Quantifying the Benefits of Rat Eradication to Lizard Populations on Kapiti Island

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Abstract

In New Zealand the introduction of mammalian predators and human modification of habitat has led to the reduction and extinction of many native species. Therefore an essential part conservation management is the assessment and reduction of exotic predator effects. Many lizard species in New Zealand are threatened, and the eradications of exotic predators from islands has aided in the recovery of many species. Where comparisons can be made on islands before and after rat eradication this can provide a unique opportunity to quantify the benefit of these actions. In 1994–1996 research was carried out on Kapiti Island by Gorman (1996) prior to the eradication of kiore (*Rattus exulans*) and Norway rats (*Rattus norvegicus*). This involved sampling six defined habitats using five methods in order to establish density data for lizard species present, as well as recording data on vegetation and weather. In the summer of 2014–2015 I repeated this research using pitfall traps, spotlighting and daytime searching to sample five habitats along pitfall trap lines and transects established by Gorman (1996). This provided data on density, size distribution, behaviour, habitat use and vegetation to compare to the 1994–1996 data.

Five species were found; common skinks (*Oligosoma polychroma*), brown skinks (*Oligosoma zelandicum)*, copper skinks (*Oligosoma aeneum*), ornate skinks (*Oligosoma ornatum)* and common geckos (*Woodworthia maculatus*) in four of the five habitats sampled. Common skinks, brown skinks, copper skinks and common geckos all increased in density based on encounter rates since the rat eradication, and were found in new locations. However, some changes were explained by measured changes in the vegetation. Ornate skinks still appear rare which may be due to the presence of avian predators like weka (*Gallirallus australis*) preventing recovery of the species. There has been little change in the size distribution of grassland skinks species, and populations still lack large (> 6 cm snout-to-vent length) individuals. This may be due to avian predators removing large individuals from the population or the change in vegetation making habitats more suitable for smaller skinks. There has also been no apparent shift toward terrestrial behaviour in common geckos. This may be caused by an arboreal food source or arboreal behaviour providing protection from nocturnal predators. My research shows that there have been clear benefits to some of the lizard species present on Kapiti, but some changes have not occurred as predicted. This provides direction for further research, including effects of avian predators, and information to improve decisions about potential translocations to Kapiti.

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Introduction

The devastating effects of introduced fauna on native species are well documented worldwide. Species declines and extinctions are occurring rapidly and increasing in prevalence, with invasions of nonindigenous species threatening native biodiversity, the functioning of ecosystems, animal and plant health as well as human communities and economies (Carey et al., 2000). Predation is a major cause for population declines and extinctions, and these impacts are particularly disastrous when exotic predators co-occur with naïve prey that lack evolved strategies for co-existence. Therefore, conservation management around the world is dominated by the need to reduce exotic predator impacts.

Island sanctuaries have been essential for the recovery of many native species. Islands occupy about 5.5% of the world's terrestrial surface area, but they contain over 15% of terrestrial species, many of which are endangered or threatened (Kier et al., 2009). Many native species became restricted to islands naturally due to invasive predators failing to colonise them, but many islands have also been put through intensive eradication programmes and quarantine procedures in order to remove invasive species and allow the recovery of native ecosystems. The eradication of invasive mammals from islands is becoming common practice and has been attempted in over 1100 islands around the world, leading to re-colonisations by formerly removed species, new colonisations, resident populations showing positive responses and opportunities for reintroductions. Overall, 856 populations of 329 native mammals, birds, reptiles, amphibians and invertebrates have benefited from mammal eradications on 281 islands globally, emphasising the importance of islands and exotic mammal eradications as a conservation tool (Jones et al., unpublished data).

There is no better example of invasive species impacts than those of exotic mammals in New Zealand. New Zealand's unique biota is the result of being an isolated archipelago island, and its endemic fauna evolved in isolation from predatory mammals, making them especially vulnerable when they arrived with the onset of human colonisation. New Zealand has the highest number of introduced mammal predators (11) compared to any other known archipelago (Towns, 2002), and human colonisation has caused large scale modification, with agriculture, exotic forest and urban landscapes now making up the majority of land area (NSBS, 2000). All these changes have led to New Zealand's endemic biodiversity experiencing many declines, extinctions and range restrictions. 2,500 species of native plants, animals and fungi are threatened. 32% of endemic birds, six reptile and amphibian species, one bat, one fish, at least 12 invertebrates and approximately 22 plants have become extinct (Wilson, 2004). On the mainland many species only persist in small populations where they are either protected from predators via human management or the habitat does not allow predators to persist. New Zealand contains a number of offshore/outlying islands which differ from the mainland, and many species have become restricted to these islands. For example native species like the tuatara (*Sphenodon punctatus*), little spotted kiwi (*Apteryx owenii*) and the kakapo (*Strigops habroptilus*) only persist on predator-free offshore islands (van Winkel, 2008). Many of these islands have become essential for conservation within New Zealand as they allow for invasive species eradications and translocations of threatened or endangered animals.

As with many New Zealand species, the native lizard fauna has gone through drastic changes since human colonisation. Of 109 known taxa, 62% are considered 'threatened' or 'at risk' largely due to habitat destruction and introduced mammals. New Zealand lizards are all endemic and are considered the most diverse and speciose genera of all our terrestrial vertebrates, demonstrating the importance of conserving them (van Winkel, 2008). As introduced mammals are usually the main reason for native species' declines, there has been extensive research on the effects of these mammals and what impact their eradication from islands may have on native species and ecosystems. In particular the introduction and spread of rodents like the ship rat (*Rattus rattus*), Norway rat (*Rattus norvegicus*), kiore (*Rattus exulans*) and house mouse (*Mus musculus*) in New Zealand has transformed the environments they have colonised. Rodents are an extremely successful group, adapting to pretty much every terrestrial and freshwater habitat, and they have become extremely abundant globally. They exhibit both a predatory effect and competitive effect on multiple plant and animal species and have caused the decline and extinction of many New Zealand native species (King, 2005). There have been several studies assessing the potential impacts of rodents on lizards, but it is often difficult to accurately measure the contribution of rats to declines of native lizard species in New Zealand. On some islands, where the complete eradications of rodents can occur, it may be possible to gain an understanding of what effects rodents have had on those islands' lizard fauna. A number of studies have been conducted on islands before and after rat eradication, authors like Towns (1991) and Newman (1994) both found significant increases in lizard species capture rates on islands after the removal of rodents. These patterns are often seen with comparisons of native ecosystems before and after the eradication of introduced predators.

Kapiti Island is one of the largest accessible island sanctuaries in New Zealand. Kapiti has been largely free of introduced mammals since 1996, and the eradications of mammals have been extremely beneficial to Kapiti's flora and fauna. Kapiti is an important sanctuary for many of New Zealand's threatened bird species, and a number of studies have attempted to quantify the effects of pest eradication on these species (Brown, 2004) but information is lacking on some other important fauna. Little is known about the current state of the lizard fauna, with the most recent work being a rapid survey done in 2013 (Barr et al., 2013). Therefore, this study aims to quantify the effect of Norway rat and kiore eradication on the island's lizards.

This thesis builds on Gorman's (1996) research carried out on Kapiti in the summers of 1994/1995 and 1995/1996, immediately before rats were eradicated. He used a number of methods to index numbers of lizards, setting a baseline study that could be subsequently used to assess the effects of the planned rat eradication. Variables like weather conditions and local vegetation were taken into account, and some results were compared to findings from Mana Island which was free of rodent, following the eradication of the house mouse (*Mus musculus*) in 1989. Gorman's (1996) study also tested the effectiveness of alternative methods for monitoring lizards. He suggested the potential effects that the rat eradication might have, anticipating changes in lizard abundance as well as potential changes in behaviour, habitat use and size distributions, and whether those changes could be attributed directly to the eradication. The intensity and diversity of Gorman's (1996) data collection provides a unique opportunity to compare lizard populations before and after the eradication of rats in the same area. The process of organised systematic sampling in Gorman's (1996) research allows quantitative comparisons to be made, providing more accurate results then some other before and after eradication comparisons. Many New Zealand lizard species are threatened, at risk or declining, and these findings can help understand risks facing our lizards and the value of eradications. Lizard data after mammal eradications also adds to our knowledge of what lizard species are present on offshore islands and the need and potential for future translocations of threatened lizard species onto islands.

1.2 Kapiti

1.2.1 Background

Kapiti is a 1965 ha island 5 km off the west coast of the southern North Island. It is about 10 km long and 2 km wide (Brown, 2004). Māori occupation of Kapiti occurred for many centuries, but early populations were small and isolated with large scale colonisation not occurring till 1823. Ngāti Toa, under the leadership of Te Rauparaha, captured the island from Ngāti Apa and Muaupoko. Te Rauparaha initiated trade with whaling and trading ships, and began cultivating plants and raising herds of cattle (*Bos taurus*) and pigs (*Sus scrofa domesticus*) (Fuller, 2004b). In 1829 the first whaling station was recorded on Kapiti, and the island's population continued to grow. The first European farmers arrived in 1838 and as whaling success diminished farming started to flourish, leading to land clearance and species introductions (Fuller, 2004b). Before the colonisation of Kapiti the vegetation consisted of mature coastal and podocarp-mixed broadleaf forest, but most of this was burnt to make pasture and this led to radical alteration of the island's vegetation, although it was concentrated to the north and south ends of island where the land was more flat. Eventually farming reduced and was restricted to the Waiorua and Okupe Valleys in the north end of the island until around 1970, while the rest of the island became officially a sanctuary in 1897 (Fuller, 2004b). The repercussions of farming became clear, with feral cattle, goats (*Capra hircus*), sheep (*Ovis aries*), brush-tailed possums (*Trichosurus vulpecula*), rats (*Rattus norvegicus* and *Rattus exulans*) and cats (*Felis catus*) all present on the island.

Eradication of these animals began in 1902. By 1926 the last of the goats were shot, but not until the 1930s were hoofed animals all eliminated, allowing Kapiti to become a true nature reserve (Fuller, 2004a). At this point the effects of possums was not well understood, but it was later estimated that they were consuming over 14 tonnes of plant material, causing regeneration issues and plant species extinction, as well as a exerting predatory and competitive pressures on native birds (MacLean, 1999). Once possums were eliminated in 1986, new growth was evident in the canopy and ground layer and native bird species benefited (Cowan, 2004). This left only two introduced predators on the island, the kiore (*Rattus exulans*) and the Norway rat (*Rattus norvegicus*). It was evident that these species were inhibiting the regeneration of plants by browsing on flowers, fruits and seeds, and they were both predators and competitors to native fauna. By the 1990s the aerial eradication of rats on Kapiti was seen as a feasible plan, and in 1996 the eradication took place. In 1999 the island was declared free of rats (MacLean, 1999; Miskelly & Empson, 2004).

A brief stoat incursion was detected in November 2010, but by 2012 the island was officially free of all introduced predators once again.

1.2.2 Current Situation

Kapiti is now one of New Zealand's largest accessible island sanctuaries and contains many native species not found on the mainland. The landscape is dominated by forested, hilly terrain, the highest point being Tuteremoana which is 521 m above sea level. There are three main flat areas of grassland present on the island, each about 70 ha (DOC, 1996). Only small areas of the original vegetation remain and Kapiti now consists of a wide variety of vegetation types (Dick, 1985); the majority of this is dominated by shrub-lands, scrub and forest, mostly made up of species like kohekohe (*Dysoxylum spectabile*), kanuka (*Kunzea ericoides*), tawa (*Beilschmiedia tawa*) and five-finger (*Pseudopanax arboreus*). Grassland cover makes up around 5-10% of the islands vegetation, and flax and tussock land account for around 3% (DOC, 1996).

Kapiti not only has a wide variety of vegetation but also a wide variety of native fauna species. Many threatened bird species have been reintroduced to Kapiti. This includes stitchbird (*Notiomystis cincta*), North Island kokako (*Callaeas wilsoni*), takahe (*Porphyrio mantelli*), brown teal (*Anas chlorotis*) and North Island saddleback (*Philesturnus rufusater*) which all were translocated there in the 1980s. Translocations of brown kiwi (Hybrid *Apteryx mantelli x A. australis)* and weka (*Gallirallus australis*) were done in the 1890s and early 1900s. The little spotted kiwi (*Apteryx owenii*) was introduced onto Kapiti, saving them from complete extinction (Miskelly, 2004). Other birds that can be seen on the island include kereru (*Hemiphaga novaeseelandiae*), North Island tomtit (*Petroica macrocephala*), kaka (*Nestor meridionalis*), whitehead (*Mohoua albicilla*), tui (*Prosthemadera novaeseelandiae*), fantail (*Rhipidura fuliginosa*), long-tailed cuckoo (*Eudynamys taitensis*), morepork (*Ninox novaeseelandiae*), kingfishers (*Todiramphus sanctus*), harrier (*Circus approximans*), Kakariki (*Cyanoramphus novaezelandiae*), robins (*Petroica longipes*) and silvereye (*Zosterops lateralis*) (Miskelly, 2004). Around the coast there is also southern black-backed gull (*Larus dominicanus*), red-billed gull (*Larus novaehollandiae*), white-fronted tern (*Sterna striata*), variable oystercatcher (*Haematopus unicolor*), reef heron (*Egretta sacra*), little (*Phalacrocorax melanoleucos*), black (*Phalacrocorax carbo*) and spotted (*Stictocarbo punctatus) shags*, gannets (*Morus capensis*, *Morus serrator*), fluttering shearwaters (*Puffinus gavial*) and little blue penguins (*Eudyptula minor*) (Miskelly, 2004). The majority of Kapiti is under Government control. The north end of island is privately owned and this area is more open to the public. However, overall access to the island is strictly controlled to protect the precious ecosystems that have been developed (Miskelly, 2004).

1.3 Rats

There are four species of rodents present in New Zealand, the Norway rat, the ship rat, kiore and the house mouse. The two that will be focused on here are the kiore and the Norway rat, as these were the only rodents present on Kapiti.

1.3.1 Kiore

Kiore, or Pacific rat, is the smallest of the three rat species present in New Zealand. This species evolved in South-East Asia and were distributed around the pacific via human colonisation. It is thought kiore arrived in New Zealand in around AD 1250-1300. This rodent quickly became widespread through much of the mainland and also reached many offshore islands. They can live in a wide range of habitats but are most abundant in grasslands. Their altitude limit is about 1300 m (King, 2005). They are predominantly nocturnal and are agile climbers that are known to nest and feed in trees. They eat a wide range of foods; protein is gained mainly from invertebrates, including weta, ants, beetles, centipedes, spiders, earthworms, and snails, and occasionally from birds and lizards. Plant material mainly consists of flower buds, flowers, leaves, petioles, rhizomes, bark, and fruits and seeds (King, 2005). Kiore breeding season is anywhere between 3–10 months long and is most often over spring and summer They average about three litters per year and, therefore, can produce anywhere from 19 to 21 young per year. Their density varies seasonally and this is linked to food availability. Their density also tends to be higher on islands not inhabited with cats, stoats or other rodent species (King, 2005). Kiore have drastically decreased in numbers throughout New Zealand since the spread of Norway rats, ship rats and mice due to competition and potential predation by the larger rat species. Morepork, kingfishers and harriers are important avian predators, and mammals like cats and mustelids also readily prey on Kiore.

Some New Zealand native species appear to coexist with kiore, but they have caused the local extinctions and general decline of many native species. Large, flightless invertebrates are very vulnerable to kiore predation, especially those on the ground. There is often a significant increase in invertebrate species like land-snails and weta when kiore are eradicated from areas. Herpetofauna are also vulnerable, with changes in abundance and behaviour noted when kiore are eradicated (King, 2005). Tuatara are known to be outcompeted for food as well as their eggs and juveniles are preyed on by these rodents. Kiore are also known to affect bird species, with predation on eggs and chicks of small, burrowing seabirds leading to increased nest failures. They have also been known to prey on kakapo chicks and saddleback nests. They are well known to have a huge effect on native flora, especially through seed predation which reduces recruitment and affects the overall forest composition. Through the use of poisons like bromadiolone and brodifacoum kiore have been eradicated from many islands around New Zealand, and the positive effects of their eradications have been noted for many plant and animal species (King, 2005).

1.3.2 Norway Rat

The Norway rat is the largest species of rodent found in New Zealand. They have a stout body, heavy tail and small ears, and can weigh up to 500 g. They are very good swimmers and can reach islands easily. They are reasonable climbers but are mostly found on the ground. This was the first

European rat to establish in New Zealand, and most likely arrived in the late 18th century on European and American ships (King, 2005). This species originated in north-eastern China and were easily transported around the world via movement of people. By the 1830s this species was common throughout the North and South Islands of New Zealand, with a widespread but patchy distribution on the mainland and colonisation of over 60 offshore islands (King, 2005). Their distribution has drastically decreased with the spread of ship rats and mustelids. On the mainland Norway rats seem to survive best in wetland habitats and on islands they are most dense in grassland, scrub and damp forest at low altitudes or near the shore. This species has been extremely successful throughout the world due to their omnivorous and opportunistic habits. The majority of their diet consists of seeds, fruits, leaves, fern rhizomes, insects, molluscs, crustaceans, annelids, larvae, weta, beetles, and less often eggs, birds and lizards. They will often scavenge carcasses and on islands they readily forage along shorelines.

Norway rats are mainly nocturnal and more ground dwelling then the agile kiore (King, 2005). They may breed all year round, with litter sizes between 6 and 8 and a gestation period of around 23 days. There is a much higher probability of Norway rats and kiore coexisting together on islands than any other rodent species, and the combination of their effects can be fatal to many native species. The main predators of Norway rats are cats, stoats, ferrets and harrier hawks. Norway rats tend to have a larger impact on native species than kiore. The terrestrial habits of Norway rats make animals that live, roost or nest near or on the ground extremely vulnerable. The occurrence of Norway rats on islands is found to be negatively correlated with the species richness of seabirds, as they will take eggs, nestlings and sometimes adults (King, 2005). They have also been found to destroy kaka nests and saddleback nests. Like kiore they also affect large, ground-dwelling invertebrates such as beetles, weta and harvestmen as well as preying on many skink species. Due to their browsing of plant material they will often constrain the regeneration of forest. The eradication of Norway rats occurs on many islands and throughout the mainland of New

Zealand and is largely successful, having huge effects on native species around the country (King, 2005).

1.3.3 Rats on Kapiti Island

There were only two rodent species on Kapiti, kiore and the Norway rat. Thankfully the ship rat never established on the island, for if it had, the impacts on the ecosystems would have been far more devastating. The first attempt to identify what rats were present on Kapiti was done in 1959 when four rats were caught; three of them Norway rats and one was a kiore (Dick, 1985). It is assumed that kiore had been present on Kapiti for quite some time, following introduction during early Maori settlement. Norway rats were likely introduced later on, when whaling began in the 1830s. Both species occurred throughout the island but their densities varied with habitat type and season (Empson & Miskelly, 2004). These two species impacted wildlife differently. Being light agile climbers, kiore caused the extinction of several small land bird species, before Norway rats reached Kapiti. Norway rats are well known for their attacks on animals living or nesting near the ground, and these became very vulnerable when these larger rodents reached the island (Empson & Miskelly, 2004).

Some of the wildlife on Kapiti seemed to manage with the two rat species present, but many did not, for instance reintroduced saddlebacks were declining towards extinction and there was evidence of reduction or apparent extinction of sooty shearwaters, ornate skinks (*Oligosoma ornatum)*, forest geckos (*Mokopirirakau granulatus)*, Wellington green geckos (*Naultinus punctatus)* and brown teal in certain areas of the island. Therefore, the rodent species present had to be eradicated to allow for a more successful nature reserve, but Kapiti was larger than any other area where rat eradications had been attempted at that time (Broome, 2009). Two techniques were considered for the eradication of Norway rat and kiore from Kapiti; aerial spread of baits via helicopter and hand-placement of baits inside bird–proof stations to reduce effects on non-target species. Trials were carried out on Kapiti and elsewhere to see what would be more effective. Aerial drops were found to be effective for both rat species whereas bird-proof stations tended to lead to exclusion of kiore by the larger Norway rat (Empson & Miskelly, 2004).

After many trials looking at methods of application and the amount of consumption of non-toxic bait by birds, it was decided that aerial application was going to be the best method. A few vulnerable bird species were removed, with samples of robins and weka released or translocated elsewhere and all takahe and brown teal placed into captivity, and some sites were identified for hand application of toxic baits. The bait used on Kapiti was compressed cereal containing 20 parts per million of brodifacoum and was died green to reduce bird consumption. On 19–20 September 1996 the first application of 20,500 kg of bait was made, followed by 11,400 kg on 15 October 1996. Within 10 days of the bait drop all rats carrying transmitters had died. Thorough monitoring was carried out to detect rat presence in 1998 and no rats were detected. The island was officially declared rat free on 16 January 1999 (Empson & Miskelly, 2004). The eradication of rats from Kapiti had a huge effect on many native species, for instance significantly improved survival rates of stitchbirds and saddlebacks in just a year after rat eradication and benefits to other taxa were quickly documented as follow up studies occurred (Empson & Miskelly, 1999). This also created the opportunity for other vulnerable species to be reintroduced. There were also benefits outside the island, with increased knowledge on effective applications of bait and confidence for future eradications on other large islands (Empson & Miskelly, 2004).

