy. In addition, I would have expected the open ground co-variate at Brooklands to have a significant negative correlation with mustelid site occupancy.

I have found two possible explanations for this discrepancy. The first is that, because the three mustelids had to be grouped together for analysis, this could have clouded any response to these variables by one of the three species. While stoats were the most common, weasel and ferret detections could have hidden the effects of bush and/or drainage channels on stoat distribution. This is likely, as the different species prefer slightly different habitats (Clapperton & Byrom, 2005; King, 2005b; King & Murphy, 2005). All three species, stoats and weasels in particular, prefer to move in cover when hunting (King, 2005b; King & Murphy, 2005), but ferrets are more varied (Clapperton & Byrom, 2005).

Second is the low number of mustelid detections in general. Fewer detections mean that PRESENCE has less data to draw on when testing the models, resulting in less accurate models. Fewer detections overall increase the probability that any correlation between detections and co-variates are co-incidence rather real.

Additionally, fewer detections reduce the accuracy of site occupancy estimates. This is particularly true for the mustelids. At Pirongia in the autumn, for example, mustelids were detected on only one camera. PRESENCE estimated from this that all sites have a probability of 1.00 to be occupied, but in each case the 95% confidence limit was 0.00 – 1.00.

A limitation of my study design is that I did not include daily temperature as a co-variate in determining detection. Literature on hedgehogs in particular shows that low temperatures can cause them to enter a state of torpor, either daily or seasonally (Jones & Sanders 2005).

While the low mustelid population may be correlated the general patchiness of detections for these species, for others it is less straightforward. That possums have favourites when it comes to New Zealand vegetation have often been discussed. (Cowan, 2005; Gormley *et al.*, 2012; Sweetapple *et al.*, 2013; Wodzicki & Wright, 1984). Gormley *et al.* (2012) showed that possum browse more in patches with preferred tree species. Sweetapple *et al.* (2013) showed that the proportion of preferred species in possum diet increases with a reduction in population numbers following possum control operations. These studies suggest that possum distribution throughout the forest habitats has a strong positive correlation with the distribution of preferred tree species. As I did not include this variable in my models, I cannot confirm this, but it does explain why patchiness in possum distribution was not correlated with the tested covariates.

As noted before, hedgehog distribution is highly dependent on the availability of food, in particular invertebrates (Haigh *et al.*, 2012; Jones & Sanders, 2005). This variable was not measured in my study, so I cannot confirm this, but it seems a likely explanation for an otherwise random distribution.

Watkins *et al.* (2010) studied trap-catch data of rats, mice and mustelids for patchiness. They found that all species produced at least some patchy samples, and that this was not affected by density in any meaningful way. This is somewhat supported by my results, but depends on habitat. The pasture areas with lower visit counts did not show significantly more patchiness for rats and. However, Maramarua had significantly more rat visits recorded than Brooklands, and was much less patchy. Watkins *et al.* (2010) also found significant patchiness in triggered traps over time. Once again, my results showed a similar result at low visit counts, but not at the higher activity levels.

These results lead me to reject my third and fourth hypotheses that species distribution is uniform and that there are no differences in the probability of detection of any species at different points within each area of pine forest habitat, or within a session.

It would be more accurate to state that species distribution within habitats *are not* uniform, and there *may be* significant differences in detection at different points within each habitat. Also, there are *likely to be* changes in the detectability of a particular species at a given camera site within the sampling period. Rather further study is required to properly investigate which if any, habitat co-variates significantly influence site occupancy.

9.6 Seasonal Effects on Species Distribution

9.6.1 Pasture

In all cases, the seasons during which each of the target species was most often detected followed the breeding season of that species. In general, all species produce their young between September and April, and this influx in numbers was reflected in the visit counts, if not always site occupancy.

For most species, my results found significant differences between the seasons. At the northern area, possums showed a clear and consistent downward trend in all measured parameters. Data for the southern area, were insufficient to identify trends.

Hedgehogs showed significant seasonal differences, particularly at the northern area, where all parameters tested were much higher in autumn and spring.

