Analysing gecko monitoring data and standardising monitoring procedures at Shakespear, Tawharanui and Whakanewha Regional Parks

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Abstract

Constant inventories of New Zealand gecko populations are important to monitor the status of the populations over time and allow diagnosis of declines in abundance. Long-term monitoring can also provide information on how effective different management schemes are for conserving a species. Populations of Pacific geckos (*Dactylocnemis pacificus*) are monitored at Shakespear and Whakanewha, and populations of forest (*Mokopirirakau granulatus*) and green geckos (*Naultinus elegans*) are monitored at Tawharanui and Whakanewha on a yearly basis. Whakanewha has a poison based regime for controlling predators, and Tawharanui and Shakespear are largely reliant on predator-proof fences.

Visual encounter surveys (VESs) provide a relative abundance estimate of the gecko populations in terms of catch per unit effort (CPUE). There was no significant change in CPUE over the three years of monitoring (2012-2014) for any of the gecko populations. It is a possibility this could be a result of small statistical power tests. Comparisons of abundance indices could not be made between parks due to the likely difference of detectability in different vegetation types.

Despite the change in activity levels of some animal species during different phases of the moon, this study found that the same phenomenon does not occur for green and forest geckos. There was no significant difference in the CPUE of the gecko species from VESs conducted during the new and full moon. Therefore, there is no need to stratify VESs based on the moon phases in order to account for changes in the activity levels of the geckos when obtaining abundance indices.

Tracking tunnels have proven an effective monitoring device for estimating the distribution and relative abundance of animal species and have increasingly been used to monitor lizard species. Its use for detecting arboreal geckos has not been completed

with any great success. One Pacific gecko was detected in this study using tracking tunnels designed for arboreal geckos, a very low tracking rate. Cell foam retreats (CFRs) were also used for detecting geckos. They were able to detect the presence of all gecko species at the three parks that were detected by VESs except for one instance: CFRs failed to detect the presence of green geckos at Whakanewha. Therefore, it is advisable that they are not used exclusively for monitoring the gecko populations.

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CHAPTER 1

Monitoring geckos for conservation

1.1 Introduction

The New Zealand government is advocating an increase in targeted research of native species that can be assisted with monitoring programmes (Yoccoz *et al.*, 2001). With the country's international reputation and trading opportunities depending in part on its biodiversity (Ministry for the Environment, 2000), it is in New Zealand's economic interests to maintain its environmental integrity. Goal three of The New Zealand Biodiversity Strategy is to halt the decline in New Zealand's indigenous biodiversity. Included in the goal is the protection of species' distribution and genetic diversity. 74 % of New Zealand's 110 lizard fauna taxa are threatened or at risk (Hitchmough *et al.*, 2013). As the costs of predator control are high and resources sparse, the instigation of predator control regimes are restricted to priority areas (Murdoch *et al.*, 2007). The Ministry for the Environment (2000) has called for an increase in targeted research to gain knowledge about indigenous terrestrial biodiversity in order to support decisions regarding priority areas. Long-term monitoring programmes can provide a means of accomplishing this as they aid in understanding the effects that changes in land-management practices can have on biotic communities (Michael *et al.*, 2012).

1.2 The Auckland Council gecko monitoring programme

The Auckland Council gecko monitoring programme was initiated in 2010. It focuses on gecko populations at three of Auckland's regional parks: Tawharanui, Shakespear and Whakanewha. To date, Pacific geckos (*Dactylocnemis pacificus*) have been recorded at Shakespear and Whakanewha and green (*Naultinus elegans*) and forest (*Mokopirirakau granulatus*) geckos at Shakespear, Tawharanui and Whakanewha. All three parks are managed for ecological restoration and for recreational benefits. Some areas of Tawharanui are also utilised for farming. Under the Regional Parks Management Plan (2010), Tawharanui is classified as a Class I park, and Whakanewha and Shakespear as Class II parks. There are three classes of parks in total. Class I parks are managed ultimately for purposes of natural conservation and Class III parks for recreational benefits. Class II parks fall between these two, with a large emphasis on the health of the natural environment, while at the same time providing recreational benefits as long as they do not clash with the health of native fauna and flora. Class I parks also provide some recreational benefits, but these are limited and tightly controlled to prevent any disturbance to wildlife.

1.2.1 Objectives of the monitoring programme

The objectives of the Auckland Council gecko monitoring programme are to quantify the population dynamics of geckos at three of Auckland's regional parks: Shakespear, Tawharanui and Whakanewha (Bell *et al.*, 2010). This will be done by determining the distribution of species, their relative abundances and their population structures. The population dynamics will continue to be assessed over time in order to monitor any temporal changes that occur for either the betterment or the detriment of the species. Monitoring the health of the gecko populations over time will also allow an assessment of the ecosystem as geckos are sensitive to habitat alterations, such as the destruction of scrubland for human development, and predator invasions including rats and mustelids (Towns & Daugherty, 1994).

1.3 Study species

The species in the present study are from three separate genera: *Naultinus*, *Mokopirirakau* and *Dactylocnemis.* These are the only species of gecko that have been detected in the Auckland Regional Parks. The Auckland green gecko (*Naultinus elegans*) (Figure 1.1) and forest gecko (*Mokopirirakau granulatus*) (Figure 1.2) are classified under the New Zealand threat classification as at risk, which indicates a species with a very large population (over 100,000 mature individuals) and low to high ongoing or predicted declines (Hitchmough *et al.*, 2013). The green gecko is an arboreal, diurnal lizard found in habitat consisting of forest and scrub, including manuka/kanuka shrubland with a diet consisting of insects, berries and nectar (Cree, 1994; McCann, 1956). The forest gecko is nocturnal and has been observed living in forest and scrublands (Newman & Towns, 1985; Whitaker, 1987). Its diet consists of insects (found in crevices) moths, flies, fruit and nectar (Whitaker, 1987). The Pacific gecko (*Dactylocnemis pacificus*) (Figure 1.3) is classed as a relict. Relict taxa are those that have undergone a documented decline within the last 1000 years and now occupy less than 10 % of their former range (Hitchmough *et al.*, 2013). The Pacific gecko is nocturnal with arboreal and terrestrial habits and has been recorded in forest and scrubland and scrubby vegetation, including flax, with a diet consisting of insects and honeydew (McCann, 1956; Whitaker, 1987; Hitchmough, 1997; Jewell, 2008). Threats to all three geckos include habitat fragmentation, predators and development pressures (Towns & Daugherty, 1994; Craig *et al.*, 2000).