1.4 Lizards

New Zealand's native herpetofuana consists of frogs (*Leiopelmatidae*), tuatara and two families of lizards, geckos (Gekkonidae) and skinks (Scincidae). The exact number of lizards in New Zealand is difficult to know as many species are cryptic and more and more appear as research increases. It is thought there are around 43 species of gecko in New Zealand, and these are currently divided into seven genera (Nielsen et al., 2011). Geckos have broad heads with large eyes, and soft skin covered in very small scales. Worldwide geckos lay eggs, but in New Zealand all geckos give birth to live young. New Zealand geckos are mainly omnivorous, primarily eating invertebrates but also taking fruits and nectar seasonally (Fitter, 2010). There are currently 35 described species and subspecies of New Zealand skinks, although the actual number of species may exceed 45. Until recently these were divided into two genera, *Oligosoma* and *Cyclodina*, but these are not distinct clades (Chapple et al., 2009). *Oligosoma* species have shallow, pointed heads, long limbs, bodies that are oval in cross section and are diurnal. *Cyclodina* species, in contrast, have blunter heads, shorter limbs, bodies that are square in cross-section and are nocturnal or crepuscular. Compared to geckos skinks are more slender, with narrow heads and smooth, shiny skin made up of larger scales (Fitter, 2010). All native skinks in New Zealand give birth to live young, except the egg-laying skink (*O. suteri*). They are primarily carnivorous, feeding mainly on invertebrates, but also taking fruits and carrion when available. Many of New Zealand's lizard species are threatened or declining, mostly due to habitat destruction and introduced mammals (Hitchmough et al., 2012)

1.4.1 Kapiti Lizards

Kapiti is known to have eight species of lizards, consisting of four skink species and four gecko species, which are all found in other parts of the Wellington region (Gorman, 1996, Whitaker, 1995; Barr et al., 2013).

Brown Skink (*Oligosoma zelandicum*)

The brown skink is a small diurnal skink species that is present in Taranaki, the western half of the southern North Island, some offshore islands and in some parts of the South Island. They are small in size, less than 75mm SVL (snout-vent length); often with a back that is pale brown and darker brown sides. They can look very similar to common skinks, but are usually distinguished by an orange or red coloured ventral surface (Gill & Whitaker, 1996). They use a wide range of habitats but tend to prefer shaded areas or areas of denser vegetation but are also found regularly in farmland or gardens. They feed mostly on small invertebrates and produce offspring around January (DOC, 2002). They are known to be sensitive to predation by rodents and weka and are currently ranked as declining (Hitchmough et al., 2013).

Common Skink (*Oligosoma polychroma*)

The common skink is also a small diurnal species that are widely distributed throughout the southern half of the North Island and much of the South Island. Like brown skinks they are small lizards, but tend to be over 70mm SVL. They are often brown with prominent stripes but vary hugely in colour and pattern depending on the habitat and area found in (Gill & Whitaker, 1996; Fitter, 2010). They tend to be most commonly found in open grasslands. They feed mainly on invertebrates and some fruit, and produce young during the summer (Gill & Whitaker, 1996). As this is a widespread and apparently abundant species, it is not regarded as under threat and is not on any conservation priority lists (DOC, 2002; Gorman, 1996).

Copper Skink (*Oligosoma aeneum*)

The copper skink is the smallest native lizard in New Zealand and they are one of the more common and widespread skink species. They are distributed throughout the Wellington and Wairarapa areas, as well as from Taupo northwards (DOC, 1999). They are a more secretive species than common skinks or brown skinks, often only being found by lifting up cover. They only reach up to 62mm SVL, with a brown back and often bright, copper coloured stripes on their edges (Fitter, 2010). They are found in a wide range of habitats but are more often in forest and grass areas with adequate cover. Their main foods tend to be invertebrates, consisting of beetles, spiders and mites, and their young are born in late January to February (Gill & Whitaker, 1996). Although this species is known to be sensitive to predation from rodents, due to their widespread distribution and abundance they are classified as 'not threatened' (Hitchmough et al., 2013; Gorman, 1996).

Ornate Skink (*Oligosoma ornatum)*

The ornate skink is a medium-sized skink and the largest known on Kapiti. They are reasonably widespread on the mainland but are often in small, scattered populations. They are found throughout most of the North Island from Wellington in the south to Three Kings Island in the north. Ornate skinks are a forest floor species, most commonly found in scree, deep rock piles and leaf litter. They reach sizes up to 80mm SVL with brown back, large pale blotches along the tail and back and a distinctive white or yellowish 'teardrop' pattern below the eyes (Fitter, 2010). Their young are born in late January/February and their diet mainly consists of beetles, spiders, mites, small snails and vegetation (Gill & Whitaker, 1996). The current distribution of ornate skinks has been strongly affected by habitat destruction and introduced predators. Due to their vulnerability and small populations, this species is threatened and is classified as declining (DOC, 1999; Gorman, 1996).

Common Gecko (*Woodworthia maculatus*)

The common gecko belongs to a cryptic species complex, which is a group of closely related but distinct species separated geographically. The population found on Kapiti is not genetically distinct from those found in the North Island and northern South Island (Gorman, 1996; Nielson et al., 2011). Common geckos are widespread throughout the mainland and are most often found in coastal areas in forest, scrub and grassland as well as on the coast line under wood and boulders. They reach up to 82mm SVL and are mainly grey or brown with many irregular markings that vary in colour and placement (Fitter, 2010). They are ordinarily nocturnal but may be seen basking during daylight hours. They tend to be less arboreal than other similar species and their young are born between February and March (Gill & Whitaker, 1996). They primarily feed on insects like moths and beetles but will also eat nectar and fruit. Common geckos are not considered to be threatened. Some populations are known to be declining due to predation by introduced mammals, but research has found some are able to avoid predation by using areas inaccessible to rats, allowing them to co-exist with introduced rodents more readily than some other native lizards (Hoare et al., 2007)

Forest Gecko (*Mokipirirakau granulatus*)

The forest gecko is also reasonably widespread but due to being mainly nocturnal, arboreal and well camouflaged, they are rarely seen and therefore it is difficult to estimate their abundance or distribution. They are found throughout New Zealand's mainland except the far north and are also on some larger offshore islands. They have been recorded in most forest types including coastal and subalpine scrub, up to 1400 m altitude (Gill & Whitaker, 1996). They are slightly larger than common geckos, reaching up to 89 mm SVL, but otherwise look quite similar though differ in their shape of head, mouth colour, feet, a distinctive, dark v-shaped mark on the head and bright white bands from eye to ear (Gill & Whitaker, 1996; & Fitter, 2010). They are nocturnal, foraging at night but may bask and hide during the day under loose bark or in crevices of trees. Their young are born in mid to late summer and their diet mainly consists of insects with some nectar and fruit when available (Gill & Whitaker, 1996). Although forest geckos seem to be reasonably widespread, they are usually in higher abundance in locations where introduced rodents are absent and are classified as declining (Gorman, 1996; Hitchmough et al., 2013)

Green Gecko (*Naultinus punctatus*)

The green gecko is diurnal but like the forest gecko, are arboreal and well camouflaged and so are difficult to find and, therefore, difficult to know much about their distribution or abundance. This species is probably found throughout the southern part of the North Island and on several offshore islands (Gill & Whitaker, 1996). They are predominately found in forest and shrub-land, particularly manuka (*Leptospermum scoparium*) and kanuka (*Kunzea ericoides*) scrub. They are reasonably large geckos, reaching up to 95mm SVL. They are one of New Zealand's most attractive lizards, being bright green in colour often with large, yellow, white or green patches on their back and a bright blue mouth (Gill & Whitaker, 1996; Fitter, 2010).

They bask during the day but hunt during the night for flies and moths. Like the other geckos they primarily feed on insects but will also take nectar and fruit when it is available (Gill & Whitaker, 1996). These animals are known to be declining throughout New Zealand and they are threatened, classified as declining (Gorman, 1996; Hitchmough et al., 2013).

Goldstripe Gecko (*Woodworthia chrysosireticus*)
The goldstripe gecko is only found on the North Island of New Zealand, in the Taranaki area as well as on Mana and Kapiti islands near Wellington. They live in a wide range of habitats including forest, scrub, coastal, farmlands and gardens and are often found on New Zealand flax plants. They are slightly smaller geckos, reaching sizes up to 70mm SVL, and are yellow/brown to olive colour with clear longitudinal stripes on their back which come together at the base of the tail (Gill & Whitaker, 1996). They are nocturnal and arboreal but many sun-bask. Their young are born in February-March. They mainly feed on small insects and other invertebrates. Goldstripe geckos have a limited distribution, with the population in Taranaki having a significant role in conservation they are classified as "at risk" and are listed as a 'relict' currently occupying less than 10% of their original range and any new populations discovered are important for the future of the species. (Hitchmough et al., 2013).

1.5 Previous Lizard Research on Kapiti

Few studies have been carried out specifically on lizards on Kapiti. Information has been gained mostly from incidental sightings during research on other native fauna and flora on the island. The first study was carried out by Whitaker (1995) to assess what species were present prior to the 1996 rat eradication. Whitaker (1995) used spotlighting, daytime searching and pitfall traps, and found six species of lizards including the common gecko, forest gecko, green gecko, common skink, brown skink and the copper skink. He also found that overall densities were very low, and that the highest abundance of lizards was along the coast where common geckos were the most abundant species. Whitaker (1995) found the lizard diversity to be low on Kapiti, attributed to rat and weka predation. He expected a recovery of the lizard species present once rats were eradicated, but noted that recovery may be slowed by the presence of weka (Whitaker, 1995).

The most relevant research to my work was that carried out by Gorman in 1994–1996 to obtain baseline data on the lizard fauna present prior to rat eradication in 1996. Gorman (1996) collected data on lizards in six different areas on Kapiti Island; Coastal Grasslands, Ridge Grasslands, Kanuka Forest, High Forest, Kohekohe Forest and Coastal Forest. He used five different methods; pitfall traps, daytime searching, spotlighting, artificial retreats and Longworth live capture traps. This research was different from previous work done on Kapiti as it involved organised systematic sampling that could be quantitatively compared with later data.

Gorman (1996) recorded six lizard species: common skink, brown skink, copper skink, common gecko, forest gecko and the ornate skink. He found spotlighting, daytime searching and pitfall traps to be the most effective methods for obtaining count data. He found common skinks to be most abundant in Coastal and Ridge Grassland and also found them in Kanuka Forest. Brown skinks were moderately abundant in Coastal Grassland and occurred in Coastal Forest. The copper skink was rarely found in Coastal and Ridge Grassland habitats and the ornate skink was very rare and limited to screes in Coastal Forest. The common gecko was moderately abundant in Coastal Grassland and rare in Kanuka Forest and Ridge Grassland. The forest gecko was seen once in High Forest habitat, and nothing was found in Kohekohe Forest. Gorman (1996) also assessed the relationship between vegetation and lizard abundance. He found brown skinks to be more common at sites with cover, suggesting this species in particular may be more affected by general vegetation succession than direct rat eradication. There was no strong relationship found between capture rates and weather variables recorded, but capture rates seemed to increase with increased maximum temperature, sunshine and to decrease with midday relative humidity. Gorman (1996) also made comparisons between his data and populations of common geckos and common skinks on Mana Island. Common geckos had higher capture rates on Mana and tended to display more terrestrial behaviour then those on Kapiti, for instance being spotlighted at ground level and caught in pitfall traps. Common skinks captured tended to be larger on Mana. These differences were seen to be linked to the absence of rats on Mana compared to Kapiti. Gorman (1996) makes a several predictions about the responses of Kapiti lizard populations to the rat eradication of rats, but noted that these would depend on changes in vegetation and avian predators on the island. He predicted:

- Increased capture rates and/or encounter rates and extended range of ornate skinks, copper skinks and common geckos
- Increased encounter rate of forest geckos and green geckos
- Increased terrestrial behaviour (spotlighting at ground level and appearance in pitfall traps) of common geckos
- Greater proportion of common skinks and brown skinks larger than 60 mm SVL

Gorman (1996) also noted that additional lizard species may be recorded on the island after the rat eradication due to greater detection probability after numbers increased.

More recently a survey was undertaken on Kapiti by members of the Society for Research on Amphibians and Reptiles of New Zealand in February 2013. This was a rapid unstructured survey that did not allow direct comparisons with Gorman's data, but did increase the information available on what species were present on Kapiti and what their apparent densities might be. The survey took place on the southern end, the coastal Rangatira point, the summit, the forest between Rangatira point and the summit, and the northern end. The methods used were spotlighting and daytime searching. They found seven lizard species in total, including the goldstripe gecko which had not been found previously. They noted that the most abundant seemed to be common geckos and common skinks, and that forested areas had very few lizards. They partially attributed the lack of lizards in forest to constant foraging by weka (Barr et al., 2013).

Overall these previous studies have documented a total of 8 lizard species, which is a low diversity for the island and suggests that rats and other predators have extirpated other species.

1.6 Outline of the Study

Gorman's (1996) research provided a quantitative baseline study on the lizards present on Kapiti, allowing comparisons between his data and future data to quantify the effect of the rat eradication. The aim of my study was to use the same methodology as Gorman (1996) in order to quantify changes in population density, size distribution and behaviour of the lizard populations, and assess whether any changes can be attributed to the eradication of Norway rat and kiore. My work was carried out over one season from December 2014 to April 2015 in five habitats throughout Kapiti, using the three best methods as recommended by Gorman (1996). Weather and vegetation variables were recorded and modelled along with the lizard data to avoid weather-related confounds and to assess whether apparent changes in abundance were attributable to vegetation change.

In Chapter 2, lizard pitfall trap data are analysed with regard to vegetation and weather variables, and compared to Gorman's (1996) data to estimate changes in density. I then discuss the potential reasons for changes, considering vegetation and avian predators as well as the rat eradication.

In Chapter 3, data on size distributions of captured skinks and the terrestrial behaviour of the common gecko are compared with Gorman's (1996) data to estimate what changes had occurred. This allows inferences about the effects of rats on these aspects of lizard populations, and whether vegetation and avian predators can help explain the results

In Chapter 4 overall conclusions are made, as well as recommendations for future research. A framework for future potential translocations is briefly discussed, indicating which lizard species would likely be best suited for translocation to Kapiti.

Chapter Two:

Effect of Rat Eradication on the Density of Lizard species on Kapiti

2.1 Introduction

Introduced predators have been known to severely impact ecosystems, and their removal more often than not results in increased abundance of vulnerable species. Before humans colonised New Zealand, lizards were widespread throughout a range of habitats on the mainland and islands, and they filled their role in the ecosystem as prey for native birds, consumers of invertebrates, fruit and nectar and aiding the reproduction of some plant species. The introduction of rodents to New Zealand as well as widespread land modification due to human colonization has led to huge changes in the abundance and distribution of lizards, causing extinctions, isolated populations and range restrictions of many species (Whitaker & Lyall, 2004).

Previous work done by authors like Whitaker (1973 & 1978), Towns (1991), Adams and Cook considered the impact of introduced rodents on New Zealand herpetofuana. Whitaker (1973) found that the diversity of lizard fauna on a number of islands was reduced when kiore (*Rattus* exulans) were present, with these islands typically having two to three fewer species than expected. With or without rats, the highest densities of lizards were found on or near the shore or in forest near the coast and few were found in deeper forested areas. The effect of rats differed among lizard species, with some severely impacted while others seemed to not be affected (Whitaker, 1978). This pattern is not just seen in New Zealand. In the Sea of Cortez, small islands with no mammalian predators have higher densities than the mainland or large islands with predators present, and similar patterns occur in the Caribbean, Seychelles, Mascarenes, and the Galapagos (Case & Bolger, 1991).

In New Zealand, lizards have been declining since human settlement and introduction of mammalian predators, with many restricted to offshore island free of introduced predators where they can reach extremely high densities (Case & Bolger, 1991). When rodents reach these islands it can have devastating effects. For example, on Lizard Island after the invasion of kiore in 1977 the decline of lizards was obvious. Capture rates from pitfall traps went from 2.3 lizards/10 trap days in 1973 to 0.2 lizards/10 trap days by 1984, and only three lizard species were recorded compared to the five recorded in 1973 (McCallum, 1986). This decrease in abundance was likely attributed to the combination of direct predation and competition for food supplies, as kiore likely reduced populations of invertebrates that lizards would have fed on. Although there are many examples where islands with and without rats are compared to see what the effect of rodents may be, these comparisons can be confounded due to other variables. These confounds include differences in island size, and the fact that no two islands will be exactly the same and cannot be assumed to have the same initial fauna or the same habitats available (Gorman, 1996). Studies that compare lizard occupancy and abundance comparisons on one island before and after rat eradication can start to overcome this issue, and can provide more accurate evidence of the effect of rodents.

Towns (1991) conducted research on Korapuki Island to estimate the change in lizard assemblages after the removal of kiore in 1986. Capture rates of coastal lizards like the shore skink (*Oligosoma smithii*) increased immediately, and in these coastal areas removal of rats also produced rapid change in habitat use. In the forested habitats significant increases took longer to observe but major increases eventually occurred (Towns, 1991). Newman (1994) monitored the lizards on Mana Island from 1985 to 1993, before and after mice were eradicated. He found that capture rates of McGregor skinks (*Oligosoma macgregori*) and common geckos (*Woodworthis maculatus*) increased significantly after the eradication of mice in 1989

(Newman, 1994). This pattern can also occur on mainland New Zealand. For example, a study on McCann's skink (*Oligosoma maccanni*) survival in coastal duneland on the Kaitorete Spit compared different treatments; predator exclusion, artificial retreats, exclusion and retreats and a control treatment with neither. The survival of the McCann's skink only increased within grids that had predator exclusion, showing that reduction in predator abundance was predicted to benefit this species more than artificial retreat supplementation (Lettink et al., 2010).

Due to their uniqueness, the tuatara (*Sphenodon punctatus*) has been widely studied with regards to the effect of introduced predators. They are usually only found on islands free of predatory mammals and do not co-exist with ship rats (*Rattus rattus*) or Norway rats (*Rattus norvegicus*). For example when Norway rats invaded Whenuakura Island the entire population of tuatara was extirpated. A similar pattern is seen when kiore invade islands, with the removal of them leading to huge increases in proportion of tuatara juveniles as well as an increase in the body condition of adult tuatara (Towns et al., 2007). This research reinforces the fact that New Zealand reptiles tend to survive better in environments free of introduced rats, and that research on an island before and after rats have been eradicated is particularly useful for testing their effects.

This chapter reports research conducted on Kapiti Island to provide an additional comparison of the lizard fauna on an island before and after rat eradication. However, the research differs from previous comparisons in two respects. First, the before and after data were collected 20 years apart, allowing a longer term perspective than previous comparisons. Second, precise data on the locations of previous sampling locations, vegetation and weather conditions made it possible to obtain particularly accurate estimates of changes in lizard density over time, and to assess whether those changes are likely to be attributable to vegetation succession rather than rat eradication. Many of the lizard species known from Kapiti are declining or threatened. Therefore information on the density, behaviour and distribution of any of these species aids in the conservation and protection of them, reinforcing the need for this work.

Gorman (1996) carried out research on Kapiti in the summers of 1994/1995 and 1995/1996 prior to the eradication of Norway rats and kiore in October 1996. He collected data on lizards in six different habitats on Kapiti: Coastal Grassland, Kanuka Forest, High Forest, Ridge Grassland near the summit of the island, Coastal Forest and Kohekohe Forest, using a range of different methods to index densities: pitfall traps, daytime searching, spotlighting, artificial retreats and Longworth live-capture traps. He also assessed the effect of vegetation on lizard abundance and weather variables on capture rates. He recorded six species: common skink (*Oligosoma polychroma*), brown skink (*Oligosoma zelandicum*), copper skink (*Oligosoma aeneum)*, common gecko (*Woodworthia maculatus*), forest gecko (*Mokipirirakau granulatus*) and the ornate skink (*Oligosoma ornatum)*. He found spotlighting, daytime searching and pitfall traps to be the most effective methods in terms of the number of lizards encountered per effort.

My sampling involved the use of pitfall traps, spotlighting and daytime searching along transects and sampling stations established by Gorman in five of the six habitats. This allows direct comparison of lizard populations 19 years after the 1996 rat eradication with populations occurring immediately before the eradication. This comparison involved modelling the lizard sampling data from 1994-1996 and 2014-2015, while accounting for weather and vegetation variables as well as random spatial variation.

2.2 Methods

2.2.1 Study Area

Kapiti is a 1965 ha island 5 km off the west coast of the lower North Island. The five habitats sampled were in the central and northern ends of the island, and the summit (Fig. 2.1 – Fig. 2.4). Although Kapiti has many vegetation types, the vegetation in the five habitats sampled covers large areas of the island and together makes up the majority of the island's vegetation. Two of the habitats are around Rangatira point, one is at a higher point on the island near the summit and two are on the north end of the island. The sixth habitat sampled by Gorman (1996) was Kohekohe Forest. Gorman's (1996) sampling effort was lower in this habitat and was not included due to its similarities in vegetation to High Forest as well as logistic constraints. The five areas sampled are as follows:

Coastal grassland and shrub land located on the north end of the island, near the coast and Okupe Lagoon. It consists of open grassland and a mixture of shrubs, tussocks and small trees.

Kanuka Forest located on the north end of the island within a large area of mature kanuka forest. Most of the sites are located along the public Okupe loop track but some are deeper into the forest canopy. This habitat is dominated by kanuka (*Kunzea ericoides*) and manuka (*Leptospermum scoparium*) trees with representatives of other forest types in the undergrowth.

Ridge Grassland located at higher altitudes in one of the ridges near the summit and the Department of Conservation Seismo Hut. This is very similar to Coastal Grasslands made up of open grassland, shrubs and tussock areas, but with a lot of flax also present.

Coastal Forest located near Rangatira Point, along the coast and into the forest near the Historic House. This is largely dominated by medium to large trees in damp, stony areas with species including karaka (*Corynocarpus laevigatus*), kawakawa (*Macropiper excelsum*), kohekohe (*Dysoxylum spectabile*), tarata (*Pittosporum eugenioides*) and mahoe (*Melictus ramiflorus*).

High Forest located in the higher altitude forest up from Rangatira Point, along former trapping lines between walking tracks the Trig track, the Wilkinson track and the Mackenzie Track. This includes a variety of forest types including tawa (*Beilschmiedia tawa*), hinau (*Elaeocarpus dentatus*), kanuka (*Kunzea ericoides*), kohekohe, mahoe, northern rata (*Metrosideros robusta*) and rewarewa (*Knightia excelsa*).

