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House mouse (*Mus musculus*) use of vertical space and impact on bird nesting success

A thesis submitted in partial fulfilment
of the requirements for the degree
of
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Abstract

Prior to human arrival, New Zealand was dominated by birds that had evolved in the absence of mammalian predators. Early Polynesian settlers brought with them the kiore (*Rattus exulans*), which subsequently decimated many native species. Following this, Europeans brought ship rats (*Rattus rattus*), Norway rats (*Rattus norvegicus*), house mice (*Mus musculus*) and an array of other mammalian predators causing even more damage to the native flora and fauna. Present day conservation strategies seek to control or eliminate invasive predator populations to give the native birds a chance to recover.

At Maungatautari – a pest-fenced reserve in the Waikato, New Zealand, mice remain as the sole invasive mammal following extensive eradication programmes. When left on their own, mouse populations are known to greatly increase. On some offshore islands in the South Atlantic and sub-Antarctic, their diet has been shown to include bird eggs and chicks, and on other islands they have used resources that were previously unavailable to them (by predator or competitive exclusion). Therefore, the aims of the present study were to examine how mice; (1) use vertical space in the presence and absence of other mammalian predators and (2) impact bird nesting success when they are the sole predator.

Chapter Two examines how mice use vertical space in the presence and absence of other mammalian predators while also quantifying how other small mammals use vertical space. Tracking devices (that included chew tags) were placed at different forest heights within two separate patches of bush, one with only mice present (Maungatautari Sanctuary) and one where all pest mammals were present

(Te Tapui Reserve). Mice were found to frequently use the lower (<5m) levels of the native bush; however, they were not detected in the canopy. In contrast, mice were detected much less frequently at Te Tapui and only on the ground. Rats and possums were detected at all forest levels. The presence of other mammals clearly constrains mouse activity through predation and/or resource competition.

Chapter Two also examined how mice use the hood of the predator proof fences at Maungatautari in the presence (external) and absence (internal) of other mammals. Cameras and tracking card were installed within the hood of the fence with tracking card also installed at the base of the fence in two areas (i.e. one with mice only present and one with all small pest mammals present) at Maungatautari Sanctuary. Mice were only found to use the base of the internal fence and were never detected in the fence hood. However both rats and mice were detected in the external fence-hood. The hood of the predator-proof fence likely provides invertebrate resources as well as a source of cover.

Chapter Three considered the impact of mice on bird nesting success when mice are the sole mammalian predator present. Bird nests were located and monitored until either chicks were fledged or they failed. Nests that were located with eggs already present were monitored for 30 days with a camera capturing any activity. These cameras were set to take an image every 5 seconds nocturnally or could be triggered at any time by movement. Of 17 nests that were found, only 2 were successful. 4 nests were found with eggs that were already deserted and 11 were abandoned during the building stage prior to egg laying. One mouse was filmed on one occasion at a song thrush (*Turdus philomelos*) nest, but it was not seen to interact with the nest contents.

Chapter Four summarises the results from the previous chapters and also makes recommendations for future research. The results presented in this thesis are consistent with the prediction that mice will occupy different forest spaces when they are the sole mammalian pest than when other mammalian predators were present. However no further evidence for active mouse predation on bird nests was found.

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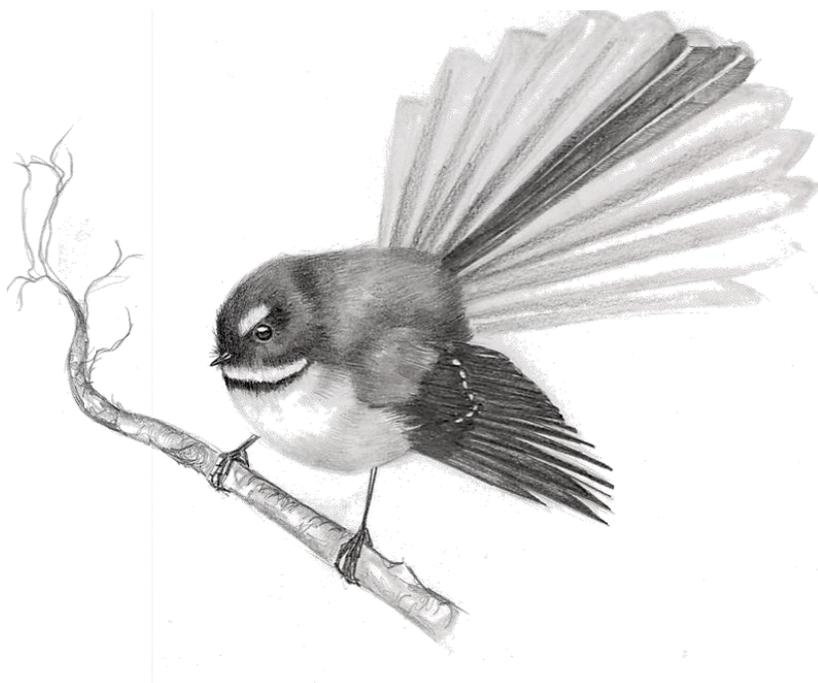
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Piwakawaka [North Island fantail] (*Rhipidura fuliginosa*)

(Drawing by author)

Chapter 1

Literature review and general introduction

1.1 Historical and contemporary New Zealand forest communities

1.1.1 Pre-human forests and fauna

New Zealand flora and fauna evolved uniquely on an isolated archipelago where birds were dominant and there were no terrestrial mammalian predators of birds (Gibbs, 2010). Prior to human arrival, native forest covered most of the land area below the tree-line (McGlone, 1989); the birdlife occurred predominantly in forest, wetland or marine habitats (Holdaway, 1989). There was a diverse and abundant array of species assemblages and systems (Holdaway, 1989).

Pre-historic New Zealand predators constituted a guild of avian predators able to target a large variety of prey sizes (Holdaway, 1989). As a result, many native birds evolved that avoided visual detection with cryptic colours/patterns and nocturnal habits (Holdaway, 1989; Gibbs, 2010). Many also evolved different nesting habits and behaviours to birds in the presence of mammals, such as ground based nesting and ‘freezing’ in the presence of a predator (Trevleyn & Read, 1989). As they had only been exposed to avian predators, native birds were naïve to mammalian predators and therefore lacked the necessary responses to avoid predators that hunted in new ways, such as by scent (Maloney & McLean

1995; Starling-Windhof et al., 2011). These factors made New Zealand native birds particularly susceptible to introduced predatory mammals.

1.1.2 Human impacts

A major extinction period for New Zealand birds began at around 1280AD when Polynesians settled and continues today (McGlone 1989). Entire species assemblages such as moa were lost following human arrival (Holdaway, 1989). This includes at least 30 species and subspecies of birds that went extinct on the mainland and many more that have become rare or uncommon (Cassels, 1984). In New Zealand, humans had a dramatic impact over a very short period of time (Holdaway, 1989). Early Polynesians burnt down forests and over-exploited native birds by hunting, decreasing both their abundance and variety (McGlone, 1989; McWethy, 2010). Areas surrounding early Maori populations were frequently heavily exploited and the native resources including birdlife and freshwater organisms were depleted (McWethy, 2010). In addition, due to the nature of the New Zealand forest, fires were particularly effective at clearing large areas of land (McWethy, 2010). It was estimated that due to Polynesian arrival and burning, more than 40% of the forest cover had been removed by 1840AD (McGlone, 1989). This therefore put more pressure on remaining forest fragments and native bird populations. In addition, early Polynesians brought with them the Pacific rat, or kiore (*Rattus exulans*) and the domestic dog or kuri (*Canis familiaris*) (Holdaway, 1989).

Assisted by the kuri, the early Maori would have been able to target and hunt the larger terrestrial birds such as the moa (Cassels, 1984). The kiore also served as an

important food source for the early Maori and was abundant in the bush during pre-European times (Taylor, 1975). As such, the nocturnal and fast-breeding kiore would have been able to hunt the smaller tree-dwelling birds (Holdaway 1989).

European explorers documented aspects of the New Zealand environment 200-300 years ago (Holdaway, 1989). Kiwi were still reported to be abundant in many forest habitats as were kiore (Gibbs, 2010). However that changed upon settlement of the Europeans. With the early European settlers came ship rats (*Rattus rattus*), Norway rats (*Rattus norvegicus*), domestic cats (*Felis catus*) and mustelids (Atkinson, 1973; Holdaway, 1989). The arrival of these pests had a dramatic impact on New Zealand's native fauna. Their presence impacted nesting success (Innes et al., 2015), caused a decline in bird populations (Kelly et al., 2005) and influenced various ecological processes such as pollination and seed dispersal (Clout & Hay, 1989; Kelly et al., 2005; Iles & Kelly, 2014). The only species that were able to remain in the New Zealand environment were those that were resilient to or isolated from the introduced predators (Holdaway, 1989).

1.1.3 Contemporary mammal abundance, distribution and impacts

The contemporary New Zealand mammalian pest assemblage consists of the rodents (ship rats, Norway rats and house mice (*Mus musculus*)), mustelids (stoats (*Mustela erminea*), weasels (*Mustela nivalis vulgari*) and ferrets (*Mustela furo*)), the lagomorphs (rabbits (*Oryctolagus cuniculus*) and hares (*Lepus europaeus occidentalis*), possums (*Trichosurus vulpecula*), cats, hedgehogs (*Erinaceus europaeus*), pigs (*Sus scrofa*), goats (*Capra hircus*) and various deer (*Cervus spp.*; Holdaway, 1989; King, 2005)

Ship rats are predominantly arboreal and Norway rats are predominantly ground-based, while kiore may use both spaces (Atkinson, 1973; Foster et al., 2012). Ship rats and mice are currently common in most habitats on the mainland, while Norway rats are most common near human habitation and kiore occur mainly on offshore islands and in Southland and Fiordland (Bramley, 2013). Ship rats have been shown to be dominant over Norway rats in forest habitats (Harper, 2006) while kiore numbers declined following the introduction of ship rats and stoats after 1860 (Atkinson, 1973). It has been suggested that when mice, ship rats and Norway rats became established, there was no niche for the kiore and they were out-competed, resulting in a population decline (Taylor, 1975). Ship rats have also been shown to exhibit aggressive behaviour towards mice in a laboratory setting (Bridgman et al., 2013). However it is unknown how rats and mice interact in the New Zealand forest. It has been demonstrated that when ship rats are removed, mouse populations tend to increase (Innes et al., 1995; Ruscoe et al., 2011; Goldwater et al., 2012). On offshore islands, kiore populations have also been shown to increase upon the removal of Norway rats (Harper & Veitch, 2006).

In beech forests, it has been shown that the abundance of stoats and ship rats is intrinsically linked with mouse abundance (O'Donnell & Philipson, 1996; King et al., 1996; Jones et al., 2011). As such, mouse abundance can often be used as an accurate predictor of stoat and rat populations (O'Donnell & Philipson, 1996). This is particularly the case in beech forests where and when mast seeding results in a dramatic increase in mouse population (King et al., 1996). This increase in mice has been shown to cause not only an increase in ship rat and stoat populations, but also an increase in bird predation as a result (Moors, 1983;

O'Donnell & Philipson, 1996; King et al., 1996; Jones et al., 2011). However, ship rats are less common than mice in beech forests and are also the prey of stoats (Jones et al., 2011).

When these larger predators are removed, the mouse population has been shown to greatly increase (Innes et al., 1995; Ruscoe et al., 2011; Goldwater et al., 2012). However little is known of the impacts of mice as the sole remaining predator following eradication of other rodents and mustelids. It is also unknown how mice utilise vertical space in the absence of larger mammalian predators. As many of New Zealand's smaller birds nest in trees, it would be particularly important to understand if mice pose a threat to the eggs and chicks of these birds.

In addition to introducing mammalian predators, Europeans also brought with them a variety of bird species. Passerines such as song thrushes (*Turdus philomelos*), blackbirds (*Turdus merula*) and various finches were all introduced to New Zealand in approximately 1862 (Blackburn et al., 2013). The silver-eye (*Zosterops lateralis*) is another non-native that was self-introduced from Australia (Blackburn et al., 2013). Unlike the native New Zealand birds, most of these introduced species had evolved in the presence of mammalian predators (Starling-Windhof et al., 2011). These species were therefore already behaviourally equipped for the contemporary New Zealand forest.

Due to the nature of the fragmentation of New Zealand forests and susceptibility of the native flora and fauna to invasive pests, it was prudent to establish predator-free zones. This began with eradication of pest mammals on offshore islands

(Newman, 1994; Towns & Broome, 2003; Griffiths et al., 2015). However, New Zealand has only a finite number of offshore islands that are capable of sustaining large, viable, forest ecosystems (Innes et al., 2012; Scofield et al., 2011). Many mainland forest fragments now have active pest control and monitoring (King & Scurr, 2013). However these reserves are faced with the constant threat of invading predators. The term ‘mainland islands’ derives from the idea of an intensively managed area surrounded by a ‘sea’ of unmanaged (usually pastoral) habitat on the New Zealand mainland (Saunders & Norton, 2001). Pest-proof fencing is a relatively new tool to limit reinvasion by pest mammals, and fenced sites are usually referred to as ‘sanctuaries’ or ‘eco-sanctuaries’ (Burns et al., 2012; Innes et al., 2012).

1.2 Fenced sanctuaries

Complete eradication of New Zealand pest mammals is only feasible on islands or areas where reinvasion is highly limited or prevented entirely (Veitch & Bell, 1990). Island sanctuaries still face the risk of accidental reinvasion by mammalian pests (e.g. as stowaways on boats or by swimming) (Bell et al., 2016). Pest exclusion using fences that surround target conservation areas on the mainland is an established method of creating mainland island sanctuaries (Connolly et al., 2009). As such, the eradication of the mammalian predators from these areas creates a sanctuary where the resident birds are released from predation pressures. One such area is Maungatautari Sanctuary in the Waikato region of the North Island.

Maungatautari is an eroded andesitic volcanic cone that supports a 3400 hectare dense mixed podocarp-broadleaf forest surrounded by 47km of predator-proof Xcluder™ fence (McQueen, 2004; Connolly, et al., 2009). This remnant forest fragment has been a site of intensive pest control with two (35ha northern and 65ha southern) of its three enclosures being free of any introduced pests with the third main 3,300ha enclosure only having mice (McQueen, 2004; Burns et al., 2012). Maungatautari has provided a sanctuary for many native and introduced birds and allowed numbers of previously uncommon birds to re-establish and increase in number (Smuts-Kennedy & Parker, 2013). The main enclosure at Maungatautari is therefore ideal for examining mouse behaviour and their impacts on bird nesting success in the absence of larger mammalian predators.