Figure 1.1 An Auckland green gecko (*Naultinus elegans*) on a flowering manuka (*Leptospermum scoparium*). Photo: Justin Latif

Figure 1.2 A forest gecko (*Mokopirirakau granulatus*) on a dead frond of silver fern (*Cyathea dealbata*). Photo: EcoGecko Consultants

Figure 1.3 A Pacific gecko (*Dactylocnemis pacificus*) displaying the effectiveness of its camouflage on a tree. Photo: The Natural Heritage Collection

The clutch size of New Zealand geckos is at maximum two but sometimes less (Hitchmough, 1982). The average annual reproductive output for New Zealand geckos is less than two per female, which is low compared to species overseas (Cree, 1994). This is because not all females reproduce on an annual basis, and some clutch sizes only consist of one (Cree, 1994). Although gestation periods of up to 11.5 months have been suggested, this has been refuted because of the possibility of sperm storage following copulation, resulting in a delay in fertilisation (Hitchmough, 1979; Cree, 1994). New Zealand geckos are generally pregnant over summer and give birth in autumn; some, such as the Auckland green gecko, give birth in winter (Cree, 1994). All New Zealand geckos are viviparous, giving birth to live young. This is thought to be an adaptation to the cool temperate climate (Wilson & Cree, 2003). Retaining the embryo for longer is thought to allow the female to maintain a constant and favourable temperature for the developing young (Shine, 2006).

Little is known about the ecology and behaviour of the three gecko species in this study specifically. Instead, generalisations are made for the three genera based on information from co-genus species. Sexual maturity in the *Naultinus* genus occurs at four years and, generally, females reproduce on an annual basis (Hare *et al.* 2007). The daily movements of these geckos are very restricted, which corresponds with their sit-and-wait method of foraging. *Naultinus manukanus* averages a distance of 0.6 metres a day (Hare *et al.* 2007). These geckos have a prehensile tail that makes them very agile climbers and less liable to undergo autotomy. *Naultinus* geckos are found in shrubland and regenerating scrubland with dominant kanuka (*Kunzea ericoides*) (Knox *et al.*, 2012). Auckland green geckos are found only in the North Island in areas north of Taranaki. There are eight other species within the genus, showing a disjunct distribution throughout the North and South Islands (Hitchmough *et al.*, 2013).

Mokopirirakau geckos are distributed throughout the North and South Island. There are four confirmed species in this genus, reaching sexual maturity at three to four years of age (Towns, 1991; Hitchmough *et al.*, 2013). They are nocturnal hunters, actively searching for their prey (Newman & Towns, 1985). They are insectivorous but also include fleshy fruits and nectar in their diets (Whitaker, 1987). They possess the ability to change the colouration of their skin within a twenty-four hour period, becoming noticeably paler at night (Jewell, 2006). This is especially advantageous when they travel between contrasting light and dark backgrounds, enabling them to remain inconspicuous to predators. Known habitat includes: shrub, podocarp forest, beech forest, mixed broadleaf and manuka/kanuka scrub (Hoare *et al.*, 2013). Many *Mokopirirakau* sightings have been on the trunks and branches of trees (Romijn *et al.*, 2013). Some records have shown daily movements of up to five metres for this genus

(Hoare *et al.*, 2013). Other accounts describe an average travelling distance of 9.5 metres in a 24-hour period (Romijn *et al.*, 2013).

There is only one confirmed species in the genus *Dactylocnemis: D. pacificus* (Hitchmough *et al.*, 2013). Pacific geckos are distributed throughout the North Island and on off shore islands. They reach sexual maturity between three and four years of age, and have both terrestrial and arboreal tendencies but have only been found in the lower levels of trees (Towns, 1991). They inhabit beech forest and manuka/kanuka scrub and mixed broadleaf forest (Whitaker, 1987; Towns, 1991). Pacific geckos start reproduction in their fourth year (McIvor, 1972). They are nocturnal, with their most prevalent times of activity occurring between two and four hours after sunset (McIvor, 1972).

1.4 Study sites

The presence of forest and green geckos has been detected at Shakespear, Tawharanui and Whakanewha (Figure 1.4). Pacific geckos have been found at Shakespear and Whakanewha.

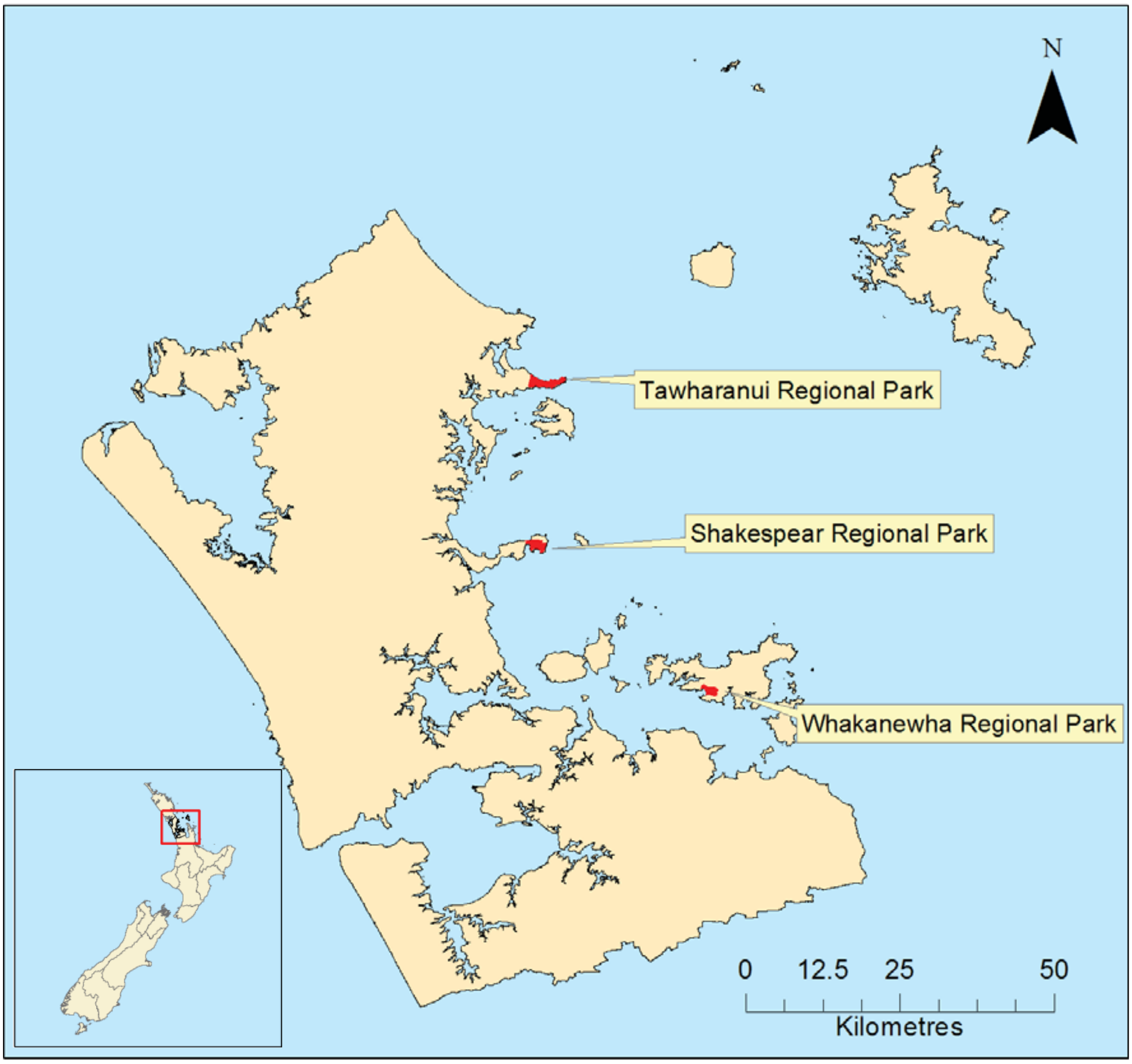

Figure 1.4 Map of New Zealand with a close-up of the Auckland Region showing the location of the three regional parks where geckos are monitored by the Auckland Council. Image: ArcGIS Desktop 10