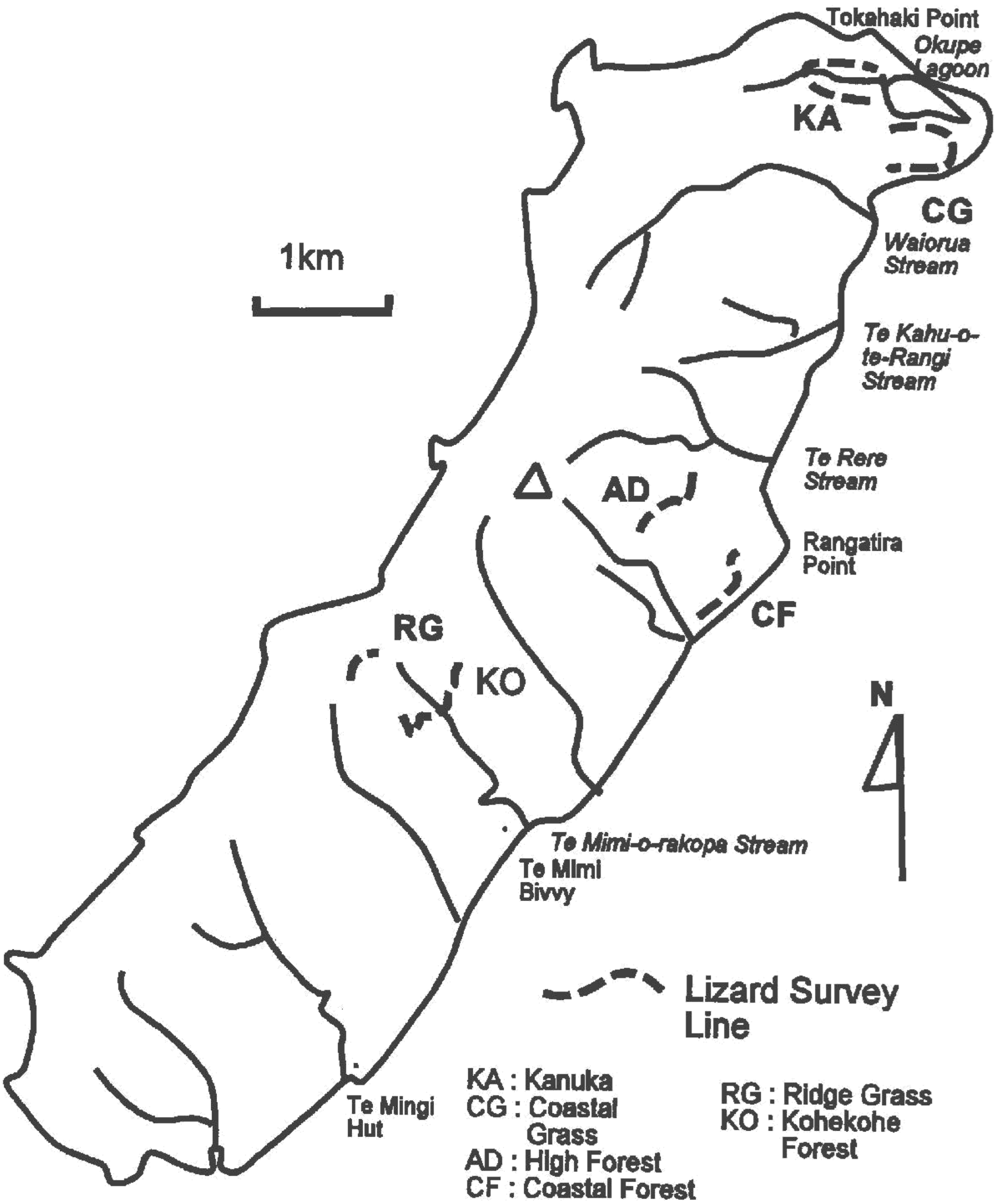

Figure 2.1: Map of Kapiti Island showing the general positions of High Forest (AD), Coastal Forest (CF), Coastal Grassland (CG), Kanuka Forest (KF), Ridge Grassland (RG) and Kohekohe (KO) habitats used in the 1994-1996 data collection. These same habitats were sampled in 2014-2015 excluding KO. From Gorman (1996).

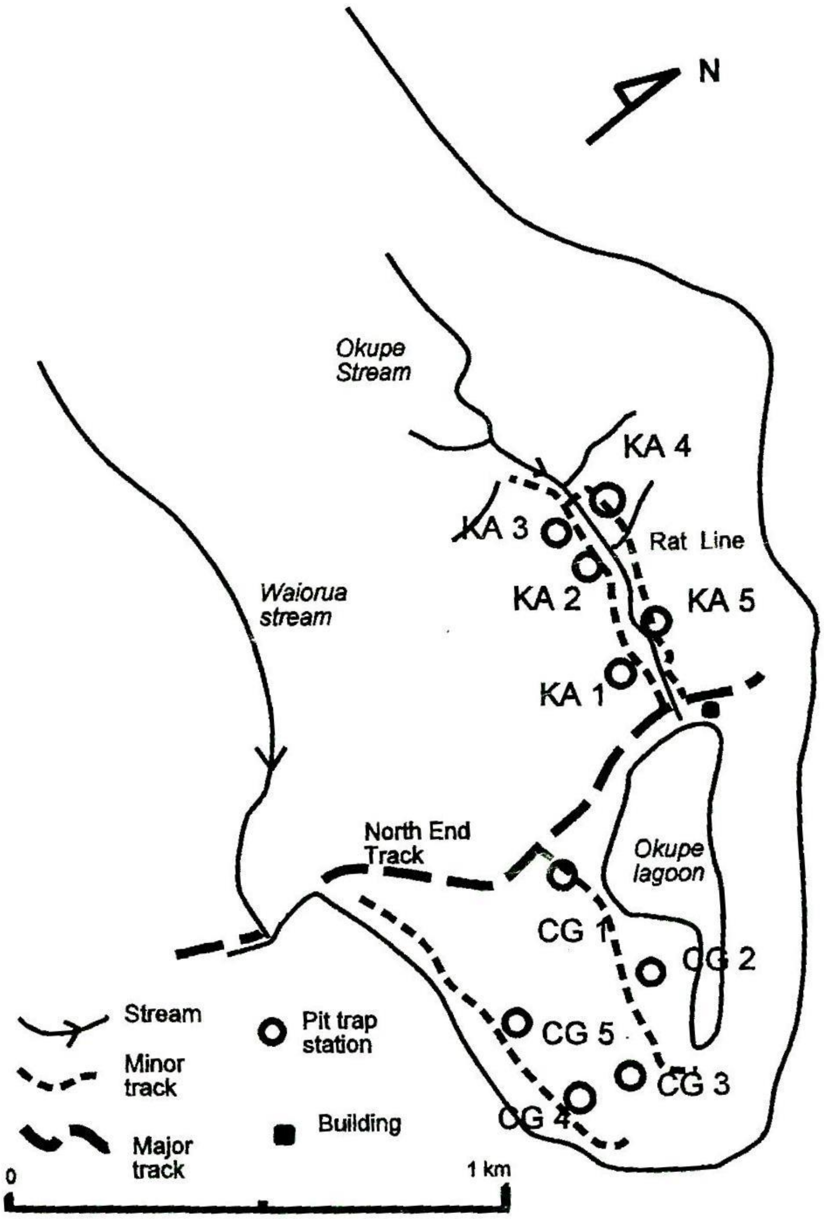

Figure 2.2: Close up of the North End of Kapiti showing the position of pitfall stations in Kanuka Forest (KA) and Coastal Grasslands (CG) in relation to walking tracks. From Gorman (1996).

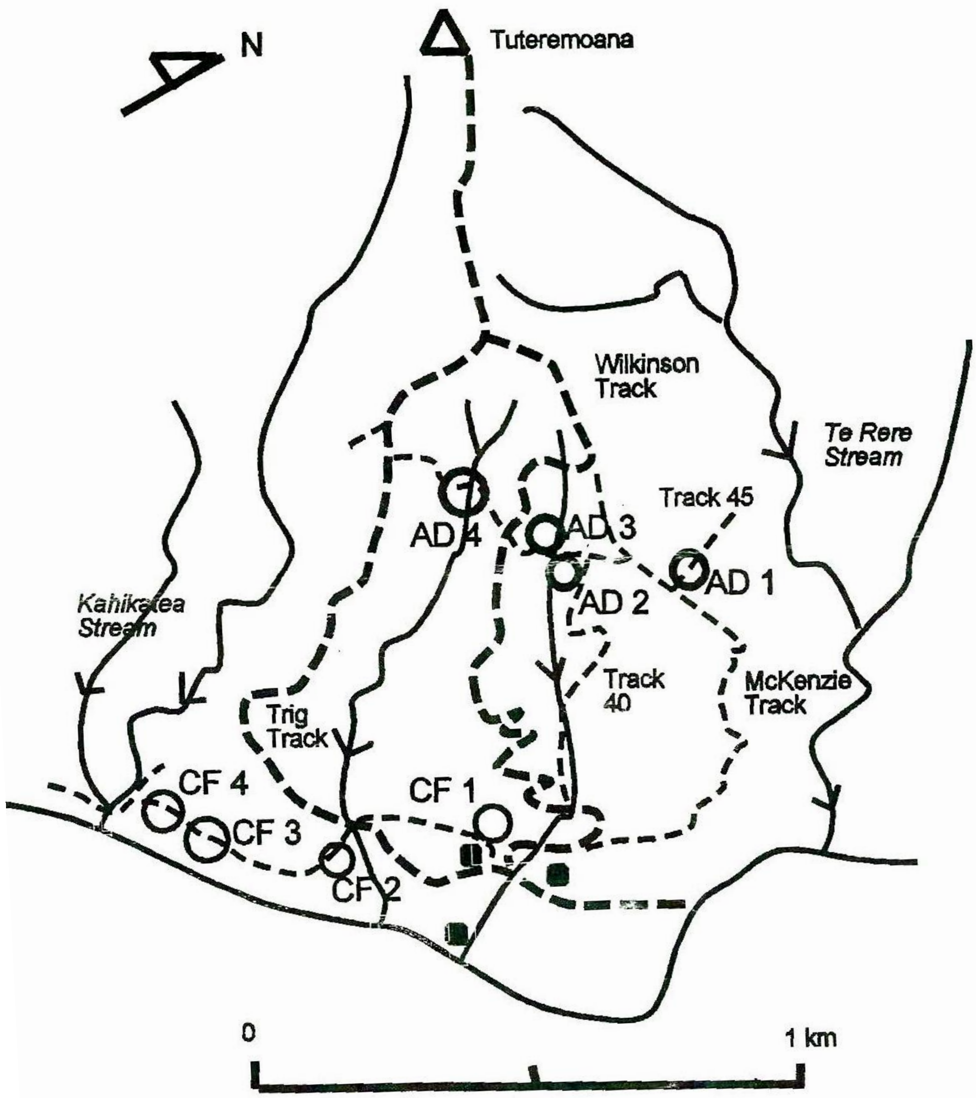

Figure 2.3: Rangatira Point on Kapiti showing the general positions of pitfall stations in Coastal Forest (CF) and High Forest (AD) in relation to walking tracks. From Gorman (1996).

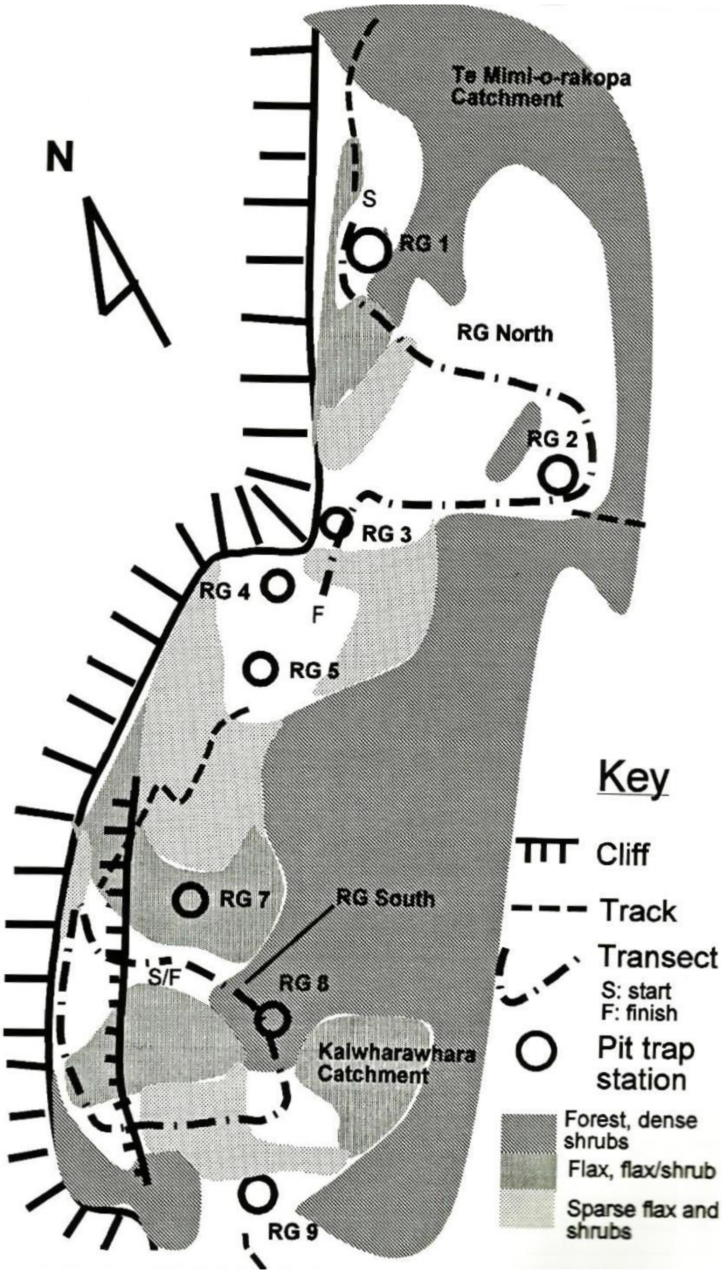

Figure 2.4: Te Mimi grassland on Kapiti showing the general positions of pitfall stations and spotlighting/daytime searching transects in Ridge Grassland (RG) habitat. In the 2014-2015 sampling only pitfall stations RG 1, RG 2, RG 3, RG 4, and RG 5 and the transect around these stations were included. From Gorman (1996).

2.2.2 Data Collection

Within each of the 5 habitats, I established 4-5 pitfall stations with five pitfall traps each, and two 200-m transects for spotlighting and daytime searching (except for Ridge Grassland where only one transect was used). The placement of these lines and transects were as close as possible to those used by Gorman (1996), as confirmed by remaining marker pegs and visual confirmation by Nic Gorman. Data were collected from December 2014 through till April 2015, over 7 sampling sessions lasting five days each.

Pitfall Traps

Pitfall traps are commonly used in lizard monitoring although they are potentially ineffective for some larger skink species and geckos which are often able to climb out (Gorman, 1996). Capture rates from pitfalls are frequently used to index abundance and distribution of lizard species. In this case comparison of pitfall capture rates before and after rat eradication allows an estimate of the proportional change in density, assuming capture rates are proportional to density. This assumption was confirmed for McGregor's skinks on Mana Island, where pitfall capture rates increased in direct proportion to population abundance estimated by toe-clipping (Newman 1994).

The five pitfall traps in each station consisted of a central pitfall trap with the rest placed in a cross formation 4 m from the central pitfall trap. This design varied slightly depending on the substrate or vegetation in the environment affecting the placement of the traps. Four-litre plastic paint tins were used as pitfalls traps, with drainage holes cut in the bottom and the handles and lids removed. The paint tins were dug into the ground or into rock piles until the rim was flush with the ground surface. Small pieces of stone, wood or leaves were placed in the bottom to provide cover for lizards, and rocks or pinned-down plywood was used to cover the traps. Each trap was individually number and marked with coloured tape. When the traps were not set, they were left with large sticks or rocks in them to allow animals to get out. When the traps were set the escape paths were removed and a teaspoon each of canned pear and a chicken- or fish-based cat food were placed at the bottom of the pitfall trap. The traps were checked as close to 24 h as possible and all were set for at least one night each sampling session, but most were set for multiple nights and checked every 24 h.

Any lizard caught in a pitfall trap was identified to species and measured from snout to vent (SVL) using a small ruler. Handling was kept to a minimum and animals were released within 0.5 m of the trap they were caught in. Some traps in Coastal Grassland were set but not baited due to attraction to the bait from ants, but if lizards were caught from them during data collection they were still counted, as in this habitat lizards were often caught in pitfall traps when they were not baited. Pitfall trap sessions from December had to be discounted due to flooding of pitfalls and bad weather preventing the checking of pitfalls on the north end of the island within 24 h hours, although the captures during this month were minimal.

Spotlighting

Spotlighting is the use of strong light and binoculars to pick up reflected eye shine from nocturnal geckos, and is an effective method of locating lizard species at night (Gorman, 1996). Each transect included at least one pitfall station but often included two or three. At least two spotlighting sessions were done along each transect. These were done on nights without rain, as reflection from rain makes it difficult to distinguish lizard eye reflection. A LED LENSER SEO 5 head lamp was used with 180 lumens and a range of 120 m, and Legacy 8x32 binoculars. On nights that I had assistance, the assistants had similar binoculars and head lamps. Approximately 2 h were spent covering each transect, and this consisted of slow movement through the transect aiming the light and binoculars towards the ground, tree trunks, crevices and canopy as well as looking in shrubs and flax bushes where present. If eye glare was spotted the animal was located and counted. If possible the lizard was captured, identified to species, measured and quickly released, although most lizards found evaded capture.

Daytime Searching

Each transect used for spotlighting was also searched during the day. Searching forest transects by day can help to detect species too rare to be detected by pitfall traps, but it often has a low success rate. In Coastal Forest, Kanuka Forest and High Forest, daytime searching consisted of looking in or under potential lizard retreats, which can include rocks, logs, fallen bark, leaf litter, etc., and looking in tree crevices and scanning foliage and canopy with binoculars. In forest areas this searching was usually within 5 m of the track making up transects. In the open Coastal Grassland habitat, where the environment consisted purely of long grass and some shrubs, transects were walked on a fine day by two or three observers about 5 m apart. Each transect was searched for 1-2 h, and any lizards seen counted and where possible captured, identified and measured.

Vegetation Variables

The changes in vegetation between 1994-1996 and 2014-2015 needed to be established to determine whether or not any changes in lizard counts could be explained by measured changes in vegetation. For each pitfall station, vegetation variables were recorded within a circle of 6-m radius centred on the central pitfall trap, using the same methods as Gorman (1996). A Braun-Blanquet estimate of percentage cover was made for 5 strata; ground layer (all plants less than 0.3 m high), large herbs and tussocks less then 3m high, shrubs (0.3 to 2m high), small trees (more than 2m high but less than 10 cm diameter at breast height) and trees (over 10 cm diameter at breast height). An overall Braun-Blanquet score was calculated for each category.

Braun – Blanquet Scale;

5 = 75-100% cover

4 = 50-75% cover

3 = 25-50% cover

2 = 5-25% cover

1 = <5% cover

+ = scarce or isolated

For analysis, vegetation scores of + and 1 were combined together and scores from 1-5 were changed to 0.1-0.5.

Weather Variables

As weather affects the activity of lizards and therefore their probability of being captured or encountered, it creates variability in capture rates that are not due to rat eradication and it must be included in any comparative analysis. The same six weather variables were recorded as Gorman (1996) for each day that sampling took place. These variables were maximum and minimum temperature, relative humidity in the morning (about 06:00), at midday and in the evening (about 18:00) and a weather score. Comparative temperature and humidity data were gained from Gorman's (1996) recorded values which were done in the field, and missing values recorded from CliFlo NIWA weather stations as close to Kapiti as possible. All weather variables for days sampled during the 2014-2015 work were taken from CliFlo NIWA weather stations as close to Kapiti as possible. The stations used were based in the Wellington area, station 3145 Paraparauman Aero and station 17029 Wallaceville Ews. Following Gorman (1996), the generalised weather conditions for the day were scored between 0 and 4, as follows:

0 = constant rain or mist
1 = overcast with some rain
2 = mostly cloudy
3 = mostly fine
4 = fine all day

If there was a major change in the weather during the day then an average was given. For example, if the day started with heavy rain but then cleared and was fine the score would be a 2. This was used in the overall data analysis in order to estimate the effect of weather on capture rates and the change between this study and Gorman's (1996) work.

2.3 Data Analysis

All data analysis was done using OpenBUGS (version 3.2.3 rev 1012), which is a Bayesian updating software that is particularly effective for hierarchical modelling, All data consisted of counts, so Poisson regression was used, this means having a log link, and, therefore the effect sizes show proportional change. With all data initial models were run using just the 2014-2015 data in order to understand which weather and vegetation variables were affecting counts, and might therefore confound the comparison over time. DIC (Deviance Information Criterion, Spiegelhalter et al., 2002) and credible intervals on effect sizes were used to establish which variables should be retained. Once the important weather and vegetation variables were identified, the 1994-1996 and 2014-2015 data were modelled simultaneously to compare capture rates before and after rat eradication. The variable "time" was used to distinguish the two time periods, and a fixed effect added to the model estimate the proportional change. In all models trap was a random effect. For both spotlighting and daytime searching models transect was a random effect. Month, weather, vegetation and time were fixed effects in all models. Month was treated as a categorical variable, with each month as a separate level, whereas weather and vegetation variables were continuous. Vegetation variables were not included in spotlighting or day time searching analysis as these data were only collected for the pitfall stations. Models were updated for 10000 Markov Chain Monte Carlo (MCMC) iterations. Significance was established if the 95% credible interval (similar to confidence interval) did not overlap 0. For random effects significance was established via visual analysis of the posterior distribution graphs.

