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# **Monitoring the impacts of invasive mammals on arboreal geckos' habitat use, cell foam retreat use, and the effectiveness of different monitoring techniques.**

A thesis submitted in partial fulfilment of the requirements for the degree of  
Master of Science in Conservation Biology  
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New Zealand

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DOC: AK 20666-FAU; General handling Permit (includes Iwi consultation) (under Dianne Brunton)

Ethics approval: Standard research handling of geckos, i.e. measuring demographics only, which does not require animal ethics approval.

“Four things on earth are small, yet they are exceedingly wise... A lizard grasps  
skillfully with its hands, and it is found in kings’ palaces”

Proverbs 30 vs. 24...28

*For Adonai*

# ABSTRACT

Gecko ecology was studied in areas of pest control and no control in four areas around Auckland. The density index of geckos was highest at Waiheke (treatment, i.e. pest control) with an average of 137.5 geckos ha<sup>-1</sup> compared with Waiheke (control, i.e. no pest control): 56 g/ha<sup>-1</sup>, Tawharanui: 20.3 g/ha<sup>-1</sup> and Shakespear: 9.5 g/ha<sup>-1</sup>. The Waiheke sites were then studied further; gecko condition was measured and males were found to have lower body conditions at the non pest controlled sites, rats were also found to be more abundant at these sites and large invertebrates less abundant. Habitat was also analysed and geckos were found to be captured under cell foam retreats (CFRs) in areas with lower canopies, higher forest density, a higher proportion of undergrowth cover and smaller canopy areas and tree diameters. These parameters were then used to compare the detectability of geckos with their densities and areas with the lowest densities were also found to have the lowest detectability. The efficiency of CFRs was then compared with VES nightspotting, Onduline artificial cover objects (ACOs) and tracking tunnels. CFRs and VES were found to be similarly efficient with 1.66 geckos hour<sup>-1</sup> for CFRs compared with 1.10 geckos hour<sup>-1</sup> for VES. ACOs and tracking tunnels did not detect any geckos during this study. The humidity at the time of capture correlated with the number of geckos captured per check, with less geckos captured as the humidity increased.

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# CHAPTER ONE

## General introduction



Figure 1.1 Rare 'yellow morph' Auckland green or elegant gecko (*Naultinus elegans*) Photo: Author

## 1.1 History of New Zealand's biota and conservation

New Zealand's evolutionary history diverged from the rest of the world's when it separated from the supercontinent Gondwana, its unique and archaic biota is the result of the subsequent ca. 80 million years of isolation (Cooper & Millener, 1993; Daugherty et al., 1994; Craig et al., 2000; Neilsen et al., 2011). While land area has varied over time due to glaciation periods, geological processes and subsequent changes in sea level, New Zealand's current land area totals 26 million ha in three main islands and 700 islands over 5 ha (Craig et al., 2000). These islands stretch from the sub-tropical to the sub-Antarctic (29°S to 52°S), creating a predominately temperate climate. New Zealand spans two tectonic plates, which results in a diverse island landscape dominated by mountain chains, volcanoes, rolling hills and river flood plains (Craig et al., 2000). This landscape has resulted in a diverse flora and fauna, which exhibits unusually high endemism and extensive radiation within some taxonomic categories. New Zealand's native lizard fauna demonstrate these characteristics to the highest extent, exhibiting 100% endemism and comprising more than 100 known taxa and undescribed entities (Hickson et al., 2000; van Winkel, 2008; Hitchmough et al., 2010; Neilson et al., 2011). This lizard fauna occupies most habitats, from subtropical beaches in the north to exposed rocky beaches in Fiordland, high altitude grasslands, treetops in many habitats, and even alpine scree and rockfaces (Daugherty et al., 1994).

Whereas the rest of the world's biota has been influenced by the evolution of mammals, birds are the dominant species in New Zealand with seabirds comprising 30% of the avifauna (Craig et al., 2000). This avian dominance influenced the form and distribution of some trees and shrubs, along with reptiles such as tuatara and some gecko and skink species (Craig et al., 2000). High densities of seabirds provide a high input of nutrients into terrestrial ecosystems, these nutrients support invertebrates and vegetation growth which in turn support reptile and avian populations (Mulder & Keall, 2001). The lack of mammalian predators in New Zealand's fauna has lead to the evolution of specialised adaptations such as flightlessness (in some birds and invertebrates), gigantism, extensive life histories, late onset of sexual maturity, and low rates of reproduction (e.g. in reptiles) (Wilson, 2004). These specialisations mean the New Zealand fauna is particularly vulnerable

to environmental modifications and stochastic events, as it is slow to recover (Daugherty et al., 1993). These circumstances have also created a ‘naive biota’ ill equipped to deal with the invasion of humans and the species they bring with them (Gibbs, 2008). For example, over the first 1000 years of human occupation 40% of the endemic terrestrial bird fauna was exterminated (Cooper & Millener, 1993; Towns & Daugherty, 1994). Human colonisation not only had detrimental effects on the avifauna but also on many other New Zealand species and ecosystems due to hunting, habitat destruction, fragmentation and predation and competition from introduced predatory mammals (Towns & Daugherty, 1994; Craig et al., 2000). Agriculture, exotic forests and urban landscapes presently comprise 63% of New Zealand’s land area and have created a patchwork of isolated fragments from a once continuous range of natural ecosystems (NZBS, 2000). In addition, New Zealand has the highest number of introduced predatory mammals of any country in the world (Towns, 2002). As a result of this, around 2,500 native species of plants, animals and fungi are considered threatened, and 40% of endemic birds, six reptile and amphibian species, one bat, one fish, at least 12 invertebrates and 22 vascular plants have become extinct over the last 1000 years (Towns & Daugherty, 1994).

The New Zealand Biodiversity Strategy (NZBS, 2000) has been developed in response to this decline in New Zealand’s biodiversity. The purpose of the strategy is to “establish a framework for action, to conserve and sustainably use and manage New Zealand’s biodiversity, with a primary focus on New Zealand’s indigenous biodiversity” (NZBS, 2000). The strategy sets several goals that cover the involvement of community, the Treaty of Waitangi, halting the decline in New Zealand’s indigenous biodiversity, and maintaining the genetic resources of introduced species. The predominant method outlined in this plan for the conservation of endangered ecosystems and species is the creation of pest free island sanctuaries, and ‘mainland island’ reserves.

Many species that were once widespread on the mainland are now confined largely or totally to pest free offshore islands. These species include, half of all frog species; tuatara (both subspecies) (Cassey & Ussher, 1999; Towns, 2002); over half of the currently identified lizard species (Towns & Daugherty, 1994); nearly all Procellariiform seabirds (Mulder & Keall, 2001); and 48% of insect species designated as protected (Gibbs, 1990). Several of these islands are strictly protected

with restricted public access and quarantine procedures, such as Little Barrier Island (Hauturu), Stephen's Island, Maud Island and Codfish Island (Whenua Hou). Much of the fauna that does persist on the mainland does so precariously, persisting only in small isolated habitats some of which are too inhospitable for mammalian predators. For example, the survival of the recently discovered skink *Oligosoma pikitanga* from Fiordland is partially attributed to the steep cliffs it inhabits and the harsh, rugged surrounding terrain, making it almost impenetrable to predators (Bell, Patterson & Jewell, 2007).

In order to safeguard mainland ecosystems and endangered species, intensive conservation effort must be made. Mainland island sanctuaries including Karori, Mangatautari, Tawharanui, Arc in the Park (Waitakere ranges) and Rotokare have been created by the Department of Conservation (DOC), regional councils and community groups, working in concert. These sanctuaries are set up either using a predator-proof fence and eradication of all pests within the fenced off area, or using an intensive baiting and trapping system, with each system having pros and cons. For example, the predator-proof fence has the greatest chance of completely excluding pests from an area, but the initial costs are excessively high. In comparison, baiting and trapping is more intensive and the costs and labour required are initially lower but are higher over the long term as the baiting and trapping systems are an indefinite process. For each method volunteers are used to offset costs and are arguably the greatest asset to conservation in these areas and to conservation in New Zealand in general.

## 1.2 New Zealand's gecko fauna: taxonomy, ecology and conservation

### 1.2.1 Taxonomy

Until recently gecko fauna was split into two genera: *Hoplodactylus* (11 species) and *Naultinus* (7-8 species). *Hoplodactylus* species are diverse ecologically, behaviourally and in body size, but are morphologically similar. They are grey to dark brown in coloration and generally nocturnal. *Naultinus* are arboreal, diurnal and predominately green but have a diverse range of colourful patterns and stripes. The species diversity of these genera has however been grossly underestimated (Hitchmough et al., 2010; Neilson et al., 2011). A recent study by Neilson et al. (2011) used a multi-gene approach to assess the phylogenetic relationships of New Zealand geckos to one another. Over 180 individuals representing all 19 recognised New Zealand taxa and all but two of 20 putatively new species suggested by previous studies were analysed. The study recognised 20 putatively new species (41 in total), including five new or resurrected genera. *Hoplodactylus* was split into six genera, including five new genera: *Dactylocnemis* (which includes *D. pacificus* and five putatively new species); *Woodworthia* (which includes *W. maculatus*, *W. chrysosireticus*, *W. brunneus* and nine putatively new species); *Tukutuku* (a distinct genus for *T. rakiurae* the harlequin gecko); *Toropuku* (a distinct genus for *T. stephensi* the striped gecko); and *Mokopirirakau* (which includes *M. granulatus* the forest gecko, *M. kahutarae*, *M. nebulosus*, *M. cryptozoicus* and six putatively new species). The *Hoplodactylus* genera now includes only *H. duvaucelli* the Duvaucel's gecko (the largest of the New Zealand geckos) and the recently extinct *H. delcourtii* the Delcourt's gecko or kawekawea, the largest gecko species in the world at over 62 cm in total length (Bauer & Russell, 1986 & 1987). The *Naultinus* genus was unsplit and includes the species *N. elegans*, *N. gemmeus*, *N. grayii*, *N. manukanus*, *N. punctatus*, *N. rufus*, *N. stellatus*, *N. tuberculatus* and the putatively new *N. 'North Cape'* (Neilson et al., 2011).

## 1.2.2 Ecology

New Zealand geckos are among the most unique reptiles in the world, having several life history traits that set them apart from other reptile species. Their breeding strategy, viviparity, is very rarely found in other reptiles, and is defined as the retention of the developing embryo within the uterus until development is complete (Guillette, 1993), a strategy most commonly seen in mammals. Another unique aspect of gecko breeding strategy is that their period of ovarian activity lasts significantly longer than that of any other known reptile or mammal (Cree & Guillette, 1995). Gestation has been known to last up to 14 months in some species such as the common gecko (*W. maculatus*) (Cree & Guillette, 1995), while the harlequin gecko (*T. rakiurae*) from Stewart Island has been known to remain gravid for up to three years (M. Lettink pers. comm., 2011). The common gecko withholds its embryos over winter in order to give birth in summer 14 months later. This act of remaining gravid when it is coldest is thought to be associated with the sex of the foetus as gametogenesis cycles of different lengths may cause different sexes to be born (Cree & Guillette, 1995). This prolonged gestation over winter is uncommon in lizards, although the southernmost gecko in the world *Homonota darwini* from Patagonia has a similarly long biennial gametogenesis cycle of up to 13 months (Ibargüengoytia & Casalins, 2007). A further unique aspect of gecko ecology is their extreme longevity. Both *W. maculatus* and *H. duvaucelli* have been recorded to live at least 36 years and potentially to over 40 (Thompson et al., 1992; Bannock, Whitaker & Hickling, 1999). This extreme longevity can in part be attributed to the temperate and cold climate of New Zealand. Many species of geckos (and New Zealand reptiles in general) are extremely cold adapted. They can withstand and remain active in very low temperatures, with approximately 30 reptile species, such as *W. chrysosireticus*, *M. cryptozoicus* and the skinks *Oligosoma grande* and *Oligosoma pikitanga* inhabiting montane and alpine habitats above 1000 m (Jewell & Leschen, 2004; Bell & Patterson, 2008; Hitchmough et al., 2010; Jewell, 2011). New Zealand also has some of the southernmost reptiles in the world, including *T. rakiurae* from Stewart Island (Thomas, 1981), which is likely to live much longer than 36 years due to Stewart Islands cold climate, and the gecko's very slow reproduction rate.

New Zealand geckos are typically omnivorous, consuming nectar, honeydew, small fruits and predating on invertebrates (Eifler, 1995; Wotton, 2002; Hoare, Pledger, & Nelson, 2007; Gardner-Gee & Beggs, 2010; Jewell, 2011). Some species of plants are thought to be at least partially pollinated by geckos, including *Metrosideros* species (rata and pohutakawa) and flax (*Phormium tenax*) (Eifler, 1995; Olesen & Valido, 2003; Jewell, 2011). Several plants' seeds are also thought to be solely dispersed by geckos (Olesen & Valido, 2003; Jewell, 2011). For example, *W. maculatus* seems to be the major frugivore of *Coprosma propinqua*, a small divaricating shrub. Wotton (2002) studied this interaction, showing that 40% of gecko droppings contained seeds, 95% of which were from *C. propinqua*. The geckos then dispersed these seeds up to 9.3 m and when excreted 72% of the seeds germinated. Whitaker (1987) suggested that divaricating plants (which consist of a dense tangle of interlacing sharp twigs, branching at a wide angle) might be adapted to seed dispersal by lizards. The fruits of divaricating shrubs are often small and inconspicuous and are located deep within the plant. Combined with the tightly interwoven branching pattern, this appears to limit the access of fruit to all frugivores except lizards (Lord & Marshall, 2001; Wotton, 2002).

New Zealand geckos have evolved in an avian-dominated ecosystem, and as such birds along with larger reptiles such as tuatara are their major native predation threats (Walls, 1981; van Winkel, 2008; Jewell, 2011). However, some invertebrates have also been recorded preying on reptiles, such as the red katipo (*Latrodectus katipo*) (Lettink & Patrick, 2006) and giant centipede (*Cormocephalus* spp.) (Pike et al., 2010a; Vallance, 2010; Jewell, 2011). Birds however are the greatest native consumers of lizard prey. Many species have been recorded predating on them, including morepork (*Ninox novaeseelandiae*) (Ramsey & Watt, 1971); New Zealand kingfishers (*Todiramphus sanctus*) (Fitzgerald, Meads & Whitaker, 1986); takahe (*Porphyrio mantelli*) (van Winkel, 2008); pukeko (*Porphyrio porphyrio melanotus*) (Carroll, 1966); weka (*Gallirallus australis*) (Coleman, Warburton & Green, 1983); New Zealand falcon (*Falco novaeseelandiae*) (Fox, 1977); banded rail (*Rallus philippensis*) (van Winkel, 2008); long-tailed cuckoo (*Eudynamys taitensis*) (van Winkel, 2008); and fernbird (*Bowdleria punctata*) (Ball & Parrish, 2005).

### 1.2.3 Conservation

Of the 109 known taxa and undescribed entities of New Zealand reptiles, two species have been listed as extinct: *H. delcourti* (Bauer & Russel, 1986) and *Oligosoma northlandii* (Hitchmough et al., 2010). Seventeen taxa have been listed as threatened, including six as nationally critical, three as nationally endangered, and eight as nationally vulnerable. Fiftyone taxa are listed as at risk, including 10 naturally uncommon, 11 relict, three recovering and 27 declining. Eight taxa are listed as data deficient; 23 are considered not threatened, and there is one introduced and naturalised species (*Lampropholis delicata*, an Australian skink) (Hitchmough et al., 2010). The six nationally critical reptile species are all South Island skinks of the *Oligosoma* genus. The three nationally endangered taxa included two *Oligosoma* skinks and the formally undescribed *Mokopirirakau* ‘Open Bay Islands’ gecko (Hitchmough et al., 2010). In total there are 12 skink and five gecko taxa listed as threatened.

The major threats to all New Zealand reptiles are predation from introduced mammals (especially rats (*Rattus* spp.), cats (*Felis catus*), mustelids (*Mustela* spp.) and potentially possums (*Trichosurus vulpecula*)), and habitat loss and degradation (Towns, 1992; Whitaker & Loh, 1995; Whitaker, 1998; Towns, 1999; Gaze, 2001; Gillies & Clout, 2003; Adams, 2009; Jewell, 2011). While the impacts of rats on many species of New Zealand fauna and flora is extensive, the impacts of rats on reptiles has often only been inferred. For example, the differences in reptile ecology where rats are present have been compared to where they have been eradicated or never been present to infer an impact (Towns & Daugherty, 1994; Towns et al., 2006).

There are few studies that identify the causal mechanism of the impacts of invasive predators on reptile populations (Barr, 2009). A study by Barr (2009) has shown the harmful effects of rats on the chevron skink (*Oligosoma homalonotum*) using a body condition index (BCI) and measuring attempted rat predation using scars and caudal autonomy. Further research by Cree et al. (1995) showed that kiore inhibit the recruitment of juveniles in tuatara (*Sphenodon punctatus*) through the competition for resources and predation on juveniles and eggs. They suggested that this low recruitment would eventually lead to the localised extinctions of tuatara on

rat-occupied offshore islands. Hoare (2006) also showed that the Duvaucel's gecko (*Hoplodactylus duvaucelli*) may persist in the presence of rats through altering their behaviour, but concluded that this may only serve to slow down the inevitable decline and extinction of the populations due to inhibited recruitment.

In order to prevent the further decline and eventual extinction of these threatened species the Department of Conservation (DOC) has drafted species recovery plans. There are currently seven recovery plans for reptiles in effect, including plans for the genera *Oligosoma* and *Cyclodina*; tuatara (*Sphenodon spp.*); Whittakers (*C. whitakeri*) and robust skinks (*C. alani*) (combined); chevron skink (*O. homalonotum*); striped skink (*O. striatum*); and Otago (*O. otagense*) and grand skinks (*O. grande*) (combined). All plans currently focus only on skinks and tuatara with no gecko plans. The Department of Conservation has however drafted an 'action plan' for lizard conservation in the Wellington conservancy. This plan includes the Wellington green geckos (*N. elegans punctatus*), Pacific geckos (*D. pacificus*), common geckos (*W. maculatus*), and the formally undescribed *M.* 'Southern North Island' and *W.* 'Marlborough mini' (Adams, 2009). The plan focuses on improving the knowledge of the reptile fauna of the area through investigating sightings and setting up surveys. It also focuses on the captive breeding and translocation of species into pest-free areas such as offshore islands. Regional Councils, such as the Auckland Council, also develop and carry out recovery plans in the local areas they govern. The Auckland Council has recently set up an action plan to understand the impacts of invasive predators on geckos and to understand the ecology of geckos in the parks around the Auckland Region (Bell et al., 2010).

The recovery plans set several ideal methods for the conservation of threatened and declining species. As the major threats to all New Zealand reptiles are for the most part the same, the recovery plans set out similar objectives for different species. Each recovery plan sets out a number of objectives which include intensive conservation work such as captive breeding, translocations and mainland island establishment. The primary focus of the majority of the plans is the eradication or control of mammalian predators in areas with populations of reptiles. A major objective of the recovery plans is the establishment of more pest-free offshore islands that can act as refuges. However, several gecko species occupy habitat that cannot be found on offshore islands, such as alpine or sub-alpine habitats. For

example, the Otago (*O. otagense*) and grand skink (*O. grande*) recovery plan (Whitaker & Loh, 1995) focuses on the protection of the habitats of existing populations through pest control and consultation with private land-owners (predominately farmers). Where this is not applicable the plan focuses on the translocation of populations to already existing reserves and the establishment of captive populations for breeding programs and advocacy.

While there are no recovery plans set out for the conservation of geckos, the flow-on effects from the recovery plans for skinks and tuatara (along with many other species) will have positive effects on gecko conservation. The recovery plans focus on maintaining and restoring ecological integrity in order to protect individual species. Therefore geckos, while not the focus of these plans, will still benefit from them.

### 1.3 Methods of monitoring arboreal reptiles

The inventory and monitoring of forest lizards, especially cryptic arboreal species such as small nocturnal geckos is currently one of the most difficult tasks facing herpetological conservation, management and research (Bell, 2009). Herpetological monitoring has become increasingly important due to recent declines in worldwide herpetofauna (Gibbon et al., 2000; Ryan et al., 2002; van Winkel, 2008). Therefore there is a need to develop more efficient methods for monitoring reptiles as successful conservation relies on robust sampling and monitoring (Bell, 2009). There are currently several methods for surveying and monitoring herpetofauna, including pitfall traps (Towns, 1991; Newman, 1994), g-minnow traps (Bell & Patterson 2008), artificial cover objects (ACOs) (Lettink & Patrick, 2006; Lettink, 2007), visual encounter surveys (VES), tracking tunnels and the newly developed cell foam retreat (CFRs) (Bell, 2009).

### 1.3.1 Pitfall traps

Pitfall traps consist of small to large sized buckets, 4 to 18 L (depending on species targeted), dug into the ground leaving their rims flush with the surface. Small holes are drilled into the bottom of the bucket to allow water to drain out (Newman, 1994; Crosswhite et al., 1999; Lettink, 2007). The traps are covered with either the lid of the bucket propped up on sticks 1-2 cm above the traps, plywood or steel lids secured with steel pegs (Lettink, 2007; Lettink et al., 2011), or natural covers such as stacked rocks (Newman, 1994). These covers are put in place to provide shade and exclude predators. The traps are usually baited with small amounts of pear or cat food (depending on species targeted) (Newman, 1994; Lettink, 2007). Drift fences are sometimes used in conjunction with pitfall traps, these consist of a length of fence usually made out of galvanised steel, approximately 30 cm high and 15 m long, dug 5 cm into the ground to prevent animals from burrowing under it (Crosswhite et al., 1999) (the fence can range in size depending on the species targeted). The fences are placed radiating out from a central pitfall trap, often with several pitfall traps placed along each fence (Crosswhite et al., 1999). The traps are set out in either a grid or transect, with traps spaced up to 100 m apart.

As with any species-monitoring tool there are many factors that affect capture success, including animal body size, home range size, daily and seasonal activity patterns, trap avoidance behaviour and weather. For example, reptile activity is often irregular and highly correlated with temperature and precipitation (Crosswhite et al., 1999).

There have been records of pitfall traps causing reptiles to be predated on by mice (*M. musculus*), and possibly weasels (*Mustela nivalis*) (Lettink et al., 2011). The gap between the lid of the trap and the lip of the bucket is small enough to exclude large predators such as rats, but will not exclude smaller predators such as mice or weasels (Lettink et al., 2011). The ethical ramifications of this trap are therefore in question as if predators enter the trap the trapped animals have no means of escape and will invariably be predated on.

### 1.3.2 G-minnow traps

G-minnow (or double-ended funnel traps) consist of a shaped cloth or aluminium mesh tube with inverted funnels at either end. They are designed to allow reptiles access into the trap but to prevent their escape. These traps are sometimes used with pitfall traps in drift fence arrays (Enge, 2001) where they are placed along drift fences where a directed reptile can move into them and become trapped. Baits are sometimes used with these traps and in New Zealand pear is most often used. Covers, such as metal or plywood sheets, are used in order to provide shade for any reptiles caught. This however does not always work as the covers can be knocked off or damaged in some way, and as a result any reptiles caught can die from desiccation if the traps are not checked regularly. Also like pitfall traps, g-minnow traps can allow access to small predators such as mice or weasels. Monitoring tools that do not allow animals to escape will always have negative ethical issues associated with them.

### 1.3.3 Artificial cover objects (ACOs)

Artificial cover objects (ACOs) consist of several types of artificial cover that can be used as retreats for reptiles. These include plywood (Ryan et al., 2002), Onduline stacks (corrugated bitumen roofing sheets), corrugated iron sheets, and concrete/terracotta roofing tiles (Lettink, 2007). The ACOs are placed on the ground in transects or grid patterns, and need to be established several weeks (if not months) before monitoring in order to habituate the target species to their presence (Lettink, 2007). The stacked ACOs, such as Onduline or corrugated iron, are made up of two to three sheets (approximately 400 × 280 mm) separated by lengths (1-2 cm) of 10 mm circular pine dowel glued beneath the corners and centre of each sheet, and weighed down with rocks (Lettink & Patrick, 2006; Lettink, 2007). The ACOs provide refuges that are quick to warm and dry out, retaining heat well throughout the day and night (Thierry et al., 2009). They also exclude predators such as rats or birds, while attracting invertebrates which could act as a food source for reptiles. They are more ethical than pitfall or g-minnow traps as they do not confine animals and consequently will not cause death from desiccation or predation.

### 1.3.4 Visual encounter surveys (VES)

Visual encounter surveys (VES) can be carried out in several ways; the most common are night-spotting and habitat searching. Night-spotting involves setting up transects along tracks, the edge of forest margins or through forest areas. These transects are then walked at night with spotlights, in groups of two or more. Using spotlights the canopy, under-storey, branches and the ground are all scanned and any reptiles found are recorded and if possible caught. This method of monitoring has several shortfalls, the primary one being that it relies on the experience of the surveyors. Training is needed to be able to spot reptiles, especially highly cryptic species such as forest or green geckos which are extremely well camouflaged. Another limiting factor is the number of surveyors; the chance of finding an animal decreases exponentially as less people are searching. With only one person searching (regardless of experience), the chances of finding an animal are very small. However, with too many people searching, noise and light may scare the animals away. With people searching at night, other factors arise such as human error, which will increase with time spent searching as fatigue increases. Finally, this technique relies heavily on weather conditions such as wind, rain and cloud cover and also potentially the cycle of the moon as more light at night may discourage nocturnal species from being active.

Habitat searching is, as the name implies, searching a habitat where reptiles are known or thought to inhabit. This is carried out by turning over natural cover objects such as logs, leaf litter and rocks and looking under loose bark or in cavities on trees. The major shortfall of this technique is the amount of time it takes to get any results. Many hours searching can turn up very few individuals, especially if the reptiles are in low densities or are cryptic, nocturnal, arboreal or highly timid.

### 1.3.5 Tracking tunnels

Tracking tunnels are a method of monitoring reptiles without capturing them. They consist of a plastic or corflute tunnel with either a specialised tracking card inside (approximately 30 × 10 cm with a sticky ink in between two blank white cards) or a tracking tray of similar dimensions that consists of an ink-soaked sponge

placed between two cards. The tracking tunnels are baited with pear at either end, and work by attracting reptiles into them and making them walk over the sticky ink or ink-soaked sponge, causing them to leave footprints on the cards. The number, size and shape of the footprints can then be analysed and a species count index can be made which estimates population size in an area. Different species can be recognised through the shape of their footprints, but this is not always highly accurate as a perfect footprint is rarely made on the tracking cards.

### 1.3.6 Cell foam retreats (CFRs)

Cell foam retreats (CFRs) are a novel reptile monitoring technique developed by Bell (2009). They were developed to target arboreal, nocturnal and cryptic gecko species, as current monitoring techniques are insufficient for these species (Bell, 2009). They consist of a sheet of closed cell foam ( $0.5 - 1\text{ m} \times 0.4\text{ m} \times 3\text{-}4\text{ mm}$ ) placed flat on a tree trunk surface (for large trees), or wrapped around the trunk (for small trees). They are specifically targeted at geckos that occupy canopy and tree trunk niches and are designed to mimic and improve natural refuges such as bark and tree hollows, providing a quick-to-warm dry area for geckos (Bell, 2009). Bell (2009) showed that CFRs are more effective at sampling populations of gecko species such as the Duvaucel's gecko (*H. duvaucelli*) than ACOs, g-minnow traps, lizard houses, spotlighting or pitfall traps, they are also more efficient and have a lower cost. Also like ACOs they do not prevent reptiles from escaping and will therefore not cause mortality due to desiccation or predation.

## 1.4 Issues in understanding gecko habitat use

When analysing and comparing the densities of any species in several distinct areas it is important to consider the variables that are associated with habitat (e.g. Janzen & Schoener, 1968; Bennett et al., 1980; Walsh & Harris, 1996; Ramsay et al., 1998; Heydon et al., 2000; Lichstein et al., 2002). Differences in habitat must be considered when comparing the effects of other variables (such as anthropogenic disturbance or invasive species presence) on target species or ecosystems. For example, Heydon et al. (2000) showed that the abundance of foxes (*Vulpes vulpes*) in Britain was not correlated with different aspects of habitat or landscape but was

more likely to be correlated with other factors such as culling by man. Therefore it is important to analyse and understand the effects of habitat as a variable on the outcomes of a study.

Using several long transects that sample a wide range of habitats and micro-habitats, the habitat use of an animal can be analysed. The discrete habitat categories (e.g. forest type; old growth, seral scrub, broadleaf, etc.) may be constant over large areas but the attributes of the habitat (e.g. forest density and diversity, undergrowth density, canopy cover, tree size, canopy height, etc.) will range across a transect. These habitat attributes can be compared and the attributes that are consistently correlated with animals occupying monitoring objects (e.g. a gecko occupying a CFR) will indicate the areas with the highest likelihood of detectability of these animals. For example if the habitat attributes where geckos are captured show consistently high forest density and low canopy height and if areas where geckos are never captured show low forest density and high canopies then this will indicate that geckos will be detected more often in areas with a high forest density and low canopies. The analysis of habitat can then be used to compare the densities of geckos with their detectability in order to show if low densities are due to unsuitable habitat, and subsequent low detectability, or other variables such as the presence and potential impact of mammalian pests.

## 1.5 Issues in understanding gecko monitoring object use

The CFR monitoring object is designed to mimic a gecko's habitat. However, it may also change it, providing an area of unrivalled warmth that would not exist naturally. An area of unnatural warmth may mean the geckos can remain active for longer, especially during winter. As such, geckos may be more likely to use the CFRs during the colder months. However, it may also have the opposite effect during summer. The CFRs may warm up to an extent where it would be harmful for a gecko to occupy them. Therefore during warmer periods geckos may avoid the CFRs. This means it is possible that inaccurate results will occur where a lower density of geckos may be estimated due to higher temperatures and geckos avoiding the CFRs.

As the geckos warm up inside the retreat their metabolism will also speed up and they will need to hunt or forage. Normally during winter geckos are not thought to hunt or forage often as they become too cold and are less capable of moving, only when it is a warm day are geckos thought to forage during winter. The CFR may provide enough warmth for the gecko to need to forage, if this occurred the gecko may leave the CFR but the ambient temperature outside may be too cold for the gecko to move and it may become trapped outside of cover. The gecko would then become prone to predation especially if there are invasive mammalian predators in the area such as rats or cats.

This area of unnatural warmth will also attract many invertebrates, including large predatory invertebrates such as spiders and giant centipedes. This will have both positive and negative effects on the geckos that occupy them. Giant centipedes are known to predate on smaller juvenile and neo-natal geckos, these refuges may then become places of increased danger for young geckos. As such the population structure of the geckos studied may be inaccurate as juveniles or smaller geckos may avoid the CFRs. This would mean the population may be thought to have low levels of recruitment and as such be in decline when it is not. The attraction of smaller invertebrates such as cockroaches, small spiders, millipedes, tree weta and cave weta may have a positive effect on the geckos by providing them with an easy food source.

## 1.6 Research objectives

**1: To establish how geckos are affected by mammalian predators such as rats. (Chapter 3)**

**Questions:**

- Does the presence or absence of rats correlate with high and low densities of geckos?
- Does the presence or absence of rats correlate with the presence or absence of certain invertebrate species?
- Is there evidence of attempted rat predation on any geckos?
- Is there evidence of an impact on gecko population structure in areas of pest control versus no control?
- Are there differences in gecko densities in the areas of pest control on Waiheke Island compared with areas of pest exclusion at Tawharanui Regional Park, and the areas of no control on Waiheke and at Shakespear Regional Park?

**2: To establish the habitat and microhabitat geckos are most likely to use CFRs in. (Chapter 4)**

**Questions:**

- Are there differences in the habitat between each of the four study sites that could explain the differences in gecko abundances?
- Are there any habitat variables that explain why *M. granulatus* is found occupying certain CFRs and not others?
- Is there a difference in habitat between the areas of pest control and no control on Waiheke Island that could explain the differences in gecko densities?

**3: To establish the effectiveness of using CFRs as a monitoring tool in comparison with visual night-spotting, Onduline ACOs, and**

## tracking tunnels, and to establish an effective method in using CFRs. (Chapter 5)

### Questions:

- Are CFRs more efficient than VES, ACOs and/or tracking tunnels for monitoring arboreal geckos?
- Are more species of gecko found using the CFR technique compared with VES, ACOs and tracking tunnels?
- Are more geckos found when using a method of monitoring that reduces disturbance?

## 4: To establish how geckos utilise the CFRs (Chapter 5)

### Questions:

- Do weather conditions correlate with the presence or absence of geckos under the CFRs?
- Is there a sex bias of geckos using the CFRs?
- Does the presence or absence of certain invertebrates correlate with the presence or absence of geckos under CFRs?

## 1.7 Thesis structure

This thesis has been split into six chapters: Chapters 1 and 2 cover the general introduction and methods. Chapters 3, 4 and 5 are research chapters which attempt to answer each of the research question outlined in this chapter. Each research chapter is set out as a research paper. Therefore there is some repetition between chapters. The final chapter is a general conclusion that binds the three research chapters together, also included in this chapter are further research ideas. A single reference section is included at the end of the thesis.