1.3 Project aims and structure

The precursor to this study was an investigation conducted by Landcare Research (Innes et al., 2014) that began to investigate the impacts of mice on the native forest community. Mice were found to be proficient climbers, being detected up to 11m. Trials with artificial nests on Maungatautari Sanctuary found that mice will readily feed at both artificial and real eggs up to Japanese quail (*Coturnix japonica*) size (30mm egg length; Innes et al., 2014). Therefore, this thesis investigates more thoroughly how mice use various layers of forest vegetation in the presence and absence of other mammals while also examining how mice impact bird nesting success.

Chapter two examines mouse arboreality within a sanctuary and also in an area with no pest control. It is well documented how mice are distributed on the

ground (King et al., 1996). As the New Zealand forest is a three-dimensional structure, this study will reveal how mice use vertical space in the presence and absence of larger mammalian predators. The first study involved the installation of tracking devices within different forest layers (including the ground) inside the Maungatautari reserve to determine how mice use available space in the absence of other mammals. The procedure was then repeated in an another reserve that has the entire array of introduced mammal pests. This was followed by a second study that involved the installation of game cameras in the hoods of pest-proof fences (a) within the Maungatautari reserve (where only mice occurred) and (b) surrounding the reserve (where all mammals were present).

In chapter three, I examine the nesting success of native and exotic birds in the presence of only mice. This involved finding and observing bird nests to determine outcomes and causes of failure within protected reserves. Mice may act as important nest predators in the absence of other mammals while native predators may fill the niche left by removed mammals.

The fourth and final chapter summarises all results from previous chapters. This includes conclusions and suggestions for future research.



House Mouse (*Mus musculus*)
(Drawing by author)

Chapter 2

Mouse arboreality in the presence and absence of other introduced mammals in Waikato forests

2.1 Introduction

Smaller predator species can sometimes be ‘released’ from abundance or behavioural constraints associated with larger predators when a top predator is controlled or removed. “Meso-predator release” can occur when a dominating predator is eliminated from the system while “competitor release” is the removal of a species competing for similar resources (Jones et al., 2011). Both mechanisms therefore allow other, previously suppressed predators to become more abundant (Soule et al, 1988; Valone & Brown, 1995). For example, on the sub-Antarctic Island of Marion and sub-Atlantic Island of Gough, house mice (*Mus musculus*) were found to have altered their predatory behaviour in the absence of larger predators (Wanless et al., 2007; Angel et al., 2009). The more effective control of the dominant predator, the larger the final population of the response species would be (Caut et al., 2007). This population change may be sudden and dramatic. Witmer et al. (2007) showed that the removal of ship rats (*Rattus rattus*) on Buck Island in the Caribbean resulted in a dramatic increase in the island’s house mouse population; this may be the result of release of mice from rat predation pressure, as ship rats display aggressive behaviour toward house mice in a laboratory setting (Bridgman et al., 2013). The risk of aggression

or predation could alter the behaviour of the mice to avoid areas where rats are more likely to occur (Lima, 1998; Arthur et al., 2004). Therefore, with the removal of the rats, niches and habitats that would previously have been avoided could be exploited by mice.

Shiels et al. (2012) examined the relationship between introduced ship rats, Pacific rats (*Rattus exulans*) and house mice in Hawaii. Like New Zealand, Hawaii lacked rodents prior to human arrival. Shiels et al. (2012) found that resource pressures drove the different species to occupy different niches. For example, ship rats were predominantly vegetarian while the house mice were predominantly carnivorous (consuming mainly arthropods and caterpillars) and Pacific rats were intermediate between these two species.

2.1.1 Use of vertical space by rodents

Of the three rat species in Tonga, only the ship rat appears to actively climb coconut trees; Norway and Pacific rats were unable to do so (Twibell, 1973). In New Zealand, ship rats are known to be predominantly arboreal while kiore are also agile but mainly found on the ground or small trees; in contrast, Norway rats are far less agile and are predominantly ground-based (Atkinson, 1973; Foster et al., 2012).

Arboreality in small rodents has been suggested by Buesching et al. (2007) and Stepankova & Vohralik (2009) to be due to predator avoidance and niche exploitation. These studies examined arboreality in wood mice (*Apodemus sylvaticus*) and yellow-necked mice (*Apodemus flavicollis*) in the United

Kingdom and Europe. Both studies found that these mice, although predominantly found on the ground, also had arboreal tendencies. Furthermore, Buesching et al. (2007) found that with higher densities and resource competition, mice were more arboreal than when the population was less dense and there was less competition from other species. Therefore, an increase in the mouse population could drive mice to exploit resources in niches or habitats they may otherwise not occupy.

While international studies suggest that various species of mice pose a conservation risk when released from mammalian predation, they may not apply in the New Zealand context and the mouse species examined were also not always house mice. House mouse populations in New Zealand have been shown to increase dramatically following the removal of rats, particularly in a forest setting (Innes et al., 1995; Ruscoe et al., 2011; Goldwater et al., 2012). House mice are also known to be more abundant in areas of thick ground cover that offer a potential predation refuge (King et al., 1996). This is because in New Zealand, in addition to cats and mustelids, rats are a main controlling agent of mouse populations (King et al., 1996; Choquenot & Ruscoe, 2000; Bridgman et al., 2013). Rats may control house mouse populations through predation and competition (Jones et al., 2011; Ruscoe et al., 2011). Release from competitive or predation pressures (associated with other introduced mammals) would open up more resources for house mice and therefore could result in a population irruption.

There is literature on the territories and distributions of mice at ground level (Fitzgerald et al., 1981; King et al., 1996; Choquenot & Ruscoe, 2000; Ruscoe et al., 2001); however there is little information on the vertical distribution of mice within vegetation (Innes et al., 2014). In New Zealand, ship rats have been shown

to be both ground-dwelling and arboreal without preference (Foster, 2011; Hooker & Innes, 1995), as reflected in Connolly et al.'s (2009) study on pest reinvasion following a breach in the predator proof fence surrounding Maungatautari. Ship rats were regularly seen climbing the fence mesh, moving up down and along the fence while mice were very rarely seen climbing the mesh; instead they steadily paced at the fence base (Connolly et al., 2009). Furthermore, it is not known if the vertical activity of mice is influenced by other introduced mammalian predators. Therefore, it would be valuable to examine the distribution of mice at various vegetation heights, both in the presence and absence of other introduced mammals. Mouse arboreality is of particular interest to those concerned with the impacts they may have on native birds nesting above the ground, especially since mice are often the only introduced species remaining in fenced sanctuaries (Burns et al., 2012).

The Waikato district provides a unique opportunity to assess the impacts of mammalian predators on the arboreal behaviour of mice (Figure 2.1). Mice are the only introduced mammals present within the main enclosure at Mount Maungatautari. In contrast, the nearby Te Tapui Reserve contains mice and all other introduced mammalian predators. This allowed me to compare the vertical activity of mice in similar habitat, but in the presence or absence of other introduced predators.

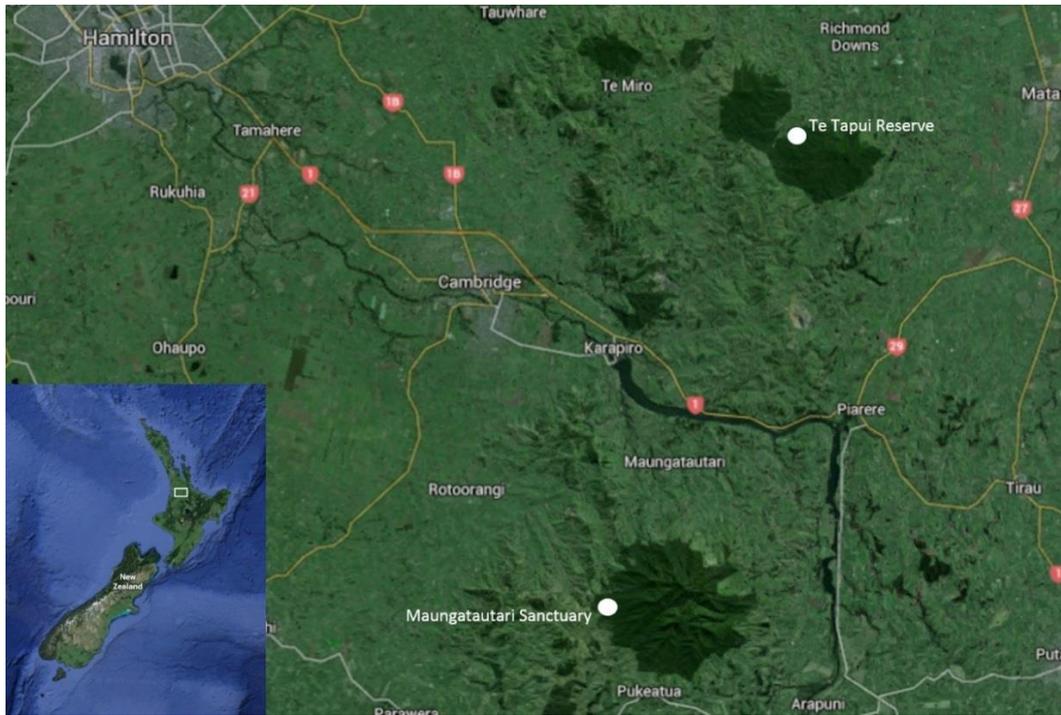


Figure 2.1. Locations of Maungatautari and Te Tapui reserves in relation to Hamilton City, New Zealand

Finally, it would be beneficial to understand if and how mice utilise the predator-proof fence that surrounds two small enclosures within Maungatautari Sanctuary; these two partly internal fences have only mice outside them, whereas Maungatautari external fences are exposed to all mainland small mammals. Connolly et al. (2009) examined how various mammals were using the perimeter fence at Mount Maungatautari in order to develop optimal breach response procedures. In addition to installing “invadable boxes” to simulate breaches at the base of the fence, cameras were installed inside the hood itself to determine what mammals used the hood. Only rats used the hood (187 rat sightings over a 20 night period) although many species were present at the base of the fence (hares (*Lepus europaeus*), hedgehogs (*Erinaceus europaeus*), cats (*Felis catus*) and various other mustelids and rodents). Mice were also present at the base of the fence (201 sightings at the base compared with 83 for the rats over a 20 night

period). Therefore, rats could potentially be preventing mice from using the hood of the fence. With the removal of rats within the reserve, the population of mice is increasing (Innes et al., 2014). The hood poses a valuable source of insects available for rodent as well as a means for the rodents to quickly access different sites (Connolly et al., 2009). It would therefore be valuable to understand if, with the removal of rats, mice will climb to access the hood and therefore increase the breach risk.

My study will determine how mice use vertical space. I will achieve this by: (1) analysing how mice use vertical layers of the forest with and without other mammals and (2) surveying mouse use of the fence hood, both within and outside the Maungatautari sanctuary.

2.2 Methods

2.2.1 Use of forest layers by mice

2.2.1.1 Study Sites

An area of native bush was selected for the research within Maungatautari Sanctuary (-38.018805, 175.575958) that has mice alone; I focused on an area to the north of 'Gorse Net' corner (-38.031145, 175.53227), an area of low-lying scrubland located on the western side of the main enclosure (Figure 2.2). Several of the tracks off the 'Gravel Road' access point north of Gorse Net corner (Ramsey, GRB, DOC 1-5, DOC 6-10 and Gorse Perimeter) were used to aid site selection. The bush in this area has a canopy of predominant tawa (*Beilschmiedia tawa*) and pukatea (*Laurelia novae-zelandiae*), an understorey of mahoe (*Melicytus ramiflorus*), coprosma (*Coprosma spp.*) and tree ferns (*Cyathea spp.*)

and undergrowth of kawakawa (*Macropiper excelsum*) and saplings from the larger trees. There was also extensive supplejack (*Ripogonum scandens*). Many of the large trees had extensive lianes and epiphytes.

The area selected for the survey outside the sanctuary (with all pest mammals present) was Te Tapui reserve (-37.835433, 175.65724; Figure 2.3) and was selected as the structure of the forest and plant species were similar to that found on Maungatautari. This reserve consists of two distinct lobes (a northern (-38.003742, 175.577192) and a southern (-38.054921, 175.567923)) that had previously been part of the Halo Project (a Waikato Regional Council initiative to attempt to increase the number of native birds in Hamilton City) but has since been released from the programme. There was therefore no active pest control in the southern lobe of the reserve. This site has a canopy of predominantly tawa, an understorey of mangaeo (*Litsea calicaris*), kohekohe (*Dysoxylum spectabile*) and tree ferns and an undergrowth of kawakawa and saplings of the larger trees. Some areas were also dense with supplejack and many trees had extensive lianes and epiphytes.



Figure 2.2. Approximate locations of mouse arboreality sampling site centres, Maungatautari



Figure 2.3. Approximate locations of mouse arboreality sampling site centres, Te Tapui

2.2.1.2 Device Construction

Tunnels to sample mouse and rat activity were designed in conjunction with Landcare Research (Hamilton, New Zealand) specifically for this study (Figure 2.4). They had to be efficient at pest detection both on and above the ground regardless of their orientation (e.g. installation up a high tree could involve the device being set upside down). Pilot trials were conducted to determine the most effective tunnel designs. Tunnels were constructed from 6cm diameter pipe cut into 15cm lengths. Card was cut into 13cm x 20cm rectangles onto the centre third of which a 3cm x 20cm rectangle of Gotcha Traps Limited Black Trakka tracking card (Mahurangi Heads, Warkworth) was attached. These were then rolled lengthwise and inserted so that there was a strip of ink running in a continuous loop within the inner third of the tunnel. In addition, a hole was drilled 1cm from the edge of one end (Figure 2.4) allowing a PCR WaxTag® (Opawa, Christchurch) to be attached internally. The tags are peanut butter flavoured, thus acting as a long-lasting rodent lure, and also record the bite marks of any animal that chews them. Just prior to installation, the tunnels were also baited with a small amount of smooth peanut butter at both ends of the device. Ground tunnels had no strings, while shrub devices had free strings so they could be tied to thinner branches (Figure 2.4).