For the pitfall traps only data from Coastal Grasslands, Ridge Grasslands and Kanuka Forest were used, as no lizards were caught in Coastal Forest or High Forest in either 1994-1996 or 2014-2015. For the Ridge Grassland data only captures from pitfall stations 1-5 in this habitat in 1994-1996 were used for analysis. Species and habitats were run separately, as the effect of vegetation and weather variables changed between species and habitats. Weather score, maximum temperature and relative humidity in the evening were found to be the only weather variables having an effect, and these were also significant in Gorman's (1996) data analysis, so were retained in further modelling. Trees and small trees in Coastal Grasslands and Ridge Grasslands were excluded due to their absence or rarity, leaving shrub, large herb and ground cover percentage to be incorporated in model. For Kanuka Forest small trees cover percentage was excluded, so variables included were tree cover, shrub cover, large herb cover and ground cover. Site was a random effect in all pitfall data models. The copper skink data from Coastal Grassland was modelled, and eventually the random effect of site had to be excluded from the model without vegetation variables in order for the model to converge. Each species within each habitat was run with just weather variables in the model and then run with weather and vegetation variables, in order to see how much vegetation variables changed the result and therefore how much of the result could be explained by vegetation changes.

For spotlighting weather score, minimum temperature and relative humidity in the evening were the weather variables used in the final model as these variables seemed likely to effect the spotlighting of geckos and were most significant in Gorman's (1996) analysis. In this case site was a fixed effect as all habitats were analysed together.

For daytime searching the data were split into geckos and skinks because the species could often not be confirmed. For geckos, weather score, relative humidity in the morning and relatively humidity at midday were the weather variables included in the model. For skinks, only relative humidity in the evening was significant so this variable as well as max temperature and weather score was used in the model.

Graphs were created to visually compare vegetation scores between 1994-1996 and 2014-2015 to assess how the vegetation had changed through succession. This was done for the three habitat types that were used in pitfall trap data analysis: Kanuka Forest, Ridge Grassland and Coastal Grassland. For Ridge Grassland and Coastal Grassland, the graphs were split into the three strata used in the analysis in OpenBUGS, which were shrub, large herbs and ground layer. The same was done for Kanuka Forest with four graphs showing scores for trees, shrubs, large herbs and ground layer and within these were the vegetation scores for each pitfall station.

2.4 Results

2.4.1 Pitfall Trap Data

Almost all pitfall captures were of common, brown and copper skinks in the Coastal Grassland, Ridge Grassland and Kanuka Forest habitats (Table 2.1, Fig. 2.5). Two captures of common geckos in pitfall traps, and a single ornate skink was caught in pitfall traps in Coastal Forest whereas none were captured in 1994–1996. No lizards were trapped in High Forest, similar to 1994–1996. No green geckos (*Nauultinus punctatus*), forest geckos or goldstrip geckos (*Woodworthia chrysosireticus*) were detected during the sampling sessions though forest geckos were detected in 1994–1996 in the High Forest. No species not already known from the island were detected.

Coastal Grassland

A total of 121 common skinks, 12 copper skinks and 13 brown skinks were trapped in the Coastal Grassland habitat type. Two common geckos were also caught in pitfall traps in this habitat. Common skinks increased significantly since 1994-1996 (Table 2.1, Fig. 2.5), but are found to be more abundant in areas with more ground cover and less large herb cover. Brown skinks and copper skinks did not increase significantly since 1994-1996 (Table 2.1, Fig. 2.5), but brown skinks do appear more abundant in areas with more ground cover. The change in copper skink density appears to be explained by changes in vegetation over the last 20 years. Weather variables appear to have an effect on capture rates of common skinks and brown skinks. Capture rates were highest in January for common and copper skinks, and highest in February and March for brown skinks (Fig. 2.6).

Table 2.1: Proportional changes in capture rates of three skink species in three different habitats between 2014-2015 and 1994–1996 on Kapiti Island. Results were generated using hierarchical Poisson regression models that included important weather variables and vegetation variables. * shows cases where nothing was caught in 1994–1996.

Habitat	Species	Proportional Change	CI
Coastal Grassland	Common Skink	12.06	5.45, 27.35
	Brown Skinks	3.53	0.58, 25.84
	Copper Skink	1.44	0.06, 32.98
Kanuka Forest	Common Skinks	*$3x10^{3*}$	0.87, $9x10^6$
	Brown Skinks	*$7x10^3$	2.18, $6x10^7$
	Copper Skink	NA	
Ridge Grassland	Common Skink	8.15	4.77, 13.74
	Brown Skink	*$9x10^5$	$5x10^2$, $4x10^9$
	Copper Skink	*$1x10^4$	66.69, $6x10^6$

Common skinks had increased about 12-fold since 1994-1996 (Table 2.1, Fig. 2.5). Weather score was found to affect capture rates, with a proportional increase of 1.31 (1.15 – 1.49) for each 1 SD increase in weather score. Common skink captures increased 11003-fold (103.85 – 1302766) as ground cover percentage increased from 0–100% and decreased by 0.00081 (0.00002 – 0.029) as large herb cover percentage increased from 0-100%. Brown skinks were estimated to have increased about 4-fold since 1994-1996 but this was not significant (Table 2.1). Brown skinks capture rates were estimated to increase 1.89-fold (1.19 – 3.30) as weather score increased by 1 SD, and to increase 305590-fold (60.58 – $2.8x10^9$) if ground cover increased from 0–100%.

Copper skinks were estimated to have increased by about 2-fold in density since 1994-1996, and this increase was significant (95% CI 1.50 – 2.55) when vegetation variables were excluded from the model. However, the proportion increase was not significant when vegetation variables were included (Table 2.1, Fig. 2.5).

Kanuka Forest

Only Common skinks and brown skinks were analysed for this habitat as these were the only species caught in the pitfall traps. A total of eight common skinks and seven brown skinks were captured in pitfall traps in the Kanuka Forest habitat type, and no copper skinks. No skinks were caught in this habitat in 1994–1996, so the estimated proportional increases of common and brown skinks are very high (Table 2.1, Fig. 2.5) despite the small numbers caught in 2014–2015. The proportional increase of common skinks was significant (CI 24.80 – $7.1x10^{8}$) with no vegetation variables in the model, but because insignificant when they were added (Table 2.1, Fig. 2.5), showing that the change in common skink density could be explained by changes in vegetation. The increase in brown skinks remained significant when vegetation variables were included (Table 2.1, Fig 2.5).

Ridge Grassland

A total of 50 common skinks, 4 copper skinks and 20 brown skinks were captured in pitfall traps in the Ridge Grassland habitat type. Two common geckos were also trapped in this habitat.

Common skinks were estimated to have increase about 8-fold since 1994–1996, and the proportional increases of copper skinks and brown skinks were estimated to be very high because none were caught in 1994–1996 (Table 2.1, Fig. 2.5). In all cases, the increases remained significant when vegetation variables were included in the model. Capture rates of common skinks increased by 1.39 (1.05 – 1.82) as max temperature increased by 1 SD and by 1.27 (1.07 – 1.51) as weather score increased. Capture rates of copper skink capture rates decreased by 0.0091 (0.00002 – 0.33) as max temperature increased.

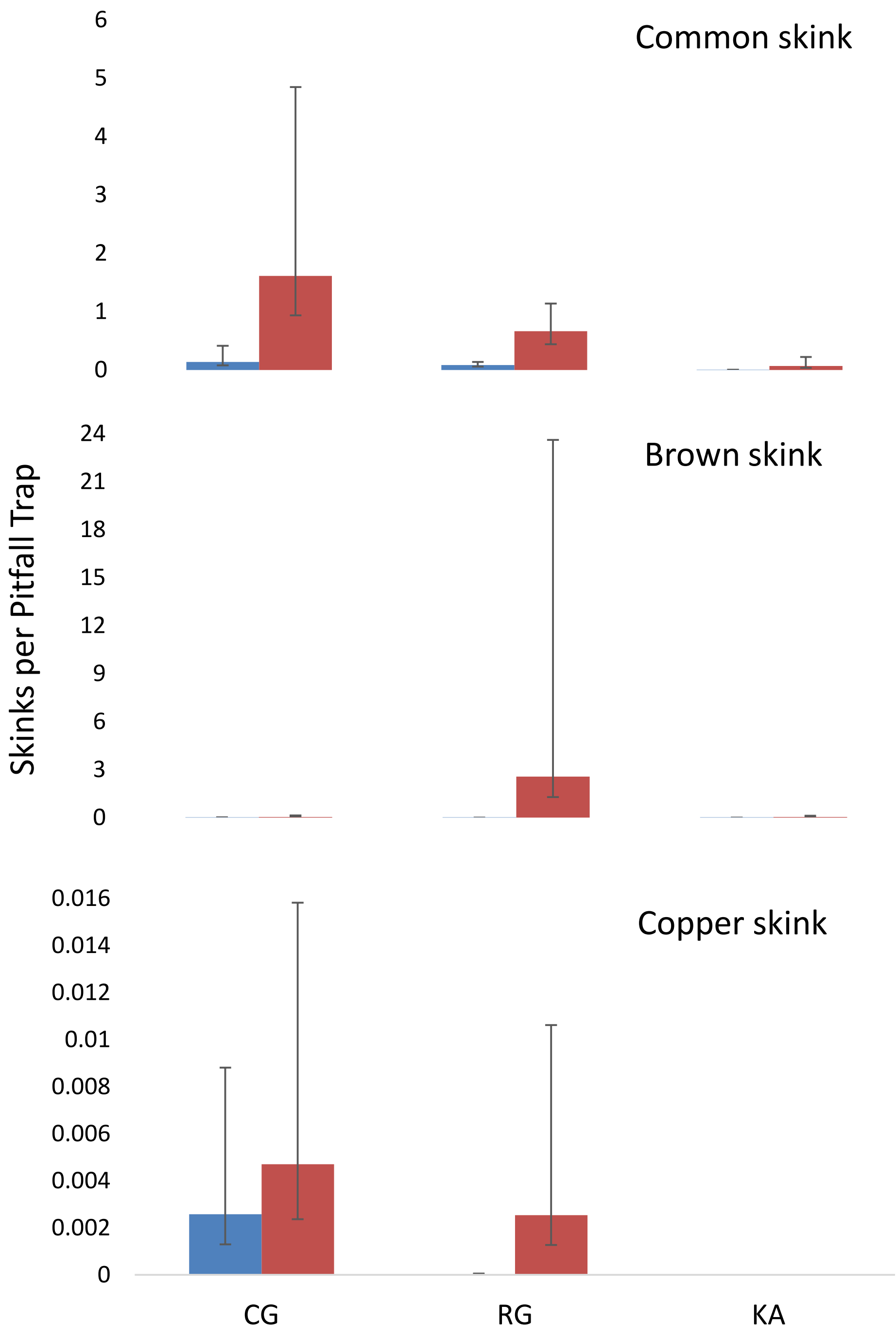

Figure 2.5: Comparison of skink capture rates per 24 h in 1994-1996 (blue) and 2014-2015 (red) in three different habitats (Coastal Grassland, CG; Ridge Grassland, RG; Kanuka Forest, KA) on Kapiti Island. Estimates shown are for an average pitfall trap in average weather in February based on hierarchical Poisson regression models. Error bars show standard errors (the asymmetry is due to the log link used in the models). Note the different scales for the three species

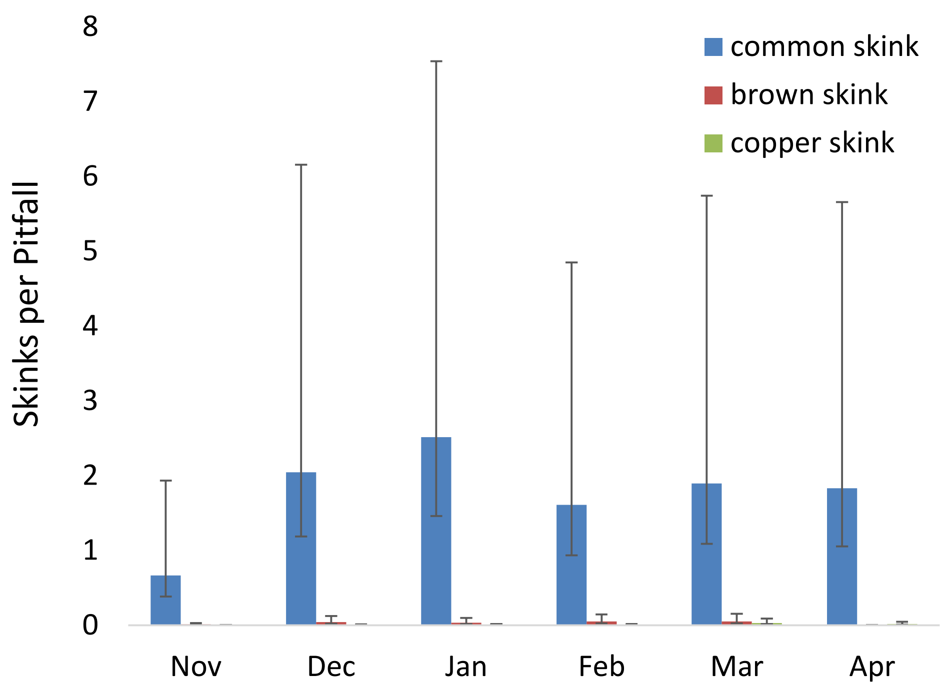

Figure 2.6: Monthly pattern in capture rates per 24 h for three skink species in Coastal Grassland on Kapiti Island. Estimates and standard errors are from hierarchical Poisson regression as in Figure 2.5.

2.4.2 Spotlighting Data

I found 101 geckos during spotlighting across the nine different transect in the five habitat types. Out of the 101 geckos spotlighted 61 were found in Coastal Grasslands, 27 in Kanuka Forest, 7 in Ridge Grasslands and 6 in Coastal Forest. 31 of these geckos were captured, and identified as common geckos. The encounter rate was 3.65 times higher (CI 1.76 – 7.60) than in 1994–1996. There was clearly variation among transects (standard version among transects estimated to be 4, with 95% CI of 1.51 – 9.69).

2.4.3 Daytime Searching Data

Geckos

A total of 25 geckos were seen during daytime searching across the eight transects in four of the five habitats, and the six that were captured were all common geckos. Out of the 25 geckos found 8 of these were in Kanuka Forest and 17 of these in Coastal Grasslands. The encounter rates were 10.7 times higher than in 1994–1996, but this was not statistically significant (95% CI 5.7E-05 – 873290) due to the small sample size. Encounter rates were estimated to increase by 48-fold (1.04 – 17765) as relative humidity in the morning increased by 1 SD. Geckos were observed in four out of five of the habitats, with 6 found in the Coastal Forest track transect where none were found in 1994–1996.

Skinks

A total of 13 skinks were seen during daytime searching of the eight transects in four of the five habitats, and the two captured were common skinks. Out of 13 skinks found, 4 of these were in Kanuka Forest and 9 of these were in Coastal Grasslands. The encounter rate was 25.18 times higher than in 1994–1996, but again this increase was not significant (95% CI 0.0035 – 420837). Skink encounters decreased by 0.00002 (1.8×10^{-11} – 0.29) in March.

2.4.4 Vegetation Changes

Ridge Grassland

My scores for shrub cover in the Ridge Grassland habitat were generally the same as recorded in 1994–1996, and where changes had occurred there were increases (Fig. 2.7). All pitfall stations show a marked increase in large herb cover since 1994–1996. Ground layer cover has generally decreased since 1994–1996, as shrubs, large herbs and tussocks have increased in prevalence and size (Fig. 2.7).

Coastal Grasslands

There has been an apparent increase of shrub cover and large herb cover in most of the pitfall stations in the Coastal Grassland habitat. In contrast, ground layer cover percentage has generally decreased, similar to Ridge Grassland (Fig. 2.7).

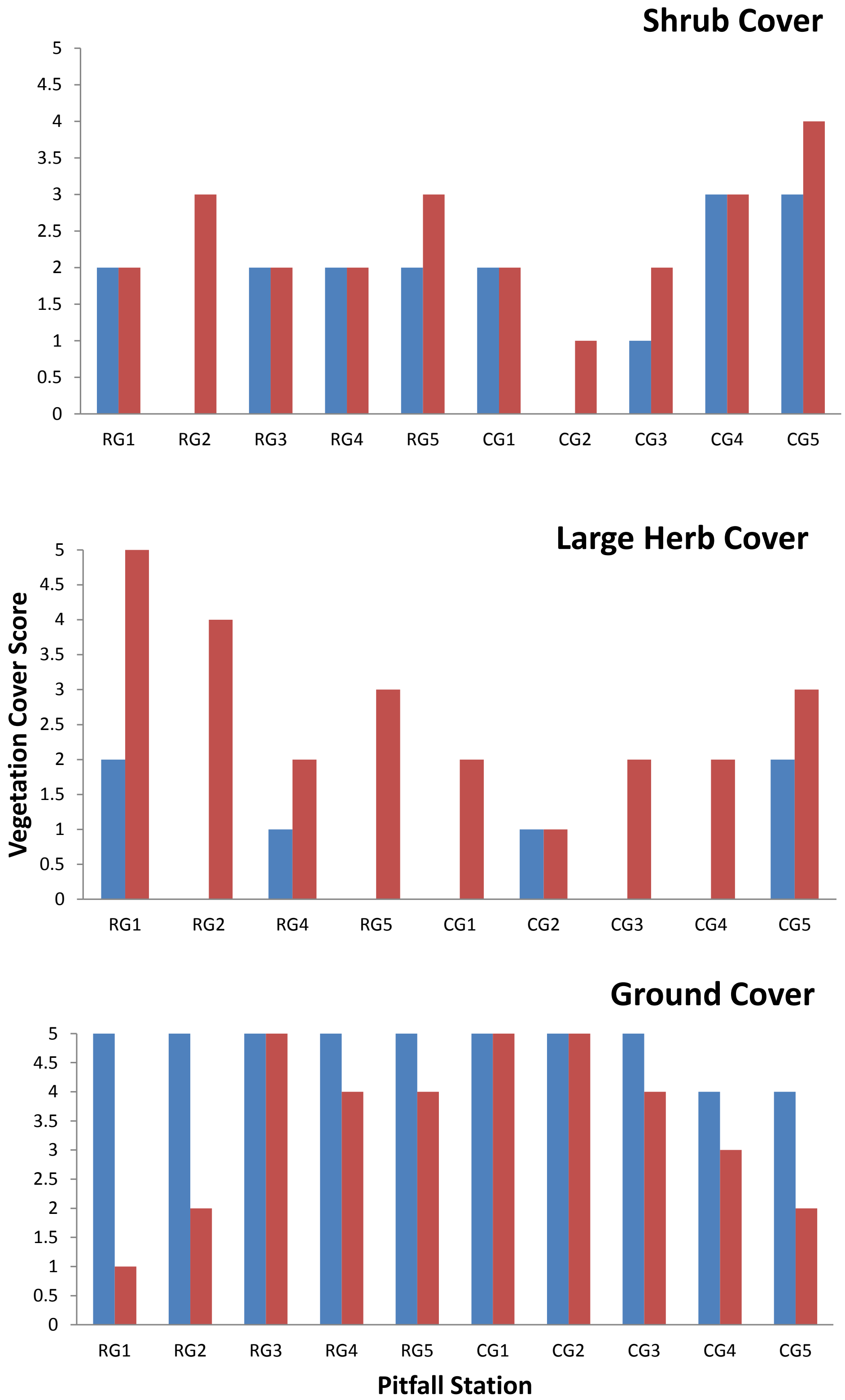

Figure 2.7: Comparisons of vegetation cover scores in Ridge Grassland (RG) and Coastal Grassland (CG) of between 1994-1996 (blue) and 2014-2015 (red) for three different layers: shrub cover, large herb cover and ground layer cover. A pitfall station is a collection of 5 pitfall traps.