# CHAPTER TWO

## General methods



Figure 2.1 (from left) Mark, Frances, & Author processing *M. granulatus* during VES nightspotting.  
Photo: D.v.Winkel

## 2.1 Study species

### 2.1.1 Forest gecko: *Mokopirirakau granulatus*



Figure 2.2 Male *M. granulatus* retreating into tree cavity. Photo: Author

#### 2.1.1.1 Morphology and biology

The forest gecko is a relatively common species in native forest and shrubland, but can be very difficult to find. The upper surfaces of the body range in colour from grey to olive green and they are capable of rapid and substantial colour changes (Jewell, 2011). The markings consist of (usually) brightly contrasting w-shaped patches running down the back, which in many individuals give rise to large outer anterior patches that may be white, cream, yellow or green. The back markings

also often have brown, orange or brick-red spots or patches and/or regular bright yellow or greenish patches. The underside is a pale cream or white that is intensely speckled and blotched with small pale grey, dark edged markings (Jewell, 2011). The sides of the head and often also lips have prominent white markings, with usually a black backwards-facing v line running across the top of the head between the eyes. The eyes range from grey to olive and brown with a purplish bloom or sometimes a blue sheen. The mouth lining is a bright yellow or orange, with a variable coloured tongue ranging from pink to orange (Jewell, 2011). The rostral scale is broad and in contact with the nostril while the last nasal scale is usually as large as the first, but in South Island populations may be smaller. The under surface of the toe is spanned by 11-14 transverse scales or lamellae. The snout to vent length (SVL) is 70-85 mm, and on occasion up to 95 mm, while the tail length is longer than the SVL.

The forest gecko is nocturnal but is also often found sun basking during the day near its retreat (consisting of loose bark or tree cavities) or among the foliage. It is primarily an arboreal gecko but other species within the *Mokopirirakau* genus can be found in alpine habitats above the tree line living on the ground among rocks (Jewell, 2011). The habitat where *M. granulatus* is most often found consists of kanuka (*Kunzea ericoides*) and manuka (*Leptospermum scoparium*) seral scrubland and regenerating forest. This may however be only an example of the habitat it is possible to find the geckos in and not a true reflection of their preferred habitat. Little is known about the breeding habits of the forest gecko, but mating seems to take place during April-May (pers. obs.). In captivity they are known to produce young during late February and have a gestation of approximately 10 months (M. Nelson-Tunley pers. comm. 2011). The forest gecko primarily feeds on invertebrates, nectar and small fruits.

### 2.1.1.2 Distribution

The forest gecko is distributed throughout the north of the North Island, from Hamilton across to Tauranga and north to Kaitaia, and the north and west

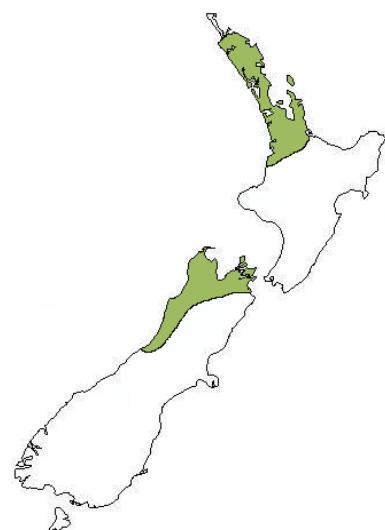


Figure 2.3 Distribution of *M. granulatus*

of the South Island, from the Marlborough Sounds west through the Nelson Lakes district, north to Farewell Spit, and south along the West Coast to Hokitika (Jewell, 2011). It also occurs on many large or well sheltered offshore islands, such as Great Barrier, Little Barrier and Waiheke.

#### **2.1.1.3 Threat classification**

The forest gecko is considered Not Threatened using the revised New Zealand Threat Classification System (Hitchmough et al., 2010).

#### **2.1.2 Auckland green, or elegant gecko: *Naultinus elegans***



Figure 2.4 Demonstrating male hemipenal sac of *N. elegans*. Photo: Lee Thoresen

### 2.1.2.1 Morphology and biology

The Auckland green or as more aptly named by Jewell (2008) the elegant gecko, is a common species but it is very difficult to find due to its highly cryptic camouflage. The elegant gecko is likely to be the most common native New Zealand reptile held in captivity, not only in New Zealand but also throughout the world. The pet trade for this gecko has now been stopped but breeders are allowed to trade among captive populations. This has given rise to poaching as it is not always possible to trace an individual gecko to a breeder, especially overseas in European countries. Poaching has become a very real threat to the entire *Naultinus* genus in New Zealand, including the elegant gecko. Other *Naultinus* species such as the jewelled (*N. gemmeus*), rough (*N. rufus*) and starred (*N. stellatus*) geckos are especially sought after and can reach values of up to \$10,000 on the black market (M. Lettink pers. comm. 2011).

The elegant gecko is bright green (rarely yellow or creamy white), often with rows of spots or continuous stripes that range from light green to yellow, white or pink and edged in black. The undersides are a pale green (females) or blue (males). The lining of the mouth is a striking deep blue, while the tongue is essentially black. The eyes are a light orange-brown. The foot pads are grey-green. The snout to vent length is approximately 55-70 mm with a tail that is longer than the SVL (Jewell, 2011). The elegant gecko is diurnal (like all of *Naultinus*) and arboreal. It inhabits forest and scrub including manuka/kanuka shrubland and during the day it can be found sun basking amongst the canopy or upper foliage of shrubs. Females breed annually, the young are born in early spring and mating takes place soon afterwards (Jewell, 2011). The elegant gecko predominantly feeds on invertebrates (including small moths), nectar and small fruits.

### 2.1.2.2 Distribution

The elegant gecko occurs widely in the central and



Figure 2.5 Distribution of *N. elegans*

northern North Island, roughly north from a line between Wanganui and East Cape, north to the Bay of Islands, it also occurs on several offshore islands such as Great Barrier, Little Barrier and Waiheke.

#### 2.1.2.3 Threat classification

The elegant gecko is considered At Risk and Declining using the revised New Zealand Threat Classification System (Hitchmough et al., 2010).

#### 2.1.3 Pacific gecko: *Dactylocnemis pacificus*

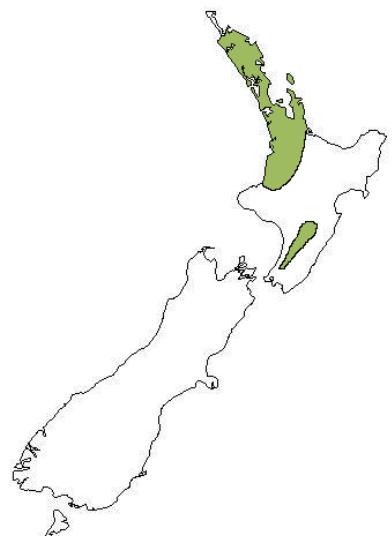


Figure 2.6 The first documented *D. pacificus* was found on Waiheke Island during March 2012, after this study had been completed. Photo: Author

### 2.1.3.1 Morphology and biology

The Pacific gecko is a uniquely timid gecko; with even long-term captive individuals maintaining a strong nervous disposition (Jewell, 2011). The upper surfaces are grey, brown or olive, with paler bands, blotches, chevrons or stripes that may be drab or bright. Individuals are sometimes found with a bright mustard yellow colour across the neck and additional blotches of the same colour may occur down the back and tail. Occasionally they are found with pink or orange shadings or spots, especially in juveniles (Jewell, 2011). The lower surfaces are a uniform pale grey or cream. The mouth lining is pink, as is the tongue, with an occasional small greyish patch on the tip. The SVL ranges from 70-90 mm with a tail of similar size. The rostral scale is broad in contact with the nostril, and the eye a brown-gold colour. The precloacal pores do not extend onto the legs (as opposed to the forest gecko where they do) and there are 10-16 lamellae on the foot pads (Jewell, 2011).

The Pacific gecko inhabits trees in forest and shrubland (with retreat sites beneath loose bark or in tree cavities), clay banks and rock bluffs, rock outcrops, and associated scrubby vegetation including flax (Jewell, 2011). It is also found along coastlines among driftwood, rocks and scrub usually well back from the high tide line. The Pacific gecko is nocturnal and by day it is very secretive but may sun bask in the entrance to a retreat site (usually retreating long before observers can get close enough to see them). Mating occurs in March-May; females breed annually and the young are born in February or March. The Pacific gecko predominantly feeds on invertebrates, nectar and small fruits.



### 2.1.3.2 Distribution

Figure 2.7 Distribution of *D. pacificus*

The Pacific gecko is widespread in the North Island, reaching great abundance on many northern offshore islands. On the mainland it is distributed from the Hutt Valley in the south to Kaitaia in the north, although it is very scarce in areas around Wellington, and in the East Cape. It also occupies offshore Islands such as Great Barrier, Little Barrier and Waiheke Island. (Although no Pacific geckos were

found during this study on Waiheke Island, during March 2012 a mature male Pacific gecko was found (Figure 2.6), the first documented sighting of this species on the Island.)

### 2.1.3.3 Threat classification

The Pacific gecko is considered Relict with >20,000 mature individuals and a stable, or increasing at >10%, population (Hitchmough et al., 2010).

## 2.2 Study areas



Figure 2.8 Map of New Zealand and the Hauraki Gulf, showing the three study areas, Waiheke Island (lowest square), Shakespear (middle) and Tawharanui (top). Photos: Google Earth

The study was conducted in New Zealand in three regional parks and on public land in the Hauraki Gulf, in the greater Auckland region. The three regional

parks were Whakanewha on Waiheke Island, Tawharanui (open sanctuary) and Shakespear (open sanctuary). The study sites on public land were located on Waiheke Island adjacent to Whakanewha Regional Park.

### 2.2.1 Whakanewha Regional Park, Waiheke Island

Waiheke Island is located in the Hauraki Gulf approximately 17 km east of Auckland city. The island is the second largest in the Hauraki Gulf (after Great Barrier) at 92 km<sup>2</sup> and the third largest of all the offshore islands surrounding New Zealand. Waiheke is the most highly populated of any offshore island with 83.58 people per km<sup>2</sup>, a population of 7,689 permanent residents and another estimated 3,400 who have secondary or holiday homes on the island (Census, 2001). The east is dominated by farmland and forest, which is predominantly manuka (*Leptospermum scoparium*) and kanuka (*Kunzea ericoides*) regenerating bush with patches of old growth broadleaf forest. Pests present on the island include rats (*Rattus spp.*), mice (*Mus musculus*), cats (*Felis catus*), mustelids (*Mustelidae spp.*), dogs (*Canis familiaris*) and hedgehogs (*Erinaceus europaeus*) (B. Wigenhauser pers. comm. 2011). Possums (*Trichosurus vulpecula*) have never been present on the island. Whakanewha is a coastal park (250 ha) that consists of several ecosystems including mud flats, sandy shoreline, salt marsh wetlands, coastal forest, regenerating manuka/kanuka forest, old growth broadleaf forest, an extensive wetland and several small streams. Whakanewha is managed and owned by the Auckland council, and two permanent staff work in the park. Pest control in the form of brodifacoum bait is being utilised on an extensive grid throughout the entire park (excluding swamp) (B.Wigenhauser pers. comm. 2011) Five cell foam retreat (CFR) and three visual encounter surveys (VES) night spotting transects were set up prior to this study within the regional park. Five CFR and three VES night spotting transects were also set up on private land adjacent to the park. The transects on private land are all within 5 km of the park, and are predominately north and east of the park. These transects have a high density of invasive plant species such as gorse (*Ulex europaeus*), mothplant (*Araujia sericefera*) and climbing asparagus

(*Asparagus scandens*), which are not seen within the park due to a weed control program.



Figure 2.9 Maps of Waiheke showing the area of Whakanewha Regional Park and the adjacent control study areas, including all 10 CFR (labelled IA to IE and OA to OE) and six VES transects. Photo: Google Earth

## 2.2.2 Tawharanui (open sanctuary) Regional Park

Tawharanui Regional Park is located on the Tawharanui peninsula, a finger of land projecting into the northernmost region of the Hauraki Gulf, approximately 50 km directly north of Auckland city. The park combines a mainland island sanctuary with farming and public recreation areas. A 2.5 km predator-proof fence was erected in 2004, which was followed by an aerial drop of poison which eradicated rats (*Rattus* spp.), feral cats (*F. catus*), possums (*T. vulpecula*), weasels (*Mustela nivalis*), stoats (*M. erminea*) and ferrets (*M. furo*). The remaining mammals that have not been eradicated include mice (*M. musculus*), rabbits (*Oryctolagus cuniculus*) and hedgehogs (*E. europaeus*) (M. Maitland pers. comm. 2011). The sanctuary covers 588 ha, with 170 ha of this being farmland. The rest of the sanctuary is made up of several habitats, including wetlands, sand dunes, manuka/kanuka regenerating bush, prostrate scrub, coastal forest, and old growth broadleaf and podocarp forest. Over the past 10 years thousands of trees have been planted throughout the park in an effort to restore the lost forest habitat. The many species of vegetation within the park include kauri (*Agathis australis*), pohutakawa (*Metrosideros excelsa*), puriri (*Vitex luciens*) and tanekaha (*Phyllocladus trichomanoides*). Many native bird species have re-colonised the area and been introduced since the fence was erected. These species include bell birds (*Aethornis melanura*), North Island robin (*Petroica australis longipes*), brown kiwi (*Apteryx mantelli*), New Zealand dotterel (*Charadrius obscurus*), fern bird (*Bowdleria punctata*) and patake (brown teal) (*Anas chlorotis*). A total of 16 species of land birds and 15 coastal birds have been recorded in the park. The park also includes a marine sanctuary covering 395 ha that extends out half a nautical mile from the northern beaches; regulations in this area prevent the taking of any marine life. The diverse coastline contains a range of subtidal habitats, including reefs with overhangs, tunnels and caves.



Figure 2.10 Map of Tawharanui, showing all five CFR transects and the predator-proof fence border.  
Photo: Google Earth

Tawharanui is managed and owned by the Auckland Council and several permanent staff work in the park maintaining tracks, the fence and checking predator-tracking stations and bait lines. The park is also maintained by a group known as the Tawharanui Open Sanctuary Society Inc. (TOSSI). This group volunteers in the park, checking bait and tracking lines and helping with habitat restoration. They also provide funding for conservation of the park, helping to reintroduce new species and supporting students and other groups studying the area. Five CFR transects were set up within the park prior to this study. Two VES night spotting transects were also set up but were not used in this study.

### 2.2.3 Shakespear (open sanctuary) Regional Park

Shakespear Regional Park is located on the tip of the Whangaparaoa peninsula in the midst of the Hauraki Gulf approximately 20 km directly north of Auckland City. The park combines many areas of native forest with farmland and public recreation areas. A 1.5 km predator-proof fence was erected in 2006 which runs across a narrow stretch of land separating the park from the nearby township. After the erection of the fence a predator control system (brodifacoum bait lines) was temporarily utilised until 2010. The control was finished leaving the park open for pests to occupy for several months before a large scale poison drop was carried out in July 2011 eradicating all pests within the park (M. Maitland pers. comm. 2011). This study took place previous to the bait drop in order to have a secondary control (i.e. no pest control) area. The data will also be used to compare the populations of geckos in the park before and after the pest eradication as a part of a long term Auckland Council monitoring program.

Shakespear consists of several habitats, including wetlands, pasture, coastal forest, regenerating scrub, and small fragments of relict broadleaf forest. Over the past 20 years thousands of trees have been planted in order to restore the lost forest habitat. Forest margins and gullies have been fenced off to exclude farm animals, and wetlands are being restored. The restored bush has been attracting birds from the nearby island sanctuary Tiri-tiri Matangi and species such as the bell bird (*Athornis melanura*), tui (*Prosthemadera novaeseelandiae*) and kakariki (*Cyanoramphus* spp.) have been spotted in the park. Several species will also possibly be introduced to the park in the future. These species potentially include the brown kiwi (*A. mantelli*), saddleback (*Philesturnus carunculatus*), robins (*P. australis longipes*), tuatara (*Sphenodon* sp.), and forest (*M. granulatus*), green (*N. elegans*), and pacific (*D. pacificus*) geckos.

Shakespear is managed and owned by the Auckland Council and several permanent staff work in the park maintaining the fence and helping with restoration of the park. An NGO group also helps to maintain the park, known as the Shakespear Open Sanctuary Supporters Inc. (SOSSI). This group provides funding for the

conservation of the park and for students and other groups studying the ecology of the park. The northern area of the peninsula is owned by the New Zealand Defence Force (NZDF) and is off limits to the public. Two CFR transects were set up prior to this study within the park and two were set up within the defence force land, with consent and permits from the NZDF. The CFR transects within the NZDF land were not used in this study, but prior to the study the Auckland Council carried out reptile monitoring along these transects and the data they collected was used with consent from the Auckland Council.



Figure 2.11 Map of Shakespear Regional Park, showing all four CFR transects, the predator-proof fence and the border with the New Zealand Defence Force. Photo: Google Earth

## 2.3 Pre-thesis study

Barr (2008) conducted night spotting arboreal gecko surveys in Whakanewha Regional Park on Waiheke Island in May and November 2008. During the May survey two people conducted a total of eight search hours and located 10 forest geckos (*M. granulatus*), 13 Auckland green geckos (*N. elegans*), and one unidentified gecko species (Barr 2008). During the November survey four people conducted a total of 21 search hours and found a total of 11 forest geckos and six Auckland green geckos. The geckos were found throughout the park, predominately in manuka/kanuka habitat. The sighting rates per hour and the overall number of geckos found indicated a high density of geckos within the park. Due to this preliminary survey the Auckland Council along with private consultancies (EcoGecko, and Bioresearches Ltd) used Waiheke as one monitoring site in a region-wide longitudinal gecko monitoring program. Also included in this program are Tawharanui and Shakespear Regional Parks, along with Ark in the Park (Waitakere Ranges) which was not included in this study or in the preliminary gecko monitoring program.

In each Regional Park, cell foam retreats (hereafter referred to as CFRs or covers) were set up using several transects placed throughout each park. VES night spotting transects were also set up along established tracks throughout each park.

During March 2011 the gecko monitoring program was initiated. Waiheke Island and Shakespear were both monitored for two weeks from March 7<sup>th</sup> to the 22<sup>nd</sup> by members of the Auckland Council, volunteers and members of private consultancies EcoGecko and Bioresearches Ltd, Tawharanui and Ark in the Park were not included.

## 2.4 Waiheke Island

### 2.4.1 Cell foam retreats



Figure 2.12 Example of CFR nailed to kanuka (left). Author checking a CFR attached to small manuka (right). Photos: Su Sinclair (left), Lee Thoresen (right).

Cell foam retreats (Figure 2.12) developed by Trent Bell (2009) of EcoGecko Consultants, consist of black closed cell foam sheets nailed onto kanuka/manuka tree trunks. Each cover is marked individually with a code (e.g. IA01, IA02.... IA40) using both a Xylene-free white paint pen (for visibility) and permanently soldered. The first letters of the code denote treatment, i.e. I = inside (inside predator-controlled areas, or treatment), and O = outside (outside predator control, or control). Letters A to E denote transect and numbers 1-40 for each CFR. 200 CFRs have been set up inside Whakanewha Regional Park and 200 outside within privately owned land. The CFRs are set up along ten 400 m transects each with 40 CFRs spaced approximately 10 m apart.

The CFRs were checked every second day for 12 days during the initial March check as a part of the Auckland Council's gecko monitoring program. Transects IA to ID were checked on the first day and IE and OA to OE were checked on the second day. These were then alternated throughout two weeks over 12 days to allow a day between each check of the transects to reduce the disturbance of opening the covers. A total of six checks of each transect were carried out during this time. Throughout the year, once every month the CFRs were checked for occupancy. Each of the five transects within the park and one transect adjacent (OA) were checked once per month. From September to November the CFRs were checked for occupancy once a fortnight, for a total of six repeats over three months. This was done to test a trial methodology of checking the CFRs every second week, as opposed to the initial method of checking the CFRs every second day.

At the beginning and end of each transect the time and weather conditions were recorded, including temperature, relative humidity, wind, percentage of cloud cover and past 24 hours rainfall (using a data logger). On the first day the covers were checked, the numbers of invertebrates found under the covers were recorded, along with their species and sex (if identifiable), and the code of the CFR. The invertebrates were only recorded on the first day as after the first check the disturbance was thought to bias any further results.

Each time a gecko was found the CFR code was recorded (e.g. IA02) along with the time of capture and weather conditions. The species and sex of the gecko was recorded (the presence of a large hemipenal sac, large cloacal spurs, and precloacal pores indicate males) along with snout to vent length (SVL; to 1 mm), vent to tail tip (VTL; to 1 mm), or if the tail was autotomised, vent to break and break to tail tip (V-B & B-T; to 1 mm). The weight of the gecko was recorded (using 30 g Pesola spring balance), and any distinguishing marks or scars were noted. Dorsal photographs were then taken for identification purposes, and to determine if the geckos were recaptured at any point. A database of captured geckos was created using these photos to easily identify any geckos caught in the future.

The time spent searching using the CFR method was calculated by adding the hours spent on each transect. This was then compared with the total number of geckos found to get a 'geckos hour<sup>-1</sup>' value to show the efficiency of the method.

This value was then compared with the efficiency of the other methods of gecko monitoring tested (i.e. VES, ACOs and tracking tunnels). The Kolmogorov and Smirnov test was used to check if the data followed Gaussian distributions, if it did not the Mann-Whitney *t*-test was used, otherwise the Student's *t*-test was used to compare the efficiency of these methods.

The densities of geckos per hectare were calculated by determining the area of each transect. A gecko territory size around each CFR was estimated as a 2.5 m radius circle with a total area of 19.63 m<sup>2</sup>. The total area of each transect was then calculated by multiplying this area by the 40 CFRs (0.78 km<sup>2</sup> or 0.078 ha). The total number of geckos found per transect was divided by this area to get a density of geckos ha<sup>-1</sup>. This value was then compared between the areas of pest control and no pest control on Waiheke and also compared to gecko densities at Tawharanui and Shakespear Regional parks. The Kolmogorov-Smirnov test was used to check if the data followed Gaussian distributions, if not the Mann-Whitney *t*-test was used, otherwise the Student's *t*-test was used to compare these densities.

#### 2.4.2 Visual encounter surveys

Three transects in the presence of predator control (designated as treatment areas, i.e. the treatment of baits and/or pest exclusion) and three on public property, in the absence of predator control (designated as control areas), were set up along established tracks in order to carry out night-time visual encounter surveys (VES) during the initial March study. Each transect was approximately 1 to 1.5 km long, one transect (Firebreak track) was designated as a 'capture transect', which was repeated three times, and all geckos found were captured (if possible). The captured geckos species sex, SVL, V-B & B-T, or TL, weight, and any distinguishing marks and scars were recorded. Weather conditions at the time of capture, including temperature, humidity, rainfall, wind levels and cloud cover, were recorded using a data logger. An identification photo of the gecko was taken and the area the gecko was caught was marked on a GPS. The other five transects were walked once and geckos found were not captured but species and if possible sex were identified using binoculars. Weather conditions were also recorded and a GPS was used to mark

where the gecko was observed. At the start and end of each transect the time was recorded, the hours spent searching were calculated and a ‘gecko hour<sup>-1</sup>’ value was calculated to compare the efficiency of this method with the CFR method.

### 2.4.3 Onduline artificial cover objects



Figure 2.13 An example of one of the double stacked Onduline ACOs used during this study. Photo: Author.

During mid-August Onduline ACOs were set up on Waiheke Island, they were left for a month before the first check to habituate any reptiles to them. The ACOs consisted of Onduline roofing cut into approximately 400 by 350 mm rectangles. Pine doweling or small scraps of wood (2.5 cm diameter) were glued (using a hot-glue gun) to the bottom CFR in order to separate the double layers. The ACOs were set up along four of the highest gecko-capture transects (three within pest control: IA, IC and ID, and one along private property outside of pest control: OA). Ten double-stacked ACOs were set up along each of the four transects, each

placed approximately 40 m apart and at least 5 m adjacent to every fourth CFR. Ten remaining ACOs were placed opportunistically along the coastal habitats (including *M. excelsa* and *Phormium tenax* habitats) within the park. A code was marked on each ACO to identify it. The code denotes the transect name (i.e. IA, IC, ID or OA) following the same format as the CFR codes, and the number of the ACO (i.e. 1-10), for example IA01 (for inside, transect A, ACO number 1). The coastal ACOs were marked with the code C1-10 (i.e. Coast, ACO number 1-10).

The ACO transects were checked once every fortnight from September to November at the same time as the CFRs were checked. Because the ACOs were placed along the same transects as the CFRs the time it took to check both the ACOs and the CFRs was recorded as a total transect time. In order to calculate the time spent checking the ACOs only, the total time for each transect was taken away from the average time spent checking a single CFR transect. For example, if it took 45 minutes to check a transect which had both ACOs and CFRs, the time to check just the ACOs was calculated by taking away the average time of a CFR check (approx 25 minutes) from the total time for both CFR and ACO, giving 20 minutes for the ACO check. Whenever a gecko was found under an ACO its demographics, along with weather conditions, were recorded (the same as previous methods), and an identification photo was taken. When any other species of reptile was found, its demographics were also recorded (if possible) and an identification photo was taken to confirm what species it was.

#### 2.4.4 Reptile tracking tunnels

During mid-August, 50 tracking tunnels were set up in an attempt to compare the reptile tracking rate with the ‘geckos hour<sup>-1</sup>’ value for CFRs, ACOs and VES night-spotting. The tracking tunnels were set up along four of the transects within the park (IA, IB, IC and ID) and one on private property outside the park (OA). Ten tunnels were set up along each transect, each set approximately 5 m adjacent to every fourth CFR and at least 5 m from any ACO. Each tracking tunnel was marked with a code that correlates with the ACO code they were adjacent to (as described in subsection 2.4.3). The tunnels were left for a month and not checked until late

September to try to habituate any reptiles to them. From September to November they were checked once a fortnight at the same time the CFRs and ACOs were checked. Each fortnight a new tracking card was placed inside the tunnels and baited with pear at both ends. The card was then left for at least 24 hours and retrieved the next day. The percentage of cards tracked by geckos and other reptiles was then calculated and the species of gecko was determined through the use of footprint identification (if possible). At the beginning and end of each CFR/ACO/tracking tunnel transect the time was recorded, during both the day of placing the cards and retrieving them. In order to separate the time spent checking the CFRs and ACOs from the time spent baiting and checking the tracking tunnels, one transect that had tracking tunnels and CFRs did not have ACOs (transect IB). The average time spent checking the CFRs only on this transect was then subtracted from the total time spent checking the CFRs, ACOs and tracking tunnels to get a time spent baiting the tracking tunnels on day one. This time was then added to the time spent checking the tracking tunnels on day two (i.e. the time at the beginning and end of each transect on day two was recorded) to get a total time spent using the tracking tunnels per transect. This time was then analysed by creating a ‘geckos tracked hour<sup>-1</sup>’ value to compare against the ‘geckos found hour<sup>-1</sup>’ value of the CFRs, ACOs and VES night-spotting.

#### 2.4.5 Pest monitoring

During early August, 36 pest tracking tunnels were placed throughout four of the five CFR transects outside of the predator-controlled areas (OA, OB, OD and OE). OC was excluded as the landowners did not give consent to use their land for this purpose. The tracking tunnels were set up along the CFR transects adjacent to every fifth CFR. Nine tracking tunnels were placed at least 50 m apart along each transect. They were labelled using the same methodology as the reptile tracking tunnels. However on one transect where the reptile and predator tracking tunnels were both used (OA), the code included either G to signify gecko or R to signify rat in order to differentiate between the two. The tracking tunnels were then left empty for one month to allow rats to become habituated to them.

Once a fortnight for three fortnights from late September to late October the tracking tunnels were set up using tracking cards and peanut butter placed at either ends of the tunnels. The cards were left for 24 hours and collected the next day. Presence/absence data were then compared with tracking tunnel presence/absence data provided (by the park rangers) from inside the park, along with the data collected on the gecko densities along each transect. The data was used to compare the presence of invasive predators within the park to the areas outside of it, and the densities of geckos in relation to invasive predators.

#### 2.4.6 Habitat analysis

Vegetation surveys were carried out during April, June and July to compare the habitat among the study areas and to understand why geckos were found occupying some CFRs and not others. The surveys were carried out using the same transects the CFRs were placed along. The habitat within a 2.5 m radius circle ( $19.63 \text{ m}^2$ ) with each CFR as the central point was analysed. This area was estimated to be the home range extent of small arboreal gecko species (T. Bell & D. Winkel, pers. comm. 2011). At every CFR each species of vegetation was recorded within the 2.5 m radius, along with the total number of plants and the canopy height. If a species was unidentifiable a photo was taken, the species was then recorded as unidentified 1 (2, 3, 4, etc.), research was later done using the photo to identify the species. The area of each 2.5 m radius circle was calculated as  $19.63 \text{ m}^2$ . The forest density was then calculated as the number of trees per  $19.63 \text{ m}^2$ , i.e. the number of trees in a gecko's estimated home range. An average canopy height and density were determined for each transect in the four study areas which were then compared. The forest diversity of the  $19.63 \text{ m}^2$  area surrounding each CFR was calculated using a Simpson's diversity index (Hill, 1973). The Simpson's diversity index is a measure of diversity which takes into account the number of species present, as well as the relative abundance of each species. As species richness and evenness increase, so diversity increases. The Simpson's diversity index calculation used is as follows:

$$D = 1 - \left( \frac{\sum n(n-1)}{N(N-1)} \right)$$

Where  $n$  = the total number of organisms of a particular species,  $N$  = the total number of organisms of all species. The value of  $D$  ranges from 0 to 1 with this index, where 1 represents infinite diversity and 0, no diversity.

The CFRs that were occupied with geckos were then compared against the CFRs that were empty to determine if forest diversity, density and canopy height were factors in a gecko's choice of CFR. The average density and canopy height were also calculated for each transect in order to compare the habitat within pest control to the habitat outside of it and to compare the habitat between the four study areas.

The microhabitat of each tree with a CFR attached to it was also analysed in order to attempt to determine why some CFRs were occupied by geckos and others were not. The species, height (m), trunk diameter (DBH in mm), canopy area (an estimate of  $m^2$ ), complexity (i.e. number of trunks/large branches), number of visible hollows/cavities, looseness of bark (i.e. solid, medium, loose, very loose), species of undergrowth, percentage cover of undergrowth (in 1 m diameter around the CFR) and the presence of suspended material in the tree (i.e. dead plant matter/branches) were all recorded.

A correlation analysis was carried out to compare each of the habitat and microhabitat variables. Variables that were closely related were excluded from the final analysis. These variables included: number of large branches and trunks, predominant canopy species, number of visible hollows, bark type, species of predominant and nearest undergrowth, proximity to undergrowth, and the amount of suspended debris/snags in tree. These variables were excluded from the final analysis for several different reasons. Some of these variables were significantly correlated with others and so were considered to represent the same effect (for example the number of branches and canopy area) and therefore one was excluded. Other variables did not show any variability, for example the predominate canopy species was kanuka. However, this species was targeted when the CFRs were being set up, and as such the majority of the trees the CFRs were placed on were kanuka, therefore the initial placement of the CFRs biased this variable. Other variables did not show large enough sample sizes for any results to be considered effective, for example the presence of suspended debris was very low across all CFR placement areas.

The final overall habitat (i.e. microhabitat and habitat) analysis consisted of six variables: tree height, canopy area, density, biodiversity, percentage cover of undergrowth and tree trunk diameter. These variables were compared between the areas where geckos occupied the CFRs and areas where they were never found, using Mann-Whitney and Student's *t*-tests.

## 2.5 Tawharanui Regional Park

### 2.5.1 Cell foam retreats

Using the same methodology as on Waiheke Island the CFRs at Tawharanui were checked six times over 12 days. Five transects of 40 CFRs were set up at Tawharanui, a total of 200 CFRs. Transects IA to IC were checked on the first day and ID and IE checked on the second, the checks were then alternated so that for any one transect there was a day between each check. There were five transects set up within Tawharanui in the area of pest exclusion; there were none set up outside of the park. The density of geckos  $\text{ha}^{-1}$  was calculated using the same method as described in section 2.4.1. These values were then compared with data from Waiheke and Shakespear to compare the densities of geckos in three different areas of pest management.

### 2.5.2 Visual encounter surveys

VES night-spotting was completed along the five CFR transects at Tawharanui Regional Park. This was carried out using reflective pegs set up the day before a VES was walked. A similar methodology to that on Waiheke was used, where before and after each transect the weather conditions and time were recorded. Every time a gecko was found it was captured (if possible) and the time, weather conditions, and demographics were recorded as described in section 2.4.2. The efficiency of the technique was determined ( $\text{geckos hour}^{-1}$ ) and directly compared with the efficiency of the CFRs within the park, this was also compared with data

from Waiheke and Shakespear to determine whether the efficiency of the techniques varied between different areas of pest management.

### 2.5.3 Pest monitoring

Pest-tracking data were provided for this study by Matt Maitland, head ranger of the North Auckland Regional Parks from the Auckland Council.

### 2.5.4 Habitat analysis

Using the same methodology as described in section 2.4.6, the habitat (tree height, biodiversity, and density only) of the CFR transects at Tawharanui was analysed to compare the habitat of the different regional parks. This was carried out in order to understand the bias of habitat in terms of differing gecko densities for each park, so that any difference could be attributed to habitat and not the presence/absence of pests or the type of pest control.

## 2.6 Shakespear Regional Park

### 2.6.1 Cell foam retreats

Members of the Auckland Council, EcoGecko Consultants, and Bioresearches Ltd used CFRs to monitor the gecko population of Shakespear Regional Park during March, at the same time as the monitoring was done on Waiheke. A total of four transects of 40 CFRs were set up in Shakespear, with a total of 160 CFRs. The same methodology as the second daily checks over 12 days as set out in section 2.4.1 was used. The data was provided for this study by the Auckland Council and was used to calculate the density of geckos  $\text{ha}^{-1}$  within the park, and the efficiency of the CFR method in ‘geckos hour $^{-1}$ ’.