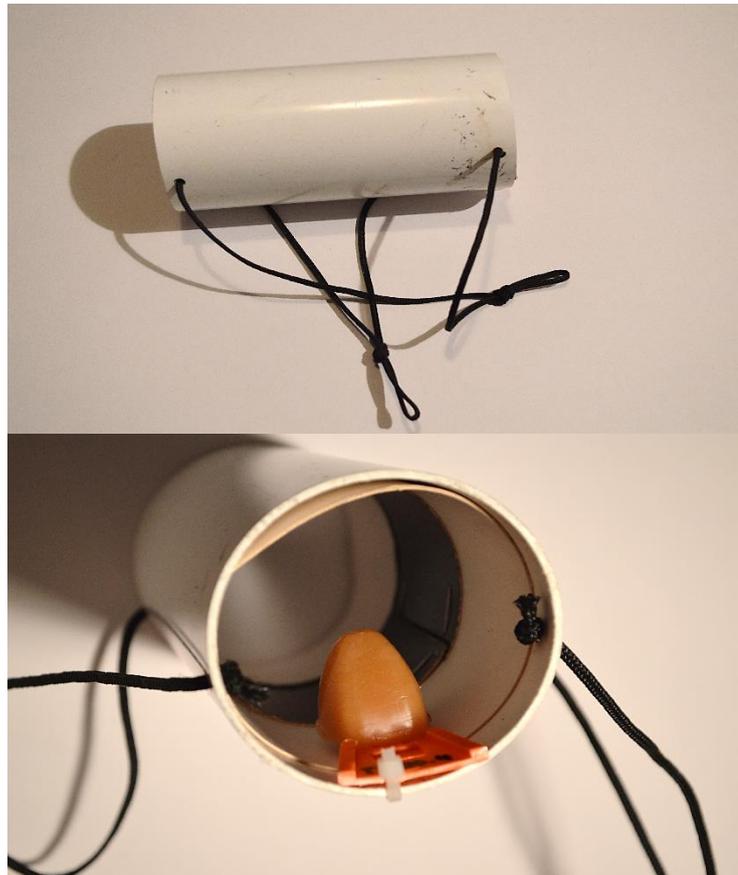


Figure 2.4. Tracking tunnel design for elevated positions. Note the black ink and Wax-Tag© inside the tunnel

2.2.1.3 Study Design

Mammal presence at various heights above ground was explored at 20 sample sites at Maungatautari (23 January 2015 – 15 February 2015) and 19 at Te Tapui (1 May 2015 – 12 June 2015). In order to ensure that a single animal would not encounter multiple sites, all sites were at least 100m apart. This was determined using a GPS device. In order to remove any biases generated by the occurrence of tracks and human movement at Maungatautari, the 20 sample sites used in the study were installed at least 20m off the track. A coin was flipped to randomise the direction I went off track. At Te Tapui, sample sites were at least 20m away from the fence line entry point (-37.823857, 175.632349). At all 39 sites, there

were 6 devices placed above ground in vegetation that mammals may use (Figure 2.5): (a) one in a shrub 1-2m above ground (b) two up a sub-canopy tree, one close to the trunk and the other away from the trunk, 3-6m above ground and (c) three up a canopy tree, one near the trunk, one at the end of a branch, and the last mid-way, over 6m above ground. Every selected shrub, and mid-size and large tree also had a device positioned on the ground, so that there were nine sampling devices in total at each site.

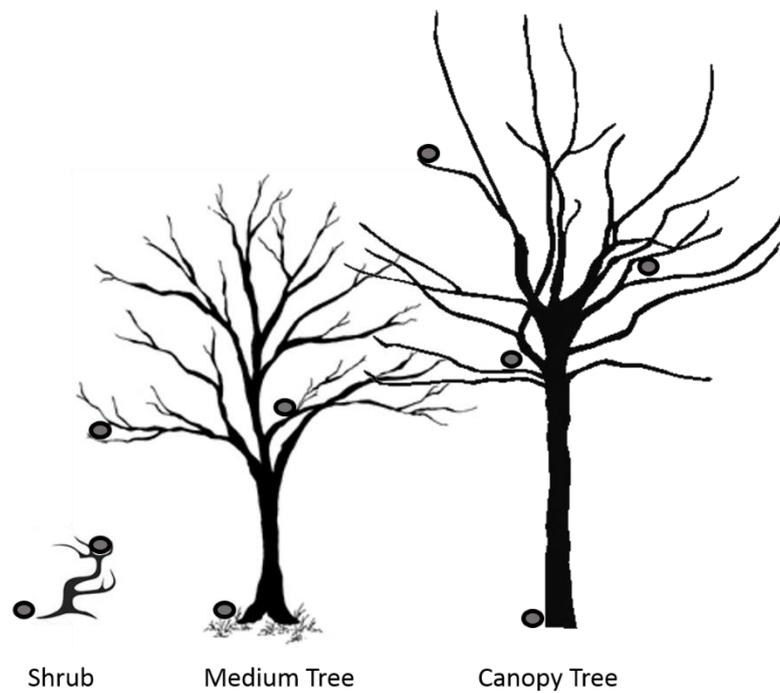


Figure 2.5. Locations of the nine track-chew devices (grey circles) used to examine small mammal arboreality at Maungatautari and Te Tapui. There was one ground device per selected tree/shrub, one elevated device in the shrub, two elevated devices in the medium tree (inner and outer) and three elevated devices in the canopy tree (inner, mid and outer)

Site centres at both Maungatautari and Te Tapui were flagged and had the GPS location recorded. Trees to support the devices were selected based on their

proximity to the site centre (occurring within 15m) and their ability to secure the device. Each selected tree was flagged and the GPS location recorded.

2.2.1.4 Installation

Ground devices were secured in place under the sample trees/shrubs. Shrub tunnels were secured with string to a horizontal branch on a plant less than 5m tall. Devices placed up trees were installed using a catapult method. A 55 gram sinker attached to braid on a surf casting reel was loaded into a slingshot and fired over the selected branch. After locating the fired sinker, it was removed and waxed string on a spool was attached to the braid. I then pulled the device up to the desired branch and secured it against the branch by tying string from both sides of the device to the ground.

2.2.1.5 Collection and Identification

All sites and devices were found again after one week, and devices were removed. First, one end of the string was pulled so that it was vertical and in line with the device and a knot was tied at ground level so that the device height above ground could be measured. Upon being lowered from the tree, the distance between the device and the knot was then measured as the height of the device.

Ink strips and wax tags were removed from the tracking card prior to inspection. Wax tags were examined under a dissection microscope to determine the species that had generated the bite marks based on known markings left by different species. Skulls of mouse, rat and possum (*Trichosurus vulpecula*) were also used to aid identification of more ambiguous marks. Marks left on tracking cards were

also identified based on known prints of the various species. Three parties independently examined each of the tracking cards and wax tags. A spreadsheet was developed that each party filled in for tracking and chew marks for each tunnel following examination. The spreadsheets were then compared and discrepancies were re-assessed. A decision was reached by majority vote. Only visible markings were assessed and identified. In cases where a subsequent animal possibly had bitten over another's mark (e.g. when much of the wax was removed), only the latest marking was able to be identified.

2.2.1.6 Data analysis

Data was analysed using Statistica Version 12 (StatSoft Inc. © 1984-2014). To assess differences in mammalian presence across heights, Cochran's Q test was selected as it examines the difference between treatments where the response variable can have only two outcomes (1-presence or 0-absence). It also takes account of the fact that the presence/absence data is recorded for each height at each site. The Q-test assesses whether the frequency of presences differs systematically between the height categories. The output also reports on a multiple comparison procedure to better define height differences where they are significant. The presence or absence of the each species at elevated devices was compared with their presence or absence at the ground level at each of the sites. The data were pooled in accordance with height category because there was only one ground device per height category; therefore the scores for elevated devices were pooled to generate a single figure to compare with the single ground device. In contrast, the histograms (Figures 2.8 & 2.9) were produced by calculating the total percentage of tunnels that were tracked by using all device data.

2.2.2 Rodents in the fence hood

To examine mammalian presence in the pest-proof fence hood (Figure X) at Maungatautari, two separate surveys were conducted simultaneously over 10 nights (5-15 January 2016). This sampling period occurred over a new moon phase.

2.2.2.1 The pest-proof fence at Maungatautari

Xcluder® (Ngapuna, Rotorua) fencing company constructed pest-proof fences that completely encircle the Maungatautari Sanctuary and also two separate enclosures within the main enclosure. The fence is manufactured from a fine stainless steel mesh that stands approximately 2m tall supported by vertical wooden posts 2 m apart. The mesh is fine enough (21 x 6 mm cells) to prevent invasion by baby mice and extends out under the ground to prevent breaches by burrowing animals. A rolled metal hood runs along the top of the fence that has a distinct lip on the inside (Figure 2.6). There are metal struts and supports at equal distances from each other that correspond with the upright vertical posts.

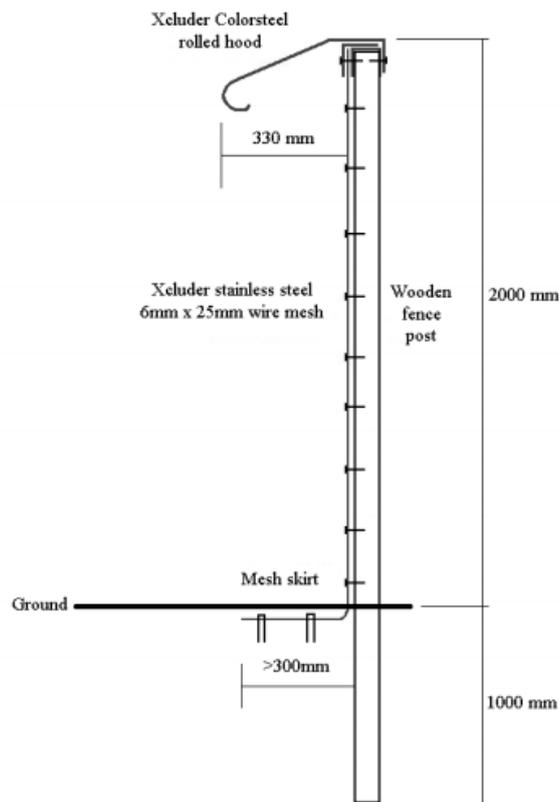


Figure 2.6. Construction of the Xcluder ‘kiwi model’ fence that surrounds Maungatautari Sanctuary – adapted from Day & MacGibbon (2007)

2.2.2.2 Study sites

Two sampling lines were used to assess mammalian presence in the hood. Both were located on the southern side of Maungatautari Mountain. The reserve interior line was located along the fence between the southern enclosure (-38.053157, 175.566378) and the main enclosure (-38.018805, 175.575958) with only house mice present outside it (Figure 2.7). This line included 15 sites that were 150m apart. A reserve exterior line was located along the outside of the fence with all mainland small mammals present outside it. Half of the sites were on a section of fence south of the Maungatautari Sanctuary Visitor Centre (-38.056013,

175.560316) while the other half were to the north of the Visitor Centre. These sites were at least 200m apart. All sites were marked with flagging tape.

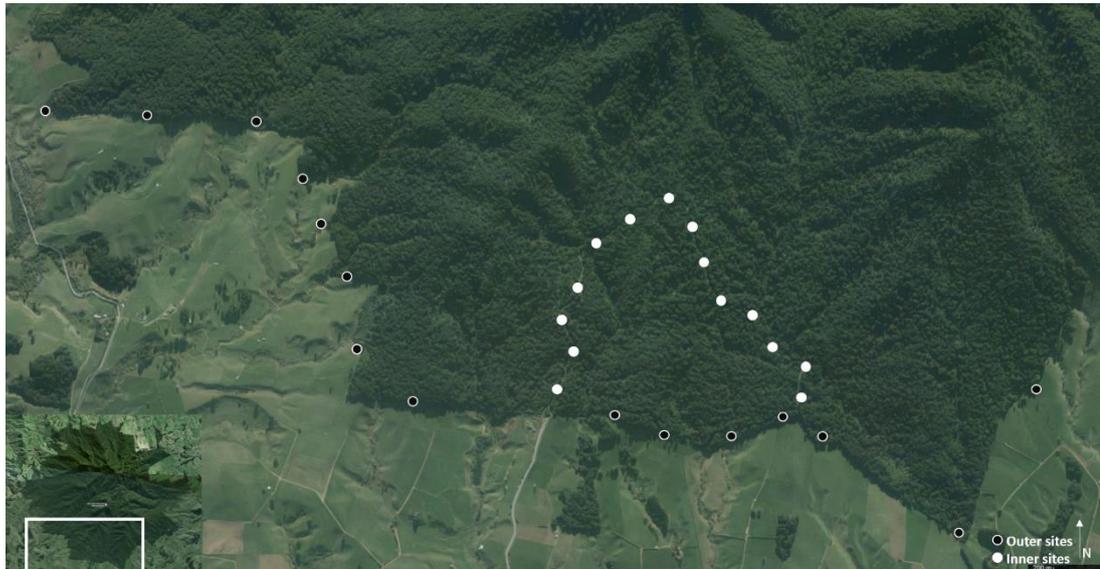


Figure 2.7. Approximate locations of hood-study sites, Maungatautari

2.2.2.3 Installation of cameras and tracking cards

Reconyx HC600 HyperFire Covert IR (Wisconsin, US) cameras were secured to the fence at each of the sites. They were attached using zip-ties to the metal struts within the hood of the fence. The lenses faced down the fence in order to identify any animals walking along the inside of the hood. In addition to being set to be triggered by movement (providing 3 photos with no delay upon trigger), each camera was also programmed to take photos at 5 second intervals with an infra-red flash between the hours of 2000 and 0700h. Gotcha Traps Limited Black Trakka tracking card were also installed next to the cameras within the hood, and tracking tunnels were also placed on the ground under every camera. Camera batteries, memory cards and hood tracking cards were replaced every day. Photos were removed from the memory cards and images examined. The ground tunnels were left for 7 nights.

2.2.2.4 Data analysis

As the outcome could only be presence or absence, a Cochran Q Test was performed in Statistica©. All marks or sightings of mammals were pooled over the 10 nights the cameras were active. The hood values were compared with those gained using the tracking card collected from the base.