1.4.1 Tawharanui Regional Park

Tawharanui Regional Park covers an area of 558 hectares, containing pastureland, mature coastal forest, restored wetlands and native forests, purchased by the Auckland Regional Authority and opened to the public in 1974 (Auckland Council, 2010). It is surrounded by a 2.8 kilometre long boundary fence which was established in 2004 (Auckland Council, 2010). Due to Tawharanui's location on a peninsula, the length of fence was less than would be necessary to fence off the same area of habitat if it was land-locked (Burns *et al.*, 2012). With the sea acting as a border and reducing the necessary length of fence needed to cordon off the park, construction and maintenance costs were reduced. Predator eradication to exterminate introduced mammalian predators was completed in 2005 (Auckland Council, 2010). The predator-proof fence is effective at keeping out all target species. However, because it is open-ended along the sea edge, the park is subject to re-invasion by pests. These are controlled where possible with poison baiting (Maitland, 2011). There is a buffer zone of intensive predator control along the outside of the fence and at the coastal edges (Burns *et al.*, 2012). Stoats and rats have re-invaded but once and have been exterminated (Day & MacGibbon, 2007). However, mice have re-established in high densities (Goldwater *et al.*, 2012). Tawharanui experiences around 160,000 visitors on an annual basis, with a campground capable of catering for 260 campers. The park is used for the protection and rehabilitation of several endangered species.

1.4.2 Whakanewha Regional Park

Whakanewha Regional Park consists of an area of 247 hectares, located on Waiheke Island, in the Hauraki Gulf. It is surrounded by residential developments, private properties, farmland and vineyards. The land was first used for farming sheep before being allowed to revert back to scrubland when it was declared a Scenic Reserve under the Reserves Act 1977 (Auckland Council, 2010). It now consists of several habitat types, including mature coastal broadleaf/podocarp remnants, kanuka forest, kauri, regenerating scrub, freshwater and saline wetlands and coastal mangroves (Auckland Council, 2010). It is known to be home to sixteen threatened animal species and experiences around 60,000 visitors per annum (Auckland Council, 2010). Although it is not surrounded by a predator-proof fence, the whole of Waiheke Island is free of mustelids and possums. It is, however, subject to a high density of rats, mice, cats and dogs, due to the large human population nearby (Auckland Council, 2010).

1.4.3 Shakespear Regional Park

Shakespear Regional Park, established as a regional park in 1967, is located on the Whangaparoa Peninsula and consists of 377 hectares of land. Habitat includes farmland and areas of native vegetation, including scrubland, mature broadleaf forest, coastal forest, salt-marsh, sand dunes and wetlands (Auckland Council, 2010). Like Tawharanui, it has an established predator-proof fence, 1.7 kilometres in length (Auckland Council, 2010). Shakespear is subject to the same problems of pest re-invasion along the open-ended coast, as is Tawharanui and, therefore, also has a dense population of mice. Tiritiri Matangi Island is located just off its coastal boundary and several native bird emigrants from the island visit the park. It experiences 500,000 visits per year for recreational purposes, which is the largest number experienced by any of the three parks, possibly due to its closer proximity and easier access to a larger proportion of the Auckland population (Auckland Council, 2010).

1.5 New Zealand lizards

1.5.1 History of lizards in New Zealand

Geckos are part of the order Squamata, consisting in New Zealand of skinks and geckos, collectively called lizards. All of New Zealand’s over eighty native lizard species are endemic. New Zealand herpetofauna is unique from the rest of the world for two reasons. Firstly, sympatric species diversity across the country is unusually high for a temperate area, and, secondly, local assemblages comprise an unusually large number of species within the same genus (Towns & Daugherty, 1994). Sympatry between closely related species is generally thought to be rare due to interspecific competition and because there is almost always an allopatric stage during speciation (Dumas, 1964; Via, 2001). A possible explanation for this high level of sympatry is the sympatric species occupying different niches, and thereby preventing negative interactions due to competition. Another explanation is that similar resources may be used by sympatric species without competition if these resources are not in high demand or in low supply (Alley, 1982).

1.5.2 Threats to lizards

Craig *et al.* (2000) have named introduced pests as being an overwhelming conservation problem in New Zealand. According to the Ministry for the Environment (2000), since the 1970s, introduced pests have posed, and continue to pose, the largest threat to New Zealand's biodiversity. Introduced fauna known to prey on lizards include the Pacific/kiore (*Rattus exulans*), Norway (*R. norvegicus*) and ship rat (*R. rattus*), cat (*Felis catus*), dog (*Canis lupus familiaris*), pig (*Sus scrofa*), mouse (*Mus musculus*), ferret (*Mustela furo*), weasel (*M. nivalis*) and stoat (*M. erminea*) (Towns & Daugherty, 1994). Arboreal lizard species are relatively safe from ground-feeding Norway rats and cats but are more prone to attack from arboreal ship rats and mustelids (Towns & Daugherty, 1994). Some lizard species are more sensitive to the kiore rat than are other species and cannot co-inhabit the same area (Towns, 1991). Despite their small size, mice are known to prey on lizards (Newman, 1994). Previous to the introduction of mammalian predators, birds and other reptiles were thought to have been the main predators of the country's herpetofauna.

The loss of appropriate habitat is the second greatest threat to lizards. Approximately 70 % of New Zealand's land area is managed unsustainably while the other 30 % is protected in reserves (Craig *et al.*, 2000). These reserves are often considerable distances apart and small in area. For these reasons, lizards, among other fauna groups, generally suffer from low population densities or local extinctions, range contractions and severe population fragmentations (Towns & Daugherty, 1994). All of these equate to a decrease in population size causing increases in inbreeding depression (Willi *et al.*, 2005). Inbreeding depression increases the extinction risk of populations as it negatively affects all aspects of reproduction and survival (Frankham *et al.*, 2002; O'Grady *et al.*, 2006).

Apart from the direct effect of introduced predators on lizards, there are also negative indirect effects. Species competition for resources can threaten populations of lizards. The diet of mice and ship rats, in some instances, can comprise primarily of invertebrates (Miller & Miller, 1995). This can lead to competition with lizard species in the area whose diets also consist largely of insects (Eason & Spurr, 1995). When these rodents are abundant, resources may become scarce and lead to local extinctions of lizards (Worthy, 1987). Another possible threat to lizards is secondary poisoning from pest eradication operations (Starling *et al.*, 2010). However, according to some studies, the negative effect on lizards is negligible (Eason & Spurr, 1995; Booth & Wickstrom, 1999; Eason *et al.*, 2011).