## 2.6.2 Visual encounter surveys

VES night-spotting was carried out during the CFR monitoring in March; which was also done by members of the Auckland Council, EcoGecko, and Bioresearches Ltd consultants. The data was provided for this study by the Auckland Council and was used to calculate the efficiency of the VES method in comparison to CFRs at Shakespear.

## 2.6.3 Habitat analysis

Using the same methodology as described in section 2.4.6, the habitat (tree height, biodiversity and density only) of the CFR transects at Shakespear was analysed to compare the habitat of the three different regional parks and the four study areas.

## 2.7 General statistics

All statistical tests were conducted using the programs ‘GraphPad Instat’ and ‘R’. Data was assessed for normality using the Kolmogorov-Smirnov test to assess whether parametric or non-parametric tests were appropriate for final analyses. Hypotheses were tested at a 5% level of significance; specific tests used are described within the relevant chapters.

## CHAPTER THREE

### The impacts of rats on geckos: behaviour, population structure and condition



Figure 3.1 Male (right) and female (left) forest geckos found under a CFR, one of many pairs found during this study. Photo: Author

### 3.1 Introduction

#### 3.1.1 Introductions and impacts of rats on New Zealand reptiles

Since separating from the Gondwanan supercontinent some 80 million years ago New Zealand has effectively been a mammalian free environment, and as such it has been isolated from the impacts of terrestrial mammals (Gibbs, 2008). Since the arrival of Polynesians in the 13<sup>th</sup> century many different terrestrial mammals have been introduced. These species, such as the kiore (*Rattus exulans*) and the Polynesian dog (*Canis familiaris*) (Gibbs, 2008) have subsequently had far reaching effects on many of New Zealand's endemic and 'mammal-naïve' fauna and of flora. The colonisation New Zealand by Europeans further damaged this unique ecology with the introduction of many more mammalian pests such as the black rat (*R. rattus*), ship rat (*R. norvegicus*), house mouse (*Mus musculus*) possums (*Trichosurus vulpecula*), mustelids (*Mustelidae* spp.), cat (*Felis catus*) and many more species. The introduction of these species, especially rats, appear to have had an extensive impact on the unique reptile fauna of New Zealand. On a nationwide scale the range contractions and extinctions (localised and complete) of herpetofauna have been shown to correlate with the arrival of humans and their associated pest species to New Zealand (Towns & Daugherty, 1994).

Although the study of the impacts of rats on many species of New Zealand fauna and flora is extensive (i.e. O' Donnell, 1996; Brown et al., 1998; Hobson, Drever & Kaiser, 1999; Robertson et al., 1999; Campbell & Atkinson, 1999 & 2002; Fukami et al., 2006; Gibbs, 2008), the study of the impacts of rats on reptiles is not. Impacts have often been inferred through studying the ecology of reptiles where rats are present to where they have been eradicated or were never present (Towns & Daugherty, 1994; Towns et al., 2006).

#### 3.1.2 The impacts of rats on invertebrates

While data on the direct impacts of rats on reptiles is scant, there are even fewer studies that have shown the impacts of rats on invertebrates (Gibbs, 1990) As invertebrates are considered a major food source of reptiles (Cooper & Vitt, 2002) it

is important to consider the impacts of rats on invertebrates to determine the effects of competition for food resources. Previous research shows that the impacts of rats on invertebrates are comparable to their impacts on vertebrate species. For example, the invertebrate species that were more susceptible were the larger, ground-dwelling, nocturnal, and flightless species (Campbell, et al., 1976; Gibbs, 2008; St Clair, 2011). Like the effects of rats on reptiles, the effects on invertebrates have mostly been derived from the fact that many large invertebrates are present on offshore rat-free islands but are absent on the mainland (Gibbs, 2008). A study by Gibbs (2008) has shown that many extinctions (localised and complete) of invertebrates have correlated with the invasion of kiore to New Zealand, and that many species once widespread on the mainland now solely occur on pest-free offshore islands. Gibbs (2008) also showed that the flightless click beetle (*Amychus granulatus*), which was once widespread on the mainland, now only persists on three rat-free offshore islands in Cook Strait. Additionally, it was shown that on one of the islands the click beetle population has declined due to an expanding population of tuatara (*S. guntherii*), showing that after causing the absence of reptiles, kiore will fill the invertebrate predator niche.

Invertebrates such as giant centipedes (*Cormocephalus* spp.) and certain spiders are known to predate on and compete with reptiles (Lettink & Patrick, 2006; Pike et al., 2010a; Vallance, 2010; Jewell, 2011). Large spiders and giant centipedes will also potentially compete with geckos for small invertebrates. Giant centipedes are the only predator of geckos that can follow them into small retreat sites due to their similar body size and proportions. They are known to overpower relatively large and active prey by the use of their powerful toxicognaths (poison claws), with which they not only grasp prey but also paralyse or even kill their victims through delivery of venom (Barker, 2004). The abundance of rats in areas without predator control may cause a decline in the abundance of these large invertebrates. This could in turn benefit geckos through releasing them from the pressure of both competition and predation.

### 3.1.3 Body condition and sub-lethal injury estimates of reptiles

Barr (2009) used a body-tail condition index (BTC) that measured the effect of tail loss on chevron skinks. BTC was calculated as tail length divided by snout to vent length. This ratio measures the direct impact of predators on reptiles through quantifying tail loss. Reptiles, such as geckos and skinks, autotomise their tails in reaction to predation attempts or while under extreme stress (Bateman & Fleming, 2009). The tail has the potential to be autotomised many times, and as such the BTC would be likely to decrease with age as the effects of multiple tail losses would compound on the geckos' condition (Barr, 2009). The BTC index was utilized during Barr's (2009) study to measure the degree of tail loss in chevron skinks to determine if there was evidence of attempted rat predation. The study showed that the BTC index decreased markedly when the skinks reach adulthood within non-pest controlled habitat where rat densities are high, supporting an impact of rats on the skinks (Barr, 2009). There has been evidence to suggest that tail loss can be an unreliable indication of predation pressure as it can indicate predator inefficiency (Jaksic & Greene, 1984). However Bateman & Fleming (2009) suggest that tail loss can be linked to predator intensity if supported by additional information on predator behaviour.

Van Winkel (2008) also used a condition index when analysing whether there were changes in the condition of the Duvaucel's gecko after a translocation. In van-Winkel's study, condition was measured by calculating the ratio between body weight and snout to vent length, using the equation BCI (body condition index) = weight/SVL (Floyd & Jenssen, 1983). This body condition index is useful when measuring impacts that may not be related to direct predation such as competition, anti-predatory feeding behaviour, habitat deterioration or parasite loads (Martin & Lopez, 1999; Perez-Tris et al., 2004; Amo et al., 2007; Civantos et al., 2010). Cree et al. (1995) measured the body weight of tuatara in areas of rat presence and absence to determine if they were being outcompeted by rats, but found no difference; however, Towns et al. (2007) showed that tuatara increase in body condition after the eradication of rats from offshore islands.

Barr (2009) also measured the attempted predations of rats on chevron skinks using the presence of sub-lethal injuries. Photographs were taken of the injuries and

scars on skinks found. These scars were compared with the foraging strategies of the different predator species present in the study area. The photographs showed that the injured skinks had scars that were consistent with the foraging behaviour of rats. The skinks had scars on their heads which indicate rat predation, as many studies have shown that rats tend to eat their prey head-first (Ivanco et al., 1996 and references therein; Barr, 2009). Also the scars shown in the photographs were the exact dimensions of a ship rat's incisors that was caught in the same study (Barr, 2009). It was also shown that the width of the skink's head, and the distance between the scars on either side of the face, is precisely the known tooth-tip to tooth-tip gape width of a ship rat.

### 3.1.4 Caudal autotomy in geckos

In lizards caudal autotomy or tail loss refers to the voluntary shedding of the tail (Bateman & Fleming, 2009) and is common in many species of gecko, including the three species found in this study (see Figure 3.2 for example). The tail is broken at a point known as the 'breakage plane' which is thought to be controlled either through the use of hormones or via the central nervous system (Bateman & Fleming, 2009). The new section of tail regenerates as a calcified rod without vertebrae and breakage planes (Dial & Fitzpatrick, 1981). Therefore the next time a tail autotomises, the breakage must occur either at the same breakage point or more proximally (M. O'shea, pers. comm. 2011). Tail loss generally occurs as a response to attempted predation or during a period of high stress (Dial & Fitzpatrick, 1981; Arnold, 1984; Downes & Shine, 2001; Pike et al., 2010a). The shedding of a tail allows the lizard to break away from a predator, especially if the predator has caught them by the tail (Bateman & Fleming, 2009). The lizard tail is an important reserve of lipids and energy that can sustain an individual through periods of low prey or food shortages (Avery, 1970; Dial & Fitzpatrick, 1981; Doughty & Shine, 1998). In order to minimise a loss of this energy the tail is dropped between one and three vertebrae anterior to the grasping point (Arnold, 1984; Perez-Mellado et al., 1997). To further distract the predator the autotomised tail continues to wiggle and squirm for several minutes, in order to let the lizard escape (Perez-Mellado et al., 1997; Pafilis et al., 2005). When facing attack or undergoing high stress some lizards will

divert attention to their tail as it is considered expendable. By curling, vibrating, or undulating their tail in the presence of predators, lizards will focus their attention away from vital areas such as the head or body (Dial & Fitzpatrick, 1981; Barr, 2009). This behaviour has been observed in the chevron skink (Barr, 2009) and also forest (*Mokopirirakau granulatus*) and elegant geckos (*Naultinus elegans*) during periods of light handling (pers. obs. 2011). Tail loss can therefore be a useful indicator of condition in relation to predation attempts, however the predator that caused the tail loss can not be identified using tail loss alone.

In arboreal geckos such as the forest gecko (*M. granulatus*) and the elegant gecko (*N. elegans*) the tail is used to anchor the gecko to a branch or as a fifth limb to aid climbing (pers. obs. 2011). As such the loss of the tail will decrease the speed and manoeuvrability of an arboreal gecko, making them more prone to predation. Tail loss also causes a decrease in a gecko's condition due to a loss of lipids stored in the tail (Avery, 1970; Doughty & Shine, 1998). Also tail loss will divert energy from other important body functions such as growth, reproduction and thermoregulation (Dial & Fitzpatrick, 1981; Perez-Mellado et al., 1997). Consequently, there is a potential high cost to tail loss. In some species tail loss also has a negative impact on social interactions. In the lizard species *Uta stansburiana* tail size is used as a status-signalling indicator of resource-holding potential (Fox et al., 1990). As such, individuals with autotomised tails become more submissive and conspecifics increase aggression towards these individuals.

### 3.1.5 Research objectives

Conservation has a need to quantify the effects of rats and other invasive predators on endemic species to supply evidence to support large-scale eradication and control programmes (Towns et al., 2006). Research on reptiles in the past mainly focused on quantifying the effects of rats on reptiles such as tuatara (*Sphenodon* spp.) and skinks (Cree et al., 1995; Gaze, 2001; Towns, Parrish, & Westbrooke, 2003; Tocher, 2006; Towns et al., 2007; Barr, 2009). Due to geckos' cryptic and elusive nature little is known about many species and little research has been done quantifying the effects of rats on their population structures and condition. Arboreal

geckos, such as forest and green geckos, are even less studied than many ground dwelling or large species, such as the common gecko (*Woodworthia maculatus*) or Duvaucel's gecko (*H. duvaucelli*), due to an inability to effectively monitor them. This chapter aims to quantify the effects of rats on population structure and condition by measuring gecko densities, body condition indices (both BTC (as in Barr, 2009) and BCI (as in van Winkel, 2008)) and demographics, and then comparing this data between areas of intensive pest control and no control on Waiheke Island. The secondary aim of this chapter is to attempt to analyse the effects of differing pest management regimes on gecko densities. This was done by measuring gecko densities at Whakanewha Regional Park (pest control through intensive baiting) and comparing these densities with Tawharanui Regional Park (pest exclusion with predator-proof fence), Shakespear Regional Park and Waiheke Island (no pest control).

#### Research questions:

- Does the presence or absence of rats correlate with high and low densities of geckos?
- Does the presence or absence of rats correlate with the presence or absence of certain invertebrate species?
- Is there evidence of attempted rat predation on any geckos?
- Is there evidence of an impact on gecko population structure in areas of pest control versus no control?
- Are there differences in gecko densities in the areas of pest control on Waiheke Island compared with areas of pest exclusion at Tawharanui Regional Park, and the areas of no control on Waiheke and at Shakespear Regional Park?

## 3.2 Methodology

### 3.2.1 Study areas

The study was conducted primarily on Waiheke Island, within Whakanewha Regional Park and the surrounding areas of private land with no pest control. Additionally, the study sites Tawharanui and Shakespear Regional Parks were also used. The study sites on Waiheke that were used included all 10 CFR transects (five within pest control (treatment) and five in areas of no control (control)) and all six VES (visual encounter surveys) nightspotting transect (three within pest control (treatment) and three in areas of no control (control)). For detailed descriptions of each study area refer to Chapter 2, section 2.2.

### 3.2.2 Study species

The forest gecko (*Mokopirirakau granulatus*), elegant gecko (*Naultinus elegans*), and Pacific gecko (*Dactylocnemis pacificus*) were all used in this study. However the Pacific and elegant geckos were found in very small numbers and as such the study focuses predominantly on the forest gecko which was the most abundant species found. The forest gecko is considered not threatened, while the elegant gecko is considered at risk and declining, and the Pacific gecko is considered relict with >20,000 mature individuals and a stable, or increasing at >10%, population (Hitchmough et al., 2010). For detailed descriptions of these species refer to Chapter 2, section 2.1.

### 3.2.3 Study design

The CFR transects were set up throughout Waiheke, Tawharanui and Shakespear prior to this study as part of a region-wide study set up by the Auckland Council. The CFRs were checked every second day for 12 days during an initial check in March.

Further CFR monitoring was carried out at Waiheke along six of the CFR transects (five treatment and one control transect) throughout the year. During May,

June, July and August the six CFR transects were checked once only; during September, October and November the same CFRs were checked once a fortnight for a total of six checks. For in depth methods of the CFRs refer to Chapter 2, section 2.4.1

At the same time as the Waiheke CFRs were checked a separate group of volunteers and Auckland Council employees checked the four CFR transects at Shakespear Regional Park using the same methodology set out for Waiheke. During April the five CFR transects at Tawharanui were checked using the same method of alternating checks every second day, for six checks over two weeks. Refer to Chapter 2 sections 2.5 and 2.6 for the methods used at Shakespear and Tawharanui.

### 3.2.4 Rat presence/absence

The presence or absence of rats was determined using tracking tunnels set up along four of the control transects (outside of predator control) on Waiheke Island (OA, OB, OD and OE) (refer to Figure 2.10 for these areas). Total densities using trapping and the Zippen removal method were not calculated as the areas of control continued to be needed as control sites in the future as a longitudinal study (over the next 20 years) for the Auckland Council. Also the control sites were on private land and as such rat trapping may not have been feasible as landowners may have objected to it. As it was, one land owner objected to the use of tracking tunnels to analyse the presence of rats on their property, as such the transect on this property (OC) was excluded from the final analysis. Refer to Chapter 2, section 2.4.5 for in depth methods of pest monitoring.

### 3.2.5 Gecko monitoring

Monitoring of geckos was carried out using CFRs. The gecko's species, sex and age classification (juvenile, sub-adult or adult) were then recorded. Measurement data were taken, including snout to vent length (SVL; to 1 mm), vent to tail tip (VTL; to 1 mm), or if the tail had been autotomised and was re-growing vent to break and break to tail tip (V-B & B-T; to 1 mm). The weight of each gecko was also

recorded using a 30 g Pesola scale spring balance, and any distinguishing marks or scars were noted. Dorsal photographs (Figure 3.2) were taken of each gecko found, to determine recaptures and to show any injuries or scars. A database of captured geckos was created using these photos to identify any geckos caught in the future.



Figure 3.2 An example of dorsal identification photographs of two mature male forest geckos (gecko OA16, and gecko ID12). Note the distinct difference in the lower back markings, especially around the tail base, the gecko on the left shows an autotomised re-grown tail. Photos: Author

### 3.2.5.1 Gecko density indices

The density of geckos was calculated for each transect. At each CFR a 2.5 m radius circle (a total of 19.63 m<sup>2</sup>) was measured, this area was estimated to be the home range extent of small arboreal gecko species (T. Bell & D. Winkel, pers. comm. 2011) The total area of each transect was then calculated by adding the area of the 40 different CFR sites to get a total estimate area of 785 m<sup>2</sup> that geckos could inhabit for each transect. The area was converted to hectares and total area was divided by the total number of geckos caught to get a density value of geckos per ha for each transect.

### 3.2.5.2 Population structure

Population structure was analysed by snout to vent size class in treatment and control sites on Waiheke Island. The size classes used were: 40-60 mm, 61-75 mm, 76-85 mm, and 86-95 mm; the smallest gecko found was S-V: 45 mm, and the largest S-V: 95 mm. The size classes were analysed between the areas of pest control and no control on Waiheke Island using Mann-Whitney non-parametric and Student's parametric *t*-tests, either Mann-Whitney or the Student's *t*-test was used depending on the results of the Kolmogorov-Smirnov assumption test.

### 3.2.5.3 Gecko condition

To measure gecko condition, body-tail condition (BTC) and body condition index (BCI) indices were carried out following the same methodologies as in Barr (2009) and van Winkel (2008). The BTC index was calculated as  $BTC = VTL/SVL$  (vent to tail tip divided by snout to vent length). The BTC index values were then compared among size categories and for each sex between areas of predator control and no control on Waiheke Island. The BCI index was calculated as  $BCI = Weight/SVL$  (weight divided by snout to vent length) (following Floyd & Jenssen, 1983 and van Winkel, 2008). The BCI index was then compared among size categories and for each sex between the areas of pest control and no control on Waiheke Island. The BCI and BTC indices were compared using both Mann-Whitney non-parametric and Student's *t*-tests, one or the other was used depending on the results of the Kolmogorov-Smirnov assumption test.

## 3.2.6 Invertebrate sampling

The first time the CFRs were checked the invertebrates found occupying them were recorded, additionally the species and sex of each invertebrate found was recorded if possible. All readily identifiable and visible invertebrates were recorded, and were identified to species level where possible, otherwise to order (See appendix A for a list of invertebrate species found). The presence and absence of large invertebrates found was compared in the treatment and control areas on Waiheke

Island and the total average invertebrates were also compared between the four study sites of Waiheke (treatment and control), Tawharanui, and Shakespear.

### 3.3 Results

Using both the CFR (cell foam retreats) and VES (visual encounter surveys) methods a total of 152 geckos were caught throughout the year over the four study areas, of which 139 were caught on Waiheke Island, eight at Tawharanui and five at Shakespear. The majority of the geckos caught were forest geckos (*M. granulatus*), with 132 caught at Waiheke and Tawharanui, including 44 recaptures. Sixteen elegant geckos (*N. elegans*) were caught over the four study areas and only three pacific geckos (*D. pacificus*) were caught solely at Shakespear Regional Park.

#### 3.3.1 Predator tracking tunnels

Of the four predator tracking tunnel transects set up in the control areas (no pest control), both OD and OE showed a 100% tracking rate with nine out of nine tunnels tracked (Figure 3.3). OA showed an 86% tracking rate, and OB showed the lowest rate with only a 55% tracking rate (Figure 3.3). The average tracking rate over the last three years for the transects ‘rabbit’ and ‘peanut’, within the treatment area (pest control) were 14% and 8% respectively (Figure 3.3). The animals tracked included rats (54% of total), mice (33% of total), hedgehogs (4% of total) and mustelids (2% of total), the remainder of the tunnels were tracked by invertebrates or were not tracked at all. The total rats and mice tracked per year for both transects within the treatment area were low (Table 4.1). Rats were not tracked above 9% over the last three years, mice were tracked higher, with the highest rate of tracking for mice occurring during March 2011 with 38%. In the control areas, rats tracked the most tunnels with 86% of tunnels tracked, and 14% tracked by mice, no tunnels in the control areas were tracked by mustelids or hedgehogs. In the treatment area mice tracked the most tunnels with an average of 18% of tunnels tracked by mice and only 6% tracked by rats. Mustelids tracked the least tunnels with only 2%. Additionally, of the four gecko tracking tunnel transects that were set up in the treatment areas in

an attempt to track reptiles, only the IB transect was tracked by predators with 20% of the transect tracked.

Table 3.1 The total combined tracking rates of rats and mice per year for the Waiheke treatment transects 'Rabbit' and 'Peanut'.

			Waiheke Treatment	
			Rats	Mice
2009	January		5%	6%
2010	January		8%	8%
	November		3%	22%
2011	March		9%	38%
	November		1%	14%

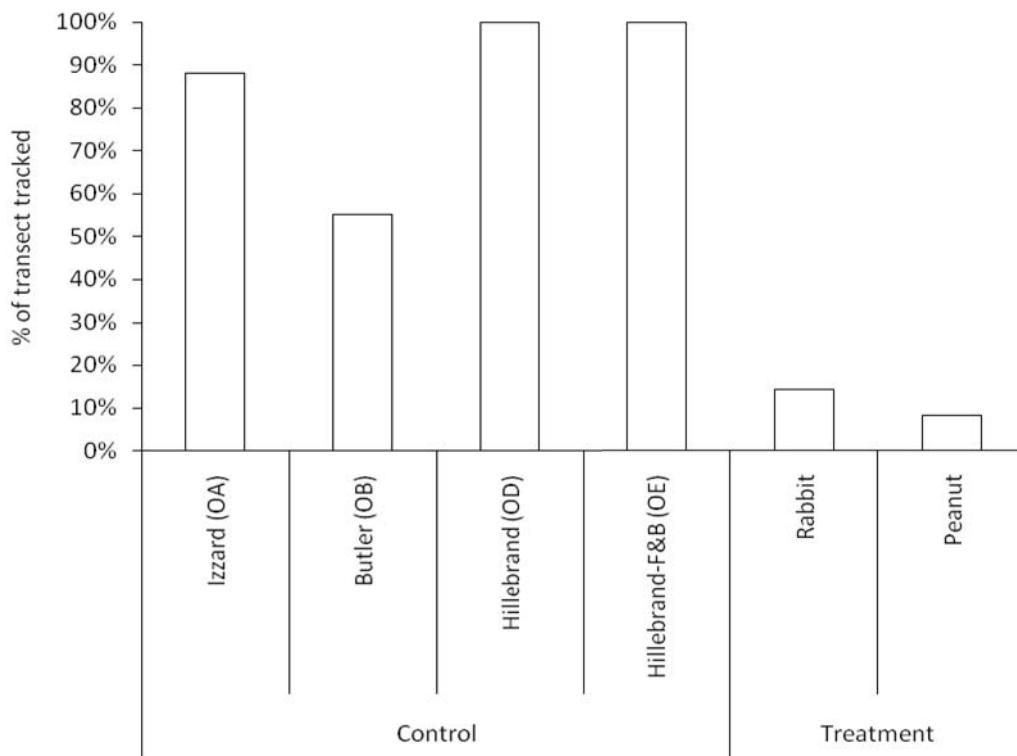


Figure 3.3 The percentage of tracking tunnel transects tracked by predators over four transects in the control areas (no pest control), and two transects in the treatment area (pest control).

### 3.3.2 Forest gecko density indices

Using the data from the cell foam retreats (CFRs), an index of the density of forest geckos per transect and per study area was calculated. The densities of geckos along each transect over the four study areas were compared (Figure 3.4). The five

transects in the Waiheke (treatment) area showed consistently high densities, with a range of 76.4 to 203.7 geckos  $\text{ha}^{-1}$ . The Waiheke (control) area showed one transect with a high density (Izzard OA with 152.8 geckos  $\text{ha}^{-1}$ ), two with relatively low densities and two with no geckos. Tawharanui showed very low densities of geckos along each of the five transects, with a range of 0 to 38.2 gecko  $\text{ha}^{-1}$ . Shakespear had only one transect out of the four with any geckos found on it, this transect showed a low density with only 38.2 geckos  $\text{ha}^{-1}$ .

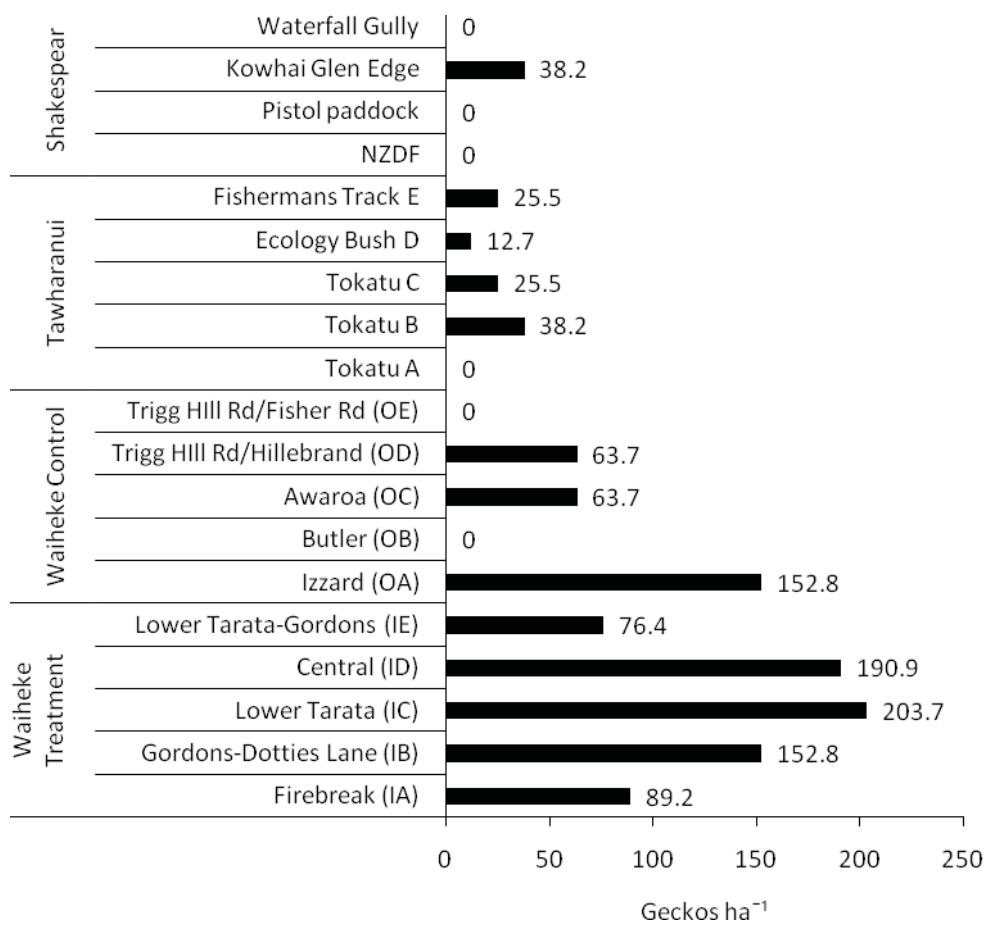


Figure 3.4 Gecko density ( $\text{ha}^{-1}$ ) indices over each transect in the four study sites.

The treatment areas at Waiheke (pest control) showed the highest gecko densities, with an average density of 137.5 geckos  $\text{ha}^{-1}$  (Table 3.2). The control areas at Waiheke (no pest control) showed the next highest density, with an average density of 56 geckos  $\text{ha}^{-1}$ . Tawharanui and Shakespear had significantly lower densities than Waiheke, with average densities of 20.4 and 9.5 geckos  $\text{ha}^{-1}$

respectively. Either Student's *t*-tests or Mann-Whitney U-tests were performed (depending on normality and standard deviation), comparing the average or median densities of geckos in each study area. Using a one-tailed (directional) Student's *t*-test the densities of geckos between the Waiheke treatment and control sites were significantly different ( $t = 2.235$ ,  $P = 0.02$ ), with the control areas having significantly fewer geckos. Using a Mann-Whitney U-test, the density of geckos was compared between Waiheke (treatment) and Tawharanui. Waiheke (treatment) showed a significantly higher density ( $U = 25.0$ ,  $P = 0.004$ ). A two-tailed Student's *t*-test was used to compare Waiheke (treatment) with Shakespear, showing that Waiheke (treatment) had a density significantly greater than Shakespear ( $t = 4.662$ ,  $P = 0.007$ ). There were no significant differences between the control areas at Waiheke and either Tawharanui or Shakespear, also Tawharanui was not significantly different to Shakespear.

Table 3.2 Average and median densities ( $\text{ha}^{-1}$ ) of geckos compared between the four study areas, where  $n$  = the number of transects per study area.

Study Areas	Mean ( $\pm\text{SE}$ )	Median (Lower and Upper 95% CI)	<i>n</i>
Waiheke (Treatment)	137.5 ( $\pm 23.268$ )	152.8 (72.19 – 202.09)	5
Waiheke (Control)	56.0 ( $\pm 28.067$ )	63.7 (-21.81 – 133.93)	5
Tawharanui	20.4 ( $\pm 6.429$ )	25.5 (2.349 – 38.392)	5
Shakespear	9.5 ( $\pm 9.549$ )	0	4

### 3.3.3 Population demographics

The snout to vent length of forest geckos captured using CFRs was used to determine population demographics. The total number of geckos caught within each of the size categories were determined, the size categories being: 40-60 mm, 61-75 mm, 76-85 mm and 86-95 mm. Although there were more geckos in the treatment area in all the size categories, the relative proportions of the sizes 40-60 mm and 76-85 mm were similar (Figures 3.5 and 3.6). There were both proportionally and as a total, much fewer geckos in the 86-95 mm size category in the areas of control compared with the areas of treatment on Waiheke Island.

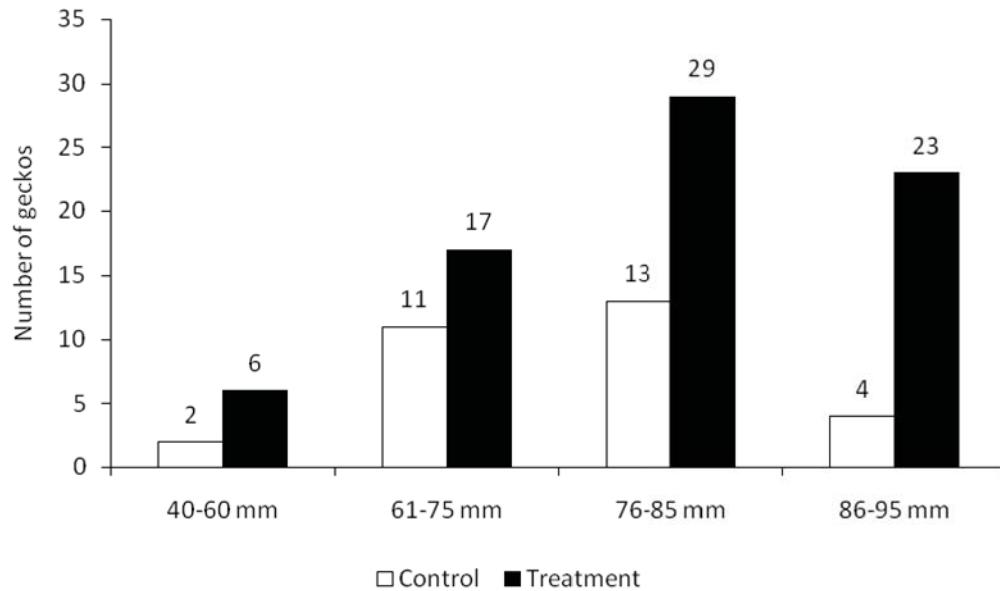


Figure 3.5 Total forest gecko captures per size category in areas of treatment (pest control) and control (no pest control) on Waiheke Island.

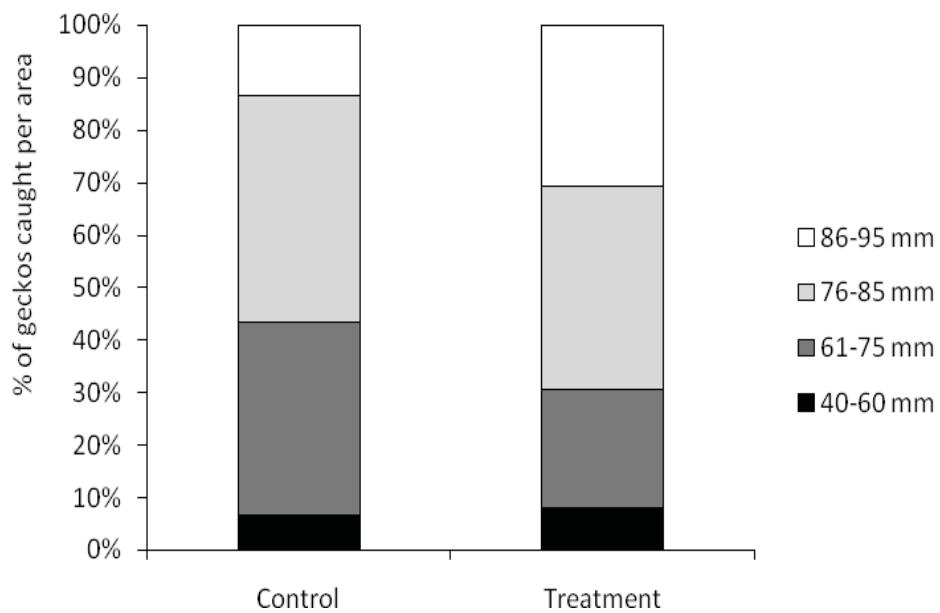


Figure 3.6 Proportion of forest geckos caught in each snout to vent size category (mm) in relation to total catch in treatment and control areas on Waiheke Island.