Rats also showed significant differences in both the detectability and the number of visits across the seasons. Most visits were recorded in autumn and spring, and while estimated occupancy was highest in winter, this is likely a consequence of lower visit counts, resulting in less accurate occupancy estimates.

While the proportion of pasture areas occupied by mice were not as seasonally dependent, most visits were recorded in autumn.

Seasons seemed to have the least effect on the detectability of mustelids, likely a result of the already low detection count. Even so, there were some differences in the visit counts between seasons, and at each pasture area, there was one season with no mustelid detections at all. For both areas, spring recorded the most visits.

9.6.2 Indigenous forest

For most species, there were significant differences between the seasons, although not always consistently across the study areas. In general, possums were least commonly found in autumn.

Hedgehogs were very rarely recorded in indigenous forests, and only in autumn and spring. On Pirongia, the cameras were left in place for a month (due to poor weather not allowing fieldwork), and still, no hedgehogs were detected.

Rats also varied significantly in both detectability and the number of visits across the seasons. Both parameters were highest in autumn, and decreased over the following year.

The proportion of sites occupied by mice decreased through the year. Visit counts were highest in autumn, declining until none was recorded in the next summer.

Seasons seemed to have the least effect on mustelid detectability, particularly in the large indigenous forests. In general, mustelids were most often recorded in summer, when their annual crop of young are first becoming independent. Seasons seemed to have the most effect at Te Miro, where no mustelids were detected in autumn or spring.

9.6.3 Pine forest

For most species, there was a significant difference between the seasons in occupancy although not always consistently across study areas. In general, possums were least commonly seen in spring.

Hedgehogs were recorded quite often in pine forest areas, but both site occupancy and visit counts were significantly lower in winter compared to other seasons, as expected for a species capable of winter torpor.

Rats showed few seasonal differences, particularly at Maramarua. Brooklands recorded more differences between seasons, with winter and spring both showing higher site occupancy and recording more visits.

The proportion of sites occupied by mice showed that site occupancy and visit counts trended downwards with the seasons. Visit counts were highest in autumn at Maramarua, decreasing through the year until none was recorded in summer. The pattern at Brooklands was quite different, with higher site occupancy and more visits recorded in winter and spring.

Mustelids were less common in spring and summer. In spring, no mustelids were recorded at any area, and although mustelids were recorded at Maramarua in the summer, site occupancy and visit counts were not as high.

9.6.4 Overall

It should be noted that none of these species was studied in isolation. As discussed in 9.7, there are likely to be other factors regulating population numbers beyond breeding and winter mortality.

Factors such as interspecific competition and predation risk can be expected to complicate simple patterns of distribution and abundance.

Differences between forest and pasture areas may be related to food availability and cover. From the studied parameters, the pasture areas seemed to fit the expected seasonal trends the best. Compared to exposed pasture, forested areas are more protected against variations the weather, and provide more food throughout the year. As with the tussock in Pye *et al.* (1999) forested areas could provide year-round shelter, and a warmer and more stable environment. These improved conditions may increase the length of the breeding season and reduce winter mortality, particularly in the areas where predators are less common (Innes, 2005b; Jones & Sanders, 2005; Ruscoe & Murphy, 2005). Even the pasture areas seemed to fit the expected trend best when competing species or predators were less common.

That camera traps are sensitive enough to detect these seasonal differences, even if detection is not perfect, bodes well for the use of cameras as a monitoring tool.

In conclusion, based on my results my fifth hypothesis, that species distribution and abundance are not affected by the seasons, has to be rejected for all species. Rather it would be more accurate to say that species distribution and abundance *are* affected by the seasons, although more in-depth study is required to untangle the effects of seasons from that of inter-specific interactions.

9.7 Species Interactions

Most of the target species varied in distribution between areas of the same habitat. In particular, the results for possums, rats, and to a lesser extent, mice, could potentially indicate interactions between species. In practice, the relationships between these species were not evident when looking at site occupancy in isolation. This is particularly true for possums and rats, as both species were present in all seasons at all areas.