1.5.3 New Zealand geckos

Until recently, geckos in New Zealand were divided into the genera *Hoplodactylus* and *Naultinus*, including eleven and seven species, respectively, as described by Hitchmough *et al.* (2010). There were estimated to be twenty *Hoplodactylus* species and one *Naultinus* species yet to be formerly described. Within the genus *Naultinus,* species show many similarities, as opposed to those in the genus

Hoplodactylus which display larger variations in ecology, behaviour and body size (Nielsen *et al.,* 2011). Many *Hoplodactylus* species are brownish or greyish in colour and are nocturnal, whereas *Naultinus* species are arboreal, diurnal and predominantly green (Nielsen *et al.,* 2011).

A recent study by Nielsen *et al.* (2011) found evidence for a different classification of taxa. The study took a multi-gene approach and analysed phylogenetic relationships between known species of geckos and those that were yet to be described. Consequently, sixteen new species of gecko were described and five new or resurrected genera, to give seven genera in total. These genera are easily distinguished and within each genus species share unique morphological characteristics (Nielsen *et al.,* 2011). With regards to the species in this study, the *Naultinus* species can be easily distinguished from the other two genera by their distinct dominant green, or very rarely yellow, colouration (Nielsen *et al.*, 2011). The *Dactylocnemis* and *Mokopirirakau* species can be distinguished by the former having at least one curved or chevron-shaped lamellae while the latter having all straight lamellae (Nielsen *et al.*, 2011).

1.5.4 Importance of geckos to our ecosystem

In New Zealand, geckos and skinks fulfil important roles in the functioning of the country's ecosystems. There is increasing evidence that geckos may be partly responsible for seed dispersal and pollination of some of the country's native flora. New Zealand geckos are now generally recognised as including nectar and fleshy fruits in their diets (Whitaker, 1987). There is also strong evidence, reported by Wotton (2002), that geckos are not merely fruit "robbers" but contribute to effective seed dispersal. It is known that geckos do not chew their food extensively, so small seeds will probably be swallowed whole (Whitaker, 1987).

Geckos and lizards in general have an important role as predators. When *Anolis* lizards were removed from islands in the Bahamas, damage to the vegetation by herbivorous arthropods increased (Spiller & Schoener, 1990). Lizards on these islands are top predators. Even clearer evidence has been found that disruptions in trophic dynamics by the removal of a reptilian predator can result in uncontrolled herbivory, leading to a decrease in plant biomass (Pace *et al.*, 1999). Western fence lizards (*Sceloporus occidentalis*) control grasshopper numbers, and, when the lizards are not present, a significant decrease in plant abundance is apparent, related to an increase in grasshopper numbers (Chase, 1998). Many of New Zealand's geckos are insectivorous or include insects in their diet. The removal of these predators in any ecosystem may cause similar disruptions to the food web, leading to decreased vegetation and an increase in insect populations.

In New Zealand, removal of geckos may occur through death by disrupted habitat or increased predation, the most significant threats to the native geckos (Craig *et al.*, 2000). Despite being surrounded by a predator-proof fence, reinvasions of mammalian predators are a constant threat to the gecko populations at Tawharanui and Shakespear (Maitland, 2011). The gecko populations at Whakanewha may be subject to development pressures, present at such close proximity to human settlement (McKinney, 2002). However, significant removal of geckos to cause disruptions in ecosystem balances is uncertain due to the unknown size of the populations at present and what reductions in numbers may occur. Trophic level dynamics of the gecko species are unknown past a general understanding that their diet consists of a diverse array of insects, fruit and nectar (Whitaker, 1987; Cree, 1994). Therefore, a removal of the geckos is only speculated to result in major effects on any one insect or plant species.

1.6 Long-term monitoring of geckos

For this research, Lindenmayer & Likens' (2009) definition of long-term monitoring is used. They define long-term monitoring as repeated empirical measurements of a population taken consistently and analysed over a period of at least ten years. The timeframe of ten years is arbitrary, and in some cases may be inappropriate, especially considering the long lifespan of many species and reproductive strategies reaching beyond this timeframe (Strayer *et al.*, 1986). For these reasons, trends in populations may not become apparent within this period (Hilty & Merenlender, 2000). Strayer *et al.* (1986) have suggested that long-term monitoring is best performed when data are collected beyond the lifespan of the key species. The lifespan of some geckos is known to reach at least thirty six years (Thompson *et al.*, 1992; Bannock *et al.*, 1999). Therefore, some trends may not become apparent until data have been acquired for over a decade (Clutton-Brock & Sheldon, 2010).

Several long-term monitoring studies of reptiles have been successfully adapted around the world. The Antiguan Racer Conservation Project (ARCP) has focused on the conservation of the critically endangered Antiguan racer (*Antiguan racer*) which faces similar problems to the gecko species in this study: range restrictions, introduced mammalian predators and the impact of tourists (Daltry *et al.*, 2001). A long-term monitoring programme was initiated in 1995 the same year black rats (*Rattus rattus*) were eradicated from the island where the last population of the racer is located (Daltry *et al.*, 2001). Through an annual census conducted over a five week period through mark-recapture there was evidence for over a twofold increase in abundance following black rat eradication (Daltry *et al.*, 2001). The same eradication programme has seen the recovery of vegetation and lizard populations evidenced from systematic and non-invasive line transect samples (Daltry *et al.*, 2001).

Habitat alterations and fragmentations also threaten the ocelated lizard (*Timon lepidus*) (Dore *et al.*, 2011). A long-term monitoring study was established in 2007 focusing on the population on Oleron Island, France, confined to 140 hectares (Dore *et al.*, 2011). Surveys are conducted every three years during spring when individuals are counted in 70 random plots to provide abundance estimates and spatial distribution through occupation models (Dore *et al.*, 2011). Habitat variables including vegetation cover are measured in order to determine whether there are any correlations with occupation and to provide information on ecological requirements that can aid with future conservation decisions (Dore *et al.*, 2011). One caveat of the study is that abundance estimate intervals are large and make it difficult to detect a change in population numbers through time (Dore *et al.*, 2011). This problem can be exacerbated with some species when stochastic changes in population numbers can be mistaken for permanent decreases in population levels (Barrows, 2006). However, the monitoring programme does provide accurate spatial distribution of the species which provides important information for management decisions (Dore *et al.*, 2011).

The European leaf-toed gecko (*Euleptes europaea*) is now restricted to relict isolated populations in and around France (Salvidio & Delaugerre, 2003). The main focus of monitoring efforts for this species is the elucidation of their distribution as there is understood to be over one hundred isolated populations in Europe and North Africa (Delaugerre *et al.*, 2011). The leaf-toed gecko population in Central Liguria was routinely monitored with three night mark-recapture surveys on an annual basis between 1996 and 2000 in order to gather information of demography, abundance and populations trends (Salvidio & Delaugerre, 2003). Salvidio & Delaugerre (2003) recommend all populations of the gecko species to be monitored on a frequent basis to understand their conservation status, enable comparisons between populations and allow measures to be taken when they show signs of stress. Delaugerre *et al.* (2011) have documented evidence for eight cases of either large demographic declines or extirpations which have been correlated with human settlements, introduced ship rat populations or the establishment of another gecko species in the area.