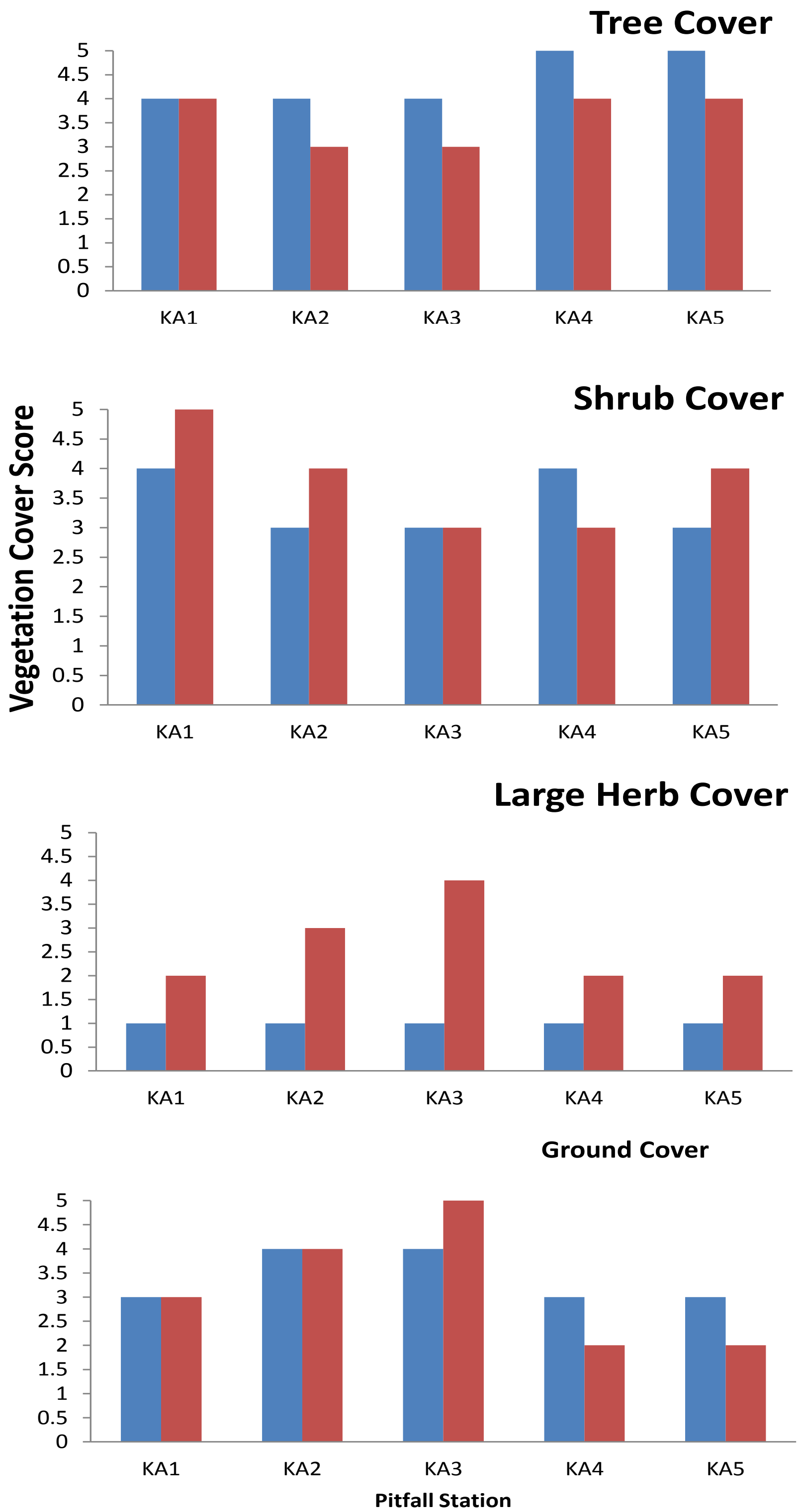

Figure 2.8: Comparisons of vegetation cover score in Kanuka Forest between 1994-1996 (blue) and 2014-2015 (red) for four layers: tree cover, shrub cover, large herb cover and ground cover. A pitfall station is a collection of 5 pitfall traps.

Kanuka Forest

Large herb cover has increased in all stations in Kanuka forest since 1994–1996. There has been little change in tree, shrub, or ground-layer cover scores, although with a few stations have slightly more shrub cover now and a few have slightly lower ground-layer cover (Fig. 2.8)

2.5 Discussion

The data from pitfall traps, spotlighting and daytime searching has generally shown increases in lizard density compared to Gorman's (1996) data collected from 1994–1996. Where sensible comparisons can be made, lizards density significantly increased up to 12-fold. In some cases changes are attributable to the measured changes in vegetation, and where this is not the case the removal of rats is the most likely explanation for the changes seen. In some cases the credible intervals are too wide to confirm a change in density (i.e. insufficient power) and in other cases measured changes in vegetation can explain the change in lizard counts rather than removing the direct predatory or competitive effects of rats. No additional species of lizards were found during my study, but that does not mean that they are not present because they may be too rare to be detected or are in un-sampled areas.

Some lizard species seem to have extended their ranges and the ratio of the three main species, common, brown and copper skinks, has changed since 1994–1996. In Ridge Grassland all species increased significantly in density, and the copper skink, which Gorman (1996) did not capture in this habitat, was detected in the last month of the 2014-2015 sampling. In Coastal Grassland, common skinks were the only species to significantly increase in density based on pitfall trap capture rates when vegetation changes were included in the model, whereas changes in copper skink and brown skink densities may be explained by vegetation changes. Kanuka Forest was one of the more interesting habitats, as a number of common skink and brown skink were captured in pitfall traps compared to none in 1994–1996, although the change in common skink density was potentially explained by vegetation change. Finally, spotlighting encounter rates for geckos increased significantly, and they may have increased their range as geckos were spotlighted in the Coastal Forest habitat where they were not found in 1994–1996. In some habitats like Kanuka Forest and Coastal Grasslands, the numbers were extremely high and little effort was required to detect geckos. The capture of four common geckos in pitfall traps in 2014-2015 probably also indicate an increase in density of this species.

No skinks or geckos were detected via any methods in the High Forest habitat in 2014–2015, though one forest gecko was detected by Gorman (1996) in this habitat. This species may be at very low numbers and the effort in this study was not enough to detect their presence, or they could have possibly increased but are difficult to detect. The encounter rates during daytime searching of both skinks and geckos increased between this study and Gorman's (1996). This was not significant, although in this study lizards were detected in Kanuka Forest during daytime searches, where previously Gorman (1996) had detected nothing. The data gained from daytime searching was limited, in both 1994-1996 and 2014-2015, and the sample sizes may have not been big enough to detect significant changes. The ornate skink still appears to be rare or has a lower detection probability then other species, though may have extended its range, with an incidental sighting of one in High Forest habitat. No green geckos or goldstripe geckos were detected, though these species were also not detected in Gorman's (1996) 1994-1996 sampling.

Although it is well understood that rodents often have devastating effects on native species, and the absence of them is often linked with higher lizard abundance, it is important to understand what effect they have on lizard species in order to directly impact their densities. As shown by this study, many lizard species on Kapiti have increased in density since Norway rats and kiore were eradicated from the island, assuming changes in encounter rates reflect changes in densities. On Kapiti, both Norway rats and kiore were detected year-round in all six habitats sampled in 1994-1996, with the highest, but most variable capture rates in Coastal

Grassland and Kanuka Forest while more stable, lower density populations found in forested habitats. Grassland habitat are where the highest lizard densities are often found, as seen in this study and previous research done on Kapiti where, in general, lizard density is very low in forested habitats (Whitaker, 1995; Gorman, 1996; Barr et al., 2013).

With interactions likely occurring between lizards and rats on Kapiti it is important to understand what portion of Norway rats and kiore diet is made up of lizards, and therefore what predatory effect they are likely to be having. A large percentage of the kiore's diet is usually plant material, and with some invertebrates, lizards and birds. This is similar to the diet of the Norway rat but they tend to be more opportunistic feeders and will readily scavenge carcasses and along shorelines (King, 2005). Dick (1985) found that through snap-trapping on Kapiti, Norway rats were estimated at a higher density than kiore. The higher densities of rats were found in mature kanuka, similar to Kanuka Forest and High Forest habitats sampled during this 2014-2015 research, and in lower grassland, which was similar to the Coastal Grassland habitat. Based on stomach samples, invertebrates dominated the kiore diet and seed tended to dominate the Norway rat diet (Dick, 1985). Lepidoptera larvae were most commonly eaten by both species, followed by spiders, dipterans and weta. The percentage of vegetation in the diet was higher in Norway rats and consisted mostly of grasses and weeds and not much native vegetation apart from kanuka. Seed and fruit was found in stomachs of both Norway rats and kiore and were mostly exotic grassland species but also included kohekohe and poroporo (*Solanum aviculare*). Skink remains were found in five Norway rats and one kiore. Therefore, invertebrates played a major role in the kiore diet, while Norway rats had a more omnivorous diet (Dick, 1985). It is clear that lizards and rats shared the same habitat on Kapiti and that lizards did play a role in the diet of kiore and Norway rat. Although they make up a small portion of the diet, this predation can still have an effect on lizard populations, and may only make up a small part of the diet because of suppression to low numbers by predation originally. This demonstrates that kiore and Norway rat may have directly impacted lizard densities on Kapiti due to predation, and the removal of these rodents should have reduced that predation pressure and cause the increases seen in some lizard species densities.

Rodents can affect lizards in ways other than predation, including competition for food. The reduction of available food in habitats within Kapiti would reduce the numbers of lizards that a habitat could sustain and, therefore, the eradication of rodents may have increased the food available and allowed lizard species to increase in density and extend their range, as seen in this study. Rodents are known to prey on invertebrates, and these often make up a large proportion of their diet, reducing the food available for other insectivores in the habitat. Rats on Kapiti in particular had invertebrates as major component of their diet and were known to consume large (> 5 mm) beetles, spiders, harvestmen, caterpillars and weta (Sinclair et al., 2005). This is a similar diet to what many native lizards would feed on, although they may take smaller invertebrate prey, as well as feeding on similar fruits when they are available. The eradication of rats usually leads to an increase in survival and reproduction of insectivorous birds and this is partly due to the reduced competition for invertebrate food. This pattern may be expected to also occur with lizards (Sinclair et al., 2005).

Throughout New Zealand there is a disjointed distribution of species of weta, moths and beetles, and many are confined to off-shore islands, most likely due to rat predation (Ramsay, 1978). After ship rats reached Big South Cape Island, entomologists visiting in 1968/1969 found that the previously abundant large flightless weevil was absent and it is now considered to be extinct, as well as a large flightless stag beetle becoming rare (Ramsay, 1978). Long-term monitoring of invertebrates through pitfall trapping on Tiritiri Matangi Island before and after the eradication of kiore showed that larger numbers of invertebrates were caught, and capture rates of large species like ground weta and spiders increased (Green, 2002). Rats have an effect on invertebrate communities within environments and therefore can affect other species that feed on them via competition and complete removal of some species. Though lizards tend to feed on smaller invertebrates there is still a potential overlap in diet between them and rats. Even if the direct predation of rats on lizards is limited, the decrease of food availability caused by rats could have detrimental effects on lizard populations. In many cases invertebrate diversity and abundance increases after rats are eradicated from islands, and this could be a similar case on Kapiti. This would, in turn, provide more food for lizards and aid the recovery of some populations, as we have seen in this 2014-2015 sampling where some of the lizard species on Kapiti have increased in density since kiore and Norway rat were eradicated.

Another way that the presence of rodents within an ecosystem can affect other species like lizards is their effect on forest structure and regenerating bush. Lizards select microhabitats where they can optimise foraging, thermoregulation and predator avoidance, so a change in vegetation can affect lizard species differently (Stephens, 2004). In this study, vegetation succession seemed to have benefitted some species, like brown skinks and copper skinks. However, it is unknown whether those vegetation changes are due to rat removal or longer-term succession changes due to past land clearance or other impacts. It is known that rodents affect vegetation as they browse on plants, flowers, seeds and fruits, and can prevent the regeneration of vegetation. On Tiritiri Matangi there has been a huge increase in fruits and seeds since kiore were eradicated and the understory in forest remnants has become denser (Graham & Veitch, 2002). Eradication of rats from islands like Putauhinu and Raratoka led to the recovery of vegetation and allowed regeneration of tree species including rare species which were originally limited by the predation of kiore on seeds and seedlings (McClelland, 2002). On Cuvier Island, kiore influenced the composition of regenerating coastal forest with changes seen in abundance of seedlings and species composition when kiore were excluded from sites. On Mokoia Island, Norway rats were found to destroy planted seedlings of tawa and podocarps (Campbell, 1978). Kiore and Norway rat also prey on vertebrates that may aid the dispersal of plants such as birds and lizards, therefore, also affecting the vegetation present (Campbell, 1978). Research on tree recruitment on islands with and without kiore found that kiore depressed the recruitment of 11 species of coastal trees with some pushed to local extinction (Campbell & Atkinson, 2002). Therefore without rats present on Kapiti Island, we may expect to see regeneration of bush, thicker understory within forested areas, re-vegetation of grasslands and more fruits and seedlings available for other animals. This may make certain areas more or less suitable for different lizard species, and may explain the apparent changes in some species' densities being due to measured changes in the vegetation on Kapiti.

These vegetation changes will affect lizard species differently. Forest skinks may increase in numbers as forest increases or as more refuges become available on the forest floor, whereas grassland species may decline in numbers as grasslands become re-vegetated, especially for species like common skinks that seem to prefer more open habitats (Stephens, 2004). This is supported by my results showing that common skinks in Coastal Grasslands had lower density in sites with less cover of large herbs. This re-vegetation of open grassland habitats may have benefited species like the brown skink and copper skink which usually prefer areas with more cover, possibly explaining why more were found in this study then in 1994–1996. In Coastal Grasslands, increases in brown and copper skinks between 1994-1996 and 2014-2015 may be explained by the changes in vegetation and, therefore, more affected by the succession of the vegetation then the actually reduction of direct effects from kiore and Norway rats. Gorman (1996) found that capture rates of brown skinks were strongly related to vegetation cover, and predicted that as time passed shrub cover would increase in grassland areas, and if an increase in brown skink populations was noted then this could be attributed to vegetation succession.

The comparisons made between the vegetation scores between 1994-1996 and 2014-2015 show that the vegetation has followed the expected changes. This involves the increase of small trees, shrub and large herbs in the open grassland habitat and an increase in understory in the forested habitats. Coastal Grassland and the Kanuka Forest habitats had some of the highest rat densities on Kapiti (Gorman, 1996). This may be why we have seen the greatest changes in pitfall trap capture rates in these habitats. However, lizards were only found at two of the five pitfall stations in Kanuka Forest. As these stations had the least tree cover, it seems likely that vegetation succession has limited the increase in skink density in Kanuka Forest. It would appear for these grassland species, especially common skinks, that further succession of the forest will make the Kanuka Forest less suitable for this species. Perhaps the increased numbers in Coastal Grasslands has caused the spread of these species to the most suitable habitat within the forest environment. Re-vegetation of the more open grassland habitats like Coastal Grasslands and Ridge Grassland has led this habitat to be more suitable for species that prefer denser vegetation like brown skinks and copper skinks. This may be the reason for the occurrence of copper skinks in Ridge Grassland in 2014-2015 sampling when they were not detected in 1994-1996. The occurrence of these species in these habitats and their apparent increase in density may be more due to succession than the direct impacts of rat eradication. Rats of course impact re-vegetation, so it is difficult to distinguish the effects of the rat eradication on lizards through predation from the indirect effects of rats on the lizards' habitat.

Lizards are ectotherms whose body temperature regulation and therefore activity depends on external sources, so capture rates are affected by weather conditions. Lizards will be active at temperatures between a critical minimum and a critical maximum and above or below this they will alter behaviour in order to regulate their body temperature (Spellerberg, 1982). As seen in this study there are apparent effects of temperature, humidity and weather conditions on the capture rates of lizards, and this is a similar pattern seen by Gorman (1996). Many of these relationships are weak and the occurrence of the sampling in the warmer months of the year reduces the range of weather conditions. Maximum temperature and weather score were the best predictors of lizard capture rates in pitfall traps in this study, and weather seems to have a greater influence on capture rates in Ridge Grassland than in Coastal Grassland. Therefore, lizard activity in Ridge Grassland may be more affected by weather, a pattern also found by Gorman (1996). This habitat is at a higher altitude and experiences winds from all directions, and therefore animals present there will experience more extreme conditions. Although some of the weather variables do seem to have an effect on capture rates, there was not a large variance in weather conditions during sampling sessions in this research or between this study and that of Gorman (1996). Differences in weather must be included as these can affect capture rates and therefore may account for differences in densities, but it is unlikely it is having a large effect as change in lizard densities over the last 20 years are unlikely due to weather and are more likely attributed to vegetation succession or rat eradication.

Although it seems likely that the eradication of rats from Kapiti has benefited the lizard fauna, either directly or indirectly, not all species have responded in the way predicted and not all have apparently increased in density. This is most notable with the ornate skink, which Gorman (1996) predicted would increase in abundance and range once rats were eradicated as it appeared quite rare from his data. During the 2014-2015 the ornate skink still appears rare, with only one official capture in a pitfall trap and a few incidental sightings (Appendix One). Possible explanations are: 1) that the regeneration of Coastal Forest has reduced habitat suitability for these skinks, 2) this particular species is difficult to detect, or 3) the presence of avian predators is having a similar effect to what rats did. Birds are a natural and important predator of New Zealand lizards, and Kapiti has many species that are known to prey on lizards. These include blackbirds (*Turdus merula*), starlings (*Sturnus vulgaris*), long-tailed cuckoo (*Eudynamys taitensis*), morepork (*Ninox novaeseelandiae*), New Zealand falcon (*Falco novaeseelandiae*), kingfisher (*Todiramphus sanctus*), pukeko (*Porphyrio melanotus*), swamp harrier (*Circus approximans*), takahe (*Porphyrio hochstetteri*) and weka (*Gallirallus australis*) (van Winkel & Ji, 2012). On many offshore islands where introduced predators have been eliminated, native bird populations can reach very high densities. Although these predator-prey relationships have evolved naturally, this predation may still reduce the restoration of vulnerable lizard populations and decrease the quality of habitat available to them. The removal of predators like Norway rats and kiore can easily affect interactions in ecosystems these rats are prey for some native bird species, and their presence may have reduced avian predation on other, more natural prey like lizards. Diet analysis of four native bird species from Tiritiri Matangi found that although no lizard remains were found in harriers, morepork or pukeko, they were present in 88% of kingfisher pellets and in 60% of nests, showing that they form an important component of kingfishers' diets (van Winkel & Ji, 2012). Blackbirds and common starlings have also been known to feed on lizards and frogs, and in one study in Wellington, blackbirds were observed preying on copper skinks in a coastal environment (Bell, 1996; David & Latham, 2011).

One of the biggest issues on Kapiti is the presence of weka, which is believed to not be native to the island but to have been introduced before the island became a reserve. They are known to be potential predators of ground-nesting birds, lizards, insects and snails, and this has led to their eradication from many islands, but their impacts on Kapiti have often been masked by the effect of introduced mammals and land clearance. Miskelly (1996) performed a five-year exclosure experiment on Kapiti to estimate the effect of weka on lizard and insect abundance. It showed that ground-dwelling lizards were almost absent from forested sites, but their recovery after rat eradication seemed unaffected by presence or absence of weka (Miskelly & Beauchamp, 2004). In an informal survey done in 2013, it was concluded the forested habitats had very few lizards and this was speculated to be due to the high density of weka and their thorough searching of leaf litter 24 hours a day (Barr at al. 2013). During my study I noted that weka were present in each habitat sampled, and especially in forested habitats like Coastal Forest and High Forest habitats where they were in high density and were actively searching for food, which may be why ornate skinks are still apparently rare in these habitats. Whitaker (1995) predicted that the recovery of lizard species on Kapiti Island would be compromised by the presence of weka, which seem to be primarily responsible for decreased lizard abundance on many New Zealand islands such as Stewart Island and Chatham Islands. Weka maintain activity levels throughout the day and night and though terrestrial, diurnal skinks are at most risk, weka can impact a range of lizard species (Whitaker, 1995). Many of the native bird species now found on Kapiti occurred there naturally, and the lizard fauna present would have evolved with them, but the effect of new bird species reaching the island and the rapid changes in bird densities since introduced predators were removed may have prevented some lizard populations from recovering.

Whitaker (1978) discussed which lizards may be more vulnerable to rodent predation, and therefore why these particular species may be lacking from rat-infested islands. Nocturnal species tend to be vulnerable, as the majority of introduced rats are nocturnal. Terrestrial species are at more risk of predation by rodents like the Norway rat and kiore than arboreal species. Larger species are also more vulnerable to predation as they may not be able to access refuges safe from rats and may compete for similar food. These aspects may explain why Kapiti lacks large skink species and why Gorman (1996) found ornate skinks to be very rare. Not all species have recovered the same on Kapiti since rodents were eradicated, and according to the 2014-2015 sampling, green geckos, ornate skinks and forest geckos are still apparently rare. Only one ornate skink was captured in pitfall traps during the 2014-2015 sampling although five were found in pitfall traps before they were baited, including four in Coastal Forest and one in the High Forest habitat (Appendix One). Therefore, ornate skinks are still present and may have extended their range, but may be too rare to be detected by the pitfall trap sampling performed. Therefore they have not responded as quickly as predicted, which may be due to avian predators preventing recovery. They are also the largest skink species known to be on Kapiti and so may simply be more adept at escaping pitfall traps then the smaller, grassland species.

Common geckos appear to have increased in density on Kapiti and were easily observed in many habitats, as well as being captured in pitfall traps and found in pitfall traps before baiting. It has been noted that this species may co-exist better with introduced rats than other species of lizards (Romijn, et al., 2014). Research carried out on large, nocturnal gecko species like common geckos and Duvacel's geckos (*Hoplodactylus duvaucelii*) has shown that spotlighting encounter rates often increase drastically straight after rat eradication before any recruitment can take place (Hoare et al., 2007). Rats will often displace these species from some habitats causing them to adapt (or 'restrict') their behaviour by becoming less conspicuous and using habitats not accessible to rats, allowing them to co-exist with introduced rodents. This may explain the apparently large abundance of common geckos present during this study compared to other species, and compared to1994–1996 when they may have been more cryptic in their behaviour. In contrast, forest geckos are both diurnal and nocturnal and are usually located on trunks and branches not often in retreats. This makes them more vulnerable to predation by rats and now avian predators, and therefore slow to recover (Romijn et al., 2014).

It is important to assess the effectiveness of methods when surveying certain species. In wildlife monitoring programmes, abundance estimation provides essential information on populations but it is rarely possible to observe all individuals within a population. Therefore, some form of count statistics over space or time is often used to estimate abundance and these are referred to as indices or index counts where it is assumed there are constant detection probabilities over space and time and among individuals (Lettink et al., 2011). Lizards can be difficult to monitor as many species are nocturnal, cryptic and are only active under particular weather conditions. Index counts for lizard research in New Zealand often involves visual and hand searches, pitfall trapping and artificial retreats. These methods are less costly and are more time effective then methods like mark-recapture and appear to provide accurate information on density (Lettink et al., 2011).