When activity levels are considered in addition to site occupancy, consistent patterns emerge, both within and between habitats. While possums were present at both pasture areas, they were most common at the northern area. Similarly, they were more common at Brooklands than Maramarua. Conversely, rats showed the exact opposite pattern. They were recorded more often at the southern pasture area and at Maramarua. Possums were less common in indigenous forest areas in general, while these were the areas with the most rats. Even so, there were differences between areas, reflected in the numbers for both species. Of all the indigenous forest areas, Pirongia had the least possums, as well as the most rats. This relationship is evident in the literature (Sweetapple & Nugent, 2007; Sweetapple *et al.*, 2013). Diets of ship rats and possums overlap, resulting in direct competition between these two species (Sweetapple & Nugent, 2007). Further, while rats are often killed in possum control operations, they increase more rapidly afterwards, often to levels much higher than pre-control (Sweetapple & Nugent, 2007; Sweetapple *et al.*, 2013).

Like possums, mice were also less common at areas where rats were abundant. This is most evident at the indigenous forest areas, where mice were almost entirely absent, but also in the other habitats. Mice were significantly more common at Brooklands, where rats were less abundant than at Maramarua. The reasons for this are two-fold. 1) Overlapping diets result in direct competition (Ruscoe & Murphy, 2005) and 2) mice are actively preyed upon by ship rats (Bridgman *et al.*, 2013; Lidicker, 1976).

Hedgehogs often showed significant differences between similar areas, generally in the opposite direction to those of mustelids, particularly stoats. This is not unexpected as hedgehogs are known to be preyed upon by stoats (Jones & Sanders, 2005), although the effects of stoat predation on hedgehog numbers is unknown

These results 1) support the literature available on interspecific interactions between my target species and 2) answer the question of whether cameras are effective in documenting the impact these interactions have on site occupancy and activity levels.

9.8 Consequences for Small Mammal Monitoring and Control

Many introduced mammals are considered pests, because they cause significant damage to New Zealand’s indigenous biota and economy. Removal of these pests is thus a priority, a fact highlighted in New Zealand’s Biological Heritage Science Challenge. One of the science programmes in this challenge is real-time biological heritage assessment, and focusses on detection and methods of control for a large number of widespread pest species (NZBH, 2017).

More recently, the government has supported the objective of reaching a predator-free New Zealand by 2050. The goal of this project is to completely eradicate rats, stoats, and possums from the New Zealand mainland, not just the surrounding islands, many of which are already pest free.

Given the social, environmental, and economic importance of eradicating invasive species, it is imperative that an efficient and cost-effective method of detection is found if we are to be successful in this endeavour. For a pest species to be effectively controlled, information is needed on where to focus control efforts, information that this project can provide.

Most of the species I studied were significantly influenced by habitat, not only for simple presence or absence but also for abundance, as indirectly indexed by site-occupancy analyses. The results documented here also highlight interspecific relationships, where removal of one species may simply allow another to increase in abundance or distribution.

Rats, in particular, present a serious problem for effective pest control. My data suggests that rats occupy forest fragments at similar densities as in the larger forest areas. King *et al.* (2011) showed that rats rapidly reinvade cleared forest fragments, and the reverse is also true. Just as fragments can be reinvaded from forest fragments, larger areas may be repopulated from the fragments. A further study on the genetics of rats at these same forest fragments (King *et al.*, 2014) showed that rats from the same litter often have different fathers. If a pregnant female carrying such a litter was to reinvade a cleared area, the first generation will already have significant genetic diversity, increasing the long-term success of the population (King *et al.*, 2014) from the first generation. Hence, for effective eradication of rats as proposed by Predator Free NZ, both large forests and fragments need to be targeted simultaneously.

My results imply that intermittent poison placement to control possums is not all that effective, at least when starting from high possum numbers. Maramarua last had pest control in 2014, consisting of an aerial 1080 drop (R. Schoonderwoerd, pers. comm.), and possum numbers there were much lower than at Brooklands during my observations between March and December of 2016. At Brooklands, bags of Feratox (cyanide) and 1080 are placed annually in autumn and spring (D. Yang, pers. comm.), and yet, possum numbers seemed to decline only after the spring placement. Additionally, possum site occupancy in spring dropped to only slightly less than half that of autumn and winter, and had already recovered somewhat by the time of my summer sampling. As this control effort is an annual event, I would have expected possum number to be much lower.