Programmes around the world show the success and knowledge gained through a consistent monitoring effort. Management and conservation decisions are helped by the ability to track changes in population demographics and abundance and help in explaining why these changes are occurring. Although it is still in its infancy (initiated in 2010), the Auckland Council monitoring programme is structured to enable it to be continued indefinitely and beyond a period of ten years. As opposed to simply monitoring the geckos to inform management decisions, the programme reported in this thesis will also be used for research purposes (Yoccoz *et al.,* 2001; Nichols & Williams, 2006).

1.6.1 Management implications

In this study, a managed population relates to the manipulation of the environment in order to prevent decreases in population numbers (Shea, 1998). This manipulation occurs through pest control and restricting the impacts of visitors, and is aimed at protecting a wide range of species at the three regional parks including the gecko populations (Shea, 1998). Monitoring managed populations is essential in picking up early warning signs of impending crises. Long-term monitoring programmes are the best tool for this. They can serve two purposes: they can provide a periodic assessment of a population during the management process, and they can provide an understanding of a population's response to certain management scheme alternatives (Pollock *et al.*, 2002).

The benefits of acquiring information on reptilian populations to aid in management is evidenced in Hitchmough *et al.* 's (2010) 'Conservation of New Zealand reptiles' report. Five taxa improved in threat status from 2005 to 2009 due to conservation management action, aided in part by inventories on the population statuses gained through monitoring. Improved knowledge of reptile species, among other factors, has also resulted in a change in threat status for twenty-four taxa since 2005. The threat status of fauna is important information as it can have a large influence on the course of management action undertaken for the species, which may have significant impacts for its future.

However, despite these improvements in knowledge, long-term information of reptile populations for the majority of taxa in New Zealand is very weak (Hitchmough *et al.*, 2010), making it impossible to highlight with confidence any trends in the populations. A possible remedy for this is improved long-term and standardised monitoring schemes. Long-term monitoring will enable the uncovering of trends in the populations. A standardised scheme across the country will allow for comparison between populations. This may be particularity useful within taxa comparisons, allowing relative measures of population health. Elucidating trends in populations is also important for categorising species into threat categories as some categories are defined by population changes (Hitchmough *et al.*, 2013).

1.6.2 Characteristics of a good monitoring programme

Nichols and Williams (2006) define two types of monitoring approaches: targeted and surveillance. Targeted monitoring calls for an integration of monitoring efforts into conservation practice, with monitoring design and implementation based on models of predicted system responses. Surveillance monitoring is a standalone procedure focused on elucidating the present state of a system without a clear purpose, based on the concept that more information is more useful. This approach has been described as ineffective and inefficient (Nichols & Williams, 2006) and most now advocate the use of the targeted based monitoring approach (Nichols & Williams, 2006). In the targeted approach, monitoring efforts have a clear focus and a predicted outcome that can be disproved or otherwise. In effect, it is driven by purpose and a time-related goal. Having a problem-oriented approach to monitoring will greatly improve its efficiency, rigour, effectiveness and usefulness (Gibbs *et al.*, 1999; Platt, 1964).

Monitoring efforts should not just result in information on the status of populations but contribute to improving the management of entire ecosystems and natural resources and be linked in to more useful and technically sound procedures (Ringold *et al.*, 1996; Gibbs *et al.*, 1999; Nichols & Williams, 2006; Lindenmayer & Likens, 2009). Monitoring is only initiated when there are alternatives to management (Elzinga *et al.*, 2009). If there are no options then monitoring is void of purpose. It is neither efficient nor meaningful to monitor a population for the sole purpose of elucidating its current status in time and space. Monitoring should be part of an action-based approach to management, fulfilling three criteria: to help guide state-dependent decisions, to measure progress towards objectives and to help in discriminating between predicted models of system response (Nichols & Williams, 2006). Therefore, it is the trends brought about by human-induced changes to the environment that need to be identified in monitoring efforts.

Monitoring should be an iterative process. The necessity of an increased rate of data collection may be caused by the development of new monitoring methods or by discovering population dynamics change over a shorter time period (Lidenmayer &

Likens, 2009). Furthermore, priorities for the monitoring programme may only become apparent once initial data has been analysed and an adaptive monitoring approach allows priorities driving the data acquisition to change (Lidenmayer & Likens, 2009; Ringold *et al.*, 1996).

However, during its most adaptive stage, methodologies may change considerably, making consistency in collected data hard to establish (Ringold *et al.*, 1996). There must be a balance between improving monitoring techniques based on new information and maintaining the integrity of long-term data. While monitoring is an iterative process, in many aspects (question setting, experimental design, data collection, analysis and interpretation), it is important to maintain the integrity of the long-term data collected (Lindenmayer & Likens, 2009). There must be enough consistency in the process to allow for comparison over time and space (Magurran *et al.*, 2010). This is especially important during the data collection phase, which has time restrictions. Therefore, it is essential that standardised techniques for monitoring be implemented as soon as possible.

1.6.3 Standardising monitoring methods

Standardising monitoring is important in order to elucidate trends in populations through time. The most difficult task in maintaining a consistent monitoring approach is the obliteration of "noise" (Gibbs *et al.*, 1999). "Noise" is a change in population counts or other population parameters that occurs on account of natural phenomena or human errors in data acquisition. The main aim in monitoring is to determine the “signal”, alterations in population dynamics, brought about by variations in management protocols (Gibbs *et al.*, 1999). Standardised monitoring provides the periodic information about population and goal-related variables needed for the informed management of any animal population (Nichols *et al.*, 1995). It is important to standardise habitats, protocols and, when possible, weather (Wilson *et al*., 2007). In this way, the count indices will be comparable. Identifying the "signal" from monitoring data is the main aim in collecting it. The “signal” is important because it is the only aspect of a population that is able to be manipulated by human intervention (Barrows *et al.*, 2005).

Important in determining the “signal” from populations is controlling for differences in detectability, spatially and temporarily. The catch per unit effort (CPUE) from visual encounter surveys (VESs) is meant as a proxy for abundance estimates. Unfortunately, the non-constant detectability of the geckos between surveys can confound this relationship. CPUE is a product of the density of animals and their detectability (Lettink & Seddon, 2007). The probability of detecting geckos in VESs is influenced by several variables, and it is rarely justifiable to assume constant detectability (Mazerolle *et al.*, 2007). Constant detectability is when the same proportion of animals from two or more populations, or from the same population at different times, is detected during a search.