2.3 Results

2.3.1 Forest arboreality by small mammals

2.3.1.1 Maungatautari (mice only)

There were significant differences in mouse detections between ground sites and each of the forest layers (Table 2.1). Mice tracked or marked at least one ground tunnel at 100% of the sites with the likelihood of detecting mice decreasing with increasing height.

Table 2.1. Cochran Q Test results for vertical distribution of mice at Maungatautari Sanctuary. Data refer to devices pooled at each site by height, not to individual devices.

Mice	p-value	%marked (ground device)	%marked (elevated device)
ground vs shrub	<0.001	100	35
ground vs sub-canopy	<0.001	100	30
ground vs canopy	<0.001	100	0

Percentage of devices marked at each height category can be seen in Figure 2.8.

Across the 20 sites, mice were detected in 93.3% of the ground devices compared to 35% in shrub and 17.5% in the sub-canopy. No mice marked any device in the canopy.

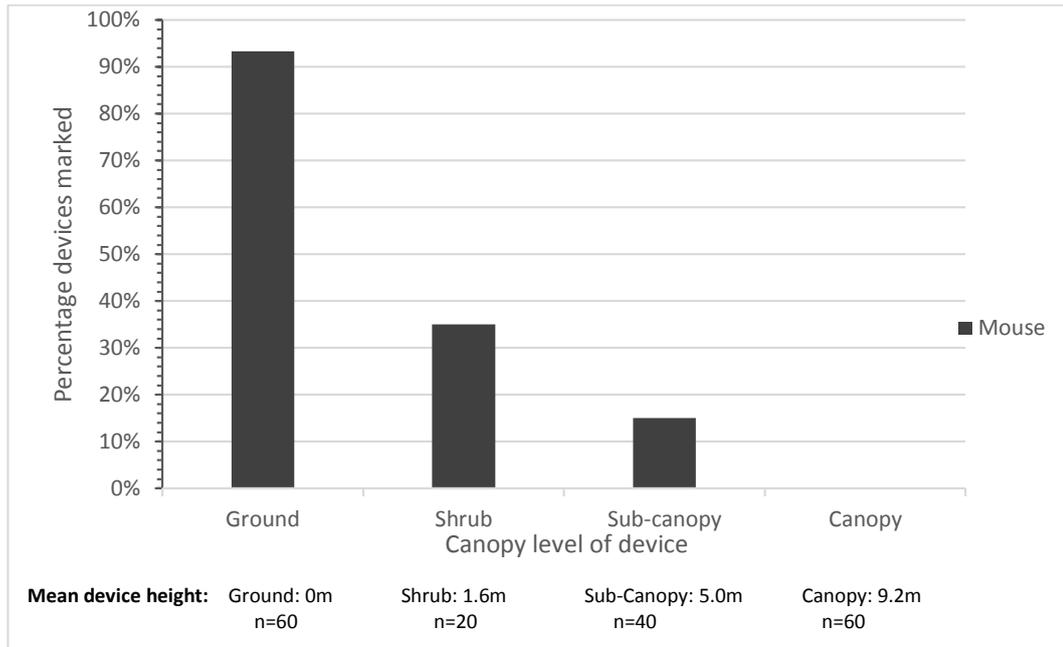


Figure 2.8. Percentage of all tunnels (not pooled) marked in each height category at Maungatautari, January 2015

2.3.1.2 Te Tapui (all mammals present)

Rats and possums were present at all assessed forest layers at Te Tapui (Table 2.2). Possums were significantly more likely to mark the ground than the elevated devices. Mice only marked a single ground device at one site; they were not recorded at elevated sites.

Table 2.2. Cochran Q Test results for vertical distribution of rats and possums at Te Tapui. Data refer to devices pooled at each site, not to individual devices.

Rats	p-value	% marked (ground device)	% marked (elevated device)
ground vs shrub	<0.002	84.21	31.58
ground vs sub-canopy	<0.035	84.21	47.37
ground vs canopy	<0.084	84.21	100
<hr/>			
Possum	p-value	% marked (ground device)	% marked (elevated device)
ground vs shrub	<0.008	47.37	10.53
ground vs sub-canopy	<0.005	47.37	5.26
ground vs canopy	<0.005	47.37	5.26

Figure 2.9 shows the percentage of all devices (i.e. data not pooled) marked at Te Tapui according to height and species. Mice marked 3.5% of devices on the ground at Te Tapui. In contrast, rats were as likely to be detected on the ground (75.4%) as they were in the canopy (73.2%). They also marked 42.1% of the shrub devices and 44.7% of the sub-canopy devices. Possums were most likely to mark ground devices, with the proportion of marked devices declining with height.

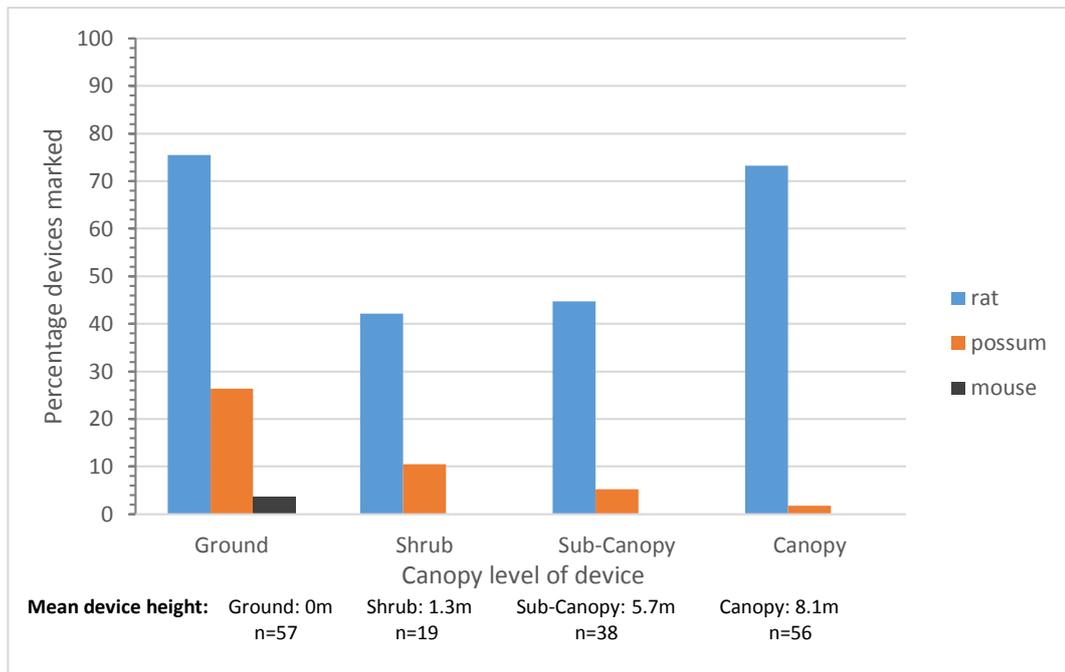


Figure 2.9. Percentage of tunnels marked (not pooled) in each height category according to species at Te Tapui, June 2015

2.3.2 Rodents in the Maungatautari fence hood

Mice were not seen in the hood of the fence on the inside of the Maungatautari Sanctuary despite 10 nights of active monitoring. However mouse prints were found on the ground at the base of the fence at 40% of sites (Table 2.3). In contrast, both rats and mice were seen in the hood on the outside of the Sanctuary (Figure 2.10; Table 2.3). Mice tracked at 33.33% of the ground tunnels outside the reserve as well as being tracked or caught on camera at 13.33% of sites in the hood of the fence. Rats were tracked or caught on camera in the hood at 60% of the sites, but never appeared on the ground. No other mammals were seen to be using the hood. However hedgehogs were tracked along the ground tunnels on the outside sites. In addition, a young possum was found in one of the ground tunnels one morning. Weta (Anostomatidae and Rhaphidophoridae) were frequently seen in the hood also, as well as several gecko (Gekkonidae).

Table 2.3. Cochran Q Test results for mice and ship rats tracked or filmed on the ground and in the hood of the internal and external pest-proof fences, Maungatautari.

	p-value	% tracked or filmed	
		Fence base	Fence Hood
Interior fence (mice)	<0.014	40	0
Exterior fence (mice)	<0.083	33.33	13.33
Exterior fence (rats)	<0.003	0	60

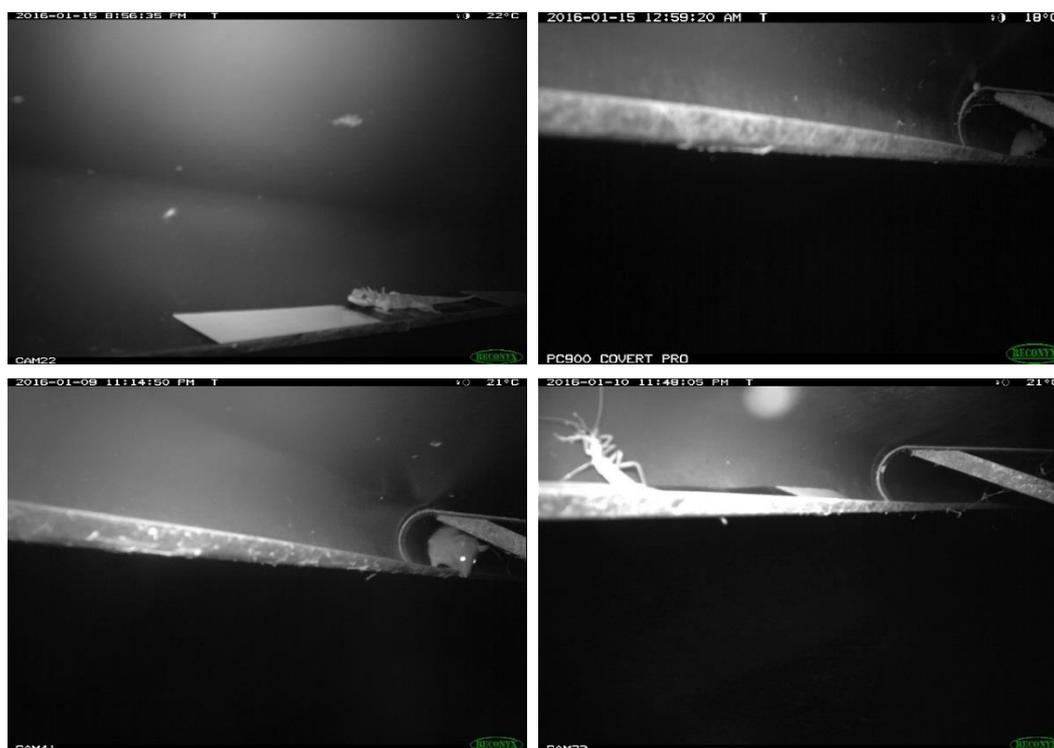


Figure 2.10. Images captured in hood of main visitors to sites; gecko (top left), mouse (top right), ship rat (bottom left) and tree weta (bottom right)

2.4 Discussion

2.4.1 Use of vertical space by mice when they are the only mammal present

In Trees and shrubs

Mouse presence at Maungatautari was significantly related to the height of detection devices. At Maungatautari, mice appear predominantly ground-based although frequently utilise low levels of vegetation. Mice were detected at 93% of ground devices, 35% of shrubs and 17% of sub-canopy trees at Maungatautari. These results clearly demonstrate that house mice are proficient climbers and, if abundant, will routinely climb vegetation at the lower levels of the forest structure. House mice have been demonstrated to be proficient climbers in a laboratory setting (Byron et al., 2013) and a single mouse had previously been detected at 11m and others observed in lower vegetation (Innes et al., 2014). The larger canopy trees may not have had the suitable branches that enable mice to utilise their tail as a form of balance or that were appropriate for mouse gripping (Byron et al., 2011). Larger tree branches tended to be more exposed than those in lower vegetation. As such, it is possible that canopy tree branches did not provide suitable cover for mice as mice have previously been shown to have preference for areas with dense cover (King et al., 1996).

On the fence

Mice living along the interior enclosure of Maungatautari do not actively use the hood of the fence. Mice were not observed at any point on the fence within the hood. They were present at the base of the fence at 40 % of the sites. The predator proof fences at Maungatautari have a gravel access road immediately adjacent to

them and King et al., (1996) demonstrated that more mice live alongside road edges than in the forest interior. Mice had previously been shown to dominantly utilise the base of the fence (Connolly et al., 2009). However, mice have also been shown to frequently use low vegetation (Innes et al., 2014) and are proficient climbers (Byron et al., 2011). The forest potentially provided enough cover (King et al., 1996) that mice did not need to take refuge in the hood of the fence.

2.4.2 Arboreality of mice when other mammal species are present

In trees and shrubs

Mice were only detected at a single ground tunnel at Te Tapui. Ship rats have been shown to suppress house mouse populations in the New Zealand bush (King et al., 1996; Choquenot & Ruscoe, 2000; Ruscoe et al., 2011) and mice are reportedly rare in the presence of rats (Speedy et al., 2007). Therefore, it is unsurprising that, in the presence of rats and other mammals, mouse tracking was greatly reduced to less than 3% of ground tunnels – they were never detected above ground at Te Tapui, probably due more to their rarity than to a behaviour difference from those at Maungatautari.

On the fence

Mice were observed at 13.3% of the sites in the hood and 33.3% on the ground at the base of the fence. Mice also occasionally occurred in the hood of the fence not only at the same site as rats, but also the same night. This could be in an attempt to access the resources beyond the fence as opposed to utilising the resources within the fence-hood (Connolly et al., 2009). Mice have previously been shown to climb low heights (Innes et al., 2014) and the fence height of 2m falls well

within mouse climbing range. This differs from results reported by Connolly et al. (2009) who found that no mammals other than rats were present in the hood of the fence surrounding Maungatautari. Rats did not track any of the ground tunnels at any of the sites where all mammals were present, but were observed at 60% of the sites inside the hood. Ship rats are known to be highly arboreal (Atkinson, 1973; Foster et al., 2012), so it was expected that they would predominantly be seen in the hood of the fence. Ship rats have been shown to exhibit predatory behaviours towards mice (Bridgman et al., 2013) and have also been demonstrated to restrict the habitats of smaller rodents through competition or predation (Bramley, 2013). However the external fence backs predominantly onto pasture (McQueen, 2004). Mice have been shown to prefer dense cover to open areas (King et al., 1996). Therefore the hood of the predator proof fence may provide a form of cover for mice.