### 3.3.4 Evidence of attempted rat predation: body condition index (BCI)

The body condition index (BCI) was compared between the control and treatment areas, between the sexes (Figure 3.7), and also for each size class (Figure 3.8). These tests were carried out to determine whether rat predation attempts or competition cause an indirect body condition loss in geckos. Using a Student's *t*-test the results showed that the BCI of males in the control area was significantly lower than the BCI of males in the treatment area ( $t = 2.689$ ,  $P = 0.009$ ). However, when the females' BCIs were compared, no significant difference was found. This may be related to the sample size, as there were only seven females caught in the control area, which was potentially not robust.

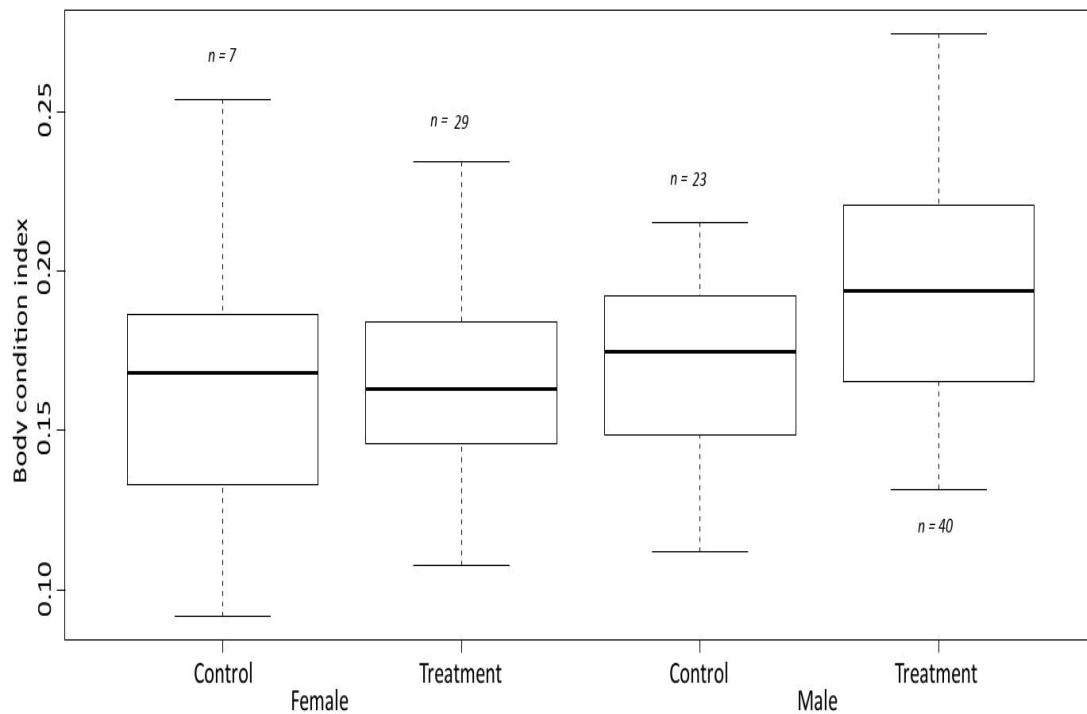


Figure 3.7 Box-plots comparing the body condition index of males and females between the control and treatment areas on Waiheke Island. (Where  $n$  = the number of geckos captured per sex, per area.)

The BCI among the size classes was also compared between the areas of control and treatment (Figure 3.8). Mann-Whitney U-tests were carried out on all

comparisons, excluding the 61-75 mm size class where a Student's *t*-test was carried out. All comparisons showed no significant results, with no size class having a significantly greater BCI in either the area of control or treatment. However, for the size classes 40-60 mm and 86-95 mm the sample sizes were very low in the control area with sample sizes of only two and four geckos.

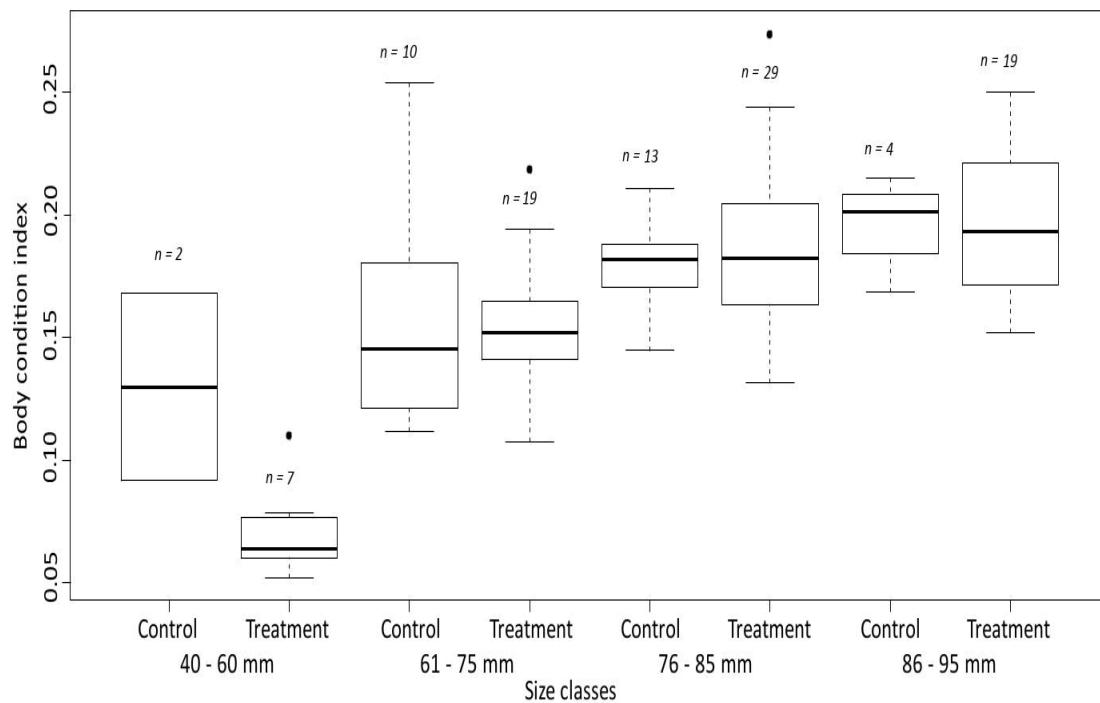


Figure 3.8 Box-plots comparing the body condition index between the size classes of 40-60 mm, 61-75 mm, 76-85 mm, and 86-95 mm in areas of control compared with treatment on Waiheke Island. (Where *n* = number of geckos captured per size class, per area.)

### 3.3.5 Evidence of attempted rat predation: body-tail condition index (BTC)

Mann-Whitney U-tests were carried out to compare the body-tail condition (BTC) index between the control and treatment areas, between the sexes (Figure 3.9) and also for each size class (Figure 3.10). These tests were carried out in order to determine whether the degree of tail loss provided further evidence of failed rat predation. The results showed that the BTC of the males was significantly higher in the treatment area ( $U = 678.5$ ,  $P = 0.001$ ), but the females did not show a significant

difference between the two areas. However, the sample size of females in the areas of control was very low, with only seven geckos found, which may not be robust.

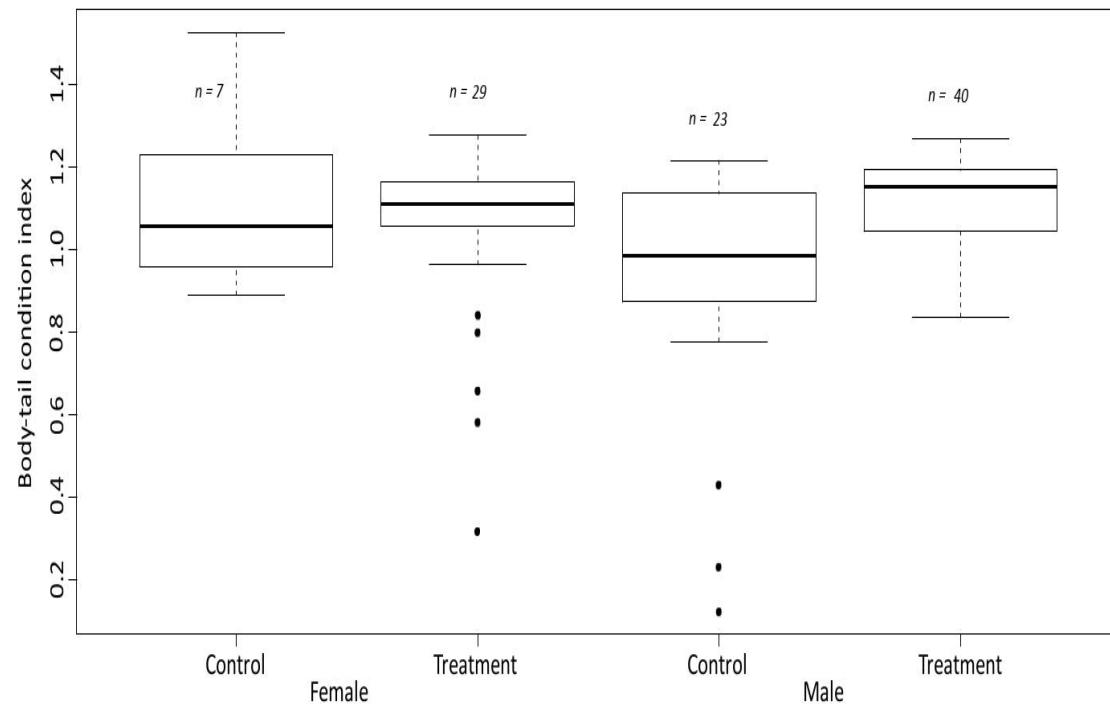


Figure 3.9 Box-plots comparing the body-tail condition index of males and females between the areas of control (no pest control) and treatment (pest control) on Waiheke Island. (Where  $n$  = the number of geckos captured per sex, per area.)

When the BTC was compared among the size classes using Mann-Whitney U-tests (Figure 3.10) the results showed that the two largest size classes showed significant differences between the areas of control and treatment. The size classes 76-85 mm and 86-95 mm both showed a higher BTC in the areas of treatment, ( $U = 277.5, P = 0.01$  and  $U = 70.0, P = 0.006$  respectively). However, the size class 86-95 mm had a very small sample size of only four geckos in the control areas, so the results for this size class may not be robust.

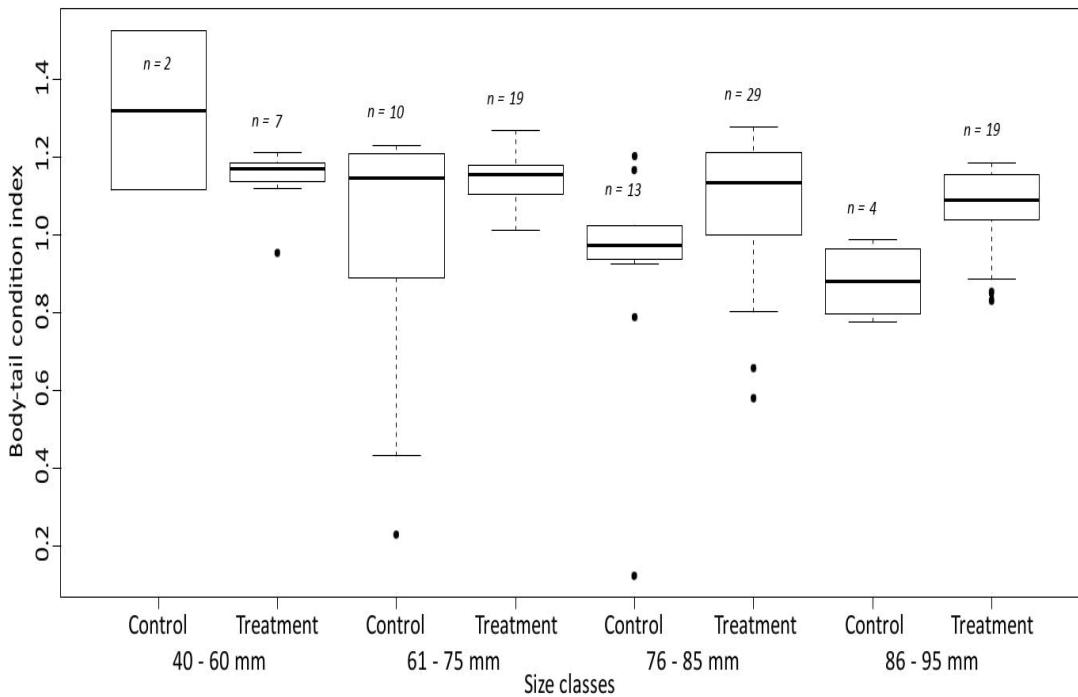


Figure 3.10 Box-plots comparing the body-tail condition index between the size classes of 40-60 mm, 61-75 mm, 76-85 mm, and 86-95 mm in areas of control compared with treatment on Waiheke Island. (Where  $n$  = the number of geckos captured per size, class per area.)

### 3.3.6 Evidence of attempted rat predation – sub-lethal injuries

Out of a total of 152 geckos, three individuals were captured with scars showing evidence of attempted predation. Many geckos also showed tail loss as evidence of predation attempts. However, only geckos with scars were analysed for evidence of attempted rat predation as the species of predator can often be determined through the scar patterns, but not with tail loss.

#### Gecko one (Figure 3.11)

Gecko one was captured during March, on the first ever check of the Izzard (OA) transect in the control area on Waiheke Island. The gecko was found under the OA31 CFR near the end of the transect, it was only captured once during the duration of this study. The gecko showed two scars approximately 4-5 mm long,

each on the shoulders/upper back area and between the front legs. There were no other visible scars, and the tail was not autotomised or re-growing.

### **Gecko two (Figure 3.12)**

Gecko two was first captured under the CFR OA32 during the second check of the Izzard (OA) transect in March. It was subsequently recaptured under the same CFR during the second of the fortnightly checks in September, and was not captured again after that. Gecko two showed the most scars of any gecko found during this study, with a total of eight scars and an autotomised re-grown tail. The scars were predominately situated around the head and mid-lower back, they were small (1-2 mm wide), puncture-like circular wounds, except for the scar on the femora region of the front right leg which was approximately 3-4 mm long.

### **Gecko three (Figure 3.13)**

Gecko three was first captured under CFR OA09 during the first check in March. It was subsequently recaptured during the fourth check in March under the same CFR. It may have been recaptured again during the second fortnightly check in September, as a gecko was found under OA09 but escaped before it could be positively identified. Gecko three showed only one scar on the upper labial and canthal scales which was approximately 3-4 mm long, it did not have an autotomised or re-growing tail.

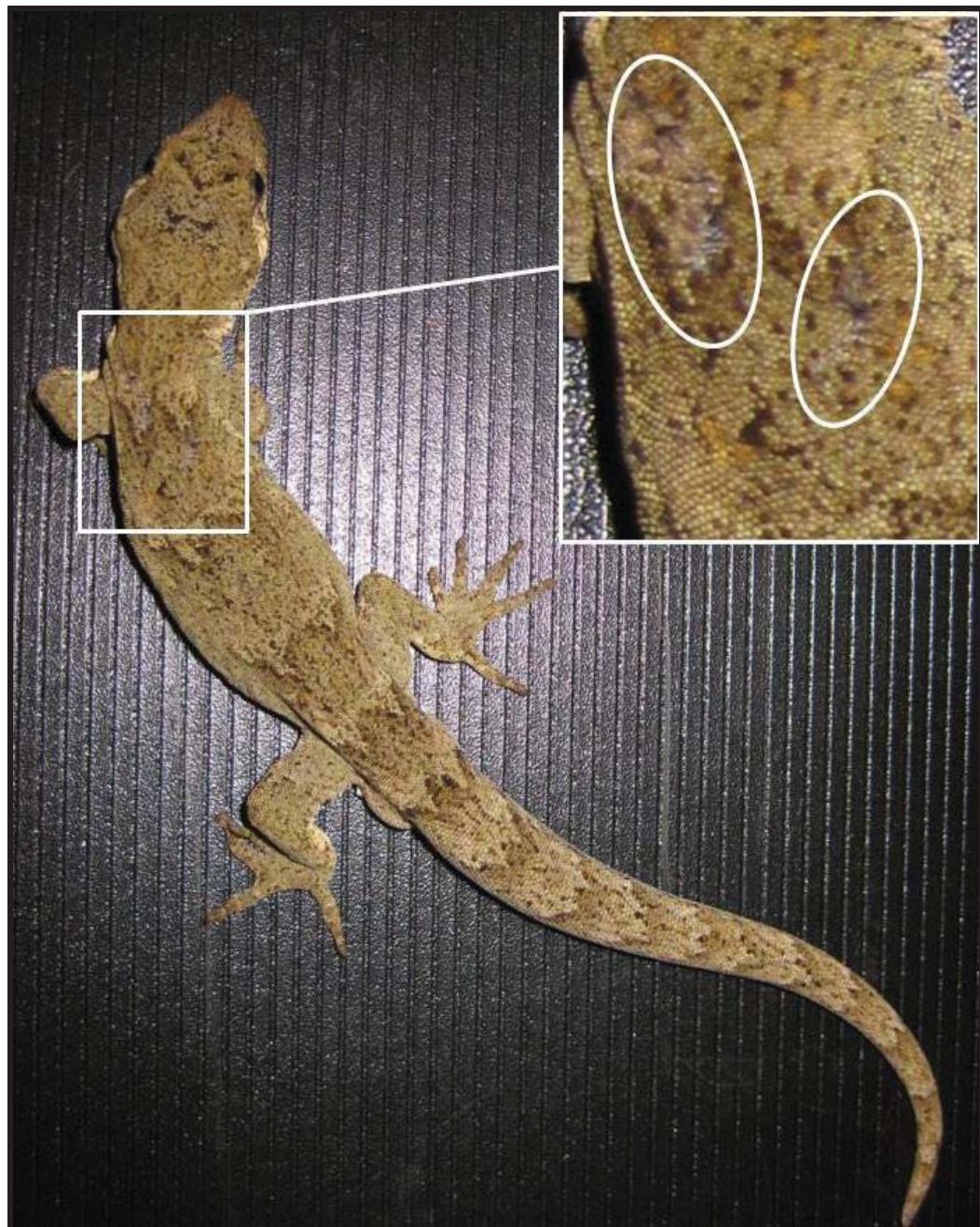
**Gecko one OA31**

Figure 3.11 Male *M. granulatus* gecko, found under CFR OA31, showing two scars on upper back in the shoulder region. No other visible scars were observed on this gecko, also the tail has not been autotomised.

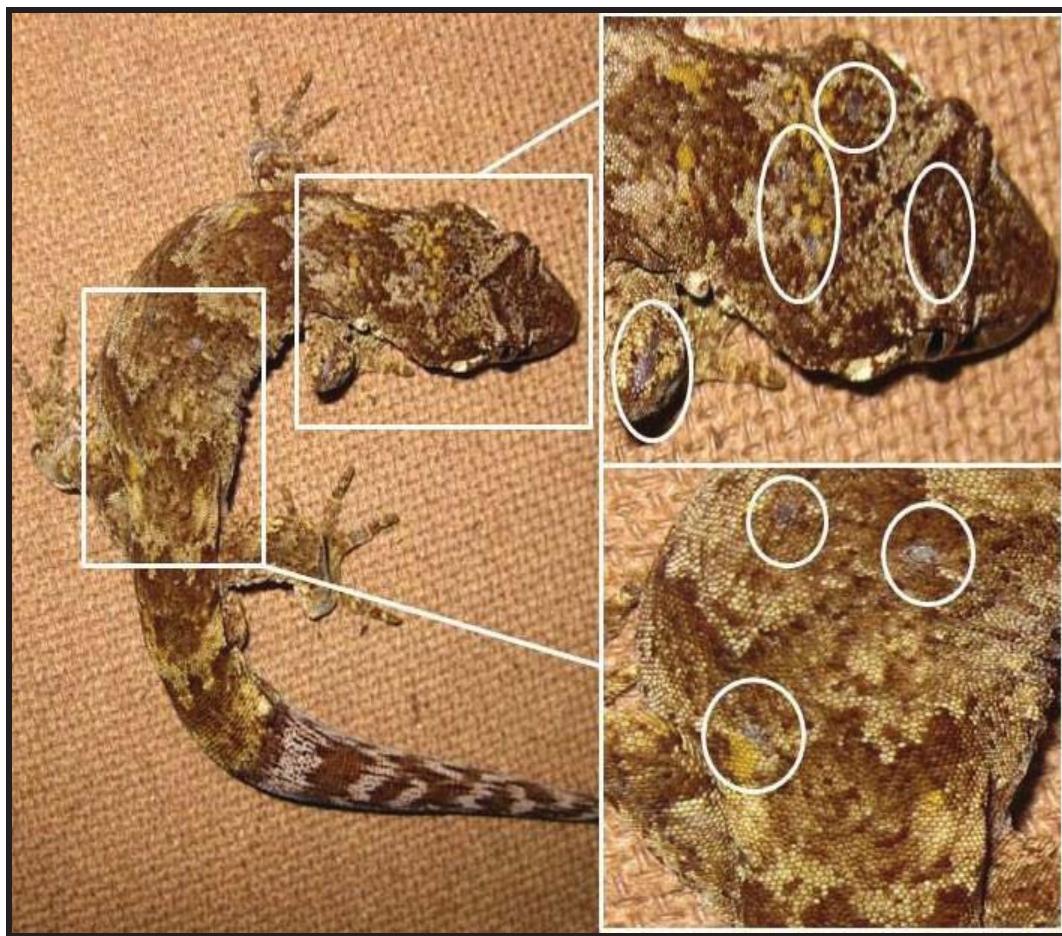
**Gecko two OA32**

Figure 3.12 Male *M. granulatus* gecko, found under CFR OA32, over eight scars were observed on the lower back and head region. The tail has been autotomised and re-grown at least once.

**Gecko three OA09**

Figure 3.13 Male *M. granulatus*, found under CFR OA09, showing a small scar on the upper labial and canthal scales. There were no other visible scars found on this gecko, and no evidence of tail loss.

### 3.3.7 Invertebrate abundance analysis

#### 3.3.7.1 Total invertebrate abundance

The abundance of invertebrates was compared between the four study areas (Figure 3.14) using a Kruskal-Wallis test ( $KW = 11.817$ ,  $P = 0.008$ ) and a Dunn's multiple comparison test. The results showed Waiheke (control) had a significantly higher median than both Tawharanui ( $P = 0.007$ ) and Shakespear ( $P = 0.01$ ). The median of Waiheke (treatment) was not significantly different from Waiheke (control), Tawharanui or Shakespear, and the median of Tawharanui was not significantly different from Shakespear. However, this abundance of invertebrates at Waiheke (control) is predominantly due to a very high number of cave weta (Table 3.3). The total species count was also much higher in the Waiheke (control) area than any of the other study areas (Table 3.2) with 21 species found compared with 14 at Waiheke (treatment) and Tawharanui, and 11 at Shakespear (Table 3.3). The two control areas in the study did not show a similar abundance of invertebrates; Waiheke (control) showed significantly higher total invertebrates, species, and median invertebrates per transect than Shakespear (Tables 3.3 and Figure 3.14). Refer to appendix A for a list of all invertebrates recorded.

Table 3.3 The total number of species, invertebrates and proportion of most common species found in each study area.

	Shakespear	Tawharanui	Waiheke Control	Waiheke Treatment
Total species	11	14	21	14
Total invertebrates	350	463	1624	864
<b>Most common species</b>				
Cave weta (sm. sp.)	0	73	1019	328
Cockroach	168	251	235	328
Tree weta	49	25	38	49
<b>Large species</b>				
Sheet-web spider	0	33	44	73
Giant centipede	0	5	1	9

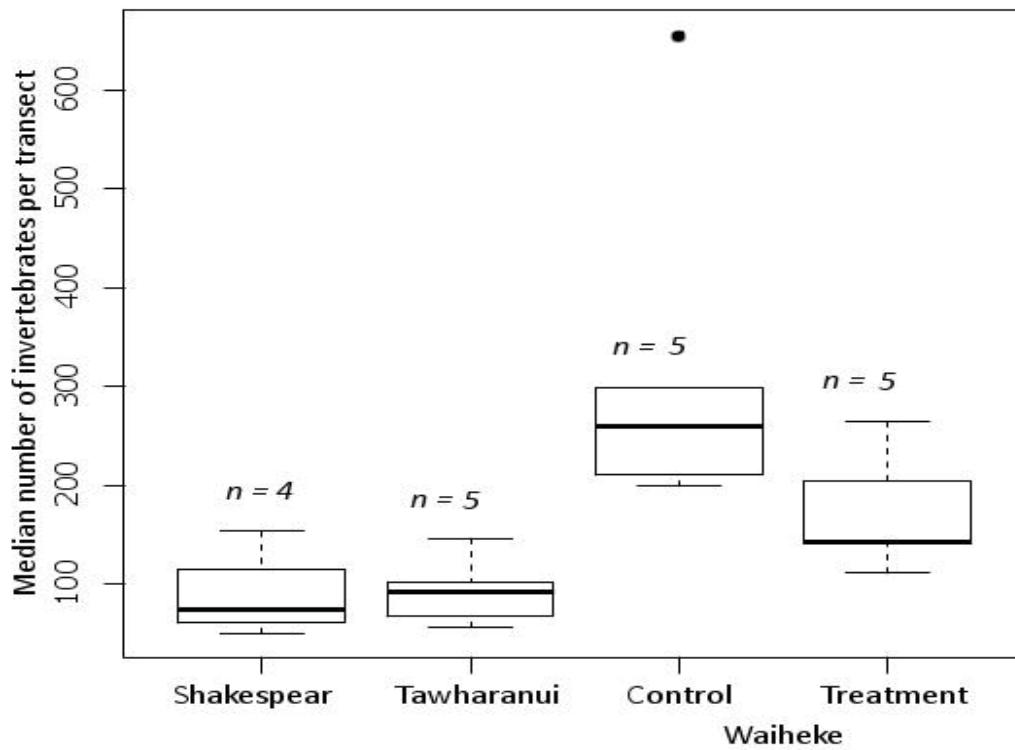


Figure 3.14 Box-plots comparing the median number of invertebrates per transect over the four study areas, where  $n$  = number of transects.

### 3.3.7.2 Large invertebrate abundance

The average abundance of three large invertebrates (sheet-web spider (*Cambridgea spp.*)), giant centipede (*Cormocephalus rubriceps*) and tree weta (*Hemideina spp.*)) per transect was analysed between the four study areas (Table 3.4). The abundance of the sheet-web spider was compared using a one-way analysis of variance ( $P = 0.0001$ ,  $F = 8.1$ ,  $df = 14$ ). The results showed Waiheke (treatment) had significantly more sheet-web spiders than Waiheke (control) ( $P = 0.02$ ), Tawharanui ( $P = 0.005$ ) and Shakespear (as no sheet-web spiders were found at Shakespear). Waiheke (control) did not have significantly more sheet-web spiders than Tawharanui.

The abundance of giant centipedes was compared between the study areas (Table 3.4) using directional Mann-Whitney U-tests and unpaired Student's *t*-tests. The abundance of giant centipedes was compared between Waiheke control and treatment using a one-tailed (directional) Mann-Whitney U-test. The results showed a significantly greater number of giant centipedes in the treatment area ( $U = 21.5$ ,  $P = 0.03$ ). No significant differences were found between Waiheke (treatment) and Tawharanui or Waiheke (control) and Tawharanui, also no giant centipedes were found at Shakespear (Table 3.4).

A one-way ANOVA was carried out to compare the abundances of tree weta (Table 3.4) between the four study areas. The results showed no significant variance among the study areas ( $P = 0.5$ ,  $F = 0.81$ ,  $df = 18$ ). However, Shakespear showed the highest abundance of tree weta.

Table 3.4 Average and medians of large invertebrates per transect: sheet-web spiders, giant centipedes, and tree weta compared between the four study areas. (Where 95% CI = Lower and Upper confidence intervals)  $n = 5$  for all areas excluding Shakespear where  $n = 4$ .

	Waiheke Control	Waiheke Treatment	Tawharanui	Shakespear
<b>SW Spider</b>				
Median (95% CI)	9 (5.2 – 12.3)	14 (9.8 - 19.3)	7 (3.0 - 10.1)	0
Mean ( $\pm$ SE)	8.8 ( $\pm$ 1.281)	14.6 ( $\pm$ 1.72)	6.6 ( $\pm$ 1.28)	0
<b>Giant centipede</b>				
Median (95% CI)	0 (-0.3 - 0.7)	2 (0.1 - 3.4)	1 (-0.2 - 2.2)	0
Mean ( $\pm$ SE)	0.2 ( $\pm$ 0.2)	1.8 ( $\pm$ 0.5831)	1 ( $\pm$ 0.44)	0
<b>Tree weta</b>				
Median (95% CI)	6 (-0.8 - 16.0)	7 (-1.8 - 21.4)	2 (-2.4 - 12.4)	12 (2.4 - 22.0)
Mean ( $\pm$ SE)	7.6 ( $\pm$ 3.04)	9.8 ( $\pm$ 4.21)	5 ( $\pm$ 2.68)	12.25 ( $\pm$ 3.09)

## 3.4 Discussion

### 3.4.1 Gecko densities and population structure

There were more geckos captured in the treatment sites on Waiheke Island than any other site. The densities of geckos was the highest in this area with an estimated 137 geckos per ha. In comparison, the densities of geckos in the other three study areas were much lower. The density of geckos at Tawharanui was low despite the fact that extensive pest control and a predator-proof fence had been erected that excludes most predators. However, Chris Wedding (pers. comm. 2011) has studied geckos at Tawharanui for several years and has found in certain areas very high densities of forest and green geckos. The results of this study at Tawharanui are therefore unrepresentative as there are high densities of geckos at Tawharanui in certain areas but the monitoring methods used in this study were unable to detect them.

Waiheke Island (both treatment and control sites) had the highest densities of geckos. The control site at Waiheke had relatively high densities of geckos, much higher than either Tawharanui or Shakespear (but not significantly higher). This site also had high abundances of rats, potentially indicating geckos can co-exist with rats. However, the high density of geckos in the control site was skewed by one transect which had a very high density of geckos (the OA transect). This transect had the third highest density of geckos in the entire study. There could be many potential reasons why OA had such a high density of geckos. The primary reason could be a difference in habitat; Chapter four (section 4.3, subsection 4.3.2) shows that of all the transects on Waiheke Island the habitat at the OA transect had the highest chance of catching geckos as it had a high average forest density and biodiversity and a low canopy height. The fact that OA did not have as high a density of geckos than some of the treatment transects shows that rats are potentially having an impact on the geckos. If there were no rats, the ideal nature of the habitat would potentially increase even further the number of geckos captured. The densities of geckos would then potentially equal or exceed the densities seen on the ID and IC transects which had less ideal habitat but higher gecko densities.

Another reason why the OA transect had such a high density of geckos may be due to predator behaviour. The Izzard transect is on the edge of a large field of long grass, which is known to provide an ideal habitat for rodents (Newman, 1994; Innes et al., 2010; Knox, 2011). There may be a very high density of mice in this area, and rats would potentially be more likely to predate on mice rather than geckos, which may be more difficult to find and predate on. Additionally, mice predate on (Knox, 2011), and will potentially compete with geckos for resources such as small invertebrates. The predation of rats on mice may then release geckos from this pressure, causing an increase in gecko densities.

The analysis of the abundances of large invertebrates showed that in the control areas giant centipedes (*Cormocephalus rubriceps*) and sheet-web spiders (*Cambridgea* spp.) were significantly less abundant. This, combined with the differences in habitat, may be a reason to explain the high densities of geckos on the Izzard transect. Giant centipedes are known to predate on small geckos (Pike et al., 2010a; Vallance, 2010; Jewel, 2011), and large spiders may predate on (Lettink & Patrick, 2006) and compete with geckos for invertebrate food sources. In areas where rats are abundant, the decrease in the abundance of large invertebrates may cause an increase in gecko densities. When this is combined with the ideal habitat for catching geckos, this may explain the high outlier in gecko densities on the Izzard transect.

There were relatively few mammalian predators within the regional park on Waiheke, and that this low number has been low for the last three years and as such it can confidently be used as a treatment site (where mammalian predators are low) to analyse the effects of rats and other mammalian predators on geckos. The tunnels outside of the park in the control areas totalled 36 tracking tunnels over four transects, a total of 30 out of 36 tunnels were tracked, predominantly by rats, mice were also found on the Izzard transect. The percentages of tunnels that were tracked ranged between each transect from 55% to 100% tracked. These results show that in the control areas rats are present and potentially abundant. This would indicate that any negative effects on the demography and body condition of geckos in these areas when compared with the treatment areas can be correlated with, and may be due to, the presence of rats.

The mammalian pests present at Shakespear at the time of the reptile monitoring (i.e. before the bait drop in July 2011) included; mice (*M. musculus*), rats (*R. rattus*), cats (*F. catus*), mustelids (*Mustelidae spp.*), hedgehogs (*Erinaceus europaeus*) and the brush-tail possum (*T. vulpecula*) (M. Maitland pers. com. 2012). As such, the main difference in pest presence between Shakespear and Waiheke is the possum, as possums have never been present on Waiheke Island. Possums are known to prey on birds, birds' eggs and chicks (Brown et al., 1993; Brown et al., 1996), so it is likely they also prey on arboreal geckos. They have strong and dexterous forelimbs with large sharp claws (Ivanco et al., 1996), as such they could tear apart loose bark and tree cavities in order to predate on geckos in their refuge sites. Epiphytes and tree holes are also utilised by possums as nesting sites (McCallum, 1986; Green & Coleman, 1987; Wilson et al., 1998), these habitats naturally support many species of invertebrates and reptiles (Affeld, 2008; Affeld et al., 2009; Bell, 2009; Blakely et al., 2011; Jewel, 2011). However, with possums occupying these habitats the biodiversity of these mini-ecosystems would potentially decline through possums predating on the invertebrates (Cowan & Moeed, 1987), reptiles and birds that may share these habitats. Possums also thin out foliage and deplete the canopy cover (Cowan, 1992; Whitaker, 1998), thinning out foraging areas and cover for geckos thus increasing the threat of avian predation (McCallum, 1986). The thinner canopy would cause the density of undergrowth to increase and the forest floor to dry out as light intensity increases (Whitaker, 1998). This could potentially cause geckos to emigrate into the undergrowth to escape avian predation. However, this would then cause geckos to become more vulnerable to predation from ground-dwelling predators such as rats, cats, pigs and mustelids. This thinning out of the canopy due to possums is thought to have an impact on the striped skink (*Oligosoma striatum*) as a drier forest floor will not support skinks (Whitaker, 1998). There are currently no studies that explore the possible effects that possums have on geckos in New Zealand.