Unless the exact population numbers are known, in which case, an abundance index becomes unnecessary, the ability to detect the same proportion of animals across sites or time periods can only be assumed (Kellner & Swihart, 2014). Densities can only be compared between sites when the proportion of animals detected is constant (Lettink & Seddon, 2007). Therefore, an assumption of constant detectability must be made. Choosing an efficient but effective method for acquiring a population index can be one of the most difficult tasks of a monitoring study due to the large number of variables that need to be controlled, or accounted for, in order to increase the validity of the assumption of constant detectability (Kellner & Swihart, 2014). Some of the variables that influence detectability are: vegetation type, observer experience and skill, weather conditions and time of year (Mazerolle *et al.*, 2007). While it may be possible to count all individuals in a population, it is often not practical or resource efficient, especially when the alternative, using an abundance index, can provide all the information that is required for a study (Kellner & Swihart, 2014).

Pollock *et al.* (2002) outlines approaches for dealing with the failure of the assumption of constant detectability. The first method is to incorporate a detailed monitoring protocol that will help reduce differences in detectability across time and space. The second method is to measure co-variates that may be influencing detectability and make appropriate adjustments to the methods (Pollock *et al.,* 2002). Environmental conditions such as temperature, wind speed and habitat type during visual searches can be recorded and correlated with counts (Anderson, 2001). However, Bailey *et al.* (2004) point out that it is neither reasonable nor efficient to account for all variables affecting detection probability.

The ideal temperature for the current study species is unknown, but warmer temperatures generally produce better results in terms of the proportion of animals detected for geckos in general, as activity is enhanced with the increased availability of solar radiation (Walls, 1983; O'Donnell & Hoare, 2012). It is also possible that detectability of geckos varies with light level, cloud cover and rainfall as it does with other reptile species (Reagan, 1992; Read & Moseby, 2001). A study assessing the effect of moonlight on nocturnal snake activity found that snakes were more active during new moon phases (Clarke *et al.*, 1996). Read & Moseby (2001) also found that darker nights with plenty of cloud cover resulted in greater capture rates of small reptiles as opposed to cloudless nights with a visible moon. This suggests the activity of the animals increased on darker nights. Walls (1983) found a decrease in the activity of tuatara (*Sphenodon punctatus*) and *Hoplodactylus* species of gecko during nights of low humidity and strong winds. Accounting for all these variables can be an arduous task, but the more variables that are accounted for, the greater confidence can be placed in abundance indices.

1.6.4 Importance of monitoring geckos

Not only is it important to monitor lizards in order to track their population health, but it can also be beneficial for monitoring the health of entire ecosystems including wetas, native skinks and native birds. The Ministry for the Environment has advised that a practical way of monitoring changes in New Zealand's biodiversity is to assess the extent of suitable habitats for several indicator species (Monks *et al.*, 2013). New Zealand has a list of indicator species it uses, which does not include any gecko species. Appropriate indicator species are chosen, based on eight characteristics that reflect biological and geographical attributes (Monks *et al*, 2013). In addition, Monks *et al.* (2013) have recommended that priority be given to those species that have a predictable population response to specific (as opposed to general) pressures and are relatively easy to monitor.

Using an indicator species can provide information useful for management purposes beyond conserving a single species. The limitation of many monitoring programmes is the lack of real objectives or objectives confined to a single species or population (Nichols & Williams, 2006). Therefore, the return for the effort is often very small. The quality of information gathered for management purposes can be increased immensely if the species being monitored is an indicator, and data collected is not based solely on its quantity (Noss, 1990). Although this may require more time and resources in the initial stages of data collection in order to determine the indicator species' response to pressures, in the longrun, the increased work may be justified by a greater return of information per unit of effort (Yoccoz *et al.*, 2001).

Geckos possess some of the attributes that would make them an important addition to New Zealand's list of indicator species. It is not necessary, nor is it generally achievable, that a taxon includes all the characteristics of an ideal indicator (Hilty & Merelender, 2000). Instead, a set of indicator species should be chosen that complement each other and together provide early warnings of impending environmental disasters (Hilty & Merenlender, 2000). Geckos possess several characteristics that may complement other indicators.

Geckos are widely dispersed throughout New Zealand, occurring from the top of the North Island to Stewart Island in the south (Pickard & Towns, 1988). Their home ranges, as with all reptiles, are relatively small and their dispersal ability is severely restricted reducing their ability to avoid an environmental disturbance (Gibbons *et al.*, 2000; Landres *et al.*, 1988). New Zealand geckos have an average lifespan of thirty years and there are some records of fifty year-olds in the wild (Thompson *et al.*, 1992; Wilson, 2010). Their longevity reduces their diversity, ensuring their unanimous response to a given pressure (Hilty & Merenlender, 2000). Most native geckos cannot survive large changes to their environment, including habitat alterations and predator invasions (Towns & Daugherty, 1994). Their population health can therefore be used to measure how other native species, prone to the same pressures, are coping. An important component is the ability to measure the population, using an explicit quantity such as abundance, growth or age structure (Hutcheson *et al.*, 1999). The catch per unit effort (CPUE) of geckos is one such quantitative measure that can give abundance estimates through time.

1.7 Monitoring methods of New Zealand geckos

Determining the method to employ in detecting the presence of geckos is dependent on the objectives of the study. Ideally, a monitoring programme will use surveys that provide reliable quantitative data while proving to be resource efficient (Michael *et al.*, 2012). However, due to the cryptic nature of much of the New Zealand gecko fauna, there are currently few robust means of measuring trends in their populations (O'Donnell & Hoare, 2012). New Zealand geckos can be difficult to locate in the field because of their small size and elusive behaviour, with many of them displaying nocturnal habits, including forest and Pacific geckos. Ryan *et al*. (2002) suggest using a combination of techniques for the inventory of entire herpetological communities in order to maximise the number of species detected. However, it may be that when focusing on a single genus or ecologically similar species a single technique works best. Indeed, several studies have shown this to be true (Doan, 2003; Grover, 2006; Michael *et al*., 2012; O'Donnell & Hoare, 2012).

Arboreal geckos are recorded most often using visual encounter surveys (VESs) (Doan, 2003). The results of VESs are recorded as catch per unit effort (CPUE) which is the number of animals caught, or sighted, per man hour. This standard measure is an abundance index that can be compared through time in order to determine any changes that occur to the population. A change in an index count is often an indication of more complicated changes within the population (Hilty & Merenlender, 2000). However, this method is also subject to several possibly confounding factors due to the reliance on individual ability to detect geckos. Possible variables in the monitoring method responsible for variations in results include observer experience in searching for geckos, motivation, torch strength and observer fatigue (Doan, 2003).

The use of tracking tunnels can complement VESs when studying a population. They can be especially useful for determining the spatial distribution of a species and can give abundance estimates (Ratz, 2000). Using two population inventory methods is especially useful for multi-species studies (Michael *et al.*, 2012), as a species that cannot be detected using one method may be detected using another. This has been found in studies looking at the biodiversity of reptiles in an area (Michael *et al.*, 2012) with different techniques complementing each other in the species they detect.