2.4.3 Arboreality of other mammal species at Te Tapui

Possoms are known to be highly arboreal and major consumers of native vegetation (Cowan & Waddington, 1990; Innes et al., 1995); however results from the Te Tapui study in June would suggest that they were primarily ground-based, as their detection rate decreased with height (47.37% on the ground compared with 5.26% in the canopy). This is in contrast with rats (probably all ship rats) that were present at over 70% of devices on the ground and in the canopy at the 19 sites. Rats could potentially have been limiting mouse population. Rodent populations have also been found to be highly reactive to season and food abundance (Murphy, 1992; King et al., 1996; Choquenot & Ruscoe, 2000); further, rat populations have been shown to suppress mouse populations through

competition (Ruscoe et al., 2011). The Te Tapui study site backed onto farmland that supports maize crops in the summer. The present study was conducted within two months of the maize being harvested. As rats have been shown to have a home range size of 1.1ha in males and 0.3ha in females (Hooker & Innes, 2010) it is likely that many rats may have utilised the fallen maize in the pasture. As such, it is possible that the rat population had increased in size due to abundant food and therefore had suppressed mouse populations. This could account for the single tunnel tracked by mice at Te Tapui, compared with the much higher tracking rate at Maungatautari.

2.4.4 Strengths and weaknesses of sampling devices

To examine arboreality, the use of tracking tunnel and wax tag combined provided two modes of detection within the same device. However, wax tags were small and often completely destroyed by interacting animal (N= 24) (see also Sweetapple & Nugent, 2011). This therefore obliterates any marks left by previous visitors. Tracking cards could potentially increase resolution where wax tags are destroyed. Tracking tunnels have been shown to have a considerably higher tracking rate than the wax chew tags (Sweetapple & Nugent, 2011). In the present study, possums were obviously unable to track in the tunnel (Appendix 1). However, mice and most rats were able walk through the tunnels. One unforeseen issue with both the wax tags and the tracking card was the interaction from invertebrates. Some cards were chewed extensively by invertebrates and many wax tags had to have kawakawa looper caterpillar (*Cleora scriptoria*) removed off them prior to removing the device (see Appendix 2). This therefore potentially obscured some chew marks that had been left prior to the invertebrate interaction.

King et al. (1996) determined mouse densities were greater closer to disturbance. Therefore in order to reduce any biases generated by activity, sites were installed at least 20m off the track and 50m away from the road edge. In contrast, the Te Tapui site had no tracks. However resident goats and deer are active and could potentially have interfered with some sites.

Camera footage from the hood study sometimes showed that ship rats and geckos were hesitant to walk across the tracking card. In several cases, multiple rats, a mouse and a gecko (N= 6, 1 & 1 respectively) were seen to approach the tracking card, only to turn around and not walk across it). One gecko almost fell off the fence appearing to be an attempt to avoid walking across the card. Rats have been shown to react to novel items, sometimes exhibiting neo-phobia (Cowan, 1976). As such, in some cases it was clear that the presence of the tracking card had an effect on the animal. This could potentially have direct implications for studies involving tracking tunnels as a means of identifying species present in an area (the current study for example). The pairing of cameras with tracking card in the present study enabled identification of species that the tracking card alone would have missed. In addition, the cameras themselves were likely audible and visible to the animals. Although no attempt was made to conceal the cameras, the infra-red flash likely fell within the detectable ranges of most nocturnal animals (Meek et al., 2014). This could potentially have influenced animals walking past sites, particularly if the camera was producing an infra-red flash every 5 seconds.

Seasonal changes could influence how animals utilize vertical space. It would therefore be beneficial to repeat my sampling protocol across seasons to determine if there are seasonal differences in tracking rates and the actual animals

present. It would also be valuable to install a game camera opposite the sampled sites to detect larger animals.

2.4.5 Implications for biodiversity and its management

Mice have previously been found up to 11m (Innes et al., 2014) and the present study demonstrated that mice, in the absence of other mammals, frequently use vegetation in the low-middle forest layers. My findings have implications for explaining bird nesting success, as many birds nest within this range (Moors, 1983). If mice were to alter their habitat use and diet when “released” from predation or competition with other mammals, as they have done in other areas (Wanless et al., 2007; Angel et al., 2009; Innes et al., 2014) then birds in sanctuaries may be placed at greater risk of mouse predation. The effect should be most obvious when house mouse population suddenly increase following the removal of other mammalian predators (Innes et al., 1995; King et al., 1996; Ruscoe et al., 2011; Goldwater et al., 2012). Low mouse tracking in the presence of other mammals could also potentially explains why mice have not been observed as possible predators of bird nests in previous studies (Brown et al., 1998; Sanders & Maloney, 2002; Jones, 2003; Innes et al., 2015) As other invasive mammals control the population of mice, it is likely that in their presence, mice are simply too rare.

My research has provided valuable further information on species utilising the hood of pest-proof fences and therefore gives insight into managing breach risks. Rats were seen frequently in the hood of the fence surrounding Maungatautari, which supported the previous report by Connolly et al., (2009). Rats therefore

pose an immediate risk to breaching the fence through the hood, while mice pose a direct risk to invasion along the ground.

2.4.6 Conclusions

Mice are competent climbers and frequently climb up to lower and middle layers of forest; they are also far more frequent at these levels in the absence of other mammals. The opposite occurred when I examined mouse use of the hood. Mice did not exploit the fence hood when they were the only invasive mammals present. In contrast, they used the fence hood (albeit infrequently) when in the presence of other mammals: however, mice did frequently use the base of the fence both in the presence and absence of other mammalian pests. Rats used all forest levels while possums were predominantly found on the ground or lowest forest levels. Rats were also only found in the hood of the fence and do not use the base of the fence frequently. This information could be used to benefit management of breaches. The location of the breach on the fence could suggest what animals are at a higher risk of invasion, and therefore subsequent pest control could be more efficient. Larger invasive mammals, such as rats, clearly have an impact on the distribution of house mice. Although my study did not assess abundance, it was evident that the presence of other mammals significantly reduced the number of devices marked by mice.



Toutouwai [North Island Robin] (*Petroica longipes*)

(Drawing by author)

Chapter 3

Nesting success of birds in a New Zealand sanctuary with the house mouse as sole mammalian predator

3.1 Introduction

Bird nesting success is negatively impacted by the presence of predators (Moors, 1983; Starling-Windhof et al., 2011; Innes et al., 2015). Perception of predation risk alone can negatively impact bird reproductive success (Fontaine and Martin, 2006; Massaro et al., 2008; Hua et al., 2014). For example, the reproductive output of Eastern bluebirds (*Sialis sialis*) declined by 40% in the presence of predators without any actual predation occurring (Hua et al., 2014).

New Zealand birds evolved mainly in the presence of avian predators; therefore, they lack behaviours that minimise mammalian predation risk (Starling-Windhof et al., 2011). Many native New Zealand birds appear naïve to introduced mammalian predators exhibiting behaviour such as tameness and ground-based foraging that would make them susceptible to capture (Innes et al., 2010). As such, the spread of mammalian predators across New Zealand has led to the decline or extinction of numerous native species (reviewed by Innes et al., 2010).

Prior to mammalian predators, New Zealand had an entire guild of avian predators (Holdaway, 1989). Many of these species were driven to extinction following

human settlement (Cassells, 1984). However, the karearea [New Zealand falcon] (*Falco novaeseelandiae*), ruru [morepork] (*Ninox novaeseelandiae*), kahu [swamp harrier] (*Circus approximans*) and koekoea [long-tailed cuckoo] (*Urodynamis taitensis*) are some of the remaining native predators of birds in New Zealand (Holdaway, 1989; O'Donnell et al., 1996). There is little literature describing how native avian predators are impacted by the presence of mammalian predators. However, native bird populations have been shown to react positively to the removal of mammalian predators (O'Donnell & Hoare, 2012; Innes et al., 2015). Therefore, it is likely the native guild of avian predators would also benefit from mammalian pest control.

Predators such as ship rats (*Rattus rattus*), feral cats (*Felis catus*), stoats (*Mustela erminea*) and hedgehogs (*Erinaceus europaeus*) are directly responsible for the decline of many bird species in New Zealand (Saunders & Norton, 2001; Sanders & Maloney, 2002; Innes, et al., 2010; O'Donnell & Hoare, 2012; O'Donnell et al., 2014). Ship rats and possums (*Trichosurus vulpecula*) are highly arboreal (Foster et al., 2011) and have been shown to be key predators of the elevated nests of some New Zealand bird species (Innes et al., 2010; Morgan et al., 2011). The removal of ship rats and possums alone significantly improves the nesting success of birds in New Zealand (Ortiz-Catedral et al., 2013; Innes et al., 2015). However, the removal of species such as ship rats also frequently results in an irruption in house mice (*Mus musculus*) populations (Innes et al., 1995; Ruscoe et al., 2011; Goldwater et al., 2012).

House mice are the sole mammalian predator on several islands around the world. Avian nesting success on these islands has been severely affected by predation by

house mice (Wanless et al., 2007; Angel et al., 2009). Nesting success on Gough (south Atlantic) and Marion Islands (sub-Antarctic) has declined greatly due to mouse predation of eggs and chicks. Tristan albatrosses (*Diomedea dabbenena*) and Atlantic petrels (*Pterodroma incerta*) on Gough Island and lesser sheathbill (*Chionis alba*) on Marion Island are at very high risk of local extinction due to house mouse predation (Wanless et al., 2007; Angel et al., 2009). In addition, the chicks being preyed on by mice are up to 8kg and do not have parental defence. As such, anything smaller than this, such as many New Zealand forest birds, could potentially be very much at risk.

In conservation efforts, all invasive mammalian species, apart from house mice, are routinely controlled over large areas to reduce their impact on the New Zealand forest (Ruscoe et al., 2011). Fenced sanctuaries, such as Maungatautari, greatly limit the reinvasion of other mammalian predators (McQueen, 2004; Connolly et al., 2009). In fenced sanctuaries or on islands, where all other invasive pest mammals are removed, mouse populations if left will increase in the absence of predatory or competitive pressures from other mammals (Speedy et al., 2007).

House mice in New Zealand have been shown to eat real eggs in artificial bird nests set on the ground (Innes et al., 2014; Innes et al., 2015). House mice have also been detected rarely at braided river bird nests in New Zealand (Sanders and Maloney, 2002). It is unknown how bird nesting success is influenced when mice are the only mammalian predator. Therefore, it is important to determine nesting success within New Zealand sanctuaries where mice and avian predators interact; this situation.

3.2 Methods

The nesting birds I studied were all native or introduced passerines with bowl-shaped nests. Sparrow (*Passer domesticus*) nests, although abundant in the study site, were excluded as the nests were not bowl shaped. Nests of birds larger than tui (*Prothemadera novaeseelandiae*) were not sought as previous research showed that mice would not eat eggs above that size (30mm length; Innes et al., 2014).

3.2.1 Nest finding

Nests were located between September and December 2015 by either following pairs of adult birds until they returned to a nest or by incidental discovery. The species that were most actively sought and followed were fantail (*Rhipidura fuliginosa*), North Island robin (*Petroica longipes*) and North Island tomtit (*Petroica macrocephala*). These species were located by identifying vocalisations and following the sound until a pair of adults was found. Two observers followed an adult each until either a nest was located or both adults were lost. To aid nest discovery, observers were briefed on nest characteristics, particularly in relation to known nest placements and nest construction by each species.

Once a nest was located, its location was recorded (by GPS) in addition to nest details (bird species, nest height, tree species supporting the nest). The nest was then observed from a distance of at least 8m until the parents returned (to confirm the nest was active).

3.2.2 Monitoring and observation

Nests where adults were in attendance (n=13) or where eggs (n=4) were discovered were monitored every second day. Reconyx PC900 HyperFire Covert IR game cameras (Wisconsin, US) were originally set up (at least 5m from the nest) to capture images triggered by movement over 24 h. However the cameras on motion triggers failed to detect birds moving around nests. Later cameras were set to time lapse during the evening hours, capturing an image every 5 seconds from 1700h to 0700h (an infra-red flash illuminated the nest and surrounding area in the dark). However the motion detector remained active during the daylight hours. If birds appeared disturbed by the cameras, the cameras were immediately removed. Batteries and memory cards were changed every two days. Nests were considered successful if at least one fledgling was raised. Nest monitoring, camera operation and determination of outcome followed a standard procedure protocol (Appendix 3). Nests that were found with eggs but already abandoned were monitored for 30 days.

3.2.3 Infra-red thermography camera

The use of an infra-red thermography (IRT) camera was assessed as a novel method of locating nests. The thermal camera detects heat radiation off an object and presents an image of the temperature distribution. Warm-blooded animals appear as a brighter colour than their cooler surrounding. Thus, eggs, chicks and incubating birds would create a “hot spot” and glow against the surrounding environment. One fantail nest (containing one parent and 4 chicks) and one sparrow nest (containing one parent) were able to be photographed during the day

and after dark. This method was used to examine the effectiveness of the use of an IRT camera at taking images of already found nests.