Shakespear Regional Park was the only study site where Pacific geckos (*D. pacificus*) were found. Forest geckos are larger and less timid than Pacific geckos (Jewel, 2011), consequently they may competitively exclude them from arboreal habitat, forcing them to inhabit ground or low lying habitat. Therefore, in areas where pests are present Pacific geckos would potentially be more prone to predation

from mammalian pests than the forest gecko. Pacific geckos may have occupied Waiheke Island and Tawharanui and become locally extinct due to mammalian predator incursions and possibly their inability to occupy the safer canopy as a result of competitive exclusion by forest geckos. For example, a Department of Conservation study on the distribution of alpine forest geckos (*Mokopirirakau* ‘Roys Peak’) showed that they may have excluded the smaller common gecko (*Woodworthia* ‘Southern Alps’) from habitat above 1000 m (Tocher, 2001) as the common geckos were only found below 1000 m. Another study on invasive geckos in the Pacific Islands showed that the introduced house gecko (*Hemidactylus frenatus*) competitively excluded the endemic species *Nactus coindemirensis* and *Nactus durrelli* from favoured refuges, increasing their risk of predation and exposure to stochastic events (Cole et al., 2005).

Despite the fact that treatment areas of Waiheke Island had much higher densities of geckos than the control areas, this result alone is not enough to prove that rats have a negative effect on geckos. Therefore the population structure of geckos in both areas was also analysed in order to provide more data on the potential effects of rats. Results showed that there were consistently more geckos in each size category in the treatment (pest control) areas of Waiheke than the control areas. However, the results also showed that the smallest size category (40-60 mm SVL) was relatively equal between the two areas. This was likely due to the small sample size for this size category. Eight geckos in total were found in this size category, six in the treatment areas and two in control. This result cannot indicate population growth or decline because of the small sample size. There may be many juveniles in the area but due to their small size and cryptic and elusive nature they may not be found.

The results showed there was a large difference between the numbers of geckos found in the largest size class (85-95 mm SVL), with 23 geckos found in the treatment and only four in the control area. This could indicate that more geckos in the treatment sites are living longer and subsequently growing larger as invasive predation pressure is lower. The life span of the forest gecko has been approximated from similar species as a mean minimum longevity of 12.7 years, with a range of 7-17 years (Bell, 2009). Forest geckos have a low annual reproductive output (usually about 1-2 young per year; Towns, 1991) and are slow to mature (estimated 3-4 years;

Towns, 1991), as such they have a slow annual population rate of increase. The potentially shorter life span in the control geckos would result in females giving birth to fewer young over their life, which would subsequently inhibit recruitment. In a species that already has a low rate of population increase, coupled with the fact that juveniles may be more prone to predation due to their small size, recruitment would further be inhibited, causing a decline in the population and, potentially, in the long term, local extinction.

### 3.4.2 Gecko condition (BCI and BTC)

The results showed that males had a lower BCI and BTC in the control areas could potentially indicate the predation pressure of rats. This shows that where rats are present in abundance, male forest geckos will have lower BCIs and BTCS, indicating that rats potentially have both a direct affect on gecko condition through inducing tail loss and also an indirect affect through decreasing body condition. However, the indirect effect (BCI) could be correlated with the direct effect (BTC), as when geckos lose their tails they will invariably lose condition as well (Avery, 1970; Dial & Fitzpatrick, 1981; Doughty & Shine, 1998; Fox et al., 1990; Perez-Mellado et al., 1997).

The comparison of size classes for BCI and BTC showed that there was an impact on the larger size classes. The larger size classes of geckos would be more likely to have a lower BTC however, as the older a gecko becomes the more likely it is that it has shed its tail at least once, and potentially multiple times. Therefore, the BTC will compound, so that a significantly lower BTC would become more likely in older geckos. Males may also potentially grow larger than females, so the largest size classes may be entirely made up of males, which would bias the results as the BTC has already shown that males have a lower BTC and BCI in the control areas.

The fact that males had lower BCIs and BTCS in the control areas while the females did not is interesting to note. Little is known about the social or behavioural ecology of forest geckos, and the fact that rats seem to have a larger impact on male forest geckos may be due to differences in behaviour between males and females. Also this male bias may be due to the fact that the smaller and female geckos may

still be predated on by rats but not be capable of escaping predation. If this were the case there would be no affect shown on the BCI or BTC indices as the geckos will not live to show these effects.

Competition between males for mates may also be a factor to consider in explaining the differences in BTC and BCI between the sexes in the area of treatment versus control. However, this competition would likely be ritualistic and would not result in tail loss or a significant loss in body condition, as many species of reptiles are known to fight ritually in order to prevent injuries when competing for mates (Carpenter et al., 1976; Dial & Fitzpatrick, 1981). Ritualistic fighting is likely to occur in arboreal gecko species, as a loss of limb or tail due to conspecific fighting would cause a significant loss in condition. Also forest geckos have the ability to change colour, becoming brighter or duller with higher (or lower) contrast in markings over a small space of time (pers. obs. 2011). In many reptile species colour is linked to fighting ability and dominance (Olsson, 1994; Sacchi et al., 2009), with the brighter individuals being more dominant. With this system, conspecific fighting is rare as individuals can gauge their chance of winning a fight and submit before any aggression takes place. Other species of New Zealand geckos, such as the Duvauzel's gecko, are known to fight when in captivity (M. Barry pers. comm. 2011). However, captivity induces stress due to several individuals living in a confined space, and as such this may not reflect natural social interactions for these species. Also, the Duvauzel's gecko is not a highly arboreal gecko, and as such, tail loss, or the loss of a toe or limb, would not have as much of a negative impact as it would for a forest gecko.

During this study many male and female pairs were found under the same CFR. Some individuals were repeatedly found in pairs over several checks, this may be evidence of pair bonding or short-term monogamy. Monogamy is rarely reported in taxa other than birds, however, recent studies have found examples of monogamous reptile species (Bull, 2000 & 1988; O'Connor & Shine, 2003). During this study the colour change of geckos captured was noted before and after handling. When an individual was captured the initial colour was usually dark with a low contrast in patterns. After handling, the gecko would then become significantly paler with a low contrast in patterns (regardless of sex). However, when a male and female were found together under a CFR this colour change was observed to be different.

The female still changed colour to become paler with less contrast but the male did not. The male changed colour to become brighter with more colour and increased contrast in patterning (see Figure 3.1). This colour change may be further evidence of a pair bond as it may show that the male is attracting a perceived predator to help the female escape, a mutualism that should only exist if the male is committed to a single female. This could also explain why the BCIs and BTCs are lower in males in areas of higher predation risk and why there is no affect on females, as males are potentially targeted more frequently. However, this phenomenon was not studied, only observed, as such the colour change may have been due to chance or other unknown factors.

Females may be less prone than males to autotomise their tails, as a loss in condition due to tail loss may adversely affect vitellogenesis. For example, studies have shown in other geckos that when females have experienced tail loss, the subsequent loss of caudal reserves resulted in the production of eggs that were significantly lower in mass and energy content than in females with intact tails (Dial & Fitzpatrick, 1981). This may be due to the effect of life span on the energy allocation of lizards. It is theorised that in long-lived species (such as *M. granulatus*), energy allocation should be prioritised towards tail regeneration due to the positive value of having a tail during predator encounters and the high probability of future breeding success (Dial & Fitzpatrick, 1981). However, this theory is hypothesised for species with a high output of young and high breeding success. In New Zealand geckos this is not the case, they have a low output, with a maximum of two young per year (Towns, 1991). Therefore, tail loss is more likely to be avoided altogether in females, as the costs on breeding success and young output may be higher than in other species.

### 3.4.3 Evidence of attempted rat predation – sub-lethal injuries

Out of the 152 geckos captured and recaptured during this study, only three exhibited scars. Each of the three geckos showed significantly different scars from each other, and as such they are presumed to each have been attacked by a different predator. Since the actual attacks were not witnessed it is problematic to

categorically determine the animal that caused these scars. The potential predators of geckos on Waiheke Island are numerous and include morepork (*Ninox novaeseelandiae*); kingfishers (*Halcyon sancta*); pukeko (*Porphyrio porphyrio*); mustelids (Mustelidae); feral pigs (*Sus scrofa*); cats (*Felis catus*); rats (*Rattus spp.*) and invertebrates such as the giant centipede (*Cormocephalus rubriceps*). It is possible to implicate the suspected predator by observing the characteristics of the injuries and associating these with the predators' foraging strategies (Barr, 2009).

There are many studies that show that rats tend to eat their prey head-first (Barr, 2009; Timberlake & Washburne, 1989). Ivanco et al. (1996) showed that rats immobilise and manipulate their prey with their forelimbs so they can eat them head-first, in order to kill their prey sooner and prevent the possibility of escape during handling. Gecko three (Figure 3.13) was the only individual to show evidence of being predated on head-first, with a small scar on the upper jaw. However, this scar was small and no other scars were in evidence, also the gecko had not autotomised its tail, which would be expected if the gecko had been predated on. Gecko two also showed scars on the head, but these scars were not consistent with rat predation as the scars were small, clustered and circular, and there were many scars over the body and lower back.

Morepork (*N. novaeseelandiae*) are known to predate on reptiles as evidenced by the remains of geckos found in their nests (Brown & Mudge, 1999; Ramsey & Watt, 1971). They capture and kill prey using their talons or beak, capturing their prey and returning to a perch or nest site to consume it (Brown & Mudge, 1999). They tend to eat their prey head-first, clutching the body with their talons (Brown & Mudge, 1999). As such, sub-lethal injuries consistent with morepork predation would consist of severe and circular puncture wounds from talons on the upper and lower back where the morepork has grasped a gecko (Barr, 2009). Also, it is likely that longer scars may be evident on the head region from the beak. Gecko two's scars (Figure 3.12) may be consistent with attempted morepork predation as they exhibit these patterns. They are small and circular and are grouped on the upper and lower back, with several scars on the head. Gecko two is also the only gecko to exhibit tail loss, which would also be consistent with attempted morepork predation.

Kingfishers (*H. sancta*) are also known to predate on reptiles. Fitzgerald et al. (1986) studied the pellets of kingfishers, showing that many reptiles were present, including forest geckos. Kingfishers are diurnal, they spot their prey from an elevated position, then swoop down and catch their victim before returning to their perch, carrying the prey crosswise in their beak (Heather & Robertson, 1996). Smaller animals are killed in the initial impact, while larger animals will be battered against the perch until dead (Barr, 2009). Sub-lethal injuries are likely to be situated at the mid-body or shoulder (Barr, 2009). Hitchmough (1979) found evidence of sub-lethal injuries on green geckos (*Naultinus spp.*) presumed to be from kingfishers, which showed large beak-shaped bruising around the body and nape. These injuries could potentially be consistent with the scars of gecko one, which showed two long scars on the upper back or shoulder region, which may be from the upper beak of the kingfisher.

Pukeko (*P. porphyrio*) are thought to predate on reptiles also. Carroll (1966) found unidentifiable fragments of lizards in the gizzards of pukeko. However, pukeko are most commonly found near swamps and around urban areas and grassland, they do not tend to inhabit forest, nor do they climb trees, additionally they are infrequent fliers and would be unlikely to predate on a gecko in the canopy. Therefore, it would be unlikely that pukeko would predate on arboreal geckos such as forest geckos.

Other than rats, potential mammalian predators include mustelids (Mustelidae), pigs (*S. scrofa*) and cats (*F. catus*). Pigs are known to predate on reptiles in New Zealand (Thomson & Challies, 1988). However, the size of the scars shown on the three geckos would not be consistent with pig predation, as they are too small to have been caused by pigs. Stoats (*Mustela erminea*) have been found to predate on geckos (King & Moody, 1982). However, due to their hyper-aggressive nature (Polkanov, 2000), it is unlikely a gecko would be capable of escaping predation. Feral and domestic cats are highly efficient predators of many species in New Zealand, including lizards (Daugherty & Towns 1991; Gillies & Clout, 2003; Barr, 2009). Domestic cats have been known to capture geckos in the Waitakere Ranges near Auckland and bring them back to their owners alive (Gillies & Clout, 2003). Domestic cats, however, would be unlikely to have predated on the three geckos showing scars in this study, due to the fact that the area where these geckos

were found is far away from any urban areas or houses, as such if cats predated on these geckos they would have been feral. Other studies have shown that the injuries inflicted on reptiles by feral cats are often fatal and always involve conspicuous puncture wounds, often around the legs and body (Barr, 2009). Also, the act of domestic cats returning prey alive to their owners is considered a form of play (Biben, 1979). Wild or feral animals are less likely to play with their prey and as such would not give the animal a chance to escape, but would instead kill it swiftly (Biben, 1979). Biben (1979) also showed that as hunger in domestic cats increased, the probability of a kill also increased. Geckos are unlikely to survive encounters with feral cats and as such the scars shown in this study are unlikely to have come from cats.

Invertebrates such as giant centipedes (*Cormocephalus rubriceps*) and certain spiders are known to predate on reptiles (Pike et al., 2010a; Vallance, 2010; Jewel, 2011). Spider predation would be due to small and juvenile reptiles accidentally becoming ensnared in webs (Lettink & Patrick, 2006) and as such must be discounted from this study. Giant centipedes will hunt smaller reptiles such as juvenile forest geckos, also they can grow to a similar size as forest geckos (around 200-300 mm (Barker, 2004)) and as such the larger centipedes could still pose a threat to mature geckos. Centipedes are efficient predators that are capable of overpowering relatively large prey with the use of venom that will paralyse or even kill their prey (Barker, 2004). Due to this venom it is unlikely that a gecko would be capable of surviving an attack from a giant centipede and therefore the injuries shown by the three geckos in this study are unlikely to have come from giant centipedes.

### 3.4.4 Invertebrate abundances

The abundance of invertebrates is an important variable to consider when looking at the effects of mammalian predators on a gecko's ecosystem. The most common invertebrates found in each area were the cockroach (*Celatoblatta* spp.) and the smaller species of cave weta (*Gymnoplectron* spp.). This is to be expected as cockroaches are generalists and can survive in most habitats and eat several different

foods, they are also ‘R’ selected breeders that can breed often and have many offspring (Zervos, 1986). Cave weta are known to retreat to dark, damp and cool places (such as CFRs) during the day and to gather in large numbers (Sherley, 1998) which could explain the abundance of this species under the CFRs. Other relatively common invertebrates included tree weta (*Hemideina* spp.) and the sheet-web spider (*Cambridgea* spp.). The abundance of large invertebrates was also analysed in each of the four study areas. The large invertebrates analysed included the sheet-web spider (*Cambridgea* spp.), the giant centipede (*Cormocephalus rubriceps*), and the tree weta (*Hemideina* spp.).

The area with the most abundant invertebrates was Waiheke (control), however this was due to the very high abundance of cave weta on one of the transects in this area. The number of cave weta on this transect was an outlier in the data, with a much higher abundance than normal. Over 1000 cave weta were found in total in the Waiheke (control) area, with over 600 of these found on the one transect. Interestingly, this transect did not have any geckos present on it. There could be many reasons for the over-abundance of cave wetas on this transect. Habitat and micro-climate may be the major contributors to this outlier, as this area may have been more favourable to cave wetas than any of the other areas. The forest in this area was relatively damp and many of the kanuka trees the CFRs were nailed to were rotting, making the area under the CFRs very damp, which would provide a favourable habitat for cave wetas (Sherley, 1998). Rats were present in abundance on this transect, with 100% of the tunnels tracked, and as such, predation by rats must not have a significant impact on cave wetas. However, rats may still influence the high abundance of weta found on this transect as they will predate on mice and potentially lift the cave weta from this predation pressure. The absence of geckos in this area would also contribute to the high number of cave weta as they could use the CFRs without the possibility of being predated on.

Waiheke (control) had a much higher total species count of invertebrates than any other area. Habitat type may be the major factor that could explain this difference. In the control areas on Waiheke the major difference in habitat was the abundances of invasive species such as gorse (*Ulex europaeus*), moth plant (*Araujia sericifera*), woolly nightshade (*Solanum mauritianum*) and climbing asparagus (*Asparagus scandens*) (see Chapter 4 section 4.4). The abundances of these plants

will cause the forest density and ground cover to increase and may subsequently favour invertebrates by creating high densities and species diversity. For example, during a study by Waipara et al. (2006) moth plant was found to support over 100 different species of invertebrates. Also, when invasive gorse scrubland was compared with the native kanuka scrub by Harris et al. (2004), invertebrate communities were found to be similarly diverse between the two areas and, while not as valuable as kanuka, gorse was considered to be a valuable habitat for native invertebrates.

Microclimate in each of the study sites and transects was not measured in this study. However, different aspects of topography, canopy cover, and watersheds will create different microclimates for each of the study areas. Therefore, humidity and temperature would be slightly different for each area. These differences may have influenced the diversity and abundance of invertebrates in each area.

The major natural predators of invertebrates, such as small forest birds, reptiles and large invertebrates, will be less abundant in the Waiheke (control) areas due to rat predation. This study has already shown that geckos, sheet-web spiders and giant centipedes are less abundant in these areas, so it is also likely that skinks and small insectivorous forest birds such as fantails (*Rhipidura fuliginosa*) and grey warblers (*Gerygone igata*) will also be less abundant. The high abundance of invertebrates found in some areas of the control sites may then be due to this absence of predators. However, it is also likely that new predators (such as rats and mice) will fill the predatory niches left empty by birds, reptiles and invertebrates.

The presence of the CFR may have also released invertebrates from predation pressure. The CFRs provide a refuge not only for geckos, but in areas where geckos are absent, for invertebrates as well. This refuge will prevent predators such as rats and birds from predating on invertebrates. Mice may be small enough to enter the CFRs and predate on invertebrates, however in areas with high rat abundances, mice densities will be low due to rat predation. This may mean the presence of CFRs will artificially increase invertebrate densities in areas of rat presence and gecko absence as they will release invertebrates occupying them from the predation pressure of potentially all native and non-native species.

The abundances of invertebrates in the control area on Waiheke indicate that rats may not have a significant impact on invertebrates. Conversely, Shakespear had a very low abundance of invertebrates and had the lowest total species count. This is interesting to note as both areas were considered controls, with no pest control taking place in either area (at the time of the study). A major difference between these two areas was habitat (see Chapter 4, section 4.4), with Shakespear having a lower canopy and higher forest diversity and density than Waiheke (control). This increase in biodiversity and density would be likely to favour invertebrates, causing an increase in their diversity and abundance. Shakespear has recently been afforested, with the previous habitat being predominantly farmland with small forest fragments. The forest is also very young, in most places being less than 10 years old. Studies have shown young forests that have been restored or regenerated from farmland are less ecologically diverse than older, naturally grown forests (Dupouey et al., 2002; Bowen et al., 2007; Chazdon, 2008).

There were significantly higher numbers of giant centipedes (*Cormocephalus rubriceps*) in the Waiheke (treatment) and Tawharanui areas compared with the control areas: Waiheke (control) and Shakespear. One giant centipede was found on the OB transect in the Waiheke (control) area. Interestingly, this transect also had the lowest rat abundance. These results potentially show that rats have a negative impact on these large invertebrates, predating on them and causing their populations to decline. Mature giant centipedes may not be predated on by rats because of their large size and venomous bites (Barker, 2004). However, predation pressure from rats would be on juveniles, which would inhibit recruitment and cause population decline.

Sheet-web spiders (*Cambridgea* spp.) were found to be more abundant in the Waiheke (treatment) areas compared with the Waiheke (control) areas. However, the spiders were not more common at Tawharanui than Waiheke (control). This may suggest a negative affect of rats, as the abundance of spiders correlated with the absence of rats on Waiheke Island. The fact that there were similar numbers of sheet-web spiders at Tawharanui compared with Waiheke (control) may be due to the abundance of mice, which have been unable to be eradicated at Tawharanui. There were no sheet-web spiders found at Shakespear which may further support a negative affect of rats on these species.

The absence of the giant centipedes and sheet-web spiders may have a positive effect on the population of geckos. In areas such as the OA transect in the Waiheke (control) study site where geckos are abundant and so are rats, this absence of these large invertebrates may be a major factor in the abundance of geckos. Giant centipedes may be the only predators that have the ability to predate on geckos while in their retreats; many centipedes were observed to occupy the CFRs during this study. Additionally both of these species will compete with geckos for invertebrate food sources. Therefore, while rats may inhibit the recruitment of geckos, they may also release them from the predation pressure and/or competition of giant centipedes and sheet-web spiders.

### 3.5 Conclusions

When considering the abundance of rats correlated with the presence and absence of geckos on Waiheke Island, the results showed that in the control areas on Waiheke (no pest control) gecko densities were significantly lower than in the treatment areas. However, one of the transects in the Waiheke (control) area (Izzard OA) showed a high density of geckos as well as a high abundance of rats. Therefore, with these results alone, rats cannot be said to have a significant impact on gecko densities. The invertebrate analysis found that the presence of rats correlated with the absence of giant centipedes in the Waiheke (control) areas. This may mean that rats have both a negative and positive impact on gecko densities; as they may predate on geckos, but they may also inhibit predation on geckos from other species.

Evidence was found which suggests that rats have a negative impact on the population structure of geckos. The results showed fewer geckos in the largest population sizes (SVL: 76-85 mm, and 86-95 mm) in the control areas in comparison to the treatment areas. This may show that geckos do not live as long in the control areas as a result of rat predation. This would subsequently inhibit recruitment, as there are less mature geckos at breeding age.

Evidence was found to show an effect of predation on male forest geckos by rats. The body condition (BCI) and body-tail condition (BTC) indices were lower in male geckos in the control areas compared with in treatment areas. Also the largest size

classes for the BTC index (SVL: 76-85 mm and 86-95 mm) had lower indices in the control area compared with in the treatment areas. This indicates that rats attempt predation on forest geckos and in doing so decrease their condition and cause tail loss. Also, the male bias for lower condition may potentially be due to the fact that small or female geckos may be predated on by rats but not survive the predation. As such no effect will be seen on the BCI or BTC indices as the geckos will not live to show them. However, there was no sex bias found for the total population of forest geckos in either area of treatment or control on Waiheke Island (see Chapter 5 section 5.3.6). This may then indicate that female geckos are not being predated on by pests such as rats.

None of the scars of the three geckos shown were consistent with rat predation. One gecko potentially showed evidence of attempted rat predation, but the scar was small and no tail loss was evident, so it was not certain. One gecko showed evidence of attempted morepork predation, and the other showed potential evidence of attempted kingfisher predation. However, no conclusive evidence was found to confirm predator species.

The differences in gecko densities between the four study sites were highly significant. Waiheke Island (both control and treatment) showed higher gecko densities than either Tawharanui or Shakespear. Tawharanui is known to have high densities of geckos, however this study did not find them, which could have been for several reasons. Shakespear had very low densities of geckos, much lower than the other control area in this study on Waiheke Island. This could be for several reasons, including the different species of pests present in the two areas. Shakespear would likely have possums present as well as rats, mustelids, cats and mice. Possums are the only pest that is present at Shakespear but absent from Waiheke Island. Possums may have a negative impact on geckos, directly through predation and indirectly through competition and habitat destruction. Research needs to be carried to study the predation habits of the brush-tail possum as little can be found in the literature.

The analysis of invertebrates found that small invertebrates such as cave weta, tree weta, and cockroaches could thrive in areas where rats are abundant. This means that rats will not have a negative impact on the prey of geckos and as such means that competition between rats and geckos for invertebrate food sources is minimal.

Also, where rats are abundant, mice will be inhibited and mice may be more likely to compete with geckos for invertebrate food sources. Rats were found to inhibit the abundance of large invertebrates such as sheet-web spiders and giant centipedes, this may have a positive impact on gecko densities as large spiders would compete with geckos for small invertebrates, and mature giant centipedes are known to prey on small and juvenile geckos.

This study suggests that not only do rats predate on geckos, directly decreasing their population size, but failed predation attempts of rats on geckos will decrease gecko body condition, subsequently decreasing their growth rate and decreasing their likelihood of longevity, which in turn inhibits recruitment. Rats may also predate on the predators of geckos such as giant centipedes and predatory bird chicks and eggs. They may also predate on species likely to compete with geckos for food sources such as centipedes, large spiders and mice. Therefore, it can be said that rats potentially have both a positive and negative impact on arboreal geckos.

## CHAPTER FOUR

### An analysis of *Mokopirirakau granulatus* habitat use



Figure 4.1 *Mokopirirakau granulatus* on *Coprosma* sp. Photo: Author

## 4.1 Introduction

### 4.1.1 Issues in understanding gecko habitat use

Differences in habitat must be considered when comparing the effects of other variables (such as anthropogenic disturbance or invasive species presence) on target species or ecosystems. For example, Ramsay et al. (1998) showed that differences in habitat caused a high variability in the densities of benthic scavengers after a disturbance event (bottom trawling). If different habitats were not included in this study then the impacts of bottom trawling on benthic communities may have been shown to be positive or negative as opposed to variable depending on habitat. Heydon et al. (2000) showed that the abundance of foxes (*Vulpes vulpes*) in Britain was not correlated with different aspects of habitat or landscape but was more likely to be correlated with other factors such as culling by man.

Understanding the habitat use of animals is an important aspect of ecology. Under certain assumptions the density of animals in a habitat can equal the availability of resources in that habitat (Manly et al. 2002). Therefore, this relationship can show the overall density of animals and the carrying capacity of a large area by analysing the habitat choice of the animals studied. For example, Edwards & Collopy (1988) analysed habitat aspects of the nest sites of ospreys (*Pandion haliaetus*) in order to understand why they chose one nest site over another. They then predicted the carrying capacity of an area based on the preferred habitat attributes and showed that there was a high carrying capacity and the ospreys were not under immediate threat from the human impacts of urbanisation.

Using several long transects that sample a wide range of habitats and micro-habitats, the habitat use of an animal can be analysed. The discrete habitat categories (e.g. forest type: old growth, seral scrub, broadleaf, etc.) may be constant over large areas but the attributes of the habitat (e.g. forest density and diversity, undergrowth density, canopy cover, tree size, canopy height, etc.) will range. These habitat attributes can then be compared between the areas where animals have been found occupying monitoring objects and the areas where they have not been found. The habitat attributes that are consistently correlated with animals occupying monitoring objects (e.g. a gecko occupying a CFR) will indicate the areas these animals will be

easily detected. Therefore these results will show the best habitat for a monitoring object to be placed to maximise the detectability of an animal. For example if the habitat attributes where geckos are captured show a consistent high forest density and low canopy height and if areas where geckos are never captured show low forest density and high canopies then this will indicate that geckos will be detected more often in areas with a high forest density and low canopies. The analysis of habitat can then be used to compare the densities of geckos with their detectability in order to show if low densities are due to unsuitable habitat, and subsequent low detectability, or other variables such as the presence and potential impact of mammalian pests.

### 4.1.2 Gecko habitat choice variables

There are several variables to consider when attempting to understand the habitat use and choice of geckos. Forest geckos (*M. granulatus*) are an arboreal species that predominantly occupy kanuka forest (Jewell, 2011) although can often be found in other tree species and types of forest. This study is not aiming to find the forest habitat these geckos occupy, instead the study aims to find why these species are found occupying CFRs in some areas of this habitat and not others. Several habitat attributes were analysed in order to attempt to understand this. These attributes included: forest diversity and density of the immediate area surrounding the CFR site (a  $19.63 \text{ m}^2$  area of forest that was measured by a 2.5 m radius circle out from every CFR), proportion of undergrowth cover (in a 1 m radius around each CFR), tree height, tree diameter (or DBH) and relative canopy area. The forest diversity and density was measured in a 2.5 m radius, or 5 m diameter circle surrounding each CFR as this area was estimated to be the home range extent of small arboreal gecko species.

#### 4.1.2.1 Forest diversity and density

The diversity and density of the immediate forest area are important variables to consider as they are both associated with resources. The more diverse and dense a habitat is, the more likely there will be resources that geckos can utilise such as

food/prey and areas of cover. Therefore, it is likely that geckos will favour areas with high density and diversity. Alternatively, areas with high density and diversity may provide areas of cover that are more effective at sheltering geckos than the CFRs and geckos may then be less likely to use the CFRs.

#### **4.1.2.2 Undergrowth cover**

Undergrowth cover is a measure of low-lying habitat density in the areas directly adjacent to the CFRs. This is an important variable to consider as geckos should prefer areas of higher density as it will provide them with more cover to hide from predators, and a habitat of higher complexity will potentially allow for more invertebrates, fruits and flowers for geckos to feed on. Undergrowth cover is different from habitat density as it focuses on the amount of cover surrounding the CFR refuge; habitat density focuses on the habitat as a whole.

#### **4.1.2.3 Tree height**

Tree height has several factors associated with it that could influence the presence or absence of geckos found under the CFRs. In theory, a lower tree would have a greater chance of having geckos occupying the CFRs as there would be a shorter distance for a gecko to travel from the retreat site (which is near ground level) to areas of foraging (i.e. the canopy). Trees with higher canopies may also prevent geckos from utilising CFRs. CFRs can only be placed low on a trunk due to the practicality of checking them. On trees with higher canopies, geckos will be more likely to inhabit the canopy and refuges that can be found in it.

#### **4.1.2.4 Tree diameter (DBH)**

Tree diameter, or diameter at breast height (DBH), is a variable that is often included in habitat analyses, this is because DBH can be used to estimate tree height, size, age and canopy area. The larger the tree the more likely it will support more than one individual gecko or more than one species. A larger tree would provide

more areas of cover and a larger area of foraging; it would support more invertebrates, and provide more nectar and fruits. Also larger trees are likely to be complex, with many hollows and supporting many epiphytes, ferns and vines. However, the fact that large trees provide more retreat sites in the form of cavities and hollows may mean that geckos will favour these natural refuges over the CFRs. Also large trees will provide a larger foraging area for geckos, this means that geckos will be less likely to find a CFR while foraging or dispersing.

#### **4.1.2.5 Relative canopy area (RCA)**

Relative canopy area is an important variable to consider as the canopy is likely to be a foraging site for arboreal geckos. Many of the food sources of geckos can be found in the canopy, including invertebrates such as moths, spiders and wetas, and other food sources such as fruits and nectar. As a result, the larger the canopy area of a tree the more food resources there will be for arboreal geckos, also a larger canopy area may support more geckos so more than one individual or species may be found in a single tree. However, larger, denser canopies will reduce the amount of light that passes through to the undergrowth. This can cause the undergrowth density to decline which will deplete cover for geckos, making them more prone to predation while near their retreats. Also less light passing through the canopy will cause a decline in areas where geckos can bask.

### **4.1.3 Research objectives**

The four areas in this study show distinct differences in the abundance of geckos (see Chapter 3, section 3.3.2), the hypothesis being that these differences are due to the differing abundances of pests. In order to prove this hypothesis several other variables must first be discounted; the principal one being habitat. If the habitat is significantly different between the four areas then the differences in gecko densities may be related to these habitat differences. The first aim of this chapter is to analyse the differences in habitat between each of the four study sites. The second aim is to analyse the differences in habitat between the CFRs where geckos are

present and absent on Waiheke in order to understand the habitat preferences of geckos, or the most likely habitat that geckos will be caught in. The final aim is to compare the differences in habitat between the areas of pest control (i.e. treatment) and no control (i.e. control) on Waiheke Island, in order to understand if any differences in gecko densities may be due to habitat differences and not the presence and absence of pests.

#### Research questions:

- Are there differences in the habitat between each of the four study sites that could explain the differences in gecko abundances?
- Are there any habitat variables that explain why *M. granulatus* is found occupying certain cell foam retreats and not others?
- Is there a difference in habitat between the areas of pest control and no control on Waiheke Island that could explain the differences in gecko densities?

## 4.2 Methodology

### 4.2.1 Study areas

The primary study was conducted on Waiheke Island within Whakanewha Regional Park and in areas adjacent to the park; minor studies were undertaken at Tawharanui and Shakespear Regional Parks. All ten transects on Waiheke were also used to analyse the forest diversity, density and canopy height and to compare the habitat between the gecko-occupied trees and non-occupied trees. However, the microhabitat was not measured for all of these transects. To measure the microhabitat six of the highest gecko capture frequency transects were used. The six transects were: IA, IB, IC, IE, ID and OA. All transects excluding OA were inside Whakanewha Regional Park (and pest control). The predominant habitat of each transect was kanuka (*Kunzea ericoides*) forest, with fragments of broadleaf forest. For a more detailed description of the study sites refer to Chapter 2, section 2.4.1.

### 4.2.2 Study species

The species studied in this chapter is the forest gecko (*Mokopirirakau granulatus*), a relatively common but especially cryptic species that is often very hard to find. Hence, monitoring of this species is difficult and as such little is known about it. *Mokopirirakau granulatus* is considered not threatened (Hitchmough et al., 2010). For a more detailed description of the study species refer to Chapter 2, section 2.1.1.