Methods other than VESs currently in use for the detection of geckos in order to provide information on their spatial distribution and obtain an index of abundance include artificial refuges (ARs). ARs create a place of refuge for the lizards where they can hide from predators while absorbing the solar radiation that is concentrated and provided by the covering material (Michael *et al.*, 2012). ARs are checked for geckos on a regular basis with long durations between checks. Disturbance caused by checking the covers too often will reduce the use of the covers by the geckos (Binckley *et al.* (2000) as cited in Michael *et al.* (2012)). ARs are a simple yet effective tool for monitoring terrestrial and some arboreal geckos, in particular nocturnal species. The temperature at the site and placement of ARs, in terms of microhabitat conditions, affect the likelihood of detecting geckos beneath them (Michael *et al.*, 2012). The probability of detection is also determined by the availability of natural refuges in the area (Wilson *et al*., 2007). If there are adequate opportunities for hiding and gathering warmth in the natural environment then artificial refuges are unlikely to be utilised.

Tracking tunnels can also be used for inventorying populations. They work by luring the animals over a strip of ink on a white card where they leave a footprint. Often a small tunnel-like structure is used to guide animals over the card, with bait placed in the tunnel to lure them inside (Russell *et al.*, 2009). An advantage of tracking tunnels is the ability to leave them unattended for several days, conserving resource use (Alterio *et al*., 1999). Tracking tunnels are a cost effective method for indexing species over a large area (Russell *et al*., 2009). Compared to VESs, they are less labour intensive and can cover a larger area while determining detailed positions of animals (Alterio *et al.*, 1999). This can reduce the necessity of using models to predict population parameters of new unstudied habitat as tracking tunnels can be employed in a new area to obtain concrete results.

Tracking tunnels are used for monitoring invasive species such as rats and mustelids, but currently there is no standardised tunnel used for tracking arboreal geckos in New Zealand. Arboreal geckos are those that spend the majority of their time in trees. For this reason, designing a tracking device for such geckos can be difficult as placement in the trees can be a complicated process. A tracking tunnel design that effectively detects the presence of arboreal geckos would greatly reduce monitoring efforts and contribute to effective management of the species.

1.8 Research Objectives

This study is focused on the Auckland Council gecko monitoring programme at three of Auckland's regional parks: Shakespear, Tawharanui and Whakanewha. It looks at data gathered so far and possible improvements to monitoring methods. The four main objectives of the study are outlined below.

1. Provide baseline data for the gecko populations at the three parks and determine any trends in data and any biases in data collection methods.

> Questions: Are there differences in population dynamics of the gecko species at each of the parks? Are there significant trends in abundance

> indices of the gecko populations through time? Are there biases in data collection methods?

2. Discuss the possibility vegetation characteristics influence the ability to detect geckos and possibilities of measuring it from a literature search.

> Questions: Can habitat types create different detectability of geckos? Is it possible the habitat where visual encounter surveys of geckos are undertaken vary between parks?

3. Compare the catch per unit effort (CPUE) of Pacific green and forest geckos between the new and full moon phases.

> Questions: Does the ability to spot geckos change significantly during the new and full moon phases? Should monitoring protocols be adjusted to reduce possible bias?

4. Trial a tracking tunnel design for determining the presence of arboreal geckos, especially of geckos in low abundance.

> Questions: Can tracking tunnels provide be used as another monitoring method for arboreal gecko species in New Zealand?

This thesis is divided into six chapters; following the beginning introductory chapter, four chapters look at each of the main objectives separately. The final chapter summarises the findings and recommends directions for future research. A single reference section is presented at the end.

CHAPTER 2

Population parameters of the gecko populations at Tawharanui, Shakespear and Whakanewha Park

2.1 Introduction

2.1.1 Importance of baseline data

Initial data on a population is essential for assessing future changes in its health. Baseline data on the gecko populations at Tawharanui, Shakespear and Whakanewha Park will be important for assessing future changes that may occur in their geographical extent or abundance (Schwartz *et al.*, 2007). These data will provide the means for not only identifying but also solving problems that may occur to the populations in the future (Hobbie *et al.*, 2003). The data will be essential for providing a comparable situation for future population inventories.

Collecting baseline data for a population may take several years. Cyclical trends must first be identified to distinguish between major changes and those that occur on a yearly basis (Wolfe *et al.*, 1987). Cyclical patterns may be a result of the life history characteristics of a species or seasonal changes in the environment (Connell & Sousa, 1983). Studies of reptiles have shown fluctuations in abundance estimates in many populations linked to natural phenomena such as differences in yearly rainfall and drought conditions (Gibbons *et al.*, 1997). Major changes occur when there is a decrease or an increase in species abundance that does not experience a reversion to a theoretically normalised abundance level through growth or decline, respectively. Long-term data are essential in the diagnosis of major changes in populations (Wolfe *et al.*, 1987). Using an arbitrary year, or time of year, in which to collect baseline data can result in abundance estimates for a population when the species is unusually abundant or scarce (Magurran *et al.*, 2010).

2.1.2 Population health indicators

There are alternative means to estimating population abundance to establish the health of a population. Body condition index (BCI) is the residual of the ratio of body mass to body length and can be an important indication of the health of an individual, and, taken collectively, the health of an entire population (Hoare *et al.*, 2006). BCI may be a good measure for the health of an individual that cannot otherwise be determined without the use of more intrusive techniques. The aim of a BCI is to gain information on body condition while controlling for body size (Green, 2001). In essence, it is a measure of the foraging success of an individual, and therefore its fitness overall (Jakob *et al.*, 1996). Extra reserves of fat for females can be a signal that they are ready and capable of reproduction, as non-reproductive individuals of similar length have less mass (Madsen & Shine, 1996). Body condition of animals can also indicate an individual's chance of survival and its parasite load (Green, 2001).

The common BCI used for lizards is obtained by regressing mass on snout-to-vent length (SVL) and then calculating residuals (Hare *et al.*, 2007). Obtaining the residuals has proven a better method than merely using the ratio, as the ratio of mass to SVL correlates with body size (Jakob *et al.*, 1996). Positive residuals are thought to indicate individuals in better body condition than average, while negative residuals indicate individuals in below average condition and therefore of lower fitness (Jakob *et al.*, 1996).

The use of residuals from the regression of body mass on body size as a measure of condition has come under scrutiny due to several caveats that are thought to make it an unreliable method (Green, 2001). However, Schulte-Hostedde *et al.* (2005) have found that these problems can be overcome if the appropriate research is undertaken. There are several conditions that must be met if the BCI is to be an appropriate indicator of overall animal health as determined by Green (2001). First, there must be a linear relationship between body size and mass. This is one of the main arguments against using body mass against SVL as a BCI, as body weight does not increase isometrically with its structural size in all species (Dudek *et al.*, 2014). For example, the sand lizard's (*Lacerta agilis*) body length increases faster than its body mass, resulting in a non-linear correlation between the two (Dudek *et al.*, 2014). However, a simple transformation can create a linear relationship between SVL and body mass for some species. The SVL of the New Zealand native gecko *Hoplodactylus duvaucelii* has a strong linear relationship with the cube root of its body mass (Barry *et al.*, 2010). Secondly, there must be no relationship between the size of an animal and its percentage body fat. Thirdly, the body size measurement used must accurately depict the structure of the animal. Finally, the size and mass of an animal must be independent and, there must be accuracy in size measurements. All of these assumptions have proven valid for some non-reptilian species and lizards (Ballinger, 1977; Schulte-Hostedde *et al.*, 2005).