3.3 Results

3.3.1 Nesting success

Table 3.1 lists all nests found including nest details. In total 17 nests were found (Table 3.1; Figure 3.1)

Table 3.1. Details of nests found at Maungatautari Sept - Dec, 2015

Nest #	Species	Date found	Nest height (m)	Tree species
1	tui	29.09.15	5	tree fuchsia (<i>Fuchsia excorticata</i>)
2	bellbird	29.09.15	4.5	mahoe (<i>Melicytus ramiflorus</i>)
3	tomtit	1.10.15	2.5	tree fern (<i>Cyathodes spp.</i>),
4	fantail	1.10.15	3	tree fern
5	tui	10.10.15	2	mangaero (<i>Litsea calicaris</i>)
6	blackbird	12.10.15	1.5	tree fuchsia
7	fantail	13.10.15	3.5	tree fern
8	tui	15.10.15	3	tree fuchsia
9	tui	19.10.15	4	mahoe
10	tui	19.10.15	3.5	mahoe
11	N.I. robin	19.10.15	10	tawa
12	fantail	25.10.15	1.5	tree fern
13	blackbird	31.10.15	1.5	mahoe
14	blackbird	31.10.15	4	mahoe
15	fantail	31.10.15	1.5	rangiora (<i>Brachyglottis repanda</i>)
16	thrush	7.11.15	1.5	mahoe
17	fantail	9.11.15	3	Pigeonwood (<i>Hedycarya arborea</i>)

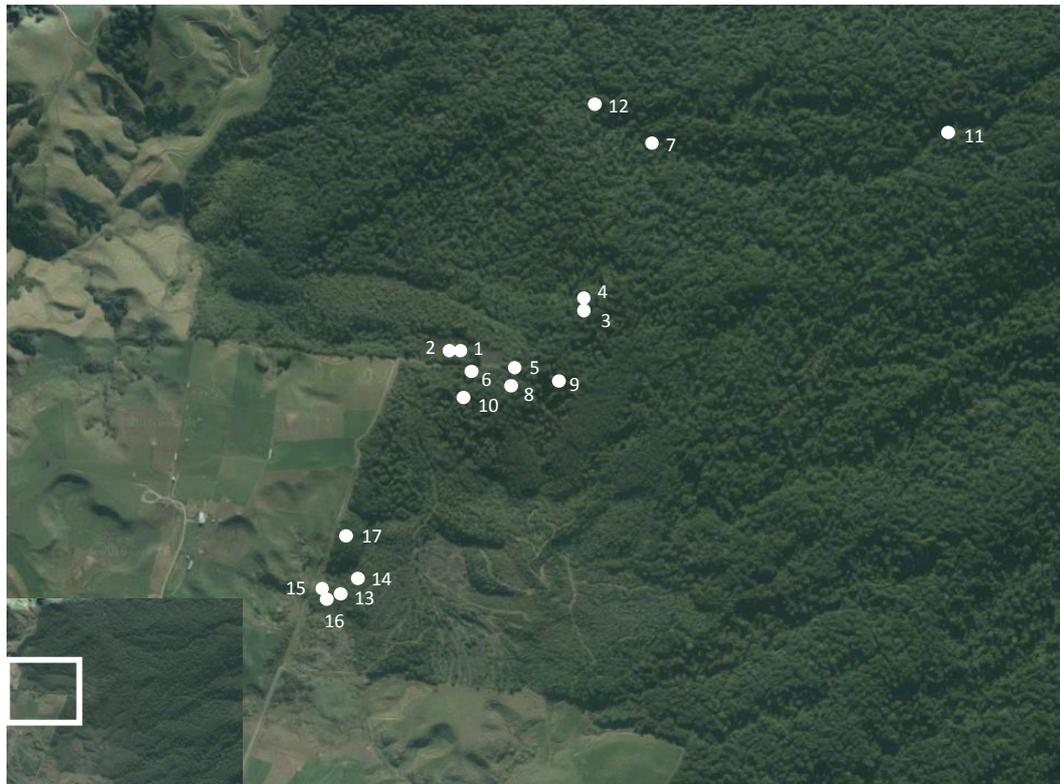


Figure 3.1. Approximate locations of nests found on Maungatautari, Sept. - Dec. 2015

Table 3.2 lists all nests found according to nesting stage and outcome. Nest 15 with a sitting female was abandoned two days after discovery; an adult male present as well. As the female was sitting on the nest at the time I found her, the nest contents could not be determined. However, over 15 minutes of observation at a distance of 10m, the female remained settled so I assumed she was incubating (this behaviour would be atypical of a fantail during nest construction). Upon returning to the nest two days later, I found she was gone and there was nothing inside the nest. This nest had not yet had a camera installed.

The robin nest that was successful (Nest 11; Table 3.1) was found during the chick stage (as they were audible from the ground) and followed through to the fledgling stage.

I also found a tui nest containing four dead chicks. The remains were almost at the skeletal stage of decomposition and appeared to be untouched with no evidence of being moved or disassembled by predators.

Three blackbird (*Turdus merula*) nests with eggs were also discovered already abandoned; the eggs remained untouched for the 30 days they were monitored.

All other nests I found were discovered during the building stages and were abandoned prior to laying.

Table 3.2. Nests found at Maungatautari, Sept. – Dec. 2015. The criterion for success was that at least one chick fledged

Nest number	Species	Stage found	Number of eggs or chicks	Cause of failure
1	tui	building	0	abandoned
2	bellbird	building	0	abandoned
3	tomtit	building	0	abandoned
4	fantail	building	0	abandoned
5	tui	building	0	abandoned
6	blackbird	eggs	4	deserted
7	fantail	building	0	abandoned
8	tui	building	0	abandoned
9	tui	building	0	abandoned
10	tui	building	0	abandoned
11	N.I. robin	chicks	unknown	successful
12	fantail	building	0	abandoned
13	blackbird	eggs	3	deserted
14	blackbird	eggs	3	deserted
15	fantail	sitting	unknown	unknown
16	thrush	eggs	1	deserted
17	fantail	building	4	successful

Figure 3.2 shows a mouse present at an abandoned song thrush (*Turdus philomelos*) nest containing eggs (12th November, 2015). This was the only mouse observed at any of the 6 nests with eggs despite 134 hours of recording and at least 420 hours of recording at each nest with eggs that was filmed. This mouse was present at the nest for a 1 minute and 45 seconds over two visits between 0117 and 0119h. The mouse did not enter the nest; it was only active on the surrounding branches.



Figure 3.2. Image of mouse present at abandoned song thrush nest containing three eggs, Maungatautari

No native avian predators were detected at any nests.

3.3.2 Infra-red thermography

Birds were highly visible in images when sitting on their nests; nests with sitting birds were also visible but to a lesser extent (Figures 3.3, 3.4 & 3.5 & 3.6). Birds and nests were distinguishable based on their heat signatures. The sparrow nest in the fern tree showed greater temperature difference between the nest and the tree during the day than at night (see Figures 3.3, 3.4 & 3.5). During the day, the nest was the warmest object in the image (22-26°C) compared to the cooler surroundings (<20°C). At night however, there appeared to be little temperature difference between the nest (10°C - 11°C) and the surroundings. Therefore the nest was not as visible at night as during the day. Increasing the distance of the camera from the nest did not increase the difference in temperature. The heat signature at 6m appeared to be larger than that at 2m or 4m during the day. At night however, the low heat difference between the nest and the surroundings meant that distance made no difference on the visibility of the nest. The opposite was the case with the fantail nest with the sitting parent and four chicks (measured at 5m) (Figure 3.6). During the day the heat signature of the fantail nest was very similar to the leaves and foliage surrounding the nest (~18°C); at night the occupied nest was warmer (13°C) than the surroundings (<11°C), therefore making it more visible (Figure 3.6). The fantail nest was not measured in the same manner as the sparrow nest as the fantails were exhibiting obvious distress at my presence.

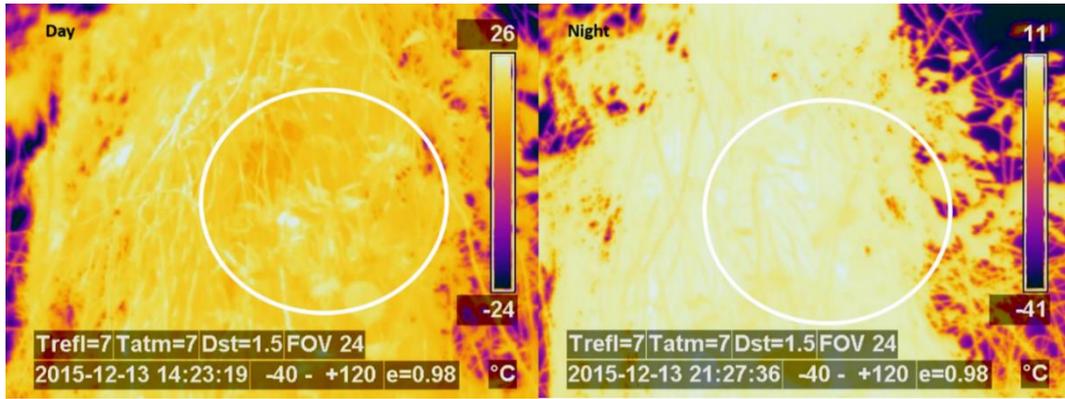


Figure 3.3. IRT image of active sparrow nest 1 containing adult in fern tree at a distance of 2m during the day (left) and at night (right)

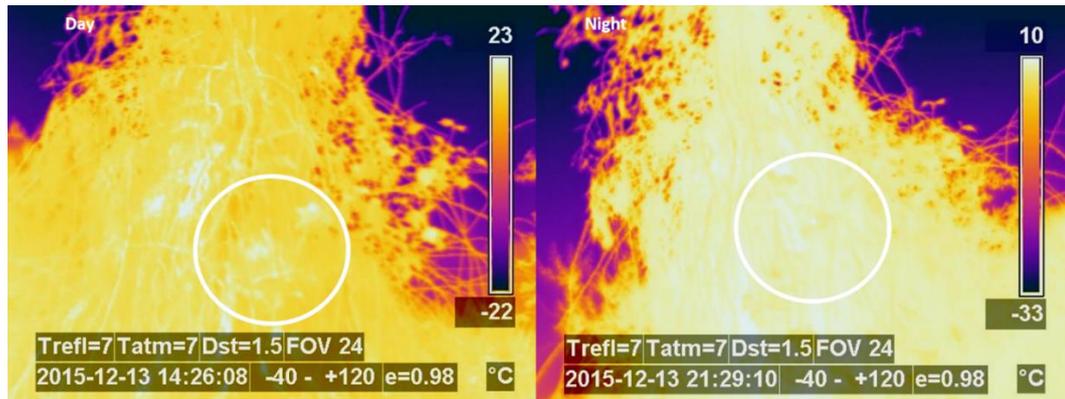


Figure 3.4. IRT image of active sparrow nest 1 containing adult in fern tree at a distance of 4m during the day (left) and at night (right)

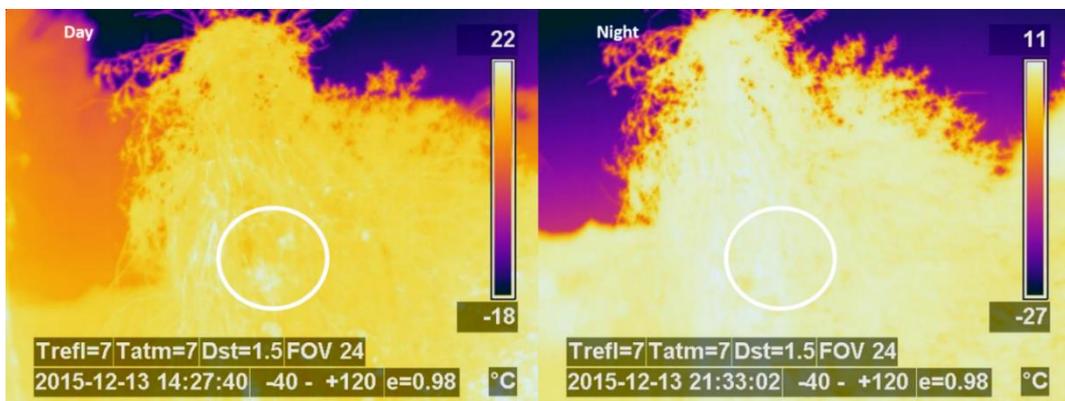


Figure 3.5. IRT image of active sparrow 1 nest containing adult in fern tree at a distance of 6m during the day (left) and at night (right)

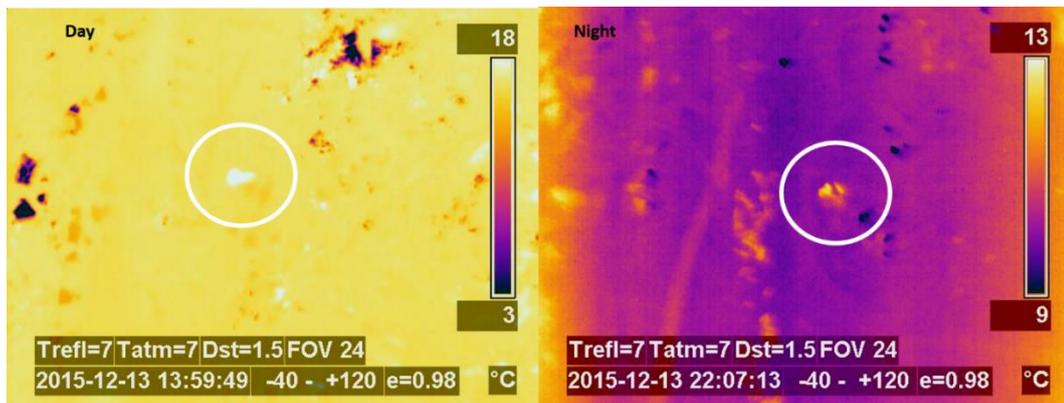


Figure 3.6. IRT image of a fantail sitting on nest with four chicks at a distance of 5m during the day (left) and at night (right)

3.4 Discussion

3.4.1 Mice as predators of native New Zealand birds

Mice were not deemed to be the cause of failure or scavenging of any of the nests monitored in this study. Of the six nests with eggs that were recorded over four weeks, only one mouse appeared at one nest and none of the eggs/nests showed sign of mouse damage. The single mouse was present for no more than 20 seconds as it passed by the nest and climbed up a neighbouring branch before coming back down within two minutes and bypassing the nest on its way back down. While it has been shown that mice will target undefended small eggs in artificial nests in New Zealand (Innes et al., 2014), they have also been shown to make non-lethal visits to braided river nests with eggs (Sanders & Maloney., 2002). However the nests monitored by Sanders & Maloney (2002) were located in a non-forest system and the eggs were likely too large for mice to eat (i.e. larger than 30mm). Mice have been shown to frequently utilise lower levels (<5m above the ground) of forest vegetation in the absence of other mammals (Chapter 2);

therefore all nests that occurred in these lower levels were within the range utilised by mice.

In forest areas without predator control, ship rats, possums and mustelids have been shown to be significant predators of bird nests (Moors, 1983; Brown et al., 1998; Innes et al., 2010; Morgan et al., 2011). In locations with no predator management, ship rat predation rates can exceed 80% of nests (Morgan et al., 2011), and nesting success has been shown to increase with pest control (Innes et al., 2015). When and where all introduced mammalian predator species are present, mice are naturally in low abundance (King et al., 1996; Choquenot & Ruscoe, 2000; Ruscoe et al., 2011). As such, it is likely that mice were simply too rare to be detected as nest predators in previous studies when other mammals are present (Moors, 1983). The other mammals would not only suppress the mouse population but they also potentially exclude mice from foraging places (Ruscoe et al., 2011). Therefore, removal of larger mammals potentially makes available resources, such as nesting birds, for mice that were previously unavailable when mammals were present.