### 4.2.3 Study design

#### 4.2.3.1 Habitat surveys

From April to June the habitat of the four study sites (Waiheke (treatment, or pest control), Waiheke (control, or no pest control), Tawharanui and Shakespear Regional Parks) was surveyed. During this time the aspects of the habitat measured included canopy height, forest diversity and density. A total of 19 transects and 760

individual CFR sites were used to measure this habitat. At each CFR site the height of each tree with the CFR attached to it was estimated by sight and recorded. A 2.5 m radius circle with the CFR tree as the central point was then set up using a measuring tape. Within this circle the number of plant species and total individuals was determined by counting each plant above 1 m in height. For more in depth methods refer to Chapter 2, section 2.4.6.

#### **4.2.3.2 Microhabitat attributes surveys**

From July to August the microhabitat attributes of each CFR tree and area along six of the 10 transects at Waiheke Island (a total of 239 individual trees) were analysed. The transects used had the highest capture rate of geckos of all the transects in this study. They included: IA, IB, IC, IE, ID and OA. All but OA were within Whakanewha Regional Park and the area of pest control. The habitat attributes analysed at each of the 239 trees included trunk diameter at breast height (DBH using a diameter tape, measured in mm), estimated relative canopy area ( $m^2$ ) and the proportion of undergrowth cover surrounding each CFR in a 1 m radius. The biodiversity, density and canopy height already analysed were then added onto these attributes to compare the habitat between the CFRs where geckos were present and absent. For more in depth methods refer to Chapter 2, section 2.4.6.

## 4.3 Results

### 4.3.1 Gecko presence/absence analyses

Mann-Whitney U tests were used to analyse the differences in habitat between the areas where geckos were present and absent under the CFRs (Table 4.1). In the areas where geckos were found (*Presence*), the habitat consisted of trees that were relatively lower ( $P = 0.01$ ), with smaller DBHs (0.004) and smaller canopy areas (0.002) in comparison to the areas where geckos were absent (*Absence*). The proportion of undergrowth cover in a 1 m radius from each CFR was compared, along with habitat density (trees per 19.63 m<sup>2</sup>), and biodiversity (species per 19.63 m<sup>2</sup>). The results showed that the proportion of undergrowth and forest density was significantly higher around the gecko occupied CFRs ( $P = 0.0009$  and 0.03 respectively) compared with the non-occupied CFRs. The Simpson's diversity index showed no significant differences between the two areas ( $P = 0.76$ ).

Table 4.1 Results of habitat analyses with median, 95% Confidence Intervals (Lower-Upper), Mann-Whitney 'U' statistic, and significance values. (\*Where SDI indicates Simpsons Diversity Index)

Habitat variable	Presence		Absence		Test	
	n	Median (95% CI)	n	Median (95% CI)	U	P
% Undergrowth	49	40 (38.6 – 50.9 )	190	30 (30.3 – 37.2)	3221.5	0.0009
CFR Tree DBH	49	140.06 (140.5 – 174.8)	190	164.57 (173.5 – 192.3)	3410.5	0.004
Canopy Area	49	8 (7.9 – 12.3)	190	12 (13.4 – 16.7)	3342.5	0.0024
Forest Density	49	10 (9.4 – 11.2)	190	9 (8.7 – 9.7)	3725	0.0312
SDI*	49	0.74 (0.6 – 0.7)	190	0.73 (0.6 – 0.7)	4523	NS
Canopy Height	49	8 (7.8 – 9.4)	190	10 (9.4 – 10.4)	3571.5	0.0117

### 4.3.2 Habitat comparisons between regional parks

The habitat was analysed at the three different regional parks to determine the differences in habitat for each area. The variables compared between the parks included Simpson's diversity index (Figure 4.2), forest density (Figure 4.3) and canopy height (Figure 4.4).

#### 4.3.2.1 Simpson's diversity index

The Simpsons diversity index (Figure 4.2) was compared using six different Mann-Whitney U-tests. The results showed that Waiheke control had the lowest species diversity compared with Waiheke treatment ( $U = 21096$ ,  $P = 0.01$ ) Tawharanui ( $U = 23200$ ,  $P = 0.0008$ ), and Shakespear ( $U = 9556.0$ ,  $P = 0.002$ ). All other comparisons of the Simpson's diversity index between the study areas were not significant.

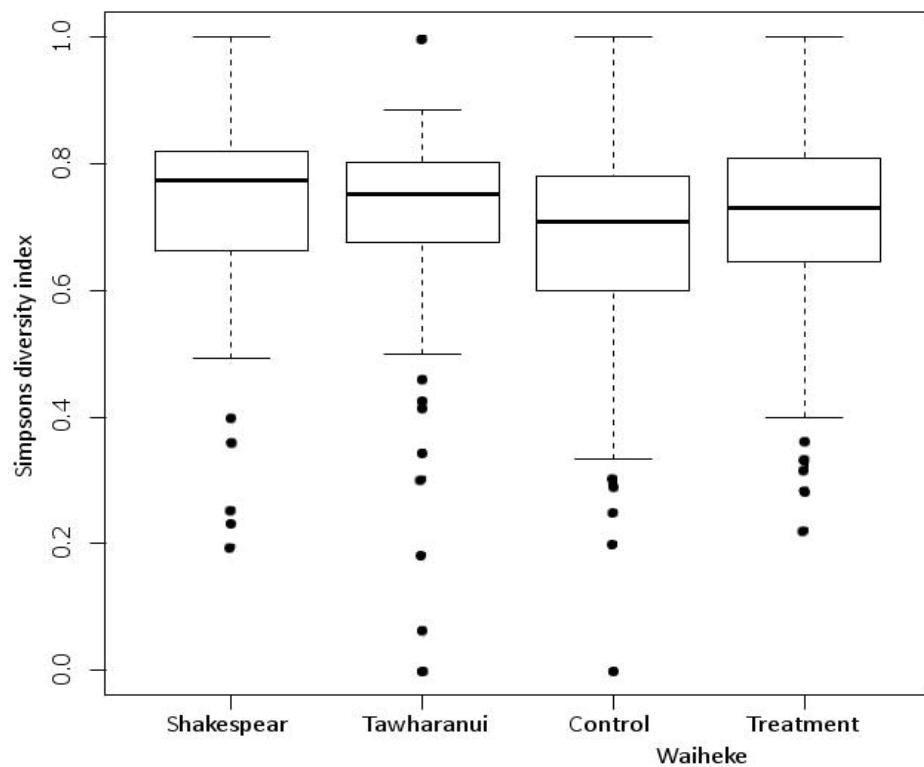


Figure 4.2 Box-plots showing the Simpson's diversity index from each of the four study areas.  $n =$  Shakespeare = 80, Tawharanui = 200, Waiheke control = 200, Waiheke treatment = 199. (Where  $n =$  the number of CFR areas analysed per study area)

#### 4.3.2.2 Forest density

A Kruskal-Wallis test was used, including a Dunn's multiple comparisons test, to compare the differences in forest density (Figure 4.3) between the four study

areas ( $KW = 155.27$ ,  $P < 0.0001$ ). The results showed that all areas were significantly different, with  $P$  values ranging from  $< 0.01$  to  $< 0.001$  for all comparisons. The study area with the highest density was Shakespear, the next highest was Tawharanui, with Waiheke control and treatment having the next highest and lowest densities respectively.

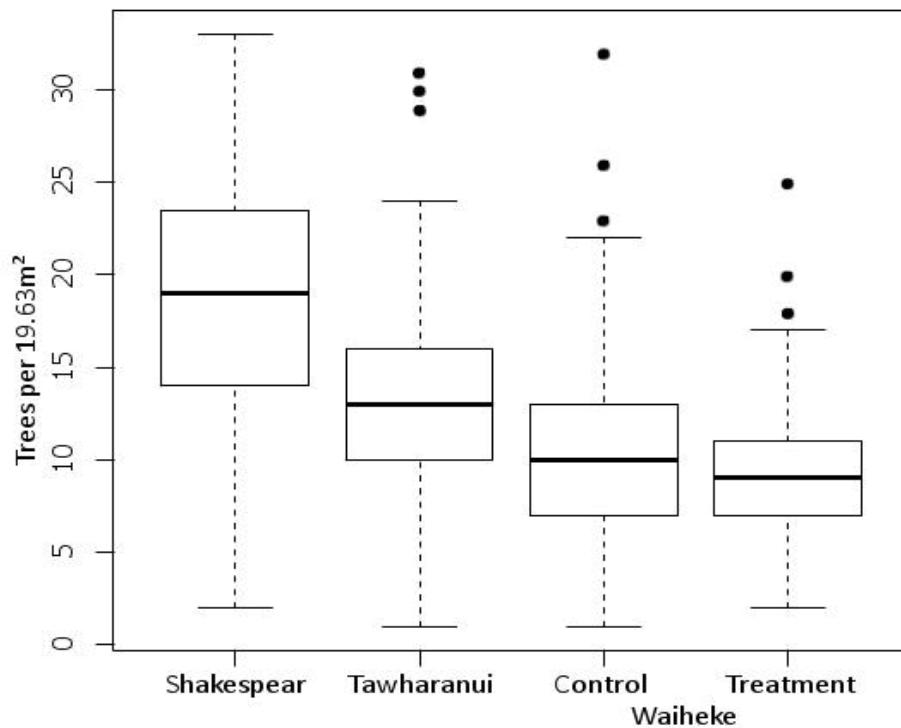


Figure 4.3 Box-plots showing the average number of trees per area around each CFR ( $19.6\text{ 3m}^2$ ), per study area. Where  $n$  = the number of CFR areas per study area; Waiheke control = 200, treatment = 199, Tawharanui = 200, Shakespear = 80.

#### 4.3.2.3 Canopy height

A second Kruskal-Wallis, including a Dunn's multiple comparisons test, were used to compare the canopy height (Figure 4.4) between the four study areas ( $KW = 224.46$ ,  $P < 0.0001$ ). Shakespear showed the lowest canopy height among all the study areas ( $P < 0.001$  for all comparisons). Waiheke control was significantly

higher than Waiheke treatment ( $P < 0.01$ ), and had the highest canopy among all study areas ( $P < 0.001$  for all comparisons).

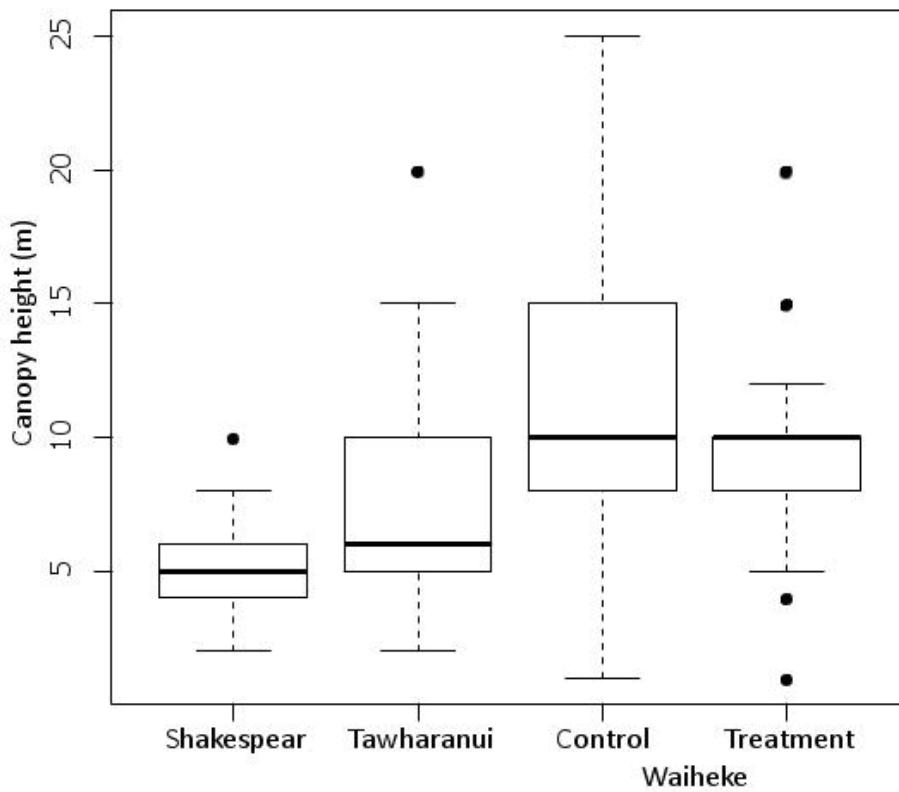


Figure 4.4 Box-plots showing the tree height (m) over each of the four study sites, where  $n$  = the number of CFR sites per study area: Shakespear  $n = 80$ , Tawharanui = 200, Waiheke control = 200, Waiheke treatment = 199.

### 4.3.3 Habitat comparisons between transects on Waiheke

#### 4.3.3.1 Simpson's diversity index

Several Mann-Whitney U-tests were used to analyse the differences in the Simpson's diversity index between the 10 transects in the areas of treatment and control on Waiheke Island (Figure 4.5). The results showed that the transects IC, ID and OA had significantly higher Simpson's diversity indices than the transects IE, OB, OC, OD and OE, with  $P$  values ranging from  $< 0.05$  to  $< 0.01$  for all

comparisons between these transects. The transects IC, ID and OA were not significantly different from each other and they were not significantly different from IA and IB.

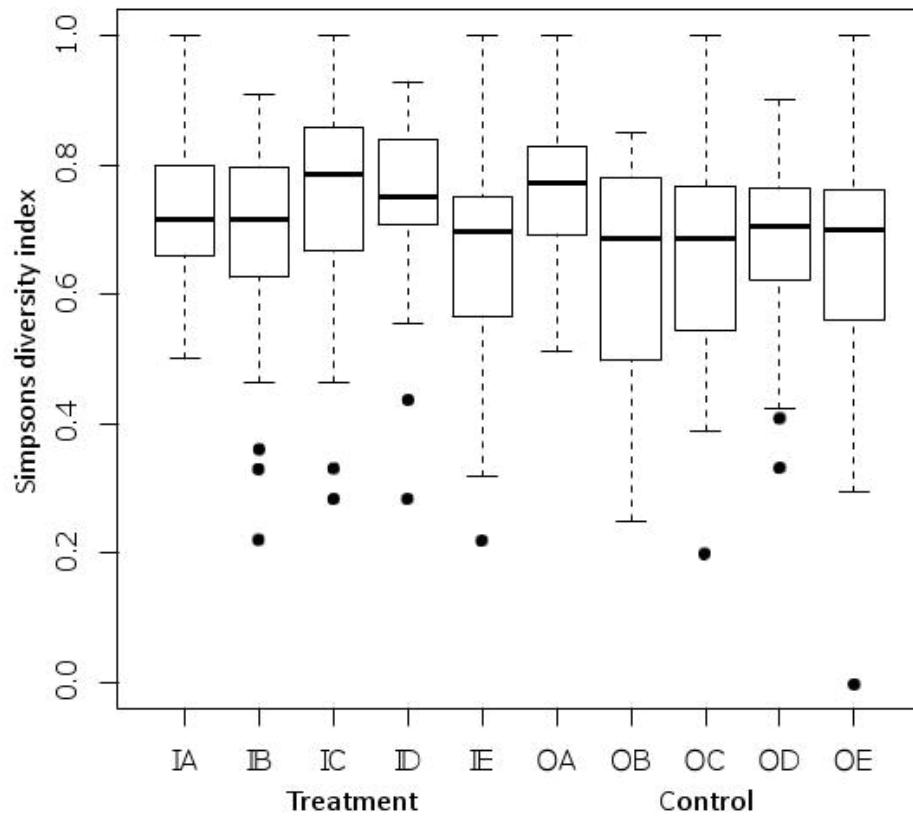


Figure 4.5 Box-plots showing the Simpson's diversity index over all 10 transects in the treatment and control areas on Waiheke Island. Where 'I' signifies treatment (Inside pest control), and 'O' signifies control (Outside pest control). The  $n = 40$  CFRs for each transect excluding IB where  $n = 39$ .

#### 4.3.3.2 Forest density

A Kruskal-Wallis, including a Dunn's multiple comparisons test, were used to compare the forest density between the 10 transects on Waiheke Island ( $KW = 38.038$ ,  $P < 0.0001$ ). Additionally Mann-Whitney U' tests were used to further compare the OA and OC transects with IA, IB, IC, ID and IE. The results showed that the transects OA and OC had forest densities that were significantly higher than

the transects IA, IB, IC, ID (only IA was different from ID) and IE, with P values ranging from  $< 0.05$  to  $< 0.001$ . There were no other significant differences between the forest density of any other transect.

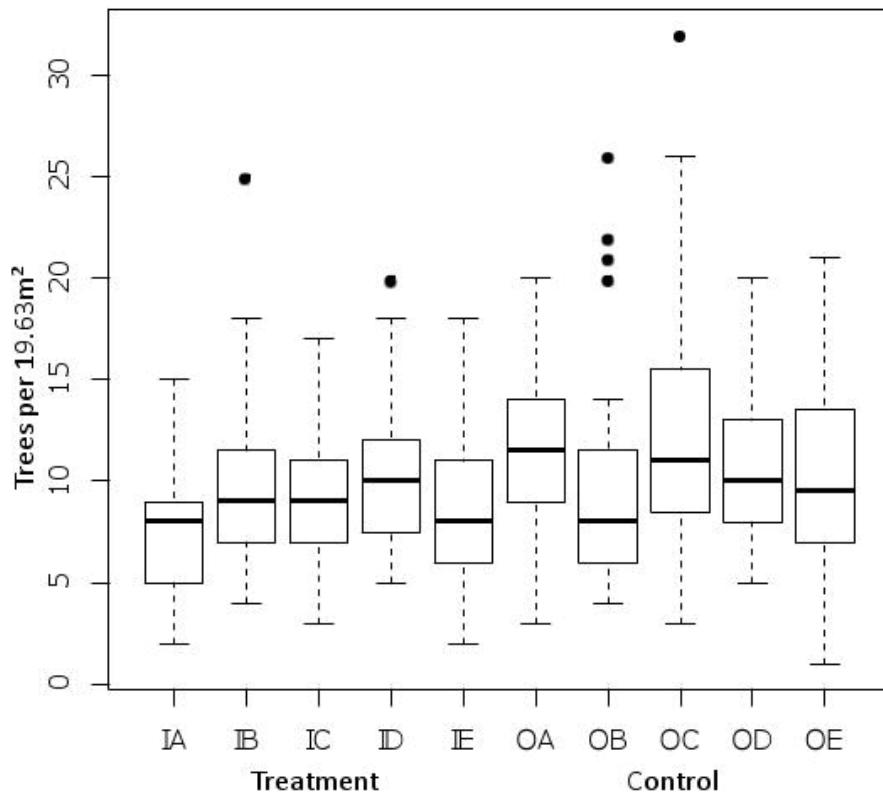


Figure 4.6 Box-plots showing the average forest density (measured as trees per  $19.63\text{m}^2$ ) over the 10 transects in the treatment and control areas of Waiheke Island. Where I = Inside regional park, denoting treatment and O = outside, denoting control. Where  $n = 40$  CFRs for each transect excluding IB where  $n = 39$ .

#### 4.3.3.3 Tree height

A Kruskal-Wallis, including a Dunn's multiple comparisons test, were used to analyse the differences between the tree height at each of the 10 transects (Figure 4.5) on Waiheke Island ( $\text{KW} = 85.678$ ,  $P = 0.0001$ ). The results showed that the OB transect was the highest when compared with IB ( $P < 0.001$ ), IC ( $P < 0.001$ ), ID ( $P < 0.01$ ), and OA ( $P < 0.01$ ). However it was not significantly different from IA, OC, OD or OE. The transect with the lowest tree height was IC when compared with IA

( $P < 0.001$ ), IB ( $P < 0.05$ ), IE ( $P < 0.001$ ), OB ( $P < 0.001$ ), OC ( $P < 0.001$ ), OD ( $P < 0.001$ ), and OE ( $P < 0.001$ ). However, it was not significantly different from ID or OA.

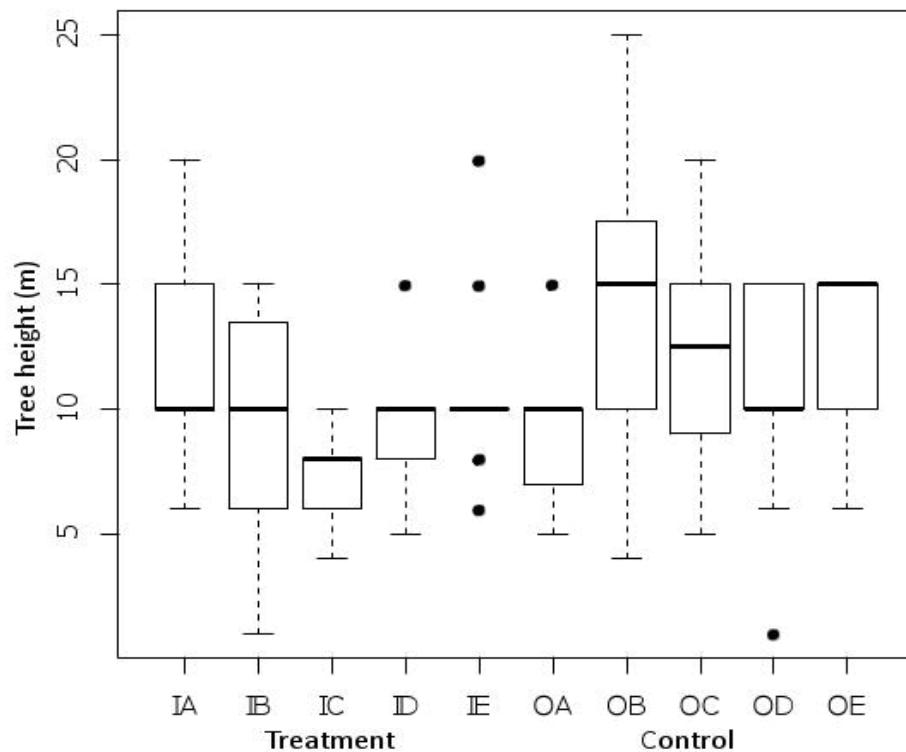


Figure 4.7 Box-plots showing the tree height (m) over all 10 transects in the treatment and control areas on Waiheke Island. Where 'I' signifies treatment (Inside pest control), and 'O' signifies control (Outside pest control). The  $n = 40$  CFRs for each transect excluding IB where  $n = 39$ .

#### 4.3.3.4 Common species assemblages

The most common species along every transect at Waiheke Island was kanuka (S1, Table 4.2). Hangehange (S2) was the second most common species, however it was absent from the OA transect. The silver fern (S7) and tree fern (S8) were also very common, while mamangi (S4) was common only along the treatment transects (IB-E) and OA. *Coprosma rhamnoides* (S5) was common along the control transects (OB-OD) but absent or uncommon along the treatment transects. Mingimingi (S9), gorse (S10) and red mapau (S3) were common along the OA

transect but absent or uncommon on all the other transects, excluding ID where gorse and mingimingi were also common. Red mapau was only found in abundance along the OA transect.

Table 4.2 The proportion of the 10 most common species along each transect in the treatment (IA-IE) and control (OA-OE) areas on Waiheke Island. (Where S1 = Kanuka (*Kunzea ericoides*), S2 = Hangehange (*Geniostoma lingustrifolium*), S3 = Red mapau (*Myrsine australis*), S4 = Mamangi (*Coprosma arborea*), S5 = *C. rhamnoides*, S6 = Mahoe (*Melicytus ramiflorus*), S7 = Silver fern (*Cyathea dealbata*), S8 = Tree fern (*Dicksonia squarrosa*), S9 = Mingimingi (*Cyathodes juniperina*), S10 = Gorse (*Ulex europaeus*).

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
IA	0.26	0.18	-	-	-	0.14	-	0.08	0.04	-
IB	0.25	0.21	-	0.02	0.03	-	0.25	-	-	-
IC	0.12	0.21	-	0.18	-	0.04	0.16	0.12	-	-
ID	0.15	0.28	-	0.12	-	-	0.17	-	0.05	0.05
IE	0.14	0.24	-	0.16	-	-	0.23	-	-	-
OA	0.17	-	0.18	0.17	-	-	0.07	-	0.1	0.05
OB	0.11	0.18	-	-	0.11	0.08	-	0.28	-	-
OC	0.14	0.34	-	-	0.08	0.04	0.08	0.16	-	-
OD	0.17	0.39	-	-	0.08	0.07	0.18	0.06	-	-
OE	0.15	0.31	-	-	-	0.09	0.19	0.05	-	-

## 4.4 Discussion

### 4.4.1 Gecko presence/absence analysis

The results showed that geckos were caught more often in trees with lower canopies, smaller canopy areas and smaller diameters. The surrounding habitat where geckos were caught more often consisted of higher density, species diversity, and undergrowth cover.

Geckos were caught more often in smaller trees (i.e. smaller, lower canopies and smaller diameters), this could have been for several reasons. Smaller trees with lower canopies will create fewer dimensions for a gecko to forage in, as such they will have a greater chance of finding a CFR. In large old-growth forests with high canopies there are several vertical layers (i.e. seedling/herbaceous, understorey, sub-canopy, canopy and emergent) where an arboreal gecko could potentially forage. If a gecko occupies any of these layers higher than the understorey it is unlikely it will be caught in a CFR that is located near the ground. The chance of a gecko finding a CFR is likely to decrease in proportion to the increase in distance between the CFR and the gecko's foraging site. Smaller trees will also not have as many areas of cover as large trees (i.e. cavities, hollows, epiphytes and loose bark). Therefore, when a CFR is attached to a smaller tree it is potentially improving the habitat; while a CFR attached to a large tree is only providing another area of cover among several. Geckos that live on or near smaller trees may therefore be more likely to inhabit the CFRs than geckos that live on larger trees.

Smaller trees with low canopies indicate a forest that is young regenerating seral scrub. Seral scrub is predominantly highly dense, with many diminutive-growing species that have a divaricating nature (i.e. a dense tangle of interlacing sharp twigs, branching at a wide angle (McQueen, 2000), such as *C. rhamnoides*, red mapau (*M. australis*), mamangi (*C. arborea*) and mingimingi (*C. juniperina*) (see Table 4.2). This divaricating nature has been shown to support geckos in New Zealand, and is thought to be adapted to lizard seed dispersal (Knox, 2011; Lord & Marshall, 2001; Whitaker, 1987; Wotton, 2002). Also, seral scrub includes introduced species such as gorse (*U. europaeus*). Gorse is a similarly divaricating species, however the leaves are very strong and sharp, and contain a toxin, and these

attributes prevent mammals larger than mice from inhabiting it (Williams & Karl, 2002). Gorse provides an effective cover from predation for many species of invertebrates (Harris et al., 2004; Sherley & Hayes, 1993; Sherley, 1998) and potentially reptiles (Knox, 2011). The transects with the highest proportion of divaricating species included the OA transect, which was the only transect with red mapau present as well as mingimingi, gorse and mamangi. The ID transect also had a relatively high proportion of divaricating species with gorse, mingimingi and mamangi present. These two transects had high densities of geckos present, so it is likely that forest geckos may favour these species.

Smaller trees with small canopies indicate that the forest canopy is not continuous. This will mean there are gaps in the canopy which increase the light on the forest floor and understorey. Forest geckos are nocturnal but are often seen basking during the day in patches of light on tree trunks near their retreat sites (Jewel, 2011). Due to the geckos' nocturnal nature they will not travel far during the day in order to bask in sunlight patches. Therefore, geckos will potentially favour retreat sites that are situated in areas with non-continuous canopies.

As CFRs are placed low on a tree, geckos that occupy them may be more likely to forage in the undergrowth as opposed to the forest canopy, especially in areas where the canopy is high. This may indicate that the undergrowth density needs to be high if the canopy is also high in order for the CFRs to detect geckos. However, where the canopy was higher the forest density was lower (see Table 4.1) indicating that geckos would be even less likely to be caught in these areas. It may also indicate that if the canopy is low then undergrowth density may not be as significant a factor in a gecko's habitat choice as the geckos can forage in the canopy and still inhabit the CFRs. However, where the canopy was lower the undergrowth density was also higher, indicating that geckos may prefer habitat that has several foraging areas.

Geckos were caught more often in areas with a high density and a high proportion of undergrowth cover directly adjacent to the CFR, this could have been for several reasons. A habitat with a higher density will provide more cover for a small gecko while basking, foraging or travelling to foraging areas (i.e. the canopy). Areas with a highly dense forest cover will potentially prevent avian predatory

species, such as morepork, from predating on geckos. The fact that geckos were caught more often in CFRs with a higher proportion of undergrowth cover surrounding them may indicate that geckos prefer retreats that provide more cover from avian predation. Geckos often bask during the day near their retreat sites, if these basking areas are open with no cover, their risk of predation will increase.

Divaricating species may artificially increase habitat density as one plant can spread profusely over an area, where it may be mistaken for several. Species such as red mapau (*M. australis*) and *C. rhamnoides* are very densely growing plants that can grow profusely over a small area. In areas as small as the study area surrounding each CFR (19.63 m<sup>2</sup>) there can be upwards of twenty plants, or potentially only one or two large plants that have spread intensively (pers. obs.).

A habitat with a high forest density may exclude predators. This may especially be the case where common species demonstrate divaricating growth forms with dense and sharp, branches and leaves. For example Williams & Karl, (2002) found that the plant gorse (*U. europaeus*) excludes mammals larger than mice from inhabiting it, therefore, in areas with a high density of gorse the number of rats in the area may be low. This may indicate that in these areas geckos will not be predated on by rats as often, potentially increasing the geckos' abundance. However, the absence of rats may increase the abundance of mice which may predate on juvenile geckos, and will compete with them for resources such as small invertebrates. The species *Coprosma rhamnoides* and mingimingi (*Cyathodes juniperina*) may have a similar effect on rats as gorse, due to their similar properties of densely divaricating growth form and sharp branches and/or leaves. However, Knox (2011) found that habitat dominated by *Coprosma* species was more likely to have rodents occupy it and predate on the jeweled gecko than kanuka habitat.

A habitat with a higher density will provide more effective, or more areas of cover for invertebrate species, which will in turn provide a high density of food availability for geckos. For example, gorse, and many *Coprosma* species provide effective cover for invertebrates from large predators such as rats and large birds (Sherley & Hayes, 1993; Sherley, 1998; Harris et al., 2004). This will decrease the competition between these predators and geckos for invertebrate food sources, potentially increasing the density of geckos in the area.

#### 4.4.2 Waiheke treatment compared with control

Geckos were caught more often in trees that were lower (Table 4.1). There were significant differences in the tree height between the treatment and control areas on Waiheke, with the control area being higher (Figure 4.4). This may mean that the differences in gecko densities were due to the differences in tree height and not the presence of rats. However, the results also showed that geckos preferred areas with high forest density (Table 4.1). The forest density in the Waiheke control areas was higher than in the treatment areas (Figure 4.3). This may indicate that the difference in gecko densities was not due to habitat, as the habitat in the control area was potentially more suited to them.

Therefore, the tree height and forest density data are conflicting; with one indicating that the differences in gecko densities may be due to habitat and the other indicating that it may be due to rats present. The control transect on Waiheke Island with the highest forest density (OA) also had the highest density of geckos of all the control areas. However, the OC transect also had a high forest density but had a low density of geckos. The major difference between these two areas was canopy height, with OC having a significantly higher canopy than OA. This indicates that where the forest density is high and the canopy is low; geckos will be detectable using CFRs. However, if the forest density is high and the canopy is high, then geckos may not be detectable. Consequently, canopy height and forest density must be considered together to compare the habitat between areas. This also indicates that the differences in gecko densities between the five control transects may be due to the differences in habitat and not the presence or absence of pests.

All the control transects, excluding OA, consisted of habitat with a high canopy and either a high or a low forest density and diversity. This means that the high density of geckos on the OA transect and the low gecko densities on the other four control transects may be due to the differences in habitat. The transects where no geckos were captured during this study (OB and OE) also had the highest canopies and some of the lowest forest densities and species diversities. This was especially the case for the OB transect, which had the highest canopy and one of the lowest densities in the entire study. This may indicate that if all the control transects had a low canopy and a high forest density and diversity like the OA transect they

may also have all had high densities of geckos. If this were the case, then the presence of pests such as rats in these areas may not have a significant impact on arboreal geckos. This could lead on to further study in the area, where CFR transects could be set up in areas of habitat as similar as possible to OA, with no pest control, in order to further understand the potential impact of pests on arboreal geckos.

The treatment transects all had relatively low forest densities, canopy heights and high species diversity. The transect with the highest gecko occupancy in the entire study (IC) also had one of the highest species diversities, a relatively low forest density and a low canopy height. The three transects in both areas with the highest gecko occupancies (i.e. IC, ID and OA) all had the highest species diversity and the lowest canopy height. The forest density varied over these three transects, with OA and ID showing high forest density and IC showing a lower forest density. The treatment transects with the lowest occupancy of geckos (IE and IA) also had the highest canopy height (IA only), the lowest forest density (both transects) and the lowest species diversity (IE only). Therefore, this analysis may indicate that the habitat differences between the transects on Waiheke Island may be the major factor to explain the differences in gecko densities and that the presence or absence of pests in these areas may not be a significant factor in the detectability, and potentially the distribution and abundance, of geckos on Waiheke Island.

#### 4.4.3 Waiheke compared with Tawharanui and Shakespear

Significant differences were found between the habitat of the four study areas: Waiheke treatment and control, Shakespear and Tawharanui Regional Parks. The average species diversity (measured as the Simpson's diversity index) was the same between all areas, excluding Waiheke control where it was the lowest out of all the study areas (Table 4.1). The average forest density was highest at Shakespear, then Tawharanui, then Waiheke control and was the lowest in the Waiheke treatment areas. The canopy height was the highest in the Waiheke control area, then Waiheke treatment, then Tawharanui and was lowest at Shakespear.