Although green geckos and forest geckos were not observed during the 2014-2015 sampling on Kapiti, this does not mean they are not present on the island in substantial numbers. In fact, there were two incidental sightings of green geckos on the north end of Kapiti during 2014-2015 (Appendix One). Therefore, they are still present but their arboreal nature and cryptic colouring makes then difficult to find and the sampling effort carried out may have not been enough to detect their presence. None of the methods used are very successful at detecting these species, except daytime searching and this method is not overly effective. Not all geckos were captured and identified, and some were viewed from a reasonably long distance, so they were not necessarily common geckos and could have been other species such as forest geckos or pacific geckos. The latter has not been found on Kapiti yet but looks similar to a common gecko and could have a high chance of reaching the island. Goldstripe geckos have only been found in the rapid survey in 2013 and this was on the south end of the island and in flax habitat on the summit ridge at the head of the Taepiro (Barr et al., 2013). These areas was not covered in this work or Gorman's (1996), and although flax exists in the Coastal Grasslands and Ridge Grasslands, goldstripe geckos may not yet have spread through the island or are still in too low of numbers to have been detected, and if they were present they may have only been detected if caught. There were also a large number of common geckos spotlighted in flax bushes during the 2014-2015 sampling, representing possible competition and the need to capture every gecko to confirm species.

In conclusion, kiore and Norway rats on Kapiti Island appear to have affected the lizard fauna present either through predation, competition or change to vegetation, and their eradication seems to have benefited several lizard species around the island. In some cases (brown skinks and copper skinks in Coastal Grasslands and common skinks in Kanuka Forest), the increases seem to be explained by measured changes in vegetation, and it is unknown whether those vegetation changes are due to rat eradication. Some species (ornate skink, forest gecko) have not shown any clear increase, and this could be due to abundant avian predators on Kapiti preventing their recovery. Lizard species like forest geckos and green geckos may also have not been detected due to limited sampling time, small populations or inappropriate methods for detection. As predicted, though, the eradication of rodents of Kapiti has benefited populations of common, brown, and copper skink, as well as common geckos, just as it has benefited other native species on the island.

Chapter Three:

The Effect of Rat Eradication on Size Distributions and Behaviour of Lizards on Kapiti Island

3.1 Introduction

The presence of rats on islands is known to have devastating effects on the density and distribution of species, but can also have more subtle impacts on populations. These include changes in behaviour and size distributions.

Many aspects of an animal's habitat select for the optimal body size. For lizards on islands, body size might be affected by food resources availability, interspecific competition, habitat availability and predation (Dunham et al., 1978). In terms of predation it is important to determine the difference of an proximate effect and a ultimate effect on the body size of an animal, a proximate effect is an immediate effect on a trait, for instance the removal of larger individuals from a population by a predator, while an ultimate effect explains why one trait may be chosen over another usually in terms of natural selection, so the evolution of smaller body size due to predation pressures (Laland et al., 2011). Body size has a strong impact on a lizard's locomotion, its ability to access retreats, its foraging behaviour and escape behaviours. Small lizards, including hatchlings and juveniles, may have limited locomotion but smaller lizards are more able to outmanoeuvre predators and access small areas of cover (Foster et al., 2015). In most cases, predators will usually select larger prey until an upper limit is reached where the costs of capturing and handling prey outweigh the benefit of the resource. Greater mortality in large individuals is usually due to four mechanisms; they are more visible and less manoeuvrable, they need more food to sustain themselves, they may reproduce earlier and therefore suffer costs of reproduction, and may be more affected by heat stress (Blanckenhorn, 2000). All these factors make a larger animal more vulnerable, and when introduced predators invade an environment, we may expect to see fewer large individuals present within a population. Once this predation pressure is released the size distribution may change and, therefore, the percentage of individuals in the upper size range may increase. This may be what we would expect to see within lizard populations present on Kapiti since the removal of rats but, of course, this will depend on the effect of other predators in the environment as well as the habitat available and whether it is otherwise more suitable for smaller or larger individuals.

Behavioural changes are expected after new predators invade due to shifts in predator avoidance behaviour. New Zealand's native lizard's main natural predators are birds which are primarily visual hunters, leading to visual crypsis and secretive behaviours allowing individuals to avoid detection by predators (Hoare, 2006). With the introduction of mammalian predators that hunt primarily using scent, these naturally evolved avoidance behaviours may not be effective. These behaviour shifts can be seen when populations are compared with and without mammalian predators present. For instance, when predatory mammals are present, Duvaucel's geckos (*Hoplodactylus duvaucelii*) shift from primarily visual anti-predatory behaviours, such as freeze behaviours and crypsis, to escape behaviours becoming more important (Hoare, 2006). Not only is this evident in New Zealand but elsewhere as well. For example, in Greece Aegean wall lizard (*Podarcis erhardii*) populations existing with high feral cat densities stayed closer to refuges, were more likely to shed their tails and fled at greater distances when approached by a perceived threat (Li et al., 2014). In the Galapagos, three species of lava lizards (*Tropidurus albermarlensis, T. bavittatus* and *T. delanonis.*) are found to have developed increased wariness and, therefore, differences in behaviour when present on cat infested islands versus cat-free islands (Stone et al., 1994). Similar changes in behaviour patterns are seen in many other animals. For instance, New Zealand tree weta, cockroaches and spiders in Fiordland had an increased escape response to being touched in locations where introduced predators were present (Bremner et al., 1989). Nymphs of mayflies were found to change their behavioural strategies when in environments where introduced brown trout (*Salmo* trutta) were present, as trout forage differently to New Zealand native fish and therefore exert different predation pressures (McIntosh & Townsend, 1994).

This Chapter assesses the differences in size distributions and behaviour of lizards caught while sampling on Kapiti via pitfall traps, spotlighting and daytime searching (Chapter 2). This involved the comparisons of snout-to-vent lengths of skinks and geckos caught during the 2014-2015 sampling with those caught by Gorman (1996) during the 1994-1996 sampling to determine whether a greater number of larger individuals are present now in the population. The terrestrial behaviour of common geckos (*Woodworthia maculatus*), which was measured as the number of geckos spotlighted on the ground during sampling, was examined, as it was found by Gorman (1996) that this behaviour occurred less on Kapiti when compared to rat-free Mana Island. After removing the rats from Kapiti, it is expected that the vulnerability of foraging at ground level would be reduced, and therefore that a greater number of common geckos would be observed at ground level if the original difference between Mana and Kapiti was caused by rats. However, the presence or absence of rats is not the only difference occurring between the two islands, and changes with regards to terrestrial behaviour may also depend on other vegetation differences, food availability and avian predators.

3.2 Methods

3.2.1 Size Distribution

Pitfall stations consisting of five pitfall traps were set up along transect lines within each of five habitat types, and set over 7 sessions from December 2014 to April 2015 (Chapter 2). Pitfall traps were baited with a teaspoon of pear and a teaspoon of chicken or fish based cat food, small stones and pieces of wood were left at the bottom to allow cover for lizards. Pitfall traps were checked as close as possible to 24 h after setting. Any lizards caught in the pitfall traps during sampling sessions were identified to species, measured with a ruler from snout to vent (cloacal opening) between the limbs, than released about 2 m from the pitfall trap. Measurements were not taken from snout to the end of the tail as skinks and geckos will often drop their tails when threatened, and individuals caught had a variety of tail regrowth lengths. Size distribution data from pitfall traps were the only ones used for data analysis as data from spotlighting and daytime searching was too limited to justify modelling.

3.2.2 Behaviour

Spotlighting and daytime searching was also carried out along transects within each of the five habitats (Chapter 2). When geckos were encountered during spotlighting it was recorded whether they were on the ground or not. The position of each gecko was categorised as either ground level (those seen at ground level, or in grasses or clumps of *Muehlenbeckia complexa* up to around 20cm above the ground) or arboreal (in shrubs, flax [*Phormium tenax* and *P. cookianum*] or large tussocks). These notes were then compared to Gorman's (1996) recordings, but the data did not allow for any other meaningful comparisons. This terrestrial/arboreal distinction does not apply for skinks since they were all present on the ground, and as common geckos were the most commonly encountered gecko during both the 2014-2015 and 1994-1996 sampling they were the only species used for comparisons.

3.3 Data Analysis

All data analysis was done using OpenBUGS (version 3.2.3 rev 1012), which is a Bayesian updating software that is particularly effective for hierarchical modelling. Normal error distribution was used as the data was approximately normally distributed. Vegetation variables were included in the analysis. All skink species and habitats were analysed separately, and the difference between 2014-2015 and 1994-1996 was analysed when possible, for some habitats there was no data from Gorman (1996) so only this current data were used. For the Kanuka Forest, the analysis included all five vegetation variables: ground cover, large herb cover, shrub cover, large trees, and small trees (Chapter 2). For Ridge Grasslands and Coastal Grasslands, there were no trees present so only the first three variables were relevant. For each species and habitat, the data was analysed first with no vegetation variables and then again with vegetation variables in order to see what impact they were having (Chapter 2). Random effects included were pitfall station and pitfall trap, while month, vegetation variables and time (1994-1996 vs. 2014-2015) were fixed effects. Models were updated for 100000 Markov Chain Monte Carlo (MCMC) iterations. Significance was established if the 95% credible interval (similar to confidence interval) did not overlap 0. For random effects significance was established via visual analysis of the posterior distribution graphs.

3.4 Results

3.4.1 Size Distribution

Coastal Grasslands

A total of 121 common skinks (*Oligosoma polychroma*), 13 brown skinks (*Oligosoma zelandicum*) and 12 copper skinks (*Oligosoma aeneum*) were found in the Coastal Grassland habitat type. Two common geckos were also caught in pitfall traps in this habitat.

The mean SVL of common skinks decreased by 0.18 mm between 1994–1996 and 2014–2015, and this change was significant (95% CI -0.34, -0.02) until vegetation variables were brought into the model (Table 3.1). This may indicate that the reduction in size is explained by changes in vegetation. There was no significant change in size of copper skinks or brown skinks between 1994–1996 and 2014–2015 (Table 3.1) and vegetation variables appear to not be having an effect.

Table 3.1: Mean snout-to-vent lengths (SVL), sample sizes and changes in mean SVL of three skinks species in three different habitats on Kapiti Island between 1994-1996 and 2014-2015. Results were generated using hierarchical Poisson regression models that included important vegetation variables.

Habitat	Species	Mean SVL (1994-1996)	Sample Sizes (1994-1996)	Mean SVL (2014-2015)	Sample Sizes (2014-2015)	Change in Mean SVL	CI
Coastal	Common Skink	5.28	240	5.27	121	-0.08	-0.35, 0.17
Grassland	Brown Skink	5.03	23	5.29	13	0.54	-1.35, 2.39
	Copper Skink	5.47	3	5.32	12	0.30	-2.42, 3.13
Kanuka	Common Skink			5.19	8		
Forest	Brown Skink			5.76	7		
Ridge	Common Skink	5.24	89	5.33	48	-0.05	-0.39, 0.27
Grassland	Brown Skink			5.49	20		
	Copper Skink			2.17	4		

Kanuka Forest

A total of 8 common skinks and 7 brown skinks were measured in the Kanuka Forest habitat type (Table 3.1), whereas no lizards were caught in this habitat in 1994–1996. There were no significant effects of vegetation variables on the sizes of skinks found.

Ridge Grasslands

A total of 48 common skinks, 20 brown skinks and 4 copper skinks were captured in the pitfall traps and measured in the Ridge Grassland habitat type. Two common geckos were also caught in pitfall traps in this habitat. There was a decrease in mean SVL of common skinks between 1994–1996 and 2014–2015, but this difference was not significant (Table 3.1). In January there was an increase of 0.43 cm (0.030 – 0.83) in mean SVL of skinks compared to other months.

Neither copper skinks nor brown skinks were caught in Ridge Grasslands during the 1994-1996 sampling. None of the vegetation variables appear to have a significant effect on the size of skinks found.

3.4.2 Terrestrial Behaviour

I found 61 geckos during spotlighting in Coastal Grassland on Kapiti. All of these were categorised as 'arboreal', being in flax bushes or *Coprosma* shrubs. 27 geckos were spotlighted in Kanuka Forest, all of which were 'arboreal', being found on kanuka trees either in the open or under bark. 6 geckos were observed in Coastal Forest, one of which was found on the track, therefore categorised at ground level, while the remaining 5 were spotlighted on tree branches or in crevices. 7 geckos were spotlighted in Ridge Grassland and all of these were 'arboreal', being either on flax bushes or in tightly branched shrubs.

During the 1994-1996 sampling, Gorman (1996) spotlighted 24 geckos in Coastal Grassland, with 1 found at ground level and the remainder in flax (*Phormium tenax*), tauhinu (*Pomaderris amoena*) or *Coprosma* shrubs. He also spotlighted 10 geckos in Ridge Grassland, with 1 found at ground level and the other 9 on the cliff or on flax or toetoe (*Cortaderi* spp.) tussocks.

In total, one gecko was at ground level out of a total of 101 spotlighted in 2014–2015, in comparison to sampling two geckos at ground level out of a total of 24 geckos spotlighted in 1994–1996, suggesting little change in the terrestrial behaviour of common geckos on Kapiti.

3.5 Discussion

There has been little change between the size distributions of skinks found during my research and those found by Gorman (1996). The only significant change in size was a decrease in common skink sizes in Coastal Grassland but this change appears to be explained by changes in vegetation. The mean SVL of common, brown and copper skinks in all habitats were 5.0–5.8 cm; therefore, the populations still lack large (> 6 cm SVL) individuals, which Gorman (1996) predicted would represent a greater proportion of the populations once rats were eradicated from Kapiti.

Whitaker (1973) described features of New Zealand lizards that made them more vulnerable to rat predation, and one of these is size. Larger species tend to be more vulnerable than smaller species as they are less able to avoid predation by accessing cover that rodents cannot access. They are also more likely to compete with rodents for food as they may feed on similarly large invertebrates, and they often need to be in the open foraging for longer in order to sustain their larger body mass (Whitaker, 1978). Adult tuatara (*Sphenodon punctatus*) are able to avoid predation due to their large size, but populations on islands with rats present often have few or none juveniles because their smaller size make them vulnerable to predation. Juvenile tuatara are similar in size to some of our large skink and gecko species, showing that this size range can be vulnerable to predation (Gaze, 2001; Towns et al., 2006). This is a similar pattern with the large Duvaucel's gecko (*Hoplodactylus duvaucelii*), where fewer smaller individuals are present where kiore (*Rattus exulans*) occur, showing an upper limit to the size of kiore prey which easily includes large individuals of common, brown or copper skinks. However, ship rats (*R. rattus*) and Norway rats (*R. norvegicus*) are larger, and their presence places adults of large reptiles as well as juveniles at risk of predation (Christmas, 1995). On Korapuki Island before rats were eradicated there was not only an effect on the shore skink (*Oligosoma smithi*) population distribution and abundance, but there were fewer large individuals compared to rodent-free islands (Towns, 1991). A similar pattern was seen on Mana Island. When the mouse (*Mus musculus*) population present there drastically increased, this decreased the average and maximum size of McGregor's skink (*Oligosoma macgregori*) (Newman, 1994).In both of these cases, larger individuals were seen after rodents were eradicated, indicating the potential for rodent predation selecting against large size in lizards (Gorman, 1996). When Gorman (1996) compared his Kapiti data to data from Mana after the eradication of mice, he found common skinks to grow to a larger size on Mana compared to Kapiti. When rats were present on Kapiti larger individuals in lizard populations may have been more readily preyed on by rats or were more affected by competition as they ate similar sized invertebrates to rats. With the eradication of rats from Kapiti, we may have expected to see an increase of larger individuals within the grassland skink species present, as well as an increase in ornate skinks. These medium-sized skinks are the largest found on Kapiti and may have been at most risk when rodents were present.

There are several possible reasons for the limited numbers of large individuals and apparent rareness of ornate skinks (*Oligosoma ornatum)* on Kapiti. Gorman (1996) predicted when comparing Kapiti and Mana that possible causes for different size distributions may be due to vegetation as well as the presence of rats and avian predators. The results from the 2014-2015 sampling have shown that where there is a significant change in skink size distribution since 1996 it is explained by the change in vegetation variables. On Mana Island, where common skinks were found to be larger, Gorman (1996) noted that there were no shrubs or flax in the area studied; suggesting that increased shrub cover may cause a reduction of a skinks maximum potential size. A lack of change or a decrease in proportion of large skinks may indicate an inverse relationship between shrub cover and lizard size. This is assuming that shrub cover has increased in the grassland habitats which it appears to have done (Chapter 2). Copper skinks have increased in prevalence in Coastal Grassland and Ridge Grassland since 1996 (Chapter 2), but much of this change was explained by an increase in vegetation as the grasslands became more vegetated by shrub and flax. The copper skink is one of the smallest skink species found on Kapiti, and the change in vegetation in the last 20 years may have made grassland areas more suitable for this species as they seem to be more associated with vegetation cover than other *Oligosoma* species. This may lead to little change in the proportion of large individuals in the grassland skink species.

Another significant effect is the presence of avian predators on Kapiti. When compared to some other islands and the mainland. Body size of lizards can be a major influence on their vulnerability to predation by birds. Some birds may prey on larger skinks while other birds like thrushes may take smaller skinks. For instance, in Australia predation by kookaburras (*Dacelo novaeguineae*) on a medium-sized diurnal skink species (*Eulamprus tympanum* Scincidae) led to a disproportional amount of small individuals being taken. It was difficult to distinguish the reason behind this but it was thought to be down to subtle shifts in behaviour where sub-adult skinks may have been forced into suboptimal habitats where they are more vulnerable, or that they may lack learned behaviours that adult skinks possess (Blomberg & Shine, 2000). In the Canary Islands, the endemic lizard genus *Gallotia* are preyed on by the southern grey shrike (*Lanius meridionalis*) and the Eurasian kestrel (*Falco tinnunculus*) which differ in their size selection of prey. Shrikes positively selected medium-sized lizards but changed their selection seasonally, whereas the kestrels appear to be more selective, positively selecting larger lizards all year round (Padilla et al., 2007).

A number of native birds that prey on lizards are present on Kapiti, including weka (*Gallirallus australis*), which are well known lizard predators. Gorman (1996) predicted that if there was no change in size distribution of skink species found on Kapiti, then this may be due to the avian predators present tending to prey on larger-sized skinks. This may also explain the absence of large skink species like the spotted skink (*Oligosoma lineoocellatum*) or speckled skink (*O. infrapunctatum*) from Kapiti although they are found in the Wellington area. If these species occurred on the island they would have been extremely vulnerable to predation when rats were present and would still be vulnerable with the avian predators occurring on Kapiti, causing them to either remain rare so, therefore, unable to be detected or potentially eradicated if recolonized. Birds are naturally the most common predators of New Zealand lizard species, and, therefore, a substantial number of different avian predators can cause selective pressures on lizard populations. On Kapiti, this may mean a low number of large (above 6 cm SVL) individuals which may be more vulnerable to predation, and apparent little change in size distribution since rat eradication.

During the 1994-1996 sampling, Gorman (1996) noted the terrestrial behaviour of common geckos during spotlighting, daytime searching and pitfall trap sessions and these results were then compared to the behaviour of geckos on rat-free Mana Island. Gorman (1996) found that on Kapiti the majority of geckos were spotlighted in shrubs or flax and were completely absent from pitfall traps, whereas on Mana, in habitat similar to the Coastal Grasslands on Kapiti, over half the common geckos were spotlighted at or near ground level and geckos were also captured in pitfall traps. Although common geckos can be found in trees in forested habitats they are primarily a terrestrial gecko (Wotton, 2002). This suggests a shift in the behaviour of the Kapiti population of common geckos. Comparisons between two sites are often not reliable evidence for a pattern, as differences in lizard behaviour could be caused by other factors rather than the absence of rats. Some of this island variation was reduced as the habitats sampled on Kapiti and Mana were similar in terms of vegetation, and the populations of common geckos on both islands are genetically similar and therefore regarded as from the same taxon (Gorman, 1996; Nielsen et al., 2011).

Gorman (1996) gave two possible explanations for this difference in behaviour. One was that there was a different food sources available the on islands, and the other was that foraging at ground level increased a lizard's risk to predation by rats. Gorman (1996) found that many of the shrubs or plants on Kapiti were found also on Mana, but that flax was scarce in the area spotlighted on Mana while abundant on Kapiti. A large majority of geckos were found on flax plants, representing a potential food source associated with flax. On the other hand, the arrival of a predominately terrestrial, nocturnal predator like kiore and Norway rat onto Kapiti could select against increased terrestrial activity.

During the 2014-2015 sampling, I found that almost all common geckos were spotlighted above the ground, but in contrast to 1994-1996 sampling, a few were also captured in pitfall traps, as seen in the results. This may represent that there has been an increase in the numbers and the terrestrial behaviour of common geckos, shown by the capture of them in pitfall traps, but that there is still something causing them to forage off the ground at night. This may be evidence for the idea of an arboreal food source but also that nocturnal terrestrial activity may increase vulnerability of predation by nocturnal avian predators, especially by weka and morepork (*Ninox novaeseelandiae*) which are abundant on Kapiti but absent from Mana. It may be that these predators are exerting similar pressures to rats on the terrestrial activity of common geckos. As common geckos mainly forage at night, this may be when they are most vulnerable to predation and, therefore, they reduce their vulnerability by remaining above the ground. Kapiti has more avian predators then Mana, and this may explain why the terrestrial behaviour of common geckos at night on Kapiti has appeared not to have changed compared to when rats were present on the island. During spotlighting, I noted that there was a persistent presence of foraging weka in all habitats. Most of the geckos spotlighted in Coastal Grasslands and Ridge Grasslands were found in tightly branched *Coprosma* shrubs from which they were extremely difficult to extract, suggesting an additional method to avoid predation. Similarly, jewelled gecko (*Naultinus* *gemmeus*) populations in Banks and Otago Peninsulas have persisted in the presence of a range of avian and mammal predators, and this is mainly due to the vegetation cover available, where divaricating shrubs and dense lianas provide protection for arboreal species (Jewell & McQueen, 2007). Avian predators may not only be affecting the size distributions of Kapiti lizards but may also be affecting the terrestrial behaviour of nocturnal geckos, potentially explaining the lack of nocturnal terrestrial activity in common geckos on Kapiti.