On islands where house mice are the only mammalian predator remaining, they have been found to pose significant risks to local birdlife (Wanless et al., 2007; Angel et al., 2009; Bolton et al., 2014). Mice have also been shown to target artificial nests with eggs in areas with pest management (Innes et al., 2014). Only one mouse was recorded at one nest in this study, and the individual did not interact with the contents of the nest. As predator control can also have a positive impact on invertebrate communities (Didham et al., 2010), perhaps an abundance of other food sources could explain the lack of mouse predation observed in my

study. Of all the nests found with eggs, none had any eggs removed or broken at any point in time. The only nest that appeared to be preyed on (i.e. eggs were cleanly removed) exhibited no signs of rodent predation (i.e. eggshell remains or disturbed nest interior). This kind of predation event is characteristic of a long-tailed cuckoo or a morepork (Brown, 1998).

A number of means exist to identify predators of nests, including examination of sign left behind after a predation event (Moors, 1983; Major, 1991; Brown et al., 1998; Lariviere, 1999). Various predators leave different evidence of the predation event. However in some cases, the sign left behind may be unreliable as a predator could leave sign that resembled that of another (Brown et al., 1998). This study utilised game cameras set on both time lapse and trigger to determine nocturnal visitors to the nests.

1.3.1 Use of infra-red thermography

The use of the IRT as a nest finding tool is promising but is in need of refinement. The present trial did not attempt to find new bird nests; instead I examined the effectiveness of imaging for already known nests at up to 8m from the camera. This method theoretically works best when the target is not subject to solar radiation (i.e. at night) (McCafferty, 2007). As the use of IRT imaging on bird nests had not been tested previously, both day and night images were taken. The fern tree containing the active sparrow nest showed more contrast during the day. In contrast, the fantail nest, which had not been exposed to direct sunlight for hours was far more obvious at night. The fact that birds appear as obvious heat-

spots mean that further quantification and practice with this tool may make it an effective means of finding bird nests without having to locate the adult first.

3.4.2 Strengths and weaknesses of the present study

In the future, similar studies should be repeated across breeding seasons as a greater sample size would be essential as inter-seasonal variation may occur. Weather and volunteer effort were the two main limiting aspects that hindered nest finding, therefore contributing to small sample size. Abandonment of nests accounted for the 10 of 15 failed nests. Weather or human disturbance are two main factors that contribute to nest abandonment (Garrettson et al., 2011; Massaro et al., 2013). In the early stages of nest building and incubation, parental energy investment is not as high as at late-stage incubation; therefore abandonment in this period due to disturbance of any kind is more likely (Garrettson et al., 2011; Johnston, 2011). Increased sample size would provide more information regarding causes of failure (i.e. comparing rates of abandonment and predation).

It cannot definitively be said that mice will ignore nests based on the single encounter reported in my study. Elsewhere, house mice have been shown to prey on local birdlife (Wanless et al., 2007; Angel et al., 2009; Bolton et al., 2014) and indeed there is some evidence for predation by mice of birds in New Zealand (cited in Innes et al., 2014). It therefore seems that ground-based nesting birds with small eggs are at high risk of mouse predation; mice have already been shown to prey on real eggs in artificial ground nests in New Zealand (Innes et al., 2014). As such, perhaps birds that are at greater risk in New Zealand are those that are those that nest on the ground (e.g. kakapo (*Strigops habroptilus*), New

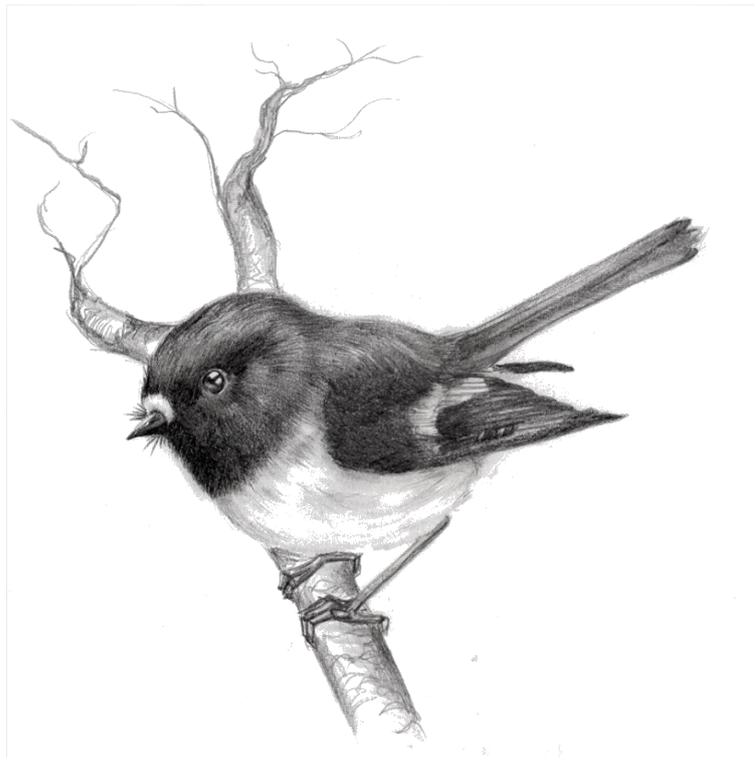
Zealand snipe (*Coenocorypha spp.*), banded rail (*Gallirallus philippensis*) or seabirds) as opposed to the present study that only examined nests in trees. It is unlikely that mice pose no threat to native birds in New Zealand in the absence of other mammals; nevertheless, clear evidence of mouse predation was absent in the present study, perhaps due to the small sample size.

3.4.3 Implications for biodiversity and its management

Pest control has been shown to positively influence invertebrate (Didham et al., 2010), lizard (Newman, 1994; Norbury et al., 2014) and bird (O'Donnell & Hoare, 2012; Innes et al., 2014) communities while also aiding in restoration of various ecological processes (Kelly et al., 2005). However, removal of most invasive mammals (i.e. mustelids, ship rats and possums) has been shown to cause an irruption in the mouse population (King et al., 1996; Choquenot & Ruscoe, 2000; Ruscoe et al., 2011). As such, native birds may still be at risk when mouse numbers increase. This study did not show active predation by mice on bird nests at Maungatautari. Moors (1983) also showed that mice were not significant predators on nesting passerines in a New Zealand bush where other mammalian predators were present. Mice alone have previously been shown to be significant predators of birdlife in other areas (Wanless et al., 2007; Angel et al., 2009; Bolton et al., 2014), specifically nests that are ground-based. As New Zealand birds evolved without mammalian predators, many species nest on the ground, such as seabirds, kiwi (*Apteryx spp.*), kakapo and many wetland birds (Innes et al., 2010; Starling-Windhof et al., 2011). This puts many native New Zealand birds potentially at risk of mouse predation.

3.4.4 Conclusions

Nests with eggs were frequently found already abandoned and many nests found in the building stage were abandoned prior to eggs being laid. The low amount of parental energy investment during this stage of incubation made abandonment due to disturbance, of any kind, more likely. Many of the nests found containing eggs were already abandoned, therefore disturbance could not have been the cause of abandonment. The lack of mouse interaction with nests at Maungatautari, including at those with no adult present, would suggest that mice are not currently significant predators of bird nests at that site. However the small sample size seriously limits any stronger conclusions.



Miromiro [North Island tomtit] (*Petroica macrocephala*)

(Drawing by author)

Chapter 4

Summary, recommendations and conclusions

4.1 Summary

Invasive mammals are known to pose significant risks to native New Zealand birdlife (Morgan et al., 2011) and their removal typically improves bird reproductive success (Moorhouse et al., 2003; Innes et al., 2015). House mice (*Mus musculus*) are generally rare in the presence of other introduced mammals (Speedy et al., 2007), however, they are frequently left as the sole remaining mammalian predator following pest control (MacKay et al., 2007). The main focus of my study was to examine how mice use vertical space in the presence and absence of other mammals. This included an examination of how mice use vegetation at various forest levels in the presence and absence of other mammalian predators and how mice interact with the pest-proof fence surrounding two enclosures on Maungatautari; one where mice were the only introduced mammal present, and one where all small invasive mammals are present. Finally, I examined how mice impacted the nesting success of birds on Maungatautari as the sole remaining mammalian predator.

Chapter Two – mouse use of vertical space

Chapter Two describes two studies examining how mice use vertical space in the presence and absence of other mammalian predators. This has not previously been examined in a systematic manner and therefore provides important information on how mice exploit above-ground resources in New Zealand forests when other

mammalian predators are absent. First, tracking devices were installed at various forest heights and left for one week. These were then compared with devices installed on the ground to determine if there was a significant difference in tracking rate. I compared the vertical distribution of mice across sites where mice were the sole mammalian predator, and those where all pest mammals were present. Second, I installed cameras in the hood of a pest-proof fence on Maungatautari Mountain. One set of cameras determined how mice interact with the internal fence when they are the only mammalian predator; another set of cameras was installed on an outside fence line where all mammalian predators were present. Tracking cards were also installed at the base of the fence to compare to tracking cards placed inside the hood.

Mice were only found to frequently use lower (<5m) vegetation and were detected primarily in shrub to sub-canopy trees. No mice were detected in the canopy. In the presence of other mammals, mice tracked significantly fewer devices at any vegetation level. Ship rats (*Rattus rattus*) were present at any device level.

Possums (*Trichosurus vulpecula*) were detected significantly more on the ground than at higher levels. As with mice, their detection rates declined with increasing height. In the pest-proof fence hood study, mice frequently used the ground at the base of the fence in areas with and without other mammals. None were detected within the fence hood at the site with no other mammals present. However, they were detected in the hood of the fence where other mammals were present (N=2).

Rats also frequently (N=9) used the fence hood but were never detected on the ground. Geckos (Gekkonidae) and weta (Anostomatidae and Rhaphidophoridae) were also frequently detected at the sampling sites (both in the

hood of the fence and at the base) while hedgehogs were detected at the base of the fence on three occasions.

One outcome of this study was the development and refinement of a tracking device that can be installed at any orientation or height and still be effective. By incorporating both tracking card and chew tags, the device can record any animal that either chews the tag or walks through the tunnel, including non-mammalian organisms (Appendix 1 & Appendix 2).

As mice have previously been shown to frequently climb to low, and sometimes greater heights (Innes et al., 2014), it was expected that mice would be found most in low vegetation – this prediction was supported by my study. Further, as found in earlier studies (King et al., 1996; Choquenot & Ruscoe, 2000; Ruscoe et al., 2011), mice were detected far less in the presence of other mammals. Connolly et al. (2009) had previously suggested that rats were the only mammals to utilise the hood of the fence. However, my study also showed that mice will occasionally use the pest-proof hood of the fence in the presence of other mammals. Mice have been shown to favour dense underbrush that provides cover from potential predators (King et al., 1996). As the perimeter of the outside fence is surrounded predominantly by pasture, it is possible that mice occasionally seek refuge in the hood of the fence. This is in contrast with inside the sanctuary where the fence is surrounded by dense native bush. Therefore mice potentially do not need to use the hood of the fence on the interior of the sanctuary due to the extensive cover that is present.

Chapter Three – impact of mice on bird nesting success

In Chapter Three, I investigated how mice impact the nesting success of birds in the Maungatautari Sanctuary. This was examined by finding and following adult pairs of birds until a nest was located, or through incidental discovery. Nests were then observed until eggs were present before game cameras were installed to capture night activity. Nests that were discovered abandoned but had eggs present within them also had game cameras installed to monitor any scavenger interactions with the nest. In addition, the use of an IRT camera as a novel method of finding nests was tested.

Only one mouse was seen at one abandoned song thrush (*Turdus philomelos*) nest containing eggs; but it was not seen to interact with the nest or contents. However, of 17 nests discovered, only six reached the egg stage and of those four appeared to be abandoned prior to discovery. One fantail (*Rhipidura fuliginosa*) nest successfully fledged four chicks (all four chicks were observed to leave the nest and perch on surrounding branches). One tui (*Prosthemadera novaeseelandiae*) nest was discovered with 4 dead chicks inside. These remains were skeletal but intact.

As only one mouse visited one nest during the period of observation and did not interact with the eggs in any way, mice may not presently represent a significant risk to nesting birds on Maungatautari. Mice have previously been demonstrated to make non-lethal visits to nesting birds in braided river environments (Sanders & Maloney, 2002). In contrast, mice have also previously been shown to eat small bird's eggs in New Zealand (Innes et al., 2014). Smith et al. (2008) could not distinguish between mouse and rat predation events on artificial ground nests in

alpine areas, so instead attributed to ‘rodents’. Therefore mice were potentially responsible for attempted predation of alpine ground-based nests. House mice have also been shown to eat seabird chicks such as black-bellied storm petrels (*Fregatta tropica*) and Tristan albatross (*Diomedea dabbenena*) when they are the sole remaining mammalian predator on islands (Wanless et al., 2007; Angel et al., 2009; Bolton et al., 2014). Unlike the present study, all of these studies examined ground-based bird nests. Moors (1983) found that mice were not significant predators of passerines in a New Zealand bush over four years. However, Moors (1983) examined predation with other mammalian species present. As such, mouse abundance was probably lower than when mice are the sole remaining introduced mammal (Speedy et al., 2007). Mice potentially pose a greater risk to eggs and chicks on the ground than in trees. At Maungatautari, the North Island brown kiwi (*Apteryx mantelli*) is presently the only ground nesting species in the main enclosure, although takahe (*Porphyrio hochstetteri*) and Chatham Island snipe (*Coenocorypha pusilla*) may potentially be introduced in the future (Smuts-Kennedy & Parker, 2013). As these species have ground-based nesting habits, mice are potentially a threat to their eggs and chicks.

Of all studies examined on predation events at bird nests in New Zealand, no failures were attributed to mice (Moors, 1983; Brown et al., 1998; Sanders & Maloney, 2002; Jones, 2003; Moorhouse et al., 2003; White & King, 2006; Morgan et al., 2011; Innes et al., 2015). The most frequently reported predators of nests in these studies were ship rats, possums and stoats (*Mustela erminea*). All of these studies were conducted on nests available to the entire guild of introduced mammalian predators. Mice are known to be relatively rare in the presence of other mammals (Speedy et al., 2007) and excluded from resources (King et al.,

1996; Choquenot & Ruscoe, 2000; Ruscoe et al., 2011). Therefore, although mice may not be significant predators of birds in New Zealand where other mammals are present, they may pose a greater risk when other mammalian predators are absent.