When this analysis was compared with the analysis of the areas where geckos were present and absent on Waiheke, the results are interesting. The results showed

that geckos were caught more often in areas with high forest density and a low canopy. However, the study area with the highest forest density and the lowest canopy (Shakespear) had the lowest density of geckos. This indicates that the differences in habitat may not be a major factor in explaining the differences in gecko densities between Waiheke (control and treatment) and Tawharanui and Shakespear.

The distinct differences in habitat between the four study areas could be for several reasons. Each study area is at a different time of succession; while they all have similar vegetation species they are each separated by the time these species have existed in the areas they do. On average, Waiheke (both areas) is a substantially higher and subsequently older habitat than either Tawharanui or Shakespear. Tawharanui and Shakespear are both regional parks that have been restored from farmland. As a result both are fragmented, with areas of forest habitat separated by large areas of farmland. Both Tawharanui and Shakespear were replanted recently, approximately 20 years ago (Murdoch, 2008; ARC, 1991); as a result the habitat is very young, only going through the very first stages of succession, with low seral scrub being the predominant habitat. Areas on Waiheke Island, such as the OA transect, are also predominantly young seral scrub forests and the results have shown that this habitat may be favoured by arboreal geckos.

The fact that both Tawharanui and Shakespear have been restored from farmland, with small fragments of old-growth forest, means that there is a human factor to consider in the way the habitat has been planted. The significantly higher forest density at Shakespear and Tawharanui could be due to a human influence of planting many different species very close together, with an emphasis on planting species such as red mapau (*Myrsine australis*), kanuka (*Kunzea ericoides*), and manuka (*Leptospermum scoparium*), as these species are commonly found in a first stage succession seral scrub habitat (McQueen, 1991).

Tawharanui and Shakespear were both recently afforested from farmland that had small remnant patches of old-growth forest. This means any geckos that are present in these parks have spread out from the remnant forest patches into the newly restored seral scrub. Consequently, the low densities of geckos in these areas may be due to the small population of geckos that the remnant forest supported, spreading

out over a larger area and therefore becoming difficult to detect. Geckos are slow breeders (Towns, 1991) and do not colonise new areas quickly (Bell, 2009), they are slow to recover from the presence of pests (Bell, 2009) and as such their densities are expected to be low in these regional parks where restoration is recent and pests are either present (Shakespear) or only recently eradicated (Tawharanui).

## 4.5 Conclusions

There are several habitat variables that may explain why *M. granulatus* was found occupying certain CFRs and not others. These variables can be used to indicate the best habitat type to place CFR in order to have the highest chance of finding a gecko. In the areas where geckos were present the percentage of undergrowth and the density of the forest in the immediate areas surrounding each CFR were higher, while the tree diameter, canopy height and canopy area were lower. These results indicate that forest geckos may be more likely to occupy a CFR in an area with higher forest density and cover, and smaller trees with lower and smaller canopies.

The transects with the highest gecko densities also had the lowest canopy heights, high forest density and a high forest diversity; while the transects with the lowest gecko densities, or no geckos found at all, had the highest canopy heights, and the lowest forest densities. This shows that in the areas on Waiheke where the density of geckos was low, the detectability of geckos was also low. Therefore, gecko density is a misnomer, but occupancy is a more apt term to use. This then indicates that the low occupancy of geckos along several of the non-pest-controlled transects was due to the low detectability of the habitat and not the presence of mammalian pest species such as rats.

There were several differences in habitat between Waiheke Island, Tawharanui and Shakespear that could potentially explain the differences in gecko abundances. The forest density and tree height were significantly different between all of the study areas. Shakespear showed the highest forest density and the lowest tree height. This indicates that the detectability of geckos at Shakespear using CFRs is high. However, as very few geckos were caught at Shakespear the habitat could

not explain this low capture rate, as such other variables, such as the presence of pest species (i.e. rats and possums), may then explain this low capture rate and possibly density.

## CHAPTER FIVE

### Quantifying the effectiveness and gecko use of cell foam retreats



Figure 5.1 Pair of forest geckos found under a single CFR, male (right) and female (left), Photo: Author

## 5.1 Introduction

Monitoring forest lizards, especially cryptic arboreal species such as small nocturnal geckos, is currently one of the most difficult tasks facing herpetological conservation, management and research (Bell, 2009). Herpetological monitoring has become increasingly important due to recent declines in worldwide herpetofauna (Gibbon et al., 2000; Ryan et al., 2002; van Winkel, 2008). As successful conservation relies on robust sampling and monitoring (Bell, 2009) there is an ever-increasing need to develop more effective and efficient methods for monitoring reptiles. When developing new monitoring methods it is important to understand their costs and benefits, and to measure their efficiency and effectiveness through comparisons with other methods.

The cell foam retreat (CFR) is a newly developed method of monitoring arboreal forest geckos as such little is known about its costs and benefits. The CFR consists of a sheet of black closed cell foam ( $0.5 - 1m \times 0.4m \times 3-4mm$ ) placed flat on a tree trunk surface (for large trees), or wrapped around the trunk (for small trees) (Bell, 2009). They work by providing a quick to warm dry refuge for geckos to inhabit, they are specifically targeted at geckos that occupy canopy and tree trunk niches, and are designed to mimic natural refuges such as bark and tree hollows. Trent Bell (2009) developed the CFR and compared its lizard occupancy rates with five other conventional methods of monitoring forest lizards: lizard houses, g-minnow traps, pitfall traps, Onduline artificial retreats and spotlighting. It was found that these other methods are ineffective and uneconomical at monitoring arboreal forest geckos and may carry several biases. This is because of: (1) the complex three-dimensional structure, and difficult access, of forests; (2) the nocturnal and/or arboreal nature of some lizard species, combined with the limited activity cycles of these lizards; (3) the potentially sparse or spatially clumped distribution of forest lizards; (4) a much-reduced species richness and abundance as a result of invasive predators; and (5) the cryptic nature of lizards in forest ecosystems due to their small size and camouflage in the environment (Bell, 2009).

Bell (2009) compared the CFR's effectiveness using three species of forest-inhabiting geckos over several sites. The geckos used were the Duvaucel's gecko (*Hoplodactylus duvaucelli*), forest gecko (*Mokopirirakau granulatus*), and Pacific gecko (*Dactylocnemis pacificus*). The study focused on the Duvaucel's gecko as it was the most abundant, and the forest and Pacific geckos were at very low densities. The study found that most methods detected the Duvaucel's gecko, but the CFRs detected them much more effectively, also at the sites where the forest or Pacific geckos were present only the CFRs detected them. Overall, the study found that CFRs offer improved population sampling of arboreal forest geckos, improved efficiency, and lower costs compared to other sampling methods.

Different monitoring methods when using CFRs will provide differing results. For example, checking each CFR once every second day over several repeated checks will likely cause a high level of disturbance which will deter geckos from using them; while an alternative method of checking the CFRs once a fortnight will likely cause less disturbance and may mean more geckos will use the CFRs.

### 5.1.1 Alternative monitoring methods

#### 5.1.1.1 Artificial cover objects (ACOs)

Artificial cover objects (ACOs) include; plywood (Ryan et al., 2002), Onduline stacks, corrugated iron sheets, and concrete or terracotta roofing tiles (Lettink, 2007). Reptiles use these ACOs as alternative areas of cover to natural areas such as rocks; they are quick to warm and dry out, retaining heat well throughout the day and night. They also exclude predators such as rats or birds, while attracting invertebrates which could act as a food source for reptiles. The ACOs are placed on the ground in transects or grid patterns, and need to be established several weeks before monitoring in order to habituate the target species to their presence (Lettink, 2007). ACOs are best used for the monitoring of ground-dwelling reptiles and it is unlikely that arboreal geckos will use these monitoring tools.

### 5.1.1.2 Visual encounter surveys (VES)

Visual encounter surveys (VES) are carried out in several ways, the most common being night-spotting. Night spotting involves groups of two or more trained people walking transects at night along bush margins or tracks using torches to spot reptiles amongst the foliage or branches of the bush. Night-spotting however, has several issues associated with it that can have an affect on the efficiency of this technique. Training and experience are needed in order to spot highly cryptic species such as forest or green geckos which are extremely well camouflaged. Also the number of surveyors has an affect on this technique. The fewer surveyors there are searching the less likely it will be that any animals will be found, however with too many surveyors any excessive light and noise may scare animals away. With people searching at night, other factors arise such as human error, which will increase with the time spent searching as fatigue increases. Finally, this technique relies heavily on weather conditions such as wind, rain, cloud cover, and also potentially the cycle of the moon as more light at night may discourage nocturnal species from being active.

### 5.1.1.3 Tracking tunnels

Tracking tunnels consist of a small plastic or corflute tunnel with cards and ink placed inside. They work by attracting an animal, with a bait, to walk over an area of ink and leave footprints on a card. These footprints can then be analysed to identify the species that made them and from this an index can be made which estimates the population size or density of this species. Tracking tunnels are usually set up in grids or along transects, the spacing between tunnels will vary depending on the territory size of the target species. The tunnels need to be placed at a sufficient distance from each other to prevent the same individual tracking more than one tunnel along a transect. The tracking tunnels are, however, less effective than other methods as a perfect footprint is very rarely made and as such identification of species can be inaccurate. Tracking tunnels are best used to monitor ground-dwelling species, however they can also be placed on large tree branches in the canopy to monitor arboreal species.

### 5.1.2 Gecko use of monitoring objects

It is important to understand how animals utilise the tools that are used to monitor them in order to understand how better to use these tools, and to understand the potential impacts these tools are having on the animal's ecology and habitat. Cell foam retreats aim to mimic the microhabitat of arboreal geckos such as loose bark or tree hollows (Bell, 2009). While the CFR may effectively mimic this habitat, it may also alter it, providing an area of unrivalled warmth that would not exist naturally, thus changing the habitat for the better, or possibly worse. An area of unnatural warmth may mean the geckos can remain active for longer, especially during winter. As such, geckos may be more likely to use the CFRs during the colder months. However, it may also have the opposite effect during summer; the CFRs may warm up to an extent where it would be harmful for a gecko to occupy them. Therefore, during warmer periods geckos may avoid the CFRs.

Once a monitoring tool is placed in a habitat, that habitat, along with the behaviour of the target species, is altered. For example Lettink (2007) suggested that the presence of artificial retreats altered the spatial distribution and movements of the common gecko (*Woodworthia maculatus*). Also, Thompson (1992) demonstrated that the presence of artificial cover objects produced a marked change in the structure and composition of a desert rodent species assemblage due to decreased predation pressure and increased areas of shade. Although the placement of a monitoring object may seem like a minor disturbance event and an insignificant habitat manipulation, Pike et al. (2010b) demonstrated that a minor act of habitat manipulation (the movement of refuges less than 30 cm) caused the endangered broad headed snake (*Hoplocephalus bungaroides*) to avoid these disturbed refuges.

During winter the warmth of the CFRs may mean that the geckos that use them become more active as their metabolisms activate and they will need to forage (Dmi'el 1972; Andrews & Pough 1985; Gillooly et al., 2001). Geckos are not thought to forage often during winter due the low temperature and the reptiles' inactive response to this. Many reptiles are known to bask and thermoregulate within their retreat sites (Bustard, 1967; Dial, 1978; Autumn & De Nardo, 1995), the CFRs may then provide enough warmth for the gecko to need to forage; if this occurred it may leave the CFR to forage, however the ambient temperature may be too low and

the geckos' metabolism may slow down causing it to become slower and potentially trapped outside of cover.

This area of unnatural warmth may also attract many invertebrates, including large predatory invertebrates such as spiders and giant centipedes. This could have both positive and negative effects on the geckos that occupy them. Giant centipedes are known to predate on smaller juvenile and neo-natal geckos; these refuges may then become places of increased danger for young geckos. The attraction of smaller invertebrates such as cockroaches, small spiders, millipedes, tree weta and cave weta may have a positive effect on the geckos by providing them with an easy food source.

Research on CFRs suggests that there may be a sex bias among the amount of geckos using them, with males potentially more prone to occupy them (T. Bell, pers. comm. 2011). However, as CFRs are a recent development, little research has been completed studying their effects on gecko's behaviour and ecology. It is then important to complete research understanding the effects of these tools on geckos

### 5.1.3 Research objectives

This study aims to analyse the effectiveness and efficiency of CFRs in comparison with VES night-spotting, artificial cover objects (ACOs), and tracking tunnels. The study then aims to understand how geckos use the CFRs; whether they use them more often when it is cold or warm, if there is a sex bias, and whether they use the CFRs as a food source. Finally, the study aims to compare two different methods of using the CFRs, the first method of checking them every second day and the second of checking them every second week.

Research questions:

- Are CFRs more efficient than VES, ACOs and/or Tracking tunnels for monitoring geckos?
- Are more species of gecko found using the CFR technique compared with VES, ACOs and tracking tunnels?

- Are more geckos found when using a method of monitoring that reduces disturbance?
- Do weather conditions correlate with the presence or absence of geckos under the CFRs?
- Is there a sex bias of geckos using the CFRs?
- Does the presence or absence of certain invertebrates correlate with the presence or absence of geckos under CFRs?

## 5.2 Methodology

### 5.2.1 Study area

The study was conducted primarily on Waiheke Island, within Whakanewha Regional Park and the surrounding areas of private land with no pest control. Tawharanui and Shakespear Regional Parks were also used as study sites, but the main focus of the study was on Waiheke Island. The study sites on Waiheke that were used included all 10 CFR transects (five within pest control (treatment) and five in areas of no control (control)) and all six VES transect (three within pest control (treatment) and three in areas of no control (control)). For detailed descriptions of each study area refer to Chapter 2, section 2.2.

### 5.2.2 Study species

The forest gecko (*Mokopirirakau granulatus*), elegant gecko (*Naultinus elegans*), and Pacific gecko (*Dactylocnemis pacificus*) were all used in this study. However, the Pacific and elegant geckos were found in very small numbers and as such the study focuses predominantly on the forest gecko which was the most abundant species found. The forest gecko is considered not threatened, while the elegant gecko is considered at risk and declining, and the Pacific gecko is considered relict with >20,000 mature individuals and a stable, or increasing at >10%, population (Hitchmough et al., 2010). For detailed descriptions of these species refer to Chapter 2, section 2.1.

## 5.2.3 Study design

### 5.2.3.1 Cell foam retreats

Four hundred CFRs were set up on Waiheke Island, 200 were set up at Tawharanui, and a further 160 were set up at Shakespear. The CFRs were checked every second day for 12 days during the initial March and April check as a part of the Auckland Council's gecko monitoring program. Throughout the year the CFRs at Waiheke were checked once every month from May – August, and once a fortnight during September – December. During every check of the CFRs the weather conditions were recorded using a data logger. The data logger was hung from a tree in a single constant location for each check and was programmed to record the temperature and humidity every 30 minutes. Each time a gecko was captured the time was recorded; the temperature and humidity were then taken from the nearest half hour to the time the gecko was captured. In addition the temperature and humidity were averaged for the day and night of each time the CFRs were checked. When comparing the temperature and humidity with geckos captured, the five checks following the initial check were excluded from the analysis as they were considered to have been biased by the high number of geckos captured on the initial day. When comparing the alternate day method with the fortnightly method the initial check was excluded as the analysis was focused on the effects of follow up checks. For an in depth methodology of the use of CFRs refer to Chapter 2, sections; 2.4.1, 2.5.1 and 2.6.1.

### 5.2.3.2 Visual encounter surveys (night-spotting)

On Waiheke Island three transects in the presence of predator control and three on public property, in the absence of predator control (i.e. control transects), were set up along established tracks in order to do night-time visual encounter surveys (VESs) during the initial March study. VES night-spotting was completed along the five CFR transects at Tawharanui Regional Park, and at Shakespear the VES night-spotting was carried out by members of the Auckland Council, EcoGecko consultants, and Bioresearches Ltd consultants. The data collected was provided for

this study by the Auckland Council. For an in depth methodology refer to Chapter 2, sections 2.4.2, 2.5.2 and 2.6.2.

### **5.2.3.3 Onduline artificial cover objects (ACOs)**

During mid-August Onduline ACOs were set up on Waiheke Island and then left for a month before the first check to try to habituate any animals to the ACOs. Ten double-stacked ACOs were set up along each of the four highest gecko-capture transects transects (three within pest control: IA, IC and ID and one along private property outside of pest control: OA), each placed approximately 40 m apart and at least 5 m adjacent to every fourth CFR. Ten remaining ACOs were placed opportunistically along coastal habitat (including *M. excelsa* and *Phormium tenax* habitats) within the park. The ACO transects were checked once every fortnight from September to November at the same time as the CFRs were checked. For an in depth methodology refer to Chapter 2, section 2.4.3.

### **5.2.3.4 Tracking tunnels**

During mid-August 50 tracking tunnels were set up in an attempt to compare the reptile tracking rate with the ‘geckos hour<sup>-1</sup>’ value for CFRs, ACOs and VES night-spotting. The tracking tunnels were set up along four transects within the park and one on private property outside of the park. The tunnels were left for a month and not checked until late September to try to habituate any reptiles to them. From September to November they were checked once a fortnight at the same time as the CFRs and ACOs were checked. For an in depth methodology refer to Chapter 2, section 2.4.4.

## 5.3 Results

### 5.3.1 Forest gecko capture/recaptures using CFRs

The number of forest geckos captured using CFRs on the first day of checking at Waiheke (March-01) was very high, with 33 geckos caught (Figure 5.2). On every subsequent check the number of geckos captured was much lower, with 13 captures being the next highest which occurred during August. New individual geckos were consistently caught throughout the year, the highest number of new individuals caught on a single check (excluding first check, March-01) was during August, with eight new geckos caught. A total of 44 forest geckos were recaptured over the year at Waiheke Island, no geckos were recaptured at Tawharanui or Shakespear, and no elegant or Pacific geckos were recaptured. Figure 5.2 shows the cumulative catch of new individuals throughout the year, which consistently increased and did not level out during the final checks.

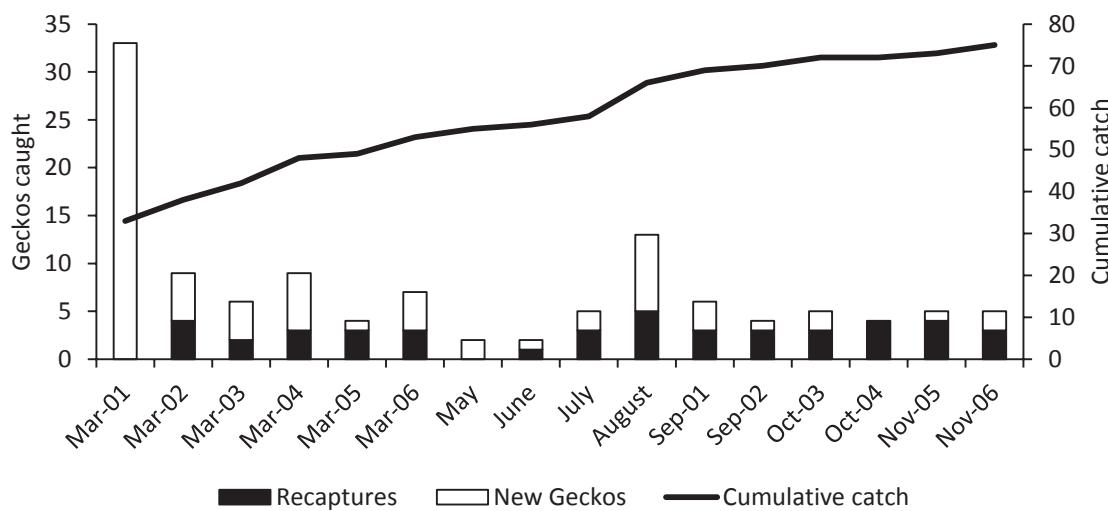


Figure 5.2 Gecko captures and recaptures using CFRs on Waiheke Island, also showing the cumulative catch throughout the three study periods: six checks during March, four checks between May-August, and six checks between September-November.

### 5.3.2 Alternate days vs. fortnightly and monthly checks of CFRs

A non-parametric Kruskal-Wallis test was used to compare the alternate day checks (excluding the first day) with the fortnightly and monthly checks (Figure 5.3). The results showed no significant difference between any of the methods with  $P =$

0.2 and  $KW = 2.8$ . As a baseline to compare with these methods, the first check on the initial day showed 33 geckos captured, substantially higher than any other subsequent check.

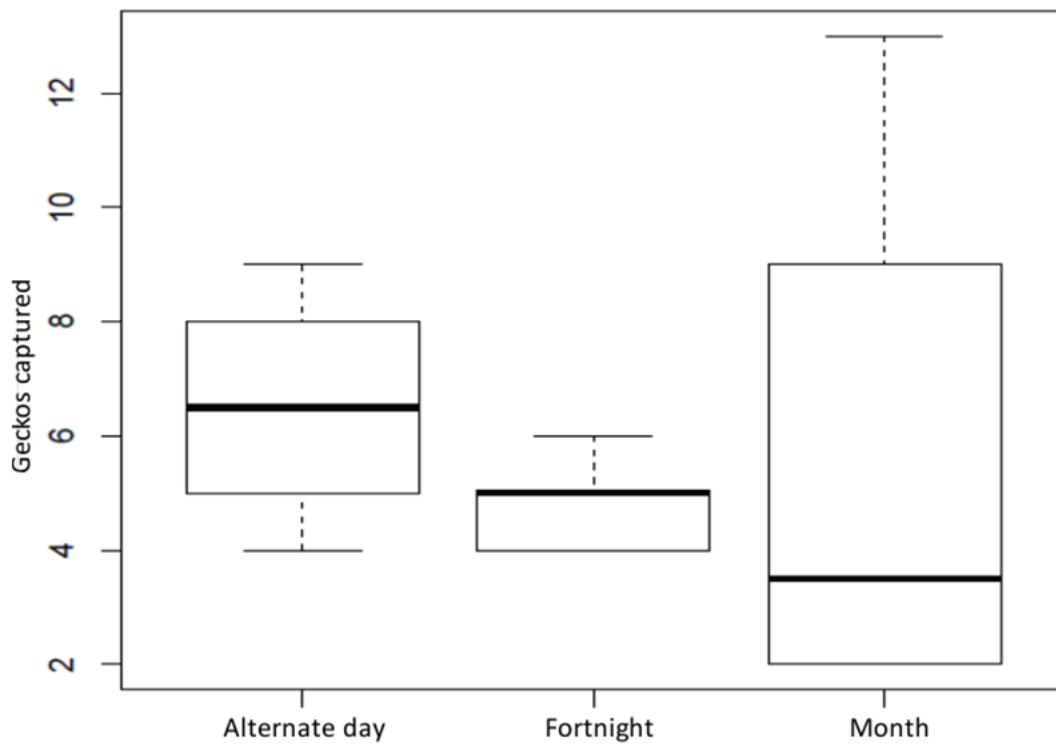


Figure 5.3 Box-plot comparing the number of geckos captured for each monitoring method. Where  $n$  = the number of checks per method ( $n = 6$  for alternate day and fortnightly, and 4 for monthly methods).

### 5.3.3 CFR vs. VES (vs. ACOs and tracking tunnels)

Overall the longest time spent searching for any method was using the CFRs, where over 90 hours of search time throughout the year was recorded (Table 5.1). The tracking tunnels showed the second longest time, with over 23 hours, while the VES and ACO methods were the shortest, with approximately 19 and 12 hours spent searching respectively. The method with the most geckos caught was the CFR method, with 119 geckos caught at Waiheke alone, 20 geckos were captured while night-spotting and no geckos were caught or detected using the ACO or tracking tunnels methods. The CFR method captured two species; the forest gecko (*Mokopirirakau granulatus*) at Waiheke and Tawharanui, and the Pacific gecko

(*Dactylocnemis pacificus*) at Shakespear. The VES method also captured two species; the forest gecko at Waiheke and Tawharanui, and the Auckland green (or elegant) gecko (*Naultinus elegans*) at Waiheke, Tawharanui and Shakespear. The ACO method captured a total of four skinks, which were likely moko skinks (*Oligosoma moco*) or copper skinks (*Cyclodina aenea*) but could not be accurately identified as they were not captured. The CFR method showed the highest rate of capture with 1.66 geckos hour<sup>-1</sup>, while the only other method to compare this with was the VES night-spotting method where 1.10 geckos hour<sup>-1</sup> were recorded (Figure 5.4). A Student's *t*-test was used to compare the capture rates of the CFR and VES methods on Waiheke Island, ( $t = 1.217$ ,  $P = 0.2$ ), showing no significant difference between the two methods. The capture rates between CFRs and VES were also compared at Tawharanui using a Mann-Whitney U-test ( $U = 8$ ,  $P = 0.3$ ) and Shakespear using a Student's *t*-test ( $t = 0.37$ ,  $P = 0.7$ ) and as an average over all three study areas using a Mann-Whitney U-test ( $U = 233.0$ ,  $P = 0.2$ ), with no significant differences (Figure 5.4).

Table 5.1 Total time spent searching using each monitoring method on Waiheke Island, including; total number of geckos found, total species found, geckos per hour, other reptiles found, geckos per trap, and other reptiles per trap. \* The four other reptile species found were thought to be moko skinks (*Oligosoma moco*) or copper skinks (*Cyclodina aeneum*) but an accurate identification could not be made. (Where TT = tracking tunnels)

	CFR	ACO	TT	VES
Total hours	90:52	12:33	23:05	19:48
Geckos found	119	0	0	20
Geckos per hour	1.66	0	0	1.101
Species	2	2	0	2
Other reptiles	0 4*		0	0
Reptiles per hour	0	0.32	0	0
Geckos per trap	0.297	0	0	N/A
Reptiles per trap	0.297	0.08	0	N/A

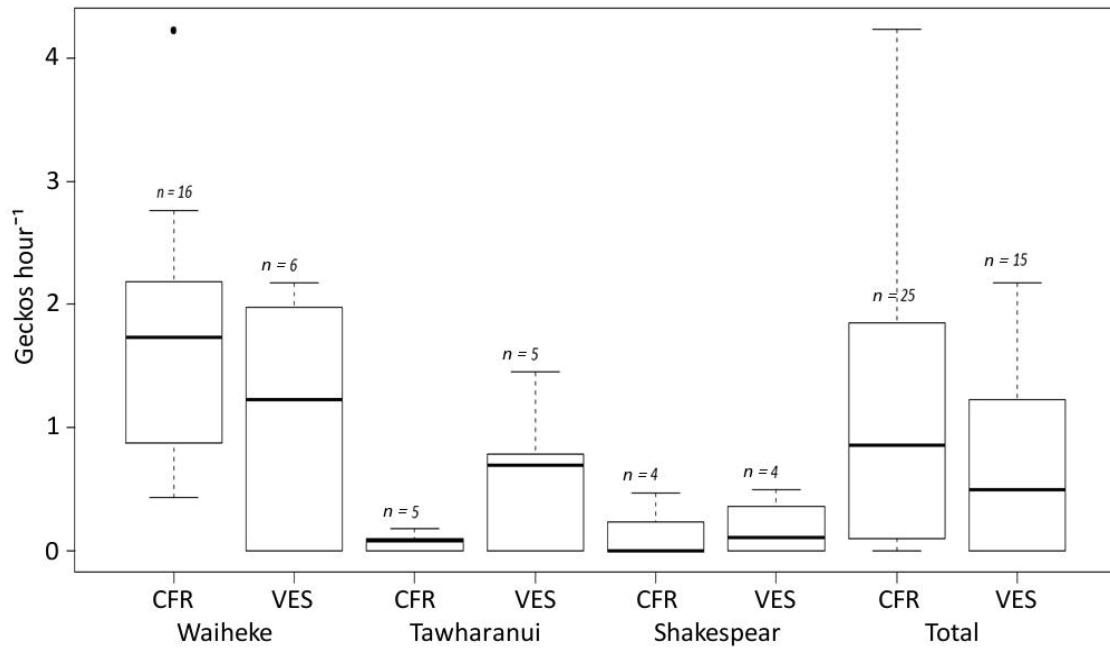


Figure 5.4 Box-plot showing the geckos captured per hour for the CFR and VES monitoring methods over each study site and as an overall total. Where  $n$  = the number of checks per method, per study area.

### 5.3.4 Monthly temperature and relative humidity

Pearson rank correlations were used to compare the number of geckos captured using CFRs during the initial first day check and all the checks from May to November with the average monthly day and night temperature and humidity. The results showed that when comparing the average day and night temperature with the number of geckos captured per check (Figure 5.5) there was no significant correlation for either ( $P = 0.8$ ,  $r^2 = 0.056$  and  $P = 0.96$ ,  $r^2 = -0.018$  respectively). The average day humidity was not significantly correlated with the geckos captured ( $P = 0.09$ ,  $r^2 = -0.53$ ), neither was the average night humidity ( $P = 0.17$ ,  $r^2 = -0.44$ ).

### 5.3.5 Temperature and relative humidity at the exact time of capture

The temperature and humidity at the exact time each gecko was caught under a CFR was also recorded in order to compare this with the average overall monthly temperature per check. Pearson rank correlations were used to compare the numbers

of geckos captured per check with the temperature and humidity at the exact time of capture. The results showed that the temperature (Figure 5.6) was not significantly correlated with the number of geckos captured ( $P = 0.6$ ,  $r^2 = 0.03$ ). However, the humidity (Figure 5.7) was significantly correlated, ( $P = 0.03$ ,  $r^2 = 0.44$ ), with fewer geckos captured as the humidity increased.

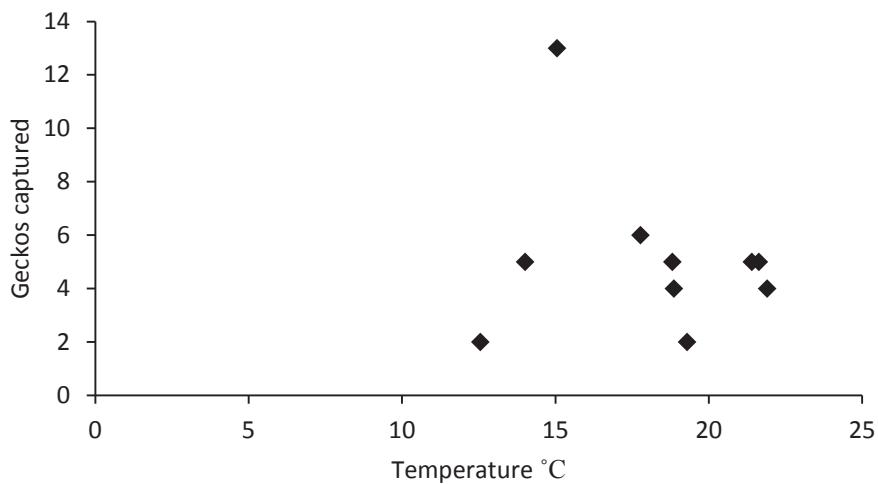


Figure 5.5 The temperature at the exact time of capture correlated with the numbers of geckos captured between May – November.

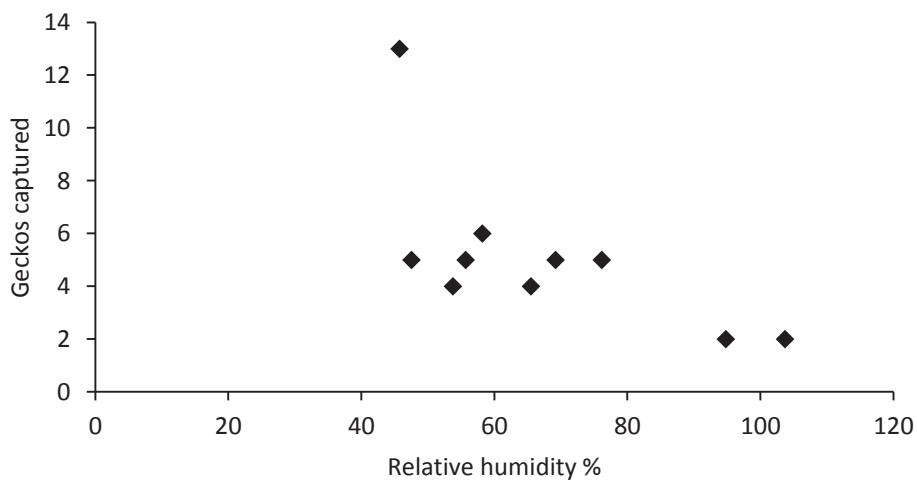


Figure 5.6 The relative humidity at the exact time of capture compared with the numbers of geckos caught between May – November.

### 5.3.6 Potential gecko sex biases

The total number of geckos of each sex captured on Waiheke Island using both the CFR and VES methods were compared (Table 5.2). VES data from the

unpublished study of Trent Bell and Jo Hoare was used (with permission) in addition to the data from this study in order to increase the sample size for the VES method. This was then compared with the geckos captured using the CFR method only, to discover whether there is a sex bias in geckos occupying the CFRs. A Student's *t*-test was used to analyse the difference between the sexes for the total geckos (CFR & VES) captured. The results showed that there was no sex bias in total on Waiheke Island ( $t = 1.054$ ,  $P = 0.2$ ). When the geckos that were captured using only the CFRs were compared using a Mann-Whitney U-test there was also no significant sex bias found ( $U = 46.5$ ,  $P = 0.1$ ).

Table 5.2 The overall differences in the number of males and females found on Waiheke Island using both CFR and VES methods (total) and only the CFR method (CFR), showing the average and medians with standard error and upper and lower 95% confidence intervals.