In conclusion, although there have been some changes in behaviour and size distributions of gecko and skink species on Kapiti, the populations have not responded in the ways predicted. With the reduction of predatory selection pressures of introduced rodents, Gorman (1996) predicted, if the presence of rats were affecting these traits of lizard populations, there would be more large individuals present in the populations and that terrestrial activity of common geckos would increase. According to this 2014-2015 sampling, there was little change in size distribution within the habitats where pitfall trap captures occurred and if any size difference was significant this seems due to vegetation changes, meaning the populations still lack over 6 cm SVL individuals. The vegetation changes that have occurred since the 1994-1996 sampling may have made the habitat more suitable for small individuals, and avian predators may be continuing to remove large skinks. In regards to terrestrial behaviour, more common geckos were caught in pitfall traps indicating some switch to terrestrial activity, but nearly all geckos spotlighted were above the ground, suggesting either that the best food sources are above ground or that geckos are vulnerable to nocturnal avian predators and foraging above the ground reduces the risk. Overall the effect of eradication of rats on the behaviour and size distribution of Kapiti's lizard fauna is more complicated than originally thought, and these traits have not changed as predicted opening the way to further in-depth study on the effects of avian predators and the potential of an arboreal food source.

Chapter Four:

Translocations, Conclusions and Future Research

4.1 Translocations

Kapiti Island has few lizard species in relation to the size of the island, with only eight lizard species known to be there. Island biogeography theory is based on the idea that an island's area can determine the number of species found there, though habitat diversity will also influence this. Williams (1981) gives the formula for a species area curve for New Zealand lizards;

$$S = 6.1A^{0.31}$$

where S = number of species and A = land area of island in km^2
Kapiti's area of 19.65 km^2 predicts an expected number of 15.4 lizard species. With the size of the island and its biogeography, Kapiti has broad habitat diversity, including lowland grassland, coastal and high altitude forest, high altitude grasslands and cliff faces, providing potential environments for a range of skink and gecko species. This diversity would normally link to a high species diversity (Gorman, 1996), but this seems to not be true at present. What this does allow is the potential for the island to be suitable for successful translocations. There are several species found in the Sounds-Wellington region that may have occurred on Kapiti naturally in the past or would be expected to be present there now. Now that the island is free of introduced mammals and the chances of pests reaching the island kept low through biosecurity protocols, those species particularly sensitive to mammalian predation would have a higher chance of persistence.

A translocation of a species is the human-mediated movement of an organism from one area to another. This may be from wild or captive populations and can be accidental or intentional. This may be done for a variety of reasons but, in this case, would be for a conservation benefit where it is intended to increase the conservation status of the species and work towards restoring natural ecosystems. If a species is translocated into parts of its previous range from which it has disappeared, this is called a reintroduction (IUCN/SSC, 2013), and potential translocations to Kapiti would likely fall in this category; i.e. species would only be considered if found in the Wellington region and likely to have been present on the island in the past. Further information would need to be gathered in order to establish what species would be most suitable for translocation, where on the island they should be placed and the effects that avian predators might have on reintroduced species.

4.1.1 Translocations of New Zealand Lizards

Translocations are a commonly used technique in the conservation of many New Zealand native species, and since the eradication of introduced mammalian predators from islands is feasible, lizard translocations can be undertaken. Translocations to mainland sites are often more challenging as it is difficult to eliminate introduced mammals permanently. Of 15 translocations of lizards to predator-free islands only five of them have been seen as self-sustaining so-far (Romijn, 2014). One of these were the four species of skinks translocated to Korapuki Island, with Whitaker's skink (*Oligosoma whitakeri*) transferred from Middle Island and the robust skink (*Oligosoma alani*), marbled skink (*Oligosoma oliveri*), and the egg-laying skink (*O. suteri*) transferred from Green islands. For the release of Whitaker's skink, artificial home sites and burrows were placed within the release site while the remaining species were released at a single location and left to disperse into unmodified habitats (Towns & Ferreira, 2001). Robust skinks and marbled skinks were released into forested habitats at separate release sites to reduce competition, while the egg-laying skink was translocated to a coastal rocky area that was most closely matched to the habitat they were in on Greens Island (Towns & Ferreira, 2001). Post-release monitoring was done for each species using pitfall traps and it was found all populations were expanding but due to low catchability and extreme longevity, monitoring would need to be done for as long as 20 years after release to truly see the success of these translocations (Towns &

Ferreira, 2001).

A monitoring study in 2011 analysed common skink abundance and distribution on Ulva Island, where they were reintroduced in 2005 and 2006. Monitoring was done using artificial covers and indicated a dramatic drop in populations as well as little dispersal, with the probable cause being limited habitat and predation/competition from weka (Sharpe, 2011).

In 2006, Duvaucel geckos (*Hoplodactylus duvaucelii*) were transferred from Korapuki Island to Tiritiri Matangi (n=19) and Motuora (n=20). Post-release monitoring was done via radio-telemetry, spotlight searches, footprint tracking tunnels, artificial refuges and funnel traps. This showed extensive post-release dispersal and use of multiple habitat types. There were no mortalities during the monitoring carried out for a year after release, and captured individuals showed increases in body condition within this time. Monitoring in 2009 showed recruitment. Further annual monitoring would determine breeding success and population growth, but both translocations appeared to be successful (van Winkel et al., 2010). In 1988, a population of Fiordland skinks (*Oligosoma acrinasum*) were released onto Hawea Island in Fiordland following the removal of Norway rats, and they increased five-fold in just five years (Lettink et al., 2010b). With regards to translocations of lizards, many attempts have been seen as unsuccessful and for many long-lived species a commitment needs to be made for some form of post-release monitoring for up to 20 years after release in order to confirm population growth.

4.1.2 Reintroduction Guidelines and Underlying Theory

There are a number of steps that need to be followed when carrying out a translocation. Structured decision making is often essential for conservation management, and involves analysing a decision by breaking it into components in order to identify the best decision with regards to particular objectives (Martin et al., 2009). First, the decision needs to be made whether a translocation is an acceptable option. This means assessing both the benefits and the risks of the translocation, and if too much uncertainty remains then other conservation solutions should be chosen (IUCN/SSC, 2013). In the case of Kapiti, many of the reintroduction candidates are at risk or are vulnerable, so their conservation status would benefit from an additional population. The main risks are uncertainties about whether the island is suitable for the species proposed for reintroduction. Although the obvious cause of extinction, rat predation, has been eliminated, the habitats have changed from their original states so it is unclear that all species formerly found on the island could persist there now. In particular, the risk of avian predators would need to be assessed more thoroughly before translocations occurred.

The next step is to start planning the translocation. This involves formulating a goal which should state the intended result of the translocation (IUCN/SSC, 2013), for instance for Kapiti it may be to re-establish the islands historic lizard fauna or increase the conservation status of a number of lizard species that may thrive on Kapiti. The objectives need to be established which will detail how the goal will be carried out addressing all threats to the species (IUCN/SSC, 2013). In terms of translocations to Kapiti this may involve establishing the magnitude of threats from native avian fauna, especially weka. There is also a need for the development of an exit strategy if the translocation does not go to plan and there is no benefit to continuing (IUCN/SSC, 2013).

Once the planning is carried out, the next step is to look at feasibility and design. Biological feasibility involves considering the basic biological knowledge of the species, habitat suitability, climate requirements, the potential founders, animal welfare, and diseases and parasite considerations. As well as biological feasibility, there is the social feasibility of the translocations, which depends on effects on human communities, for instance, the involvement of the iwi that are linked closely with Kapiti. There is also the need for the translocations to meet any regulatory requirements governing movements of organisms and release at the destination site (IUCN/SSC, 2013).

Last of all the availability of resources needs to be understood. This determines if funding is available at all levels and that the budget is sufficiently flexible to allow the changes to translocations that commonly occur. A risk assessment will need to be carried out where all possible hazards during the translocation and after release are assessed in advance and involves; ecological risk, disease risk, genetic risks, socio-economic risks and financial risks (IUCN/SSC).

Once the risk assessment is complete, implementation of the translocation can begin. This involves selecting release areas and sites, which meet all the requirements of the species. IUCN/SSC (2013) guidelines state that a species should not be released without detailed evaluation of habitat quality but it is not always clear how this should be done. One of the biggest reasons for failure of translocations is the habitat quality within the release area. In order to assess release sites for a particular species we need to identify what habitats are and how they may affect the species. A habitat is a species specific complex that is made up of a range of interacting physical and biotic components, which includes other species, and favours species persistence (Osborne & Seddon, 2012). This means that when assessing the suitability of a site it must be understood that characteristics vary spatially and so will species' adaptions to the environment, and that these will change over time.

This can mean that historical locations where the species once persisted may not indicate that it is suitable presently (Osborne & Seddon, 2012). There can be a huge amount of change that can occur within a site since the local extinction of a species, so it can be incorrect to assume historical sites are still suitable even when the obvious reason for decline is eliminated, such as eradication of mammalian predators. Kapiti, for instance, has been through a huge amount of change since human colonisation of the island, with changes in vegetation, decreases and increase in native bird densities, introduction and eradication of exotic species and the current occurrence of species that may not have naturally been found on the island like weka, and exotic birds like blackbirds (*Turdus merula*).

But it can also be incorrect to assume a site where the species is absent means that the site is unsuitable. It cannot be expected that a species will occupy all locations that meet their basic needs, unoccupied areas may mean that the population is still expanding, that habitats are rejected due to occurrence of same or other species, or the presence of predators therefore, making it hard to distinguish between unsuitable sites and habitat that is simply unoccupied (Osborne & Seddon, 2012). On Kapiti goldstripe geckos have only been documented in certain areas of island, but this does not mean that other parts of the island are unsuitable. It may just mean they are yet to expand that far or conspecifics and predators are preventing occurrence. This can also be reversed, meaning that locations where species presently occur may not indicate habitat that will support the species in the long-term. For instance long-lived species could persist for a reasonable length of time after conditions have become unfavourable for breeding. Individuals will not always have perfect knowledge of habitat quality and choose accordingly, especially when humans have altered habitats. This outlines the difficulty in choosing habitat for translocations, as just because the species may have persisted there in the past does not mean they will persist there now. We also cannot place a species in a site that appears to meet all the basic needs of the animal as other factors may make it unsuitable, for instance it may be too small for long-term viability (Osborne & Seddon, 2012).

Once release sites have been evaluated and chosen there is also a need for a release strategy, which includes the type of individuals and numbers to be translocated, how many releases will occur, how to minimise stress during the release, and management interventions to enhance performance. When deciding on what type of individuals to release there is often a choice between a wild source and captive-bred source for translocations. In general captive-bred founders have lower survival rates, though most of the evidence of this is from birds and mammals, but the majority (92.5%) of lizard translocations so far have been done with using wild animal founders (Romijn, 2014). Wild source populations may therefore be the best option for a translocation to Kapiti, especially as many of the suggested species persist in the Wellington region.

When translocating species between areas, there is often a holding time between capture and release that allows for disease testing and increasing of body condition. Lizards do not require the large captive spaces that birds and mammals may need but need appropriate environmental conditions and group composition. Hygiene practices are especially important to avoid transmission of diseases, especially *Salmonella*, which is common in translocated lizards. The length of time in captivity needs to considered as it affects body condition and stress, and this can go on to affect survival after release. The release of lizards specifically often involves release-site management, as this can increase the survival of lizards. Post-release management may include pest control or eradication, providing artificial refuges and supplemental food, and an immediate release strategy is common for lizard translocations (Parker et al., 2015).

With regards to the release of lizards into areas of Kapiti, solutions to manage the impact of native avian predators may include release into areas where avian predator densities are lower, release outside birds' breeding seasons, selection of sites with refuges and food sources, and potentially adding refuges for protection (van Winkel & Ji, 2012). Once the release has been carried out the population will need to be monitored and may need continuous management. This allows the performance of the released individuals to be assessed and, therefore, allows for the adjustment of objectives or activation of an exit strategy. Monitoring involves assessing demographic performance, behaviour, ecology, genetics and health of the population (IUCN/SSC, 2013). Lizard monitoring may not be as intensive due to practical limitations. Any translocations occurring on Kapiti should involve some form of post-release monitoring, though in order to establish useful information on the impact of translocated species on the current lizards on the island as well as the impact of the avian predators monitoring will have to be over a long time frame.

Although birds are natural predators of many lizard species, the translocation of lizards into new areas can disrupt their behaviour and increase their activity as they explore, making them vulnerable to predation (van Winkel & Ji, 2012). Small translocated populations may be unable to persist under predation pressures due to a small founder size. When these predator-prey dynamics are not understood, these can severely impact the success of a species translocation (van Winkel & Ji, 2012). It is also essential to understand the potential effects of newly translocated lizards on the island's resident lizards. If the habitat is at carrying capacity, this could cause the loss of the released animals or the displacement of resident lizards (Romijn, 2014). With regards to Kapiti, the island is known to have a fewer species than predicted and is likely capable of sustaining and, therefore, there should be plenty of room for new species, but releases may need to be done in habitats with not as many conspecifics occurring. Some translocations will require continued management, such as exclusion of avian predators like weka and, therefore, the updating and changing of management regimes and on-going monitoring will provide the essential information on the success of any translocations to Kapiti.

4.1.3 Candidate Species

When carrying out a translocation a key step is deciding which species to translocate. The majority of translocations carried out in New Zealand are done in order to improve the conservation status of a species as large numbers of native species have become endangered due to human modification of habitats and introduction of invasive species. IUCN advise that translocations should normally be only done within the historic range of a species, and introducing a species outside its historic range only carried out if no habitat is identified within that range (IUCN/SSC, 2013; Armstrong & Seddon, 2007). So when choosing which species to be translocated to Kapiti, we should aim to select species that previously occurred on the island. If it is unlikely that species did occur on Kapiti then introductions should only occur if it will largely benefit the conservation status of that species, and if there is little to no habitat within the species' historic range. As many of these lizard species are vulnerable to introduced mammalian predation, this can restrict their suitable sites to mammalian predator-free islands like Kapiti.

If it is established that a species did occur on Kapiti previously, or Kapiti has been seen as suitable for an introduction, it must be evaluated that habitat exists for that species. Weka are present on Kapiti, and they are known to be keen predators of lizards and may be the major reason for the slow recovery of currently occurring species like ornate skinks (Chapter 2). For Kapiti to provide habitat for many of the species suggested for translocation, there will need to be some form of weka control, especially in the early release stages. This may involve weka exclusion via fences around release sites, refuge supplementation to provide safe areas of cover for lizards and releasing lizards into areas with lower weka densities. Weka tend to prefer marginal bush and open scrubland (Carroll, 1963) and may occur in reasonably high densities in Coastal Forest and Kanuka Forest on Kapiti. Therefore it may be best to avoid releases into these habitats and instead focus releases into grassland areas to attempt to reduce effects of weka.

For some species more intensive monitoring, not translocations, may be needed to establish if and where they are present on Kapiti. For instance the goldstripe gecko is known to be present on Kapiti, although they were not encountered in this 2014-2015 sampling. This potentially provides another secure population of the species (Brown et al., 2015). There is no need for translocations of this species at the current time, but further monitoring will establish population trends and the success of their recovery and any need for future aided movement to different areas of the island. This may be similar for the Duvaucel's gecko, as Whitaker's (1995) survey on Kapiti may have detected their presence based on eye reflection from a large gecko spotlighted at the top of the western cliffs above Taepiro stream. Where this species co-occurs with rats, it is restricted to sub-optimal habitats like cliff faces that are inaccessible to predators. Such habitats occur on the western side and north-western end of Kapiti. Therefore this species may have remained in small numbers in these areas. Spotlighting sessions may need to be carried out in potential habitats to establish if this species is already present. If their presence cannot be confirmed then there is a potential for reintroduction into the western cliffs. In general, before any translocations take place it will be important for some further intense monitoring over a number of summer seasons in a range of habitats to establish the presence of species that may have been missed by previous survey efforts.

Gorman (1996) and Whitaker (1995) agreed on several species that might be expected to be found on Kapiti in the absence of rats, and therefore, be appropriate for future translocations. Many of these species are threatened or declining, so any establishment of new populations would benefit the species as a whole. A draft has been developed for Kapiti Island Ecological Restoration Strategy by DOC (Brown et al., 2015), and this puts forward lizard species for translocations. This strategy looks to maintain and restore ecosystems, protect threatened fauna and flora, manage threats, translocate plant and animal species naturally found or previously found in lowlands of south-west North Island and islands of northern South Island and to translocate appropriate threatened species from elsewhere to Kapiti. It is important to note that this strategy does not aim to restore Kapiti to an original state but it assumes that if threats are managed and appropriate species added, Kapiti will restore itself. The lizard species most appropriate for translocations to Kapiti are discussed below.

Pacific Gecko (*Dactylocnemis pacificus*)

Pacific geckos occur throughout the North Island but are one of the rarer gecko species in the Wellington region, only occurring in the Hutt Valley area, and are particularly vulnerable to introduced predators (Whitaker, 1995). It is possible that this species has reached Kapiti since the rats have been eradicated from it, or a relict population was always present and had increased to a detectable size. Their similarity to common geckos can lead to misidentification, but all common geckos captured on Kapiti were confirmed as common geckos by the examination of the rostral scale. Little is known about the past distribution of the species in the lower North Island but it is likely that it may have occurred on Kapiti in the past. As this species is classified as a relict, meaning the population is either stable or increasing, and further monitoring is needed to establish if the species would have extended their range to include Kapiti, they are a low priority for translocations (Brown et al., 2015)

Spotted Skink (*Oligosoma lineoocellatum*)

Spotted skinks are widespread in the Wellington area but exist in small, scattered populations and are only reasonably common on some islands. They are a large, diurnal skink, and their size appears to make them vulnerable to predation. In the Wellington area, they are generally in coastal habitats but also occupy grassy, scrubby and rocky habitats further inland (Whitaker, 1995). Potential habitat exists on Kapiti Island, such as boulder beaches at Kurukohatu point, Okupe lagoon, Rangatira point and in Wharekohu Bay (Whitaker, 1995). Spotted skinks were not observed in either this study or that of Gorman (1996), but the boulder beaches were not extensively searched so further sampling may need to be done to establish presence. If they are not detected, translocations may occur into sites that are protected from weka, as this species does not do well in areas with predators, with much higher population densities of spotted skinks found on islands free of mammalian predators and weka, such as Motuanu Island (Lettink et al., 2010b). Establishment of a population on Kapiti would extend the species' range and restore some of its past distribution in a site free of introduced mammals. However, this species is classed as a relict making them a medium priority species for translocation compared to other more vulnerable species (Brown et al., 2015).

Speckled Skink (*Oligosoma aff. Infrapunctatus* "southern North Island")

The speckled skink is another large, diurnal skink that is sensitive to mammalian predators. It is widespread on many islands as small populations in fern, shrub, rocky areas and coastal forest (Whitaker, 1995). This species is usually easy to find and reaches high densities on islands free of introduced mammalian predators, for instance on Stephens Island and Whale Island, so it is unlikely to have avoided detection on Kapiti if present (Whitaker, 1995). On the mainland they have a scattered distribution but may have once been widely distributed throughout the North Island. In the lower North Island they are known from sites between Patea and Wanganui and a few sites in the Wairarapa (DOC, 2002). Speckled skinks are known from areas near Kapiti and it is likely that this species may have previously occurred on Kapiti. The species is known to reach high densities on islands free of introduced predators, so also has the potential for successful establishment on Kapiti. Habitat for this species does occur on the island, especially in the Coastal Grasslands and forest areas of the north end and Rangatira Point which were covered during this 2014-2015 sampling, and this area may be the first choice for any future translocations. This species is nationally vulnerable, and therefore is a high priority for future translocations in order to secure the future of the species (Brown et al., 2015).

Whitaker's Skink (*Oligosoma whitakeri*)

The Whitaker's skink is a rare species with one population remaining on the mainland and many restricted to predator-free islands. They previously occurred at low elevation throughout the North Island, but predation by introduced mammals caused many local extinctions (Whitaker, 1995). The only area on the mainland where they were known to persist in recent times was at Pukerua Bay near Wellington where deep boulder beds offer some protection. They are also found in the Mercury Islands and have been translocated within the Mercury group (Whitaker, 1995). Whitaker's skinks are largely nocturnal and forage on the forest floor, making them extremely vulnerable to predation. Deep boulder bed habitats exist on Kapiti, especially on the north coast between Toakiti Point and Arapawaiti Point, at Wharekohu Bay and areas of Rangatira Point (Whitaker, 1995). Suitable scree with rock piles exist extensively in some areas of the coastal forest habitat, and extended pitfall trapping may need to occur to determine whether this species is present, their presence may be unlikely as they are highly sensitive to predation and are found in very few places. It is very likely this species was present on Kapiti, as a population is found close by at Pukerua Bay and there appears to be areas on Kapiti that allows protection from predators. For the successful translocation of this species to Kapiti there would be a need for some form of weka exclusion or refuge supplements to help protect this species, as their habits may make them very vulnerable to weka predation. This species is nationally endangered and is a high priority for translocations to potentially suitable sites like those found on Kapiti (Brown et al., 2015).