The IRT camera proved to have potential as a nest finding device. A fantail sitting on chicks appeared as a clear “hot spot” on the imager and was distinct from the surroundings at night. This was not as obvious when observed during the day. However, the IRT camera did not appear as effective on an active house sparrow (*Passer domesticus*) nest (an adult pair was seen in attendance carrying insects, although the actual contents were not examined). This nest was outside of a closed canopy environment that was subject to high amounts of solar radiation and heat. This meant that at night when the nest should be most visible (McCafferty, 2007) there appeared to be little contrast to distinguish it from the surroundings.

4.2 Future research

As mice have been shown to frequently use the lower levels of the forest, researchers could examine in more depth how mice use the lower forest levels and how they interact with other organisms occupying that space. Examination of competition for resources between mice and native species and analyses of predatory behaviours towards these species would provide valuable information on mouse interactions with native animals in the New Zealand bush. Weta have been shown to benefit from removal of mammalian predators (Watts et al., 2011) while beetle abundance declined following pest eradications at Zealandia, Wellington (Watts et al., 2014). This is potentially due to the increase in bird

number following pest control (O'Donnell & Hoare 2012), therefore placing greater predation pressure on beetle communities. However, mice as a sole mammalian predator have been shown to significantly impact invertebrate communities on offshore islands (Rowe-Rowe et al., 1989; Russell, 2012). Gut analysis and comparisons of mice both within and outside of the sanctuary would not only provide information on the difference in mouse diet in these two environments, but would provide information on the differences in food availability and preference across these two areas.

Devices in the present study had two forms of detection (WaxTag© and tracking cards) however rodents have previously been shown to show neo-phobia to novel objects (Cowan, 1976). It is possible that rodents avoided devices even though they were present at that forest level. Animals in the hood of the fence avoided walking on the tracking card on numerous occasions (N= 6 rats, 1 gecko & 1 mouse). Investigation into how frequently rodents avoid the tracking devices they come across would provide useful information for operators of tracking and bait lines, therefore aiding in pest eradication efforts.

Further investigation into how predators interact with nesting birds may prove beneficial. While my current study did not yield any evidence of active mouse predation on bird nests at Maungatautari, this may not be the case in other years, or other areas of bush. Furthermore, there was found to be a lack of literature regarding native avian predation on bird nests in New Zealand. Removal of mammalian pests serves to help restore native ecological processes (Kelly et al., 2005; Anderson et al., 2011; Iles & Kelly, 2014) in addition to benefitting native bird populations (Innes et al., 2009; Ortiz-Catedral et al., 2013; Innes et al., 2015).

Removal of these introduced predators should benefit native bird predators and therefore restore native food-webs where avian predators are dominant.

Indigenous dominance has been recognised as a critical component of ecological restoration (Lee et al., 2005). However further investigation into how pest management benefits native predators and restores native food-webs would provide valuable measures of the success of conservation projects.

The present study also identified a high rate of nest abandonment. Weather events and nest type (e.g. cavity vs open vs ground) have been shown to be predictors of nest failure in some New Zealand birds (Sanders & Maloney, 2002; Massaro et al., 2013). The protocol I followed (Appendix 3) was established to ensure minimal disruption to the birds being observed. Any visible distress exhibited by the birds (e.g. alarm calls) prompted the immediate withdrawal of observers. All measures were taken to ensure minimal disruption to the birds and nests.

Garrettson et al., (2011) examined investigator-induced abandonment in dabbling ducks (*Anas spp.*). Most nest abandonments due to investigator disturbance occurred during early laying. In the building and early laying stages, energy investment in the nest is not as high as late incubation or chicks, therefore abandonment due to disturbance is more likely (Garrettson et al., 2011; Johnston, 2011). Therefore it is possible that disturbance during the building phase prompted nest abandonment in the present study. This disturbance could be observer-induced or from other factors such as the weather. There is little that could be done in addition to the protocol described to minimise disturbance as there will always be an element of investigator-induced disturbance when nest finding. Further investigation into the factors that contribute to the success or

failure of nests may provide information on how to improve nesting success in sanctuaries.

The IRT camera could prove to be a useful new tool for nest finding. However, for it to be more effective, it would require more refinement of methods and practice. I did not attempt to locate new nests through the use of the IRT camera. Instead my study focussed on determining how effective the IRT camera was at imaging known bird nests and was seen as the first step towards using the IRT camera as a nest finding device. Comparison of active and empty nests would serve to quantify differences in the signatures between nests with an active heat source (e.g. incubating adult) and those without. In the future, determining the effectiveness of the IRT camera at locating unknown nests would further determine how useful a tool it is. Further examination of active bird nests would also provide information on the range at which the IRT camera could detect heat effectively.

4.3 Conclusions

This thesis demonstrated that house mice are proficient climbers of low vegetation in New Zealand bush. They frequently use lower levels of native forest in the absence of larger mammalian predators. However, in the presence of other introduced mammals, they were not detected as frequently. This study also quantified how other mammalian predators (possums and ship rats) use forest layers of the New Zealand bush. Rats were frequently detected at all levels of the forest while possums were most detected on the ground. Therefore, mammalian pests are likely to be present at all levels of the forest in areas of no pest control

and all vulnerable native animals that are present in these levels in the presence of these pests are potentially at risk. Ship rats have been also shown to frequently use the hood of the predator-proof fence that surrounds Maungatautari. They therefore pose a great risk of reinvasion if damage to the fence hood were to occur. In contrast, mice were predominantly present at the base of the fence. Mice therefore pose a different risk of invasion, should a breach at the base of the fence occur. This knowledge could potentially be used to generate different breach responses. As mice were demonstrated to be proficient climbers, it is likely that they interact with birds nesting in the lower levels of the New Zealand forest. Although this study did not find any active predation of eggs or chicks by mice, further investigation into how mice interact with bird nests in New Zealand bush is essential.

House mice in the New Zealand bush should not be considered a passive presence. In the absence of other mammalian pests, the risks that mice pose to New Zealand birds are increased, because mice use become more abundant and also use space that other mammals elsewhere exclude them from. Therefore, by understanding how mice use forest levels and their interaction with birds, we can identify whether mice pose a risk to specific species, and if so, establish strategies to protect these species.

Appendix 1

Images of mammals interacting with ground devices during Maungatautari and Te Tapui studies.



Top left: House mouse (*Mus musculus*) standing in tunnel, site 20- Maungatautari

Top right: Ship rat (*Rattus rattus*) manipulating ground tunnel, site 15 – Te Tapui

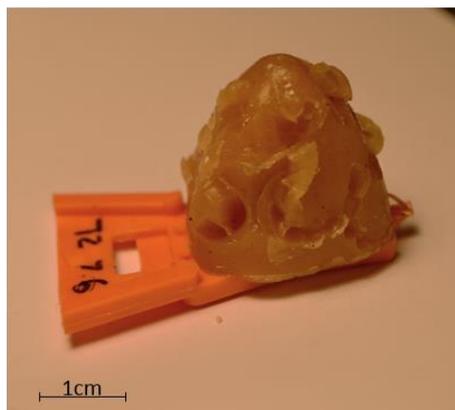
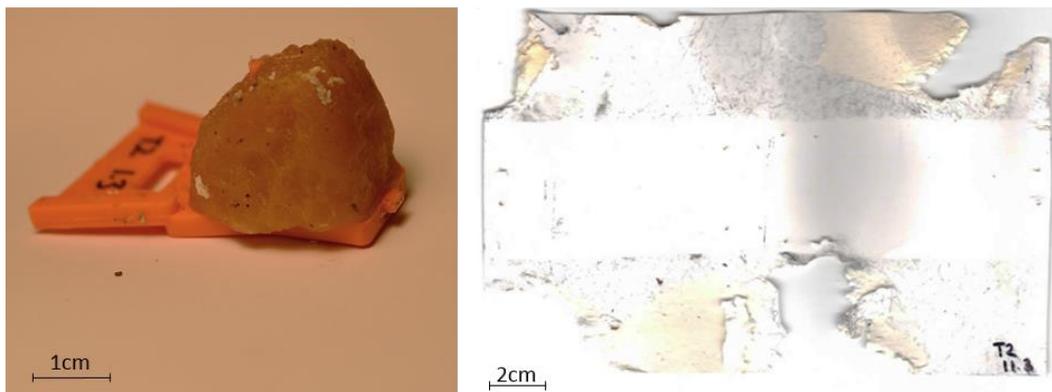
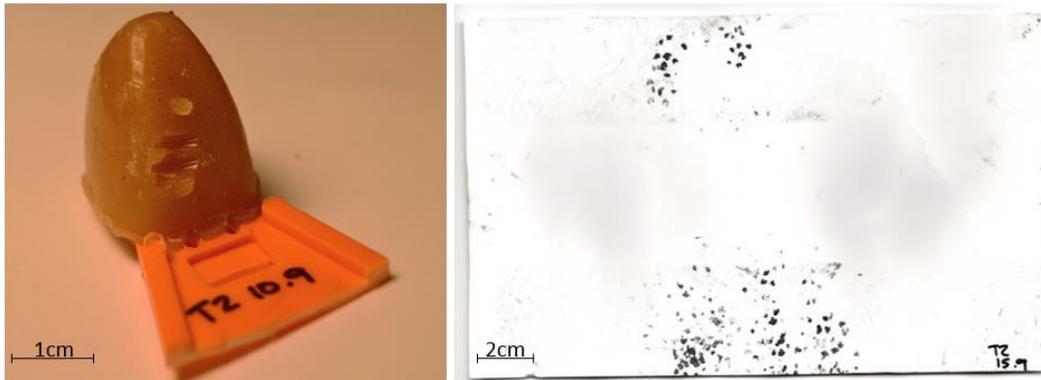
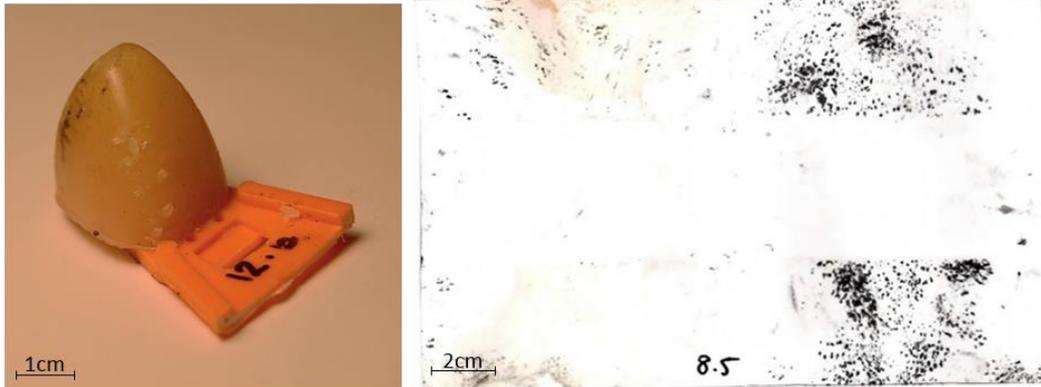
Centre left: Possum (*Trichosurus vulpecula*) manipulating a ground tunnel at Site 15, Te Tapui

Centre right: Possum chewing wax tag of ground tunnel at Site 15, Te Tapui trail

Bottom centre: Cat running past ground tunnel at Site 15, Te Tapui

Appendix 2

Images of typical marks left during mouse arboreality surveys



Top left: House mouse chew marks on Wax-Tag©, Maungatautari

Top right: House mouse footprints, Maungatautari

Centre left: Rat (*Rattus spp.*) chew marks on Wax-Tag©, Te Tapui

Centre right: Rat footprints, Te Tapui

Bottom left: Invertebrate chew marks on Wax-Tag©, Te Tapui

Bottom right: Invertebrate damage on tracking card, Te Tapui

Bottom centre: Possum chew marks on Wax-Tag©, Te Tapui

Examples of prints from hood survey, Maungatautari



Left: Gecko (Gekkonidae) and weta (Anostomatidae and Rhabdophoridae)

Centre: House mouse

Right: Hedgehog (*Erinaceus europaeus*)

Appendix 3

Protocol for nest finding and monitoring

Attempts to minimise the impact of observer(s) at the nest included not using flagging tape near the nests and disturbing the birds on the nest as little as possible. The contents of a nest were only checked to establish the number of eggs in the nest and the stage of incubation. These observations were kept to a minimum when possible. When it was necessary to check the stage of nest incubation, the observer would wait until the adult left the nest, typically when the pair changed over incubation duties.

Guidelines used for observing and determining the status of a nest:

- Once a nest was located it was monitored every two to four days to observe the nests progress and outcome.
- A nest was deemed to have become active once eggs/chicks at the nest was seen. If the nest did not achieve this stage of incubation, the nest was regarded as having been abandoned before eggs were laid.
- When activity ceased at a nest which had formerly had eggs or chicks the nest was recorded as having failed. Typically a nest would only be regarded as having been successful if fledglings were seen or heard within the territory of the adult birds where the nest had been monitored. If bird droppings were found to have accumulated directly below the nest, it indicated that the chicks were well developed and was good corroborating evidence.
- If the nest was physically compromised in some way (e.g. structure damaged or broken), then the nest was regarded as having failed. However

if the nest was intact with no signs of predation, then the nest was regarded as abandoned. However the default assumption was that the nest had failed. The cause of failure in such cases was listed as unknown.

- When a nest was deemed to have failed, the identity of the nest predator was determined whenever possible. If no evidence remained within the nest, the predator could not be identified unless the predation event had been filmed.
- A nest was considered successful if at least one chick was fledged.

Camera operation:

The cameras used were Reconyx PC900 HyperFire Covert IR game cameras (Wisconsin, US). Upon being discovered, a camera was installed at a nest at least 5m away. Birds were then observed to ensure minimal disturbance by the camera. If birds exhibited signs of distress (e.g. alarm calls or abnormal behaviour), the camera was immediately removed. Footage from the camera was checked the following day to ensure correct placement and angle to nest. Battery changes were kept to a minimum (once every two days) to avoid disruption to the nest. Time spent at camera was also kept to a minimum and battery changes were done as quickly as possible.

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