	Average ( $\pm$ SE)	Median (95% CI)
Male total	4.7 ( $\pm$ 0.85)	4 (2.9-6.6)
Female total	3.5 ( $\pm$ 0.68)	3 (2.1-5.0)
Male CFR	5.7 ( $\pm$ 0.97)	5.5 (3.4-8.0)
Female CFR	3.6 ( $\pm$ 0.7)	3.5 (1.9-5.2)

### 5.3.7 Invertebrates

The numbers of invertebrates under the CFRs were analysed to attempt to discover whether geckos were utilising the CFRs as food sources. A Mann-Whitney U-test was used to compare the abundance of invertebrates where geckos have been caught (Presence, Figure 5.8) to where they have never been caught (Absence). The results showed that there was a very significant difference ( $U = 6522.5$ ,  $P < 0.00001$ ), with more invertebrates found under the CFRs never used by geckos. (For a list of all invertebrate species recorded refer to appendix A)

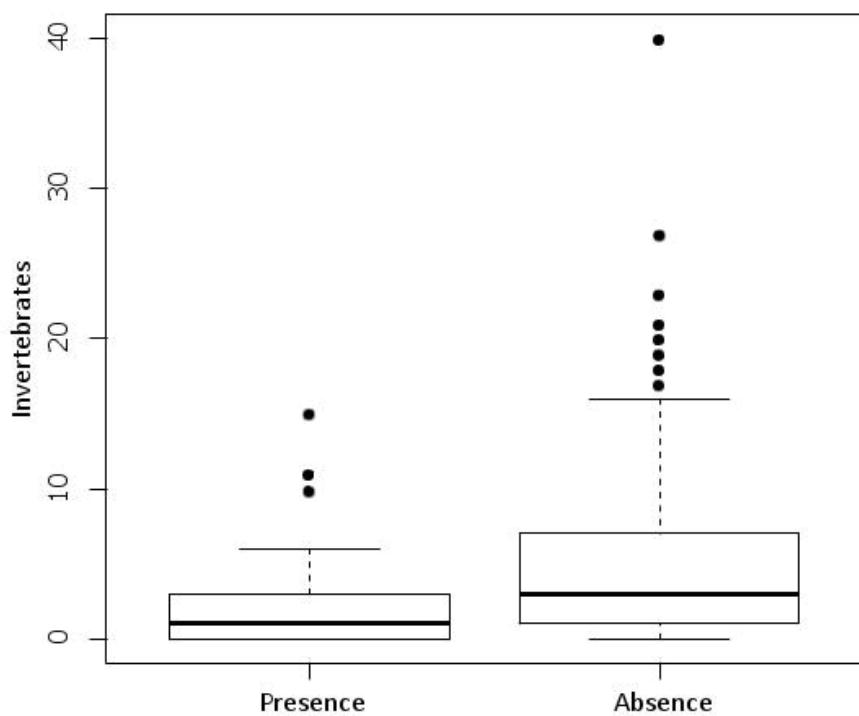


Figure 5.7 Box-plot showing the median number of invertebrates under the gecko-occupied CFRs (Presence) compared with the non-occupied CFRs (Absence). Where  $n$  = the number of CFRs per area, where  $n$  presence = 49, absence = 190.

## 5.4 Discussion

### 5.4.1 Forest gecko capture/recaptures using CFRs

Using CFRs a total of 119 geckos were captured throughout the year on Waiheke Island; 75 geckos were new captures and 44 were recaptured. On the first check of the CFRs a total of 33 geckos were captured (the highest number of captures all year), the second check showed only nine captures and out of these only four were recaptured, a substantial drop of 72%. The cumulative catch of geckos increased all year and did not level out, as would be expected once the population size limit has been reached. This may indicate a very large population of geckos in these areas on Waiheke Island, as at 75 individuals the population is still increasing. This also indicates the effectiveness of the CFR monitoring object as it shows that a very high number of geckos can be caught using this method.

Throughout the year the total number of geckos captured per check never rose to the same level as the first check. The next highest total capture of geckos was during August, where 13 geckos were captured, eight of these being new individuals and five recaptures. The reason for this substantial drop in geckos captured from the first check to all other checks is most likely to be due to the initial disturbance and stress of opening the CFRs and handling the geckos. This disturbance and stress must have been pervasive enough to cause many of the geckos captured to emigrate from the area.

While many geckos were captured once and never again, others were recaptured several times. One male and female pair on the OA transect were recaptured consistently throughout the year. Either the male or the female, or both, were found during every check of this CFR. Beneath the CFR was a small hole that led to a cavity within the tree trunk; several times only the tail of either gecko was found protruding from this hole. During one check the female was found under the CFR and the male was in the hole with its tail protruding. After the female was released she then entered the hole with the male still in it, indicating that the cavity was large enough for both geckos to occupy at once. The presence of this cavity meant the geckos occupying this CFR could escape capture while remaining under cover and is the reason why these geckos were observed or captured consistently throughout the year. Other geckos that were recaptured several times included a

juvenile on the OD transect, which was captured four times, and an adult male on the OE transect, which was captured three times. These examples where geckos were recaptured consistently may suggest that different individual geckos have different tolerances for disturbance and handling.

There were examples where geckos that were captured once during March were not recaptured again until the end of the year in November nine months later. This may suggest that the initial stress and associated avoidance of the CFRs will last a relatively long time, but after several months it will wear off and the geckos will return. The geckos that were only captured once may have emigrated from the area after capture and release and never returned, however in many cases this left the CFRs open for new individual geckos to utilise.

Some geckos, especially during winter, were observed to bask while being handled and potentially benefited from this warmth. They were very cold and lethargic initially but after handling became warmer and significantly more active. This behaviour has been observed in other cold-blooded species and is termed ‘kleptothermy’, an additional category of thermoregulation where an animal effectively ‘steals’ the warmth from another (Brischoux et al., 2009). However, this may have been more likely to have negatively affected the geckos captured, as once they were released the geckos usually moved immediately from the CFR to escape perceived further capture and stress. The warmth, stress and potentially adrenaline from capture and handling (Cash et al., 1997; Moore et al., 2000; Cree et al., 2003) will cause the geckos to be able to move quickly for a short period of time. This may mean that they will be able to move away from the CFR quickly but then once their warmth and adrenaline is depleted they will become slow and lethargic again. They will then become more prone to predation as they may not be able to effectively escape predators and may become trapped in an area without effective cover.

During handling the contact with the geckos was minimalised as much as possible to attempt to avoid overt stress on the geckos. The geckos were only handled when absolutely necessary, especially when they were cold to start with as the stress of heating up to quickly may cause coronary failure (T. Bell, pers. comm. 2011). As such, when the geckos were not being handled but were still needed they

were left in an area where they could be watched and contained but that did not provide excessive warmth, such as on a jacket or bag.

#### 5.4.2 Fortnightly vs. alternate day checks of CFRs

There was no significant difference between the median numbers of geckos captured for the alternate day checks in March compared with the fortnightly check from September to November. However, this study was highly biased by the first check in March where 33 geckos were captured. It was likely that the initial disturbance of this first check had an extensive and long-lasting impact on the geckos captured. Subsequently, they associated the CFRs with stress and avoided them or emigrated from the CFR area and did not return. This biased the attempt to compare these two methods. However, it does show that the disturbance on the first check is enough to substantially decrease the numbers of geckos captured for up to nine months afterwards. This indicates that the disturbance of the initial check will bias the subsequent checks using either method of checking the CFR, once a fortnight or once every second day.

#### 5.4.3 CFR vs. VES (vs. ACOs and tracking tunnels)

The CFR and VES methods were similar in the rate of geckos captured per hour spent searching. However, these results do not take into account the many differences between these two methods which are important to consider when comparing the effectiveness of these methods. An important difference is in the experience of the surveyors; when using CFRs there is little to no training that must be done in order to ensure volunteers can carry out the monitoring. When using the VES night-spotting method training is needed to ensure volunteers can spot highly cryptic reptiles amongst the foliage and branches. In addition, at least one experienced surveyor must be used or it is likely no animals will be found, as geckos are very difficult to find for people with little experience. Another limiting factor of the VES method is the number of surveyors that must be used. When using the CFR method the most effective number of surveyors is two, as one can open each CFR and the other can help to catch any geckos found. When using the VES method the

chance of finding an animal decreases as less people are searching for them. With only one person searching, regardless of experience, the chances of finding an animal are very small. However, with several people searching, excessive noise and light may scare the animals away from the search area. Also when using the VES method human error factors must be considered; for example, as the time spent searching increases with no animals being found, the chance of finding an animal will decrease. This is due to a lack of expectation or a mindset that there are no animals in the particular search area to be found, an increase in fatigue from searching at night, and a drop in the confidence of the searchers in their own ability. Finally, both methods may rely heavily on weather conditions; rain, wind, cloud cover, temperature, humidity and moon phases may all influence the numbers of geckos that can be captured (Read & Moseby, 2001).

In areas with small populations of reptiles, or areas where they are thought to persist but have not been found before, the VES method may become less effective. However, at Shakespear, where geckos were not expected to persist, the VES method was as effective as the CFRs (see Figure 5.4). Also, at Tawharanui more geckos were found using the VES method than the CFR method. However, this may reflect the fact that there is a large population of geckos at Tawharanui (C. Wedding pers. comm. 2011), but they were not found occupying the CFRs. This could have occurred for various reasons. Research by Hoare (2006) has shown that in the presence of mammalian predators the Duvaucel's gecko (*Hoplodactylus duvaucelli*), along with other species such as the common gecko (*Woodworthia maculatus*) and common skinks (*Oligosoma nigriplantare polychroma*), alter their behaviour. This may also be the case for the forest gecko. At Tawharanui where there are no large mammalian predators the geckos may be less likely to seek the cover of loose bark or tree hollows that the CFRs mimic. As arboreal geckos' major native predators are avian they may naturally rely on their cryptic camouflage to escape predation from these avian predators whose main predation strategy is visually oriented (Brandon & Huheey, 1975). However, the predation strategy of mammalian pests is mainly scent based (Hoare, 2006), this may mean that in the presence of mammalian predators arboreal geckos may change their behaviour to include hiding under cover during the day. Conversely, the majority of invasive mammalian predators are nocturnal hunters (Alterio & Moller, 1997; Tempero et al., 2007). As such, the arboreal geckos taking

cover during the day may not be related to the presence or absence of these pests as they would not hunt them during the day.

A major difference between the study areas of Tawharanui and Waiheke was the habitat. The forest density and the common species in each study area were significantly different. Tawharanui showed habitat that was significantly denser than Waiheke. Chapter 4 shows that the detectability of geckos will increase in habitat that is dense. However, there may be a point where the density is excessively high and this may cause a decrease in the detectability of geckos. This may be because a very high forest density will decrease the light that penetrates through to the areas of the trunk where the CFRs are placed. This light may be an important factor in the choice of retreat sites for geckos, as they are known to bask in patches of sunlight near their retreats. The predominant forest species at Tawharanui was manuka (*Leptospermum scoparium*), compared with kanuka (*Kunzea ericoides*) at Waiheke. This also may have had an impact on the detectability of geckos. The bark of manuka is very loose, in many cases significantly more loose than kanuka, this may mean that geckos have effective retreat sites in the form of this loose bark. Consequently, they may not occupy the CFRs as they do not provide as effective retreats as the bark.

When comparing the CFR and VES methods the species that are captured must be considered as well. Using the CFR method over the four study sites, two species were captured; the forest gecko (*M. granulatus*) at Waiheke and Tawharanui, and the Pacific gecko (*Dactylocnemis pacificus*) at Shakespear. Using the VES method two species were also captured; the forest gecko and the Auckland green (or elegant) gecko (*Naultinus elegans*). A major issue that must be considered when deciding which method to use is the species of gecko targeted. Using the CFRs it is highly unlikely that a gecko from the *Naultinus* genus (green geckos) will be found occupying one as they do not live on the trunks of trees but in the canopy (Jewell, 2011). As such, if the species to be monitored is from the *Naultinus* genus then VES night-spotting would be the most effective method for monitoring. However, if the species to be monitored is from the *Mokopirirakau* genus (forest geckos), then the most effective method to use will be the CFRs as they do not require as much time or effort as the VES method and will capture geckos even in areas with very low densities (Bell, 2009).

The four methods used in this study targeted different species. The VES and CFR methods target arboreal (or semi-arboreal) gecko species such as forest (*M. granulatus*), green (*N. elegans*) and Pacific (*D. pacificus*) geckos. The ACOs and tracking tunnels targeted ground dwelling (and semi-arboreal) species such as the Duvaucel's (*H. duvaucelli*), common (*W. maculatus*) and Pacific (*D. pacificus*) geckos (Jewell, 2011), along with most species of skink in New Zealand. The fact that no geckos were captured using the ACOs or tracking tunnels probably means that no ground-dwelling geckos are present in the areas of this study on Waiheke Island and that arboreal geckos spend little time, if any on the forest floor.

#### 5.4.4 Temperature and relative humidity

The monthly average night temperature was not correlated with the number of geckos captured. However, as forest geckos are nocturnal reptiles the night temperature may be an important factor in their behaviour (Huey et al., 1989). As the night temperature increases, the geckos will be able to effectively thermoregulate their body temperatures so that they can remain active, they may then be more likely to leave their retreats to forage or search for mates. As the ambient temperature increases, causing the gecko's body temperature to increase, the gecko's metabolism may become more active and as such they will be more likely to forage or hunt (Dmi'el 1972; Andrews & Pough 1985; Gillooly et al., 2001). Geckos may also remain under cover during the night due to the colder temperatures. Nocturnal reptiles are known to theromoregulate while in their retreat sites during the day (Bustard, 1967; Dial, 1978; Autumn & De Nardo, 1995). Due to cold temperatures at night, forest geckos may search out areas of cover, or remain under cover, in order to thermoregulate their body temperatures during the day in an area that is safe from predation.

As the day temperature does not correlate with the number of geckos captured this may indicate that high temperatures do not cause the geckos to overheat and vacate the CFRs during the day. However, as the six checks during March were left out of the analysis this may have caused the average daily temperature to decrease as the temperatures during March were the highest of all the study periods. There were no study periods during summer and as such excessively

high temperatures were not recorded all year, consequently high temperatures may still cause the geckos to vacate the CFRs due to overheating.

As the relative humidity during the time of capture increased fewer geckos were captured, or as the humidity decreased more geckos were captured. This could have occurred for several reasons. Evaporative water loss has long been recognised as an important factor in the adaptation of reptiles to terrestrial environments (Spotila & Berman, 1976). Many reptiles have differing integument permeability and as such they have different tolerances for ranges in humidity (Spotila & Berman, 1976). As the relative humidity decreases forest geckos may be more likely to search out areas of cover in order to find areas with higher humidity. The geckos may search out more humid areas in order to prevent desiccation through excessive evapotranspiration due to the low humidity. Many of the areas under the CFRs were damper than the surrounding trunk (pers. obs. 2011), this may indicate that the humidity is higher within these retreats and that geckos may become more likely to occupy them when the relative atmospheric humidity is lower.

The relative humidity may influence many aspects of a gecko's behaviour, including foraging and mating behaviours (Spotila & Berman, 1976). In addition, forest geckos have been observed mating at night during wet and rainy conditions of high humidity (pers. obs. 2011; M. Nelson-Tunley pers. comm. 2011). Increased humidity may also indicate rain which may cause geckos to vacate their retreats in order to prevent themselves from being washed out. Also during rain, avian predators may be less likely to hunt, and invertebrate prey will be more active due to the increased humidity (Ludwig, 1945). This may mean the nocturnal geckos may forage during the day if it is raining or the humidity is high and as such will not be captured in the CFRs.

During the August check the second highest numbers of geckos were caught (after the first March check). This high number of geckos captured means that either the disturbance of the initial March check and other checks prior to August had not affected the geckos, or another factor (such as temperature or humidity) was superseding this disturbance. It is interesting to note that August 2011 was the coldest recorded month throughout New Zealand for over 50 years and snow was recorded falling in Auckland (Met service, 2011). The weather during August was

deemed as an extreme event and as such may have biased the results. Consequently, normal winter temperatures may not be sufficient to force as high a number of geckos to seek cover as were seen during August 2011.

#### 5.4.5 Gecko sex biases

No significant sex bias was found in the geckos using CFRs, also when using both CFR and VES monitoring methods (including unpublished VES data from Bell & Hoare) no sex bias was found in the entire population of geckos on Waiheke Island. This is a positive result for the monitoring of these geckos as it shows that the CFR will target both males and females equally.

#### 5.4.6 Invertebrates

There were significantly more invertebrates found under the CFRs where geckos have never been present. Thus geckos are either eating the invertebrates that enter their CFRs, or that invertebrates avoid CFRs where geckos are found. It may also mean that geckos are occupying the CFRs over a long period of time and are using the CFRs as their nesting sites. This may be the case as the invertebrates were counted during March, while geckos were found under new CFRs throughout the year. Despite the fact that geckos were not found under some CFRs at the beginning of the year, these CFRs still had low numbers of invertebrates occupying them. This may indicate that there were geckos occupying these CFRs at the beginning of the year, but were not captured until the end of the year, suggesting that the geckos have occupied the CFRs sporadically throughout the entire year. It is also possible that invertebrates preferred damper and cooler CFRs which may have been avoided by geckos. Measuring the humidity and temperature beneath the CFRs would have been useful in order to understand this, however it was not during this study due to constraints in equipment used.

## 5.5 Conclusions

The study found that the CFR method is more effective than the ACOs or the tracking tunnels at monitoring forest and pacific gecko species as no geckos were found using these latter two methods. No sex bias was discovered in either the overall population of geckos on Waiheke, or the geckos that occupy the CFRs. This shows that the CFR monitoring tool is an effective method for monitoring arboreal geckos as it does not exclude either sex for any reason.

There were significantly more invertebrates found occupying the CFRs where geckos were absent. This indicates that geckos may be using the CFRs as food sources, that invertebrates may avoid the CFRs where geckos are present, and that geckos may be occupying the CFRs in the long term.

The efficiency of the VES night-spotting was not significantly different from the CFR efficiency. However, the CFR method reduces the effect of human error on the number of geckos captured and as such it can be said to be the more effective method of monitoring arboreal geckos. Different species were captured using the different methods: VES captured green (*N. elegans*) and forest (*M. granulatus*) geckos, while the CFR method captured predominantly forest (*M. granulatus*) and a few Pacific (*D. pacificus*) geckos. Each method captured two different species, however if green geckos were to be monitored only the VES method would be effective as they will not use CFRs.

The two different methods of monitoring geckos using CFRs (a check of every cover every second day compared with every second week) were compared to determine whether reduced disturbance would allow for more geckos to be recaptured on subsequent checks. The study showed that the initial check during the first monitoring period in March biased the numbers of geckos captured for every subsequent check throughout the entire year. This meant that a comparison could not be effectively made between these two methods. For an effective comparison to be made the two methods must be carried out in two different areas with similar sized gecko populations.

Weather conditions were analysed to determine the effect temperature and humidity have on geckos occupying the CFRs. The study showed that the average

monthly night temperature and the humidity at the time of capture both correlated with the number of geckos captured. More geckos were caught as the night temperature and humidity decreased, or fewer geckos were captured as the night temperature and humidity increased. This is likely to be due to the thermoregulatory and evapotranspiration physiology of the forest geckos.

# CHAPTER SIX

## Conclusions and future research



Figure 6.1 Male *N. elegans* Auckland green or elegant gecko, showing distinctive cream markings outlined in black. Photo: Lee Thoresen

## 6.1 Conclusions

The tracking tunnels were used as a means of comparing rat abundances between control and treatment areas. The data were collected over four periods between January 2009 and November 2011. Overall, the percentages of tracking tunnels tracked (pooled across mice, rats, hedgehogs, and mustelids) were 14% and 8% for the two tracking tunnel transects (rabbit and peanut) within the treatment areas. Within the park rats had a low rate of tracking (< 9%) but mice were commonly detected (38%). These values show that there are relatively few mammalian predators within the regional park for the last three years and as such it can confidently be used as a treatment site to analyse the effects of rats and other mammalian predators on geckos.

In areas outside the park where pests were not removed 30 out of 36 tunnels were tracked, predominantly by rats, mice were also found on one transect. The percentages of tunnels that were tracked ranged from 55% to 100% cross the four transects. These results show that outside the park rats are present and potentially abundant. This would indicate that any negative effects on gecko's demography and body condition in these areas when compared with gecko's inside the park.

Not all of the CFRs available as refuges were used by geckos. Several habitat variables may explain *M. granulatus* CFR preference. Six habitat variables were analysed and all, excluding the Simpson's diversity index, showed significance effects on CFR use. Preferred CFR's had large amounts of undergrowth and dense forest nearby, and they had lower tree diameter, canopy height and canopy area.

Rat abundance was found to influence densities of geckos on Waiheke Island. Control (no pest removal) areas were generally found to have lower gecko densities than treatment areas with pest management. However, one transect within the (control) area, (OA) showed a high density of geckos as well as a high abundance of rats. When comparing the habitat between all transects this transect was found to have one of the lowest canopy heights, a high forest density and high forest diversity, thus contained CFR's in preferred locations. The microhabitat locations of the CFR's in OA may be the reason for the observed high density of geckos on this transect despite the abundance of rats. The other four control transects had habitat

with a low detectability (high canopies, large trees, and low forest density). The habitat on the transects within Whakanewha Regional Park in the areas of pest control (treatment) ranged in habitat type. This may indicate that the presence and absence of rats is not the sole predictor of arboreal forest geckos densities on Waiheke Island.

During the course of this study, evidence was found suggesting that rats have a negative impact on the population structure of geckos. More large geckos (SVL: 76-85mm, and 86-95mm) were found in the pest managed areas than in areas without pest control. This may show that geckos do not live as long in the presence of rodent predators. A population age structure with fewer large reproductive adults will have lower recruitment of individuals into the breeding population. Evidence was also found that male forest gecko condition was impacted by predation. The body condition (BCI) and body-tail condition (BTC) indices were lower in male geckos in areas with rats compared with areas without rats, additionally only males were found with sub-lethal injuries. This indicates that rats may attempt predation on forest geckos and in doing so decrease their condition and cause tail loss. Male geckos may be more vulnerable to predators if they have a greater home range, are more active or use more exposed habitat compared to females. However, as no sex bias in number was found for the total population or the treatment and control areas separately it is likely that predation rates were similar for both sexes.

Three geckos captured using CFRs exhibited scars from attempted predation, these scars were analysed and compared with morphological and behavioural hunting strategies of potential gecko predators. None of the scars were consistent with rat predation. One gecko potentially showed evidence of attempted rat predation, but the scar was small and no tail loss was evident so it was not certain. One gecko showed evidence of attempted morepork predation, and another, potential kingfisher predation. However, no conclusive evidence was found to confirm predator species.

The differences in gecko densities between the four study sites were highly significant. Both Waiheke Island sites showed higher gecko densities than either Tawharanui or Shakespear. Tawharanui is considered to have moderate densities of geckos, previous studies using VES night-spotting have found many geckos in

different areas of the park. However, this study did not detect them using CFRs. This was possibly due to the differences in habitat between the study areas. In general forest at Tawharanui is more dense than Waiheke; on Waiheke forest was predominantly made up of more open kanuka (*K. ericoides*) compared with manuka (*L. scoparium*) at Tawharanui. This difference may have caused geckos to avoid the CFRs at Tawharanui as they may have been excessively shaded from the dense foliage which would have prevented the geckos from basking while in their retreats during the day.

Shakespear had the lowest densities of geckos and had the highest forest density and the lowest tree height. The low canopy should indicate a high detectability of geckos, however, the habitat density may have been too high, excessively shading the CFRs and causing the geckos to avoid them. Previous studies have also detected very few geckos in this area, as opposed to Tawharanui where many have been detected. However, this area has had a suite of predators, including possums, until very recently. It is possible that possums have a negative impact on geckos, both directly through predation and indirectly through competition and habitat destruction.

The analysis of invertebrates found that small invertebrates such as cave weta, tree weta, and cockroaches could thrive in areas where rats are abundant. This means that rats did not have a negative impact on the prey of geckos and as such means that competition between rats and geckos for invertebrate food sources is likely to be low. Also, where the rats are abundant, mice will be inhibited and mice predate on (Knox, 2011), and may be more likely to compete with geckos for invertebrate food sources due to their small size and ability to enter small tree cavities. Rats were found to inhibit the abundance of the large invertebrates; sheet-web spiders and giant centipedes, this may have a positive impact on gecko densities as large spiders would compete with geckos for small invertebrates, and mature giant centipedes are known to prey on and compete with geckos (Pike et al., 2010a; Vallance, 2010; Jewell, 2011). In addition, there were significantly more invertebrates found occupying the CFRs when geckos were absent. This may indicate that geckos are using the CFRs as food patches or that invertebrates may avoid the CFRs where geckos are present.

The study found that the efficiency of the CFR method is similar to the efficiency of the VES night-spotting method for geckos detected per hour. Both the Onduline ACO and tracking tunnels were shown to be ineffective at monitoring arboreal geckos as no geckos were captured using these monitoring methods. The best detection method is determined to some extent by the species of interest: Different species were captured using the different methods. VES captured green (*N. elegans*) and forest (*M. granulatus*) geckos, and the CFR method captured predominantly forest (*M. granulatus*) and pacific (*D. pacificus*) geckos. The Onduline ACOs and tracking tunnel methods will primarily target ground-dwelling reptiles such as common (*W. maculatus*) or Duvaucel's (*H. duvaucelli*) geckos. The fact that none of these species were found using these methods during this study may indicate that they are not present on Waiheke Island.

When employing the CFR's as a mean of monitoring, the frequency of checking influences the detection effectiveness. This study showed that the initial more frequent checks during the first monitoring period in March reduced the use of the CFR's by geckos and hence a comparison could not be effectively made between these two methods. For an effective comparison to be made the two methods should be carried out in two distinct areas with similar habitat and gecko population sizes.

Weather conditions were analysed to determine the effects temperature and humidity have on geckos occupying the CFRs. More geckos were caught as the humidity decreased. This is likely to be due to the thermoregulatory and evapo-transpiration physiology of the forest geckos (e.g. Bustard, 1967; Spotila & Berman, 1976; Dial, 1978; Autumn & De Nardo, 1995). Hence CFRs may be best utilized for monitoring during dryer months.

Overall, cell foam retreats can be considered to be a robust and effective method for monitoring geckos in areas of both high and low gecko densities. The CFRs are most effective when placed in dense forest with a low canopy and when checked during dryer periods. The frequency of checks will have an affect on the number of geckos captured. However the initial check will likely always have the highest number of geckos and a substantial drop off in gecko numbers is likely to occur whether the CFRs are checked on a daily, alternating day, fortnightly or monthly basis.

## 6.2 Further research

1. *The impact of possums.* Possums are absent from Waiheke and this study found one site where the densities of geckos was high despite with the presence of rats (and other mammalian predators excluding possums), these areas should be compared with areas of similar habitat on the mainland in the presence of possums.
2. *The mating habits of forest geckos (*M. granulatus*).* During this study interesting aspects of forest gecko (*M. granulatus*) mating behaviour and habits were observed several times; during June, geckos were observed mating in the wild, the first time forest geckos species have been observed doing so, additional observations are needed including a potential link between colour or colour change and sexual selection.

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## Appendix (Species lists)

**Invertebrates:** A list of all invertebrates identified throughout the study. The invertebrates are identified from class (top centre), then order (top left) family (beneath order), genus and species (centre, beneath class), with the common names in the right column. Invertebrates were identified to species level where possible, otherwise to genus or family.

ARANEAE	ARACHNIDA	
Theridiidae	<i>Steatoda capensis</i>	False katipo
Stiphidiidae	<i>Cambridgea spp.</i>	Sheetweb
Pisauridae	<i>Dolomedes minor</i>	Nurseryweb
Zoropsidae	<i>Uliodon spp.</i>	Vagrant
GASTROPODA	MOLLUSCA	
Athoracophoridae		Leaf vein slug
Endodontidae	<i>Suteria ide</i>	Leaf litter snail
TURBELLARIA	PLATYHELMINTHES	
Terricola	<i>Newzelandia spp.</i>	Flatworm
COLEOPTERA	INSECTA	
Scarabaeidae	<i>Heteronychus arator</i>	Black scarab
ORTHOPTERA		
Anostostomatidae	<i>Hemideina thoracica</i>	Auckland tree weta
	<i>Gymnoplectron longipes</i>	Cave weta (lg)
	<i>G. uncata</i>	Cave weta (sm)
DERMAPTERA		

Forficulidae	<i>Forficula auricularia</i>	European earwig
<b>HEMIPTERA</b>		
Ricaniidae	<i>Scolypopa australis</i>	Passion vine hopper
<b>HYMENOPTERA</b>		
Formicidae	<i>Monomorium antarcticum</i>	Southern ant
Vespidae	<i>Vespa vulgaris</i>	Common wasp
<b>ISOPODA</b>		
Armadillidiidae	<i>Armadillidium</i> spp.	Slater/Pill bug
<b>CHILOPODA</b>		
Scolopendridae	<i>Cormocephalus rubriceps</i>	Giant centipede
	<i>Cryptops</i> spp.	Centipede (small species)
<b>DIPLOPODA</b>		
Blaniulidae	<i>Ophyiulus pilosus</i>	Millipede
<b>BLATTODEA</b>		
Blatellidae	<i>Celatoblatta vulgaris</i>	Bush cockroach
	<i>Drymaplaneta semivitta</i>	Gisborne cockroach

**Vascular plants:** A list of every species of plant identified during the study, both native and adventives species are listed (\* denotes adventive species). The plants are identified following the same method as invertebrates.

<b>FILICOPSIDA</b>		
Dicksoniaceae	<i>Dicksonia squarrosa</i>	Wheki
Cyatheaceae	<i>Cyathea dealbata</i>	Ponga
	<i>C. medullaris</i>	Mamaku
Polypodiaceae	<i>Phymatodes diversifolium</i>	Hound's tongue
Pteridaceae	<i>Pteridium aquilinum</i> var. <i>esculentum</i>	Bracken
Blechnaceae	<i>Blechnum filiforme</i>	Thread Fern
Polypodiaceae	<i>Pyrrosia eleagnifolia</i>	Leather leaf
	<i>Microsorum pustulatum</i>	

<b>SPERMATOPSIDA</b>		
Podocarpaceae	<i>Podocarpus totara</i>	Totara

Araucariaceae	<i>Phyllocladus trichomanoides</i>	Tanekaha
	<i>Dacrydium cupressinum</i>	Rimu
	<i>Agathis australis</i>	Kauri
<b>ANGIOSPERMAE</b>		
Piperaceae	<i>Macropiper excelsum</i>	Kawakawa
Verbenaceae	<i>Vitex lucens</i>	Puriri
Rutaceae	<i>Melicope ternata</i>	Wharangi
Violaceae	<i>Melicytus ramiflorus</i>	Mahoe
Asteraceae	<i>Brachyglottis repanda</i>	Rangiora
Myrtaceae	<i>Metrosideros excelsa</i>	Pohutukawa
	<i>Kunzea ericoides</i>	Kanuka
	<i>Leptospermum scoparium</i>	Manuka
Epacridaceae	<i>Cyathodes juniperina</i>	Prickly mingimingi
Tiliaceae	<i>Entelea arborescens</i>	Whau
Meliaceae	<i>Dysoxylum spectabile</i>	Kohekohe
Corynocarpaceae	<i>Corynocarpus laevigatus</i>	Karaka
Monimiaceae	<i>Hedycarya arborea</i>	Pigeonwood
Araliaceae	<i>Pseudopanax crassifolius</i>	Horoeka, lancewood
	<i>P. arboreus</i>	Five finger
	<i>P. laetus</i>	Seven finger
Solanaceae	<i>Solanum nigrum*</i>	Black nightshade
	<i>S. mauritianum*</i>	Woolly nightshade
Polygonaceae	<i>Muehlenbeckia complexa</i>	Pohuehue
Loganiaceae	<i>Geniostoma lingustrifolium</i>	Hangehange
Rubiaceae	<i>Coprosma repens</i>	Taupata
	<i>C. rhamnoides</i>	
	<i>C. robusta</i>	
	<i>C. rotundifolia</i>	
	<i>C. arborea</i>	Mamangi
Rosaceae	<i>Rubus cissoides</i>	Bush lawyer
Papilionaceae	<i>Sophora microphylla</i>	Kowhai
Asclepiadaceae	<i>Araujia sericifera*</i>	Mothplant

Myrsinaceae	<i>Myrsine australis</i>	Mapau
Winteraceae	<i>Pseudowintera axillaris</i>	Horopito
Malvaceae	<i>Hoheria populnea</i> var. <i>populinea</i>	Lacebark
Lauraceae	<i>Beilschmiedia tarairi</i>	Taraire
	<i>B. tawa</i>	Tawa
Fabaceae	<i>Ulex europaeus</i> *	Gorse
Pittosporaceae	<i>Pittosporum eugenioides</i>	Tarata
	<i>P. crassifolium</i>	Karo
Oleaceae	<i>Nestegis cunninghamii</i>	Black maire

#### MONOCOTYLEDONES

Agavaceae	<i>Cordyline australis</i>	Cabbage tree
	<i>Phormium tenax</i>	Harakeke, flax
Smilacaceae	<i>Ripogonum scandens</i>	Supplejack
Ranunculaceae	<i>Clematis paniculata</i>	Puawhananga
Gramineae	<i>Cortaderia selloana</i> *	Pampass
Cyperaceae	<i>Gahnia</i> spp.	Gahnia
Arecaceae	<i>Rhopalostylis sapida</i>	Nikau
Asteliaceae	<i>Astelia solandri</i>	Kaiwharawhara
Juncaeeae	<i>Juncus pallidus</i>	Giant sedge
Asparagaceae	<i>Asparagus scandens</i> *	Climbing asparagus