While I cannot definitively say that the different control methods are the reason for the differences in possum populations, it is one of the biggest differences between these two study areas.

Finally, this study provides some guidelines regarding habitat choice by a range of pest mammals, including the three that are part of the predator-free project.

Naïve occupancy gives a lower limit to occupancy, while the upper limit of occupancy was taken from estimated occupancy as given by PRESENCE, ie, allowing for missed observations. For each species and habitat type, a seasonal average was calculated for both naïve and estimated occupancy, displayed on the graphs below (Figure 9-1). For each species, the lower limit to occupancy is determined by the mean naïve occupancy, and the upper limit by mean estimated occupancy as given by PRESENCE.

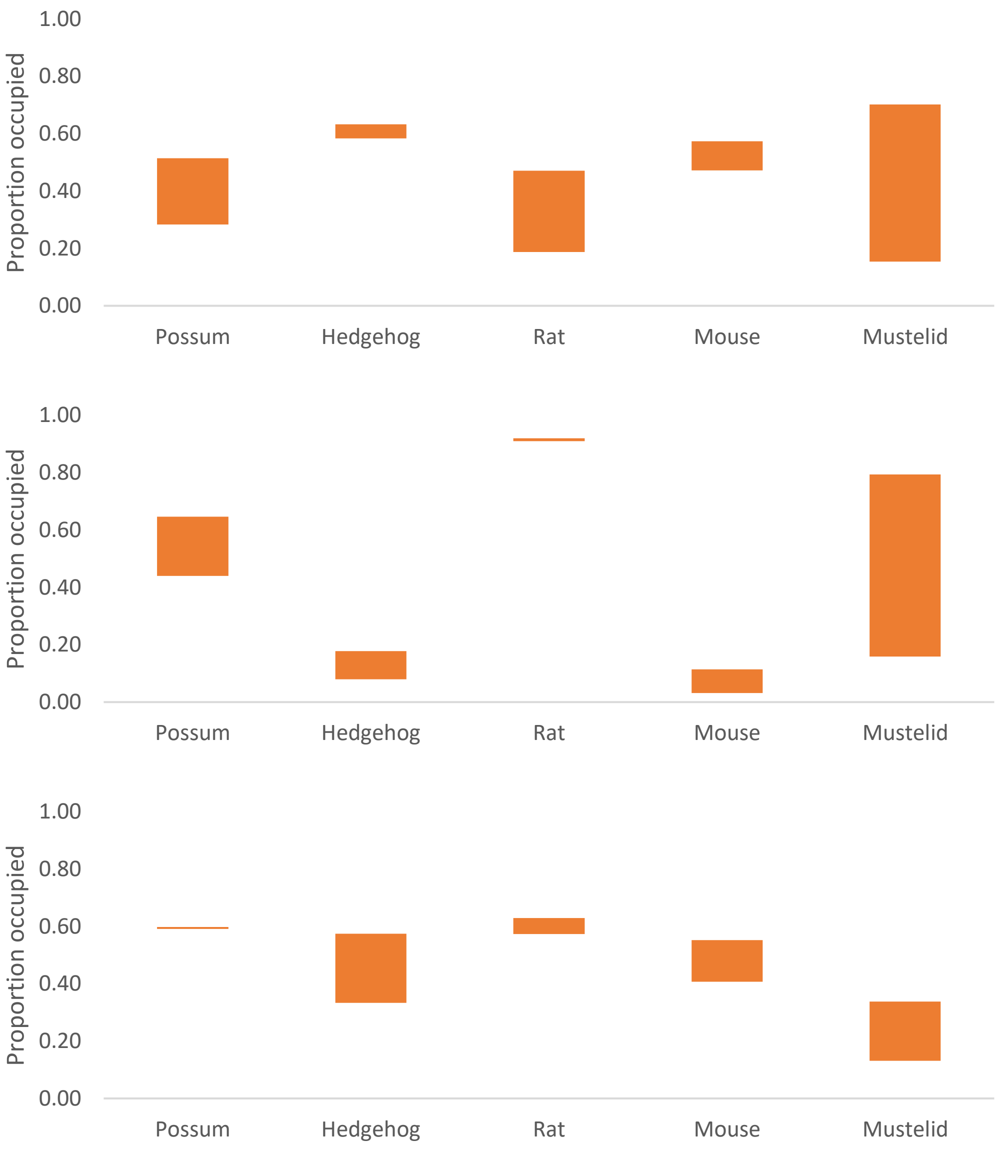


Figure 9-1 Range of proportions of pasture (top) indigenous forest (middle) and pine forest (bottom) areas occupied by each target species.

When correcting the proportion of each habitat occupied for the percentage of the Waikato that these habitats cover (total 82%: pasture 52%, indigenous forest 19%, and pine forest 11%), the true distribution of these pests become clear. For example, the maximum proportion of sites occupied by rats is 0.47 for pasture and 0.96 for indigenous forest (Figure 9-1). When corrected for proportion of habitat in the Waikato Region, these values become 0.25 and 0.18 (Figure 9-2). So, while rats are less common in pasture, this habitat still supports a larger number of rats overall.

As with Figure 9-1, the difference between the upper and lower limits indicate the precision of the results, and the usefulness of cameras in detecting these species.

There is still much uncertainty over the real proportion of sites occupied by each species in the Waikato Region. While precision was very much site-specific, the general results for hedgehogs and mice were most precise, and for mustelids least precise overall. The majority sites where possums were recorded were in the pasture areas. While the results for the forest areas were more precise, even the lowest estimate for pasture occupancy was higher than for the other habitats. The same was true for hedgehogs and mice. For rats and the mustelids, pasture still contributed a significant proportion of the total occupancy, but for both species, indigenous forest could potentially contribute more to the total proportion of the Waikato occupied. This provides some useful information on where to focus eradication efforts.

It should be noted that these graphs are only an indication of site-occupancy, and more parameters need to be considered when choosing where to focus eradication efforts. For example, rats may occupy more pasture sites, but visitation rates indicate a much larger population in the indigenous forests. Both parameters need to be considered when making these decisions.