McGregor's Skink (*Oligosoma macgregori*)

McGregor's skinks are present on many islands around New Zealand including Motuharakeke, Mauitaha, Sail Rock and Mana, and have been reintroduced to Lady Alice and Whatupuke (Whitaker, 1995). Like Whitaker's skinks, McGregor's skinks are large and nocturnal and forages on the forest floor, making them very vulnerable to predation and only persisting in areas free of introduced mammalian predators (Whitaker, 1995). Habitat for them does appear to exist on Kapiti, and surveys would need to be carried out first to establish if any populations have persisted on the island. Reintroduction would need to be limited to sites where weka can be excluded, or into sites where natural protection occurs like deep boulder banks. In addition, McGregor's skinks are aggressive and can competitively exclude smaller skink species from sites (Brown et al., 2015). They do not co-exist with other members of the genus on Motuharakeke Island or Sail Rock, so may negatively impact other *Oligosoma* species occurring in an area they were released in. McGregor's skink is a medium priority for translocation as it is recovering and other species should be established first (Brown et al., 2015)

Robust Skink (*Oligosoma alani*)

The robust skink is another potential species to reintroduce to Kapiti. They are widely distributed on the North Island and based on fossils are known to have occurred on Mana Island in the past (Whitaker, 1995). Translocated populations are present on Koropuki, Stanley, Red Mercury and Motu o Pao. They are large, nocturnal skinks, and therefore, vulnerable to predation and largely restricted to rat-free islands off the northern North Island (Whitaker, 1995). It is likely they occurred on Kapiti historically, but unlikely that they survived the long period of mammalian predation. If they did persist, they would have been restricted to boulder banks and scree, but their success on other rodent-free islands may make them suitable for reintroduction to Kapiti (Gorman, 1996; Whitaker, 1995). This species is known to be recovering and is a medium priority for translocations as more vulnerable species should be established first (Brown et al., 2015).

Striped Gecko (*Toropuku stephensi*)

The striped gecko is one of New Zealand's rarest lizards. It has only been found on Stephens Island and Maud Island in shrub-land and forest. Individuals have recently been found in the Coromandel, and genetic data show them to be conspecific to those from the Cook Strait region (Whitaker, 1999). This species is nocturnal and arboreal, and although it is present on rat-free islands, it is either rare or elusive as there are often very few sightings. On Stephens, they are known to be sensitive to tuatara predation and on Maud Island are readily preyed on by morepork and other nocturnal avian predators, which might be why they are still apparently rare. They are readily found in shrubland and kanuka remnants (Whitaker, 1999) which occur on Kapiti, so habitat may be available. If, after sampling potential habitat on Kapiti, the species was not detected on the island, then translocations might potentially take place. However, the priority for this species is low as although it is nationally vulnerable, other Marlborough Sound islands and islands off the Coromandel Peninsula are more appropriate for translocations of the species, as it is very difficult to establish from its current distribution whether it would have naturally occurred on Kapiti (Brown et al., 2015).

Marbled Skink (*Oligosoma oliveri*)

The marbled skink is found only on the Poor Knights Islands, Mercury Islands and Aldermen Islands. It is a crepuscular to nocturnal skink that mostly inhabits coastal forest and scrub, spending the majority of its time in leaf litter (Brown et al., 2015). There is potential habitat for the species in the coastal forest and scrub areas of Kapiti, but the existing range of the species gives no indication that it would have occurred on Kapiti. Surveying of appropriate habitat would need to be done in order to determine their presence, and if not found, a translocation should only be attempted if it is confirmed they did occur previously on the lower North Island. Weka would need to be excluded from a large enough area to establish a translocated population. Translocation to Kapiti is of low priority as the species is a relict, there are suitable islands closer to source populations, and there is no evidence this species naturally occurred on Kapiti (Brown et al., 2015).

Tuatara (*Sphenodon punctatus)*

The tuatara is a rare long-lived reptile that is the only extant member of the Order Sphenodontia and is only found in New Zealand. They were once found throughout the mainland but since the introduction of rodents were restricted to offshore islands (Towns et al., 2006). Due to the uniqueness of the species they are extremely important to New Zealand and recognised internationally and, therefore, the establishment of new populations hugely benefits the conservation of the species. Tuatara have been translocated to islands as well as to fenced sanctuaries on the mainland. They were probably present on Kapiti, but the introduction of kiore (*Rattus exulans*) would have impacted recruitment and Norway rats (*Rattus norvegicus*) would have quickly wiped out the population (Brown et al., 2015). If reintroduction to Kapiti is considered Cook Strait populations would be the best source. As there are more suitable areas available for translocations, and vulnerable or declining lizard species may be the first choice for translocations of kapiti, as well as juvenile tuatara potentially being vulnerable to weka predation, tuatara is a low priority for reintroduction to the island (Brown et al., 2015).

4.2 Restoring the Reptile Fauna of Kapiti Island

The majority of the species in the Wellington area that may be successful on Kapiti are at risk, with species like the speckled skink and the striped gecko nationally vulnerable and Whitaker's skink nationally endangered. There are a number of relict species up for potential translocations including Duvaucel's gecko, spotted skink, marbled skink, pacific gecko and the tuatara. This means their populations include less than 20000 mature individuals but the population is stable or increasing. A few species like McGregor's skink and the robust skink are known to be recovering, and may not be as high of a priority for translocation as other species (Hitchmough et al., 2013). The speckled skink and Whitaker's skink are seen as the highest priority for future translocations, as it is essential for the conservation status of these species to establish additional populations on predator-free islands, and they likely previously occurred on Kapiti. As these species are particularly vulnerable, it may be better to attempt a translocation with a relict species like the Duvaucel's gecko or the spotted skink. This may provide the information needed to assess the success of a lizard translocation to Kapiti and establish whether avian predators like weka can be excluded from release sites long enough for viable populations to develop, as many translocations would be dependent on this. The use of a less vulnerable species means that if there is a loss of population or if an exit strategy is necessary, it is less likely to have detrimental effects on the conservation status of a recovering or stable species then one that is declining.

For deciding on which species to attempt translocations with to Kapiti, it is important to establish whether the aim is to restore Kapiti's original lizard fauna or to improve the conservation status of vulnerable lizards regardless of whether they occurred on Kapiti previously. If we are aiming to restore Kapiti ecosystems to a historic state, this may mean species like striped geckos or the marbled skink are not an option for translocations as there is little evidence they ever occurred on the island. Then again, Kapiti has changed greatly since human establishment and if habitat currently exists for a species on Kapiti but not in its historic range, and if a translocation will truly benefit that species' recovery, then the list for potential species to translocate may expand. Overall, several lizard species would benefit with the establishment of a new population on Kapiti, and with a wide range of habitats available as well as the reduction and control of potential risks, Kapiti has the potential to hold a number of different species successfully.

Overall, Kapiti has the potential for successful translocations of a number of different lizard species. The size and diversity of the island provides adequate ecological niches for many different lizards and the addition of new populations can make a huge difference to the conservation status of vulnerable species. As seen from my research, the populations of a number of skink and gecko species that already occur on Kapiti have increased and may have expanded their ranges since the eradication of rats from the island. With the removal of rats from Kapiti we remove a key reason for the restriction and extinction of lizard species on Kapiti, therefore allowing for potential translocations. Several species have already been prioritised for future translocations and currently there is the need for additional sampling to establish the presence of certain species and then a risk assessment of the effect of avian predators like weka. Any future translocations will involve detailed planning and research as well as continuous management and monitoring but will aid in the establishment of ecosystems closer to those that occurred on Kapiti previous to human colonisation.

4.3 Overall Conclusions

This research carried out over the 2014-2015 summer months examined aspects of the lizard fauna present on Kapiti in order to quantify the potential benefits of the rat eradication in 1996. Through the use of Gorman's 1994-1996 sampling, I could accurately estimate changes in densities, behaviour and size distribution of a range of lizard species present, allowing a more comprehensive understanding of the effects of rats as well as the potential for future research and reintroductions.

Some of the lizard populations on Kapiti have apparently benefited from the eradication of rats, but not all aspects have changed as predicted by Gorman (1996). Common skinks (*Oligosoma polychroma*), brown skinks (*Oligosoma zelandicum*), copper skinks (*Oligosoma aeneum)* and common geckos (*Woodworthia maculatus*) all appear to have benefited from the eradication of rats as their densities increased up to 12 fold and they were found in habitats where they were not previously recorded. In some circumstances, analysis of brown skink and copper skink densities indicated that increases were explained by changes in vegetation, and though this might be an indirect effect of an absence of rats these changes cannot be directly attributed to rat eradication. Changes in Kanuka Forest are particularly interesting; during the 199/1996 sampling there were no pitfall trap captures and encounters during daytime searching and spotlighting were limited, but in this 2014-2015 sampling eight common skinks and seven brown skinks are found in this environment and common geckos are readily observed both day and night.

The three remaining species known to be on Kapiti before the rat eradication, the green gecko (*Naultinus punctatus*), forest gecko (*Mokipirirakau granulatus*), and ornate skink (*Oligosoma ornatum)*, have apparently not responded as predicted and are still seemingly rare. The green gecko and the forest gecko are two arboreal, cryptic species which are not caught in pitfall traps and are difficult to find via spotlighting and daytime searching so it is difficult to define whether they are still rare or the methods were not sufficient to detect them. The forest gecko was not detected at all during my study. There were two incidental sightings of the green gecko on the north end of the island during the2014-2015 sampling season (Appendix One), so they are still present on the island. The ornate skink was predicted by Gorman (1996) to increase in abundance and range, as being a medium-sized skink in coastal forest habitats they may have been at most risk from rodents. Only one ornate was caught in pitfall traps and a few others seen via incidental sightings, suggesting they are still rare on Kapiti. An incidental sighting of one ornate skink in the High Forest habitat shows a potential extension of range but the absence of rats appears not to have benefited this species.

Goldstripe geckos (*Woodworthia chrysosireticus*) were discovered on Kapiti in 2013, but the areas where they were found were not included in the 2014-2015 sampling since those areas were also not included in the 1994-1996 sampling by Gorman (1996). Goldstripe geckos were not found during my study despite appropriate habitat existing on the north end of the island, either because they are yet to reach this area or are still too rare to be detected.

Introduced predators not only affect diversity and habitat choice of lizards but also their behaviour and size. There appears to have been no change in size distribution of the three grassland skink species on Kapiti over the last 20 years, with the Kapiti populations lacking large (> 6 cm SVL) individuals. It was predicted by Gorman (1996) that with the removal of rats there would be an increase in large individuals present as these would have been more vulnerable to rat predation, but this has not occurred. The lack of change may be due to birds exerting a similar predation pressure to rats or the change in vegetation being more suitable for small individuals. Gorman (1996) also documented the lack of terrestrial behaviour of common geckos, which he defined as how many geckos were encountered on the ground during spotlighting and captured in pitfall traps, and how this might change as rats are removed from the island. During this 2014-2015 sampling the terrestrial behaviour of common geckos was also noted to see if there was any apparent change. A number of common geckos were caught in pitfall traps showing a potential increase in terrestrial movement and numbers, but during spotlighting sessions nearly all geckos were found off the ground. With the removal of rats, it was thought by Gorman (1996) that the vulnerability to predation would decrease and more of the population might be found foraging on the ground. The population may not have followed this prediction because there is a food source present on flax and in shrubs or that off the ground foraging allows more protection against nocturnal avian predators. As with density changes other aspects of the populations have not followed the predicted course after rat eradication and this may be due to a number of other variables present in the habitat.

4.4 Further Monitoring and Research

4.4.1 Monitoring

As my research was carried out for comparison with data collected by Gorman (1996) from 1994–1996, there was little room for changes to the sampling design as this would have reduced the validity of comparisons. Also, some methods and sampling areas were removed based on recommendations made by Gorman (1996). If research in this same area was carried out again different methods and more habitats could be added to increase the chance of detecting apparently rare or cryptic lizard species. Artificial retreats may be good for environments like Coastal Grasslands where many common geckos and skinks were found under retreats like logs and traps, and the use of them in the Coastal Forest may increase the chance of ornate skink captures if pitfall traps are not effective. When artificial retreats are compared to methods like capture-mark-recapture pitfall trapping, skink counts from retreats in good weather conditions provide a reasonably accurate and highly precise index of population size (Lettink et al., 2011).

There is room for the inclusion of methods to catch the more arboreal, cryptic species like green geckos and forest geckos as these proved to be quite elusive with the methods used during the research on Kapiti. Since 1996, additional methods have been developed to collect data on lizards. Although pitfall traps, spotlighting and daytime searching are still popular and usually effective detection methods, they only suit certain species, and searches may not result in the capture or correct identification of species. For instance, the use of closed cell foam covers as artificial retreats on trees was found to detect the presence of geckos more effectively than conventional methods, and in some cases forest geckos and pacific geckos

(*Dactylocnemis pacificus*) were only detected using this method (Bell, 2009). This method has the advantage of capturing a more representative sample of lizard populations as it more effectively detects arboreal species, and is also able to detect lizards in low-density populations, and have lower costs and maintenance (Bell, 2009). Another method is the use of tracking tunnels which has been used in invertebrate and lizard monitoring with much success (van Winkel, 2008). Tracking tunnels can allow the identification of lizard species through footprints, and, therefore, are capable of detecting highly cryptic species and provide presence and absence data. For example, a small population of geckos on Tiritiri Matangi were only discovered when their footprints appeared in rodent tracking tunnels (van Winkel, 2008). With the addition of some new methods, there may be more chance to capture some of the rarer species on the island, especially those that are arboreal and cryptic.

Not all of Kapiti was monitored in this study, and the addition of new habitats may expose new species not known to the island or extend our knowledge on species only briefly encountered previously. The south end of the island would be a good area for future sampling, including both a grassland and forest habitat, as this is the area where most of the goldstripe geckos were previously found (Barr et al., 2013). Forest habitat near to the summit would also be interesting to include, as during the 2014-2015 sampling when walking back from spotlighting in the Ridge Grassland geckos were readily seen in the stretch of forest there. Although some of this forest is very similar to the High Forest habitat sampled, the higher altitude could make a difference to the species found there. The 2014-2015 sampling season was reasonably short and with some aspects of the population like the size and behaviour a larger sample size is needed, as well as more sampling effort to pick up rare species. It would be beneficial for research to be carried out over a number of summer seasons using more observers with more herpetological experience. These additions to the methods would provide more data on the lizard fauna on Kapiti and allow a deeper understanding of what is occurring within these populations. Further monitoring would also help to establish if the rainbow skink (*Lampropholis delicata*) has arrived on the island. This is an invasive species introduced from Australia, and has been known to outcompete native New Zealand skink species in a captive environment (West, 1979). It is likely that the current range of this species will continue to extend south (Peace, 2004). The Department of Conservation are interested in quickly detecting this species' presence on islands like Kapiti and preventing further spread as they can have detrimental effects on translocated or already present, recovering lizard species.

4.4.2 Research

This research and those carried out previously simply open the way for more in-depth research on all aspects of lizard populations on Kapiti. This current research has exposed what changes have occurred since rats were removed from the island and although it provides some answers it also raises a number of questions. With the large numbers of skinks and geckos captured in Coastal Grassland, Ridge Grassland and Kanuka Forest, these habitats provide potential for large enough sample sizes to carry out research on aspects of the populations like survival, reproduction and behaviour. A bigger sample size, especially of geckos, would also provide more convincing data on the size distribution of species.

As some of the results from the 2014-2015 sampling were not what was predicted, further research may expose what other factors are at play. Avian predators may be having the biggest effect on the recovery of certain species as well as on their average size and behaviour. Therefore, it is important to establish the true effect of these natural predators. For instance exclusion experiments could be carried out. This is when areas where skinks and geckos are found are fenced off or blocked in some way to reduce predator interaction and then these plots compared to unfenced plots to quantify the difference in the lizard populations. This has been done on Kapiti to determine the impacts of weka on abundance of lizards, though this research was never officially analysed or published, therefore there is potential for similar projects to be carried out and properly analysed.

Comparisons can be made between Kapiti and other places, in order to see the same species in habitats where certain avian predators are not present. This was done briefly by Gorman (1996) in the 1994-1996 sampling when he compared skink size and gecko behaviour between Kapiti and Mana, which the latter at that time had fewer species of avian predators like weka (*Gallirallus australis*), long-tailed cuckoo (*Eudynamys taitensis*) and morepork (*Ninox novaeseelandiae*). Additionally it would be beneficial to analyse the specific diet of some of these birds on Kapiti to establish what percentage of their diet is made up of lizards, this can be done by looking at regurgitated pellets, faeces, nest samples and gut analysis. On Tiritiri Matangi diet analysis of kingfisher (*Todiramphus sanctus*), morepork and pukeko (*Porphyrio porphyrio*) through a number of methods found that 88% of a kingfisher's diet was made up of lizards (van Winkel & Ji, 2012). Not only can these methods provide information on birds' predatory effects but also can show overlap between diets of birds and lizards, therefore, exposing competitive effects as well.

As the limited terrestrial behaviour of common geckos may be linked to a nocturnal, arboreal food source the diet of the lizard species on Kapiti should be analysed as well and compared to other similar islands, for instance, Mana or mainland areas to see if differences in diet can explain the differences in behaviour. Further research into the effect of vegetation on skink species could help to explain why some changes in lizard density were explained by vegetation changes rather than the eradication of rats. This could involve looking in more detail at the vegetation present in habitats like Coastal Grasslands, Ridge Grasslands and Kanuka Forest and comparing a number of patches within habitats to see which species prefer which areas more. This may also decide whether vegetation is also having an impact on size distribution and behaviour of species which may involve again comparing vegetation differences within two similar habitats and establishing what effect this is having.

As in most eradication programmes, the benefits to species can be difficult to predict due to a large number of other factors present in the environment. This is what has occurred on Kapiti, and although this research has increased the knowledge on the densities of lizard populations present, and many lizard species appear to have dramatically increased, there is still information lacking and the continued need for research to be carried out.

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Appendix One: Incidental Sightings

- On 8 December 2014, a common gecko was found on the beach under some driftwood on Rangatira Point, and later that day an ornate skink was found under some wooden boards near the boat shed.
- On 9 December 2014, a common gecko was found under driftwood on the beach on the north end of the island, near where the boat lands.
- On 15 January 2015, a common gecko was found under the seats in the visitor's shelter at the north end of the island though this was the only one captured there were a substantial number present in this area.
- On 16 February 2015, a common gecko was found on 16b track back to the Seismo Hut from Ridge Grassland habitat near the summit of the island, and another gecko was spotted further along on a tree eating a weta.
- On 24 March 2015, a brown skink and a common gecko were seen and captured in Seismo Hut near the summit of the island.
- Many lizards were found in pitfall stations before they were baited. In Ridge Grassland, five common geckos, nine common skinks and two brown skinks were found this way. In Coastal Grasslands 10 common geckos, 11 common skinks, four brown skinks and one copper skink were found this way. In Kanuka Forest, two common geckos and one common skink were found this way.
- An ornate skink was found on 11 January 2015 in a pitfall trap in the High Forest habitat and four more ornate skinks were found in pitfall traps in the Coastal Forest before they were baited.
- On morning of 1 January 2015, a green gecko was seen by Manaaki, a Kapiti Island Nature Tour guide. It was found on flats by the lodge at the north end of the island.

- On 10 March 2015 at 10:30 another green gecko was seen by one of the assisting rangers on Kapiti Island, Nick Fisentidis. It was sunning itself on a north-facing bank on the northern section of the Okupe loop track, the same habitat that the 2014-2015 Kanuka Forest transects cover.

Appendix Two: Locations of Pitfall Stations and Transects

Pitfall Station	GPS Location	Altitude (metres)	Notes on Location
CF1	E2672795 N6037429	27	In rock pile behind historic house
CF2	E2672662 N6037193	38	Start of Wilkinson walking track, off track just after stream
CF3	E2672461 N6036982	24	In forest along the coast
CF4	E2672408 N6036955	23	In forest along the coast
AD1	E2672358 N6037960	290	By trap 233, line 45
AD2	E2672358 N6037767	291	Along line 40a
AD3	E2672333 N6037739	311	Along line 40
AD4	E2672210 N6037689	304	Along line 40. Metal stake found, exact spot as Gorman (1996)
RG1	E2670031 N6036912	-14	Just off 16B track in flax
RG2	E2670015 N6036851	-6	In flax area
RG3	E2669948 N6036883	6	Metal stake found, exact spot as Gorman (1996)
RG4	E2669948 N6036882	7	Metal stake found, exact spot as Gorman (1996)
RG5	E2669921 N6036870	5	Metal stake found, exact spot as Gorman (1996)
CG1	E2674205 N6040173	-4	Close to shrubline. Metal stake found, exact spot as Gorman (1996)
CG2	E2674396 N6040178	-4	Metal stake found, exact spot as Gorman (1996), in

			grass
CG3	E2674407 N6040042	-8	60° from 5-finger tree. Metal stake found, exact spot as Gorman (1996)
CG4	E2674417 N6039906	-4	Within shrubs and small trees
CG5	E2674338 N6039906	-6	By track along coast
KA1	E2673970 N6040548	-1	Just off walking track through kanuka forest
KA2	E2673886 N6040552	11	Just off walking track through kanuka forest
KA3	E2673779 N6040588	19	Just off walking track through kanuka forest
KA4	E2673810 N6040663	18	Leave track, into forest
KA5	E2673881 N6040631	16	Leave track, into forest

Spotlighting and Daytime Searching Transects

Coastal Forest – 2 Transects

1st: Starts as enter forest off the coast and goes through pitfall stations CF4 & CF5 then back again to the coast

2nd: Follows Rangatira Loop track above pitfall station CF1

High Forest Lines – 2 Transects

1st: Off Wilkinson walking track along old rat trapping line 40 to trig track through pitfall stations AD3 & AD4 and back to Wilkinson

2nd: Off Wilkinson walking track along old rat trapping line 40a to Mckenzie walking track through pitfall stations AD2 and back to Wilkinson

Ridge Grassland – 1 Transect

Starts on the edge of forest and grassland on track 16B till pitfall station RG2 then goes off track into grassland through pitfall stations RG1, RG3 & RG4 and then back to track 16B and finishes at forest edge.

Coastal Grassland – 2 Transect

1st: Follows track that goes along coast passing pitfall stations CG5 & CG4 then back along track to start

2nd: Starts on walking track towards Okupe lagoon then goes into grassland by CG1 and then through CG2 & CG3 and then back again to start

Kanuka Forest – 2 Transects

1st: Goes along track in Kanuka Forest passing pitfall stations KA1, KA2 & KA3 and then back again to start

2nd: Goes off track through Kanuka forest through pitfall stations KA4 & KA5 and then back again to start