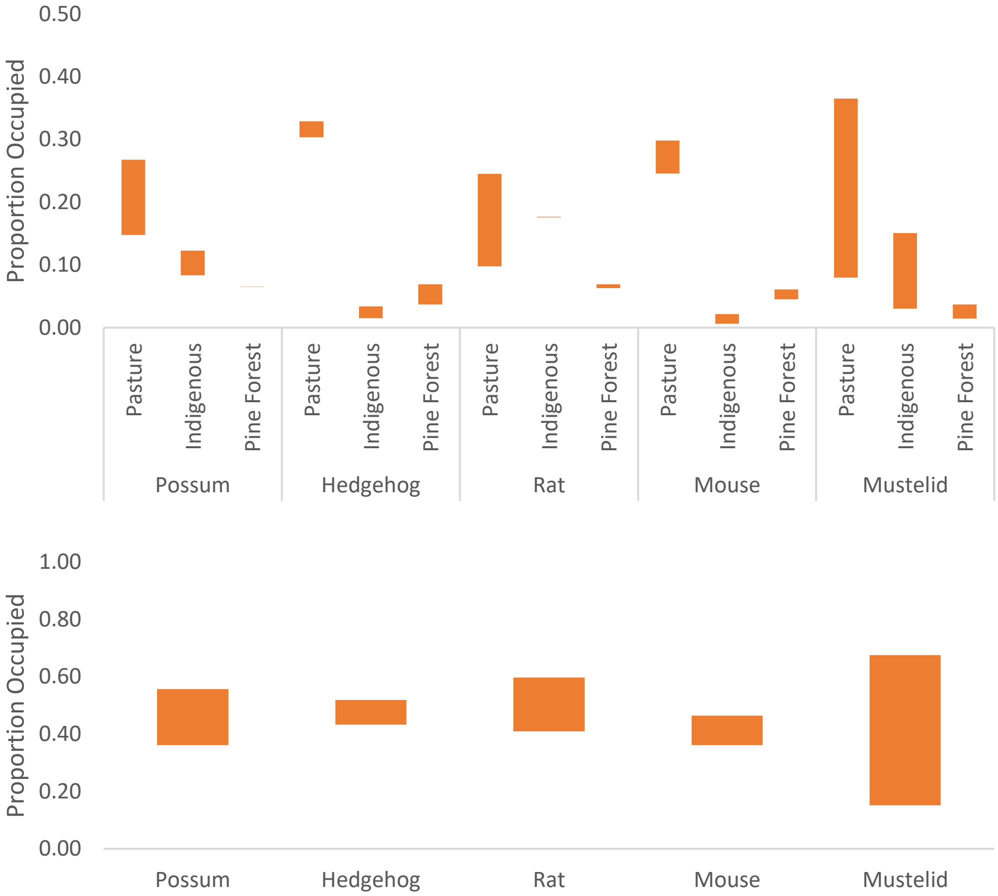


Figure 9-2 Estimated proportion of the Waikato Region occupied by each target species, corrected for relative proportion of each habitat type available (top), and overall proportion of the Waikato landscape occupied by each species, corrected for habitat coverage of the region.

9.9 Future study

This project has provided some interesting results regarding pest mammals in the Waikato Region, but improvements can be made. First, by increasing the number of co-variates measured at each study area, modelling of estimated occupancy can be improved. Further improvements can be made simply by increasing the number of cameras used in each area, and the number of replicates of each habitat studied. This will improve the precision of the results. Finally, the region-wide occupancy estimate of each species will be made more accurate by increasing the number of habitats studied.

The results for mustelids were least precise of all species. A controlled comparison of cameras and other passive detection methods such as tracking tunnels could provide more insight on this. Are cameras not suited for mustelid monitoring, or is the higher variation in detection an inherent characteristic of mustelid populations in general.

9.10 General Conclusion

Overall, using cameras to study small mammals in the Waikato Region has proved useful and quite effective. While there were some problems, this technique provided the ability to study a range of parameters related to species distribution and abundance, even when individuals could not be identified. Cameras were most effective in monitoring hedgehogs and mice, and least precise in monitoring mustelids.

None of my hypotheses could be accepted in their original form as they relate to pest mammals in the Waikato Region. While basic species composition was most often similar for areas with similar habitats, this was not always true. Additionally, possible interspecific interactions influenced the apparent abundance of species at otherwise similar areas. While my results could not definitively prove, or disprove, that habitat features and/or rain significantly impact species distribution and detectability, these are likely to have an impact. Also, season most definitely impacted species distribution and abundance, although species interactions and external factors made explaining these differences difficult.

The data collected here suggest that the species presence and activity in any one area are often dependant on the presence of another species, and that areas with similar habitats do not always have similar faunas. I also found that at least one forest fragment featured a similar species composition to larger forests, even when isolated by large stretches of pasture.

Finally, this study has provided some useful results regarding the proportion of the Waikato Region occupied by each of the target species, both by habitat and overall.

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Appendices

For each of the following appendices, please see the included CD Disk

Appendix 1 - LCDB v.4.1

Database showing the amount of land covered by each habitat type for the Waikato Region

Appendix 2 – Possum Site-Occupancy

PRESENCE analysis output for brushtail possums at all areas in all seasons.

Appendix 3 – Hedgehog Site-Occupancy

PRESENCE analysis output for European hedgehogs at all areas in all seasons.

Appendix 4 – Rat Site-Occupancy

PRESENCE analysis output for ship rats at all areas in all seasons.

Appendix 5 – Mice Site-Occupancy

PRESENCE analysis output for house mice at all areas in all seasons.

Appendix 6 – Mustelid Site-Occupancy

PRESENCE analysis output for mustelids at all areas in all seasons.

Appendix 7 – Species Presence-Absence

Summary of the seasonal presence-absence of each species detected over all study areas.