Caution is advised as regressing mass on SVL can be an unreliable indicator of reproductive output for some lizard species (Dudek *et al.*, 2014). BCI may not always be correlated with characteristics that indicate an increase in health or reproductive ability. Hare *et al.* (2007) used the residuals of a regression of log-mass on log-SVL as the BCI to assess condition change of *Naultinus manukanus* across seasons. Individual variation explained the majority of variation in BCI, more so than did any other factor including season of data collection, sex, mite load, tail regeneration and pregnancy status. Van Sluys (1998) discovered that fat stores had no relationship with body condition for the lizard *Tropidurus itambere*.

However, the BCI based on the residuals of the regression of SVL with mass has proven effective for other lizard species. Ballinger (1977) found that reduced fat storage due to a lack of food availability reduced the clutch sizes of the tree lizard *Urosaurus ornatus*. Therefore, the BCI based on the residuals showed a direct relationship between the species' mass corrected for size and the reproductive output of the animals. A previous study showed a similar result: reduced fat cells in the body directly decreased reproductive potential in this species (Hahn & Tinkle, 1965). Genus specific, if not species specific, studies should be undertaken in order to determine whether the BCI used is an appropriate indicator of an individual's reproductive success.

There are two problems with using photos to identify individual geckos: whether natural markings are different enough to differentiate between individuals and, whether these markings change over time (Shaw, 1994; Wilson & Cree, 2003). With some gecko species, natural markings and colour patterns are variable enough to identify individuals (Knox *et al.*, 2013). However, the identification of individuals with natural markings has only been used over the short term, studying pregnancy occurring within 14 months, and toe clippings used as confirmation (Wilson & Cree, 2003; Knox *et al.*, 2013).

The possibility that individual markings change over time means using photo identification to estimate demographics of gecko populations can introduce error in estimations (Knox *et al.*, 2013). It is possible that some gecko species maintain markings over a long-term period (Knox *et al.*, 2013). It has been shown that individual jewelled geckos (*Naultinus gemmeus*) can be accurately identified within a four year time period by consistent patterns through photo identification (Knox *et al.*, 2013). While scarring can provide another cue for distinguishing individuals, some geckos have the ability to heal wounds within 45 days without scarring and should not be relied on for any period of time (Peacock, 2014). Using natural markings to identify individuals reduces stress for the animals and any effects on behaviour that may bias the estimation of population parameters (Willson *et al.*, 2011; Knox *et al.*, 2013).

2.2 Objectives

1.) Provide baseline data on the Pacific, forest and green gecko populations at Tawharanui, Shakespear and Whakanewha including sex ratios, abundance indices, morphometrics, demographics and body condition.

2.) Determine whether any trends in population parameters are apparent in the populations at this stage of the monitoring programme. Parameters are expected to remain similar over such a short period of monitoring.

    a. Compare the proportion of sexes and juveniles, the morphometrics and the body condition of the geckos across the parks and across the years of monitoring.

3.) Analyse data collection methods and animal ecology that may be a source of bias in the estimation of population parameters.

2.3 Methods

2.3.1 Auckland Council's baseline data for geckos

The baseline data for the Pacific gecko populations at Shakespear and Whakanewha, and forest and green gecko populations at Tawharanui and Whakanewha were collected by the Auckland Council from 2012 to 2014. Data were collected during March and April each year because of increased activity of the animals at this time and, therefore, the greater likelihood of encountering them in visual surveys. Maintaining the same time of data collection each year negates the need to account for the effect of cyclical changes due to the different seasons.

Nighttime visual encounter surveys (VES) were used for data collection. In total, five transects were searched at Shakespear, four at Tawharanui and five at Whakanewha (Appendix I). These transects were set up in scrub (manuka or kanuka) dominated areas of vegetation. They were along edges of the bush or man-made trails and were between 700 and 1,500 metres long. The aim was to provide samples over a large area of each of the parks in order to be representative of the populations. The different length of the transects was controlled for by measuring the time taken to search each one and using it in the calculation of search effort.

The VESs were undertaken by teams of between one and four observers, always including at least one experienced observer who was positioned in the middle of the transect to search both sides when necessary. Observers walked at a casual pace that allowed the scanning of all vegetation from the ground to the top of the canopy. The VESs continued until the entire transect was searched. For each VES, a catch per unit effort (CPUE) was calculated by dividing the number of geckos caught or spotted by the time it took to search the transect and by the number of observers present. Thus, the units for CPUE were the number of geckos sighted per hour per person.

When a gecko was spotted, when possible, it was caught and its weight, snout-to-vent length (SVL) and snout to tail length (TL) were measured. A photo of the dorsal surface of the gecko was taken for identification purposes. The species of the gecko was noted, along with its maturity and sex. The height of the tree the gecko was spotted in, how high in the tree the gecko was positioned and the distance the gecko was from the track were estimated. A GPS location was taken. Further details of the data collection procedures can be found in the Auckland Council gecko monitoring programme (Bell *et al.*, 2010).

Cell foam retreats (CFRs), a type of artificial retreat, were also set up in each park. They consisted of closed-cell foam cut into about 32cm x 70cm rectangles nailed onto tree trunks. Transects were randomised across the parks for a large coverage of each park. They were separate from VES transects and did not run along edge habitat but internally through the bush. Two hundred gecko covers were arranged into five 400m transects of 40 covers (spaced 10m apart) per park (Shakespear, Tawharanui and Whakanewha). All covers were checked in each park in 2012 (between March 1 and March 21) and 2013 (between March 2 and March 21). All CFR transects were checked once each year to provide an abundance index. In 2012 covers were checked seven times over a two week period where possible to provide closure.

2.3.2 Data analysis

All statistical analyses were performed using the statistics programme IBM Statistical Package for the Social Sciences (SPSS, version 21).

2.3.2.1 Difference in catch per unit effort between years

For each gecko population, Friedman’s non-parametric test for related samples was performed to determine whether there was any significant difference in catch per unit effort (CPUE). The CPUE from VESs of each independent transect were compared with each other across the years. If more than one VES was performed on the same transect within the same year, an average CPUE from the VESs was used.

Tallies of the number of geckos of each species found under covers at each park across the years were determined. The gecko species found under CFRs at each park were compared with the species encountered in VESs to determine whether there were differences in the gecko species detected by each monitoring technique.

2.3.2.2 Sex ratios

The sex or juvenile status was determined for 19 Pacific geckos, 75 green geckos and 87 forest geckos. Individuals were categorised as juveniles if it was not possible to determine whether an individual was a male or female through external characteristics such as cloacal spurs or prominent pores in the scales (Jewell, 2006). For each population of geckos, the sex ratio was determined for each year of monitoring and tested for significant deviation from a 1:1 ratio with a non-parametric Kruskal-Wallis test.

2.3.2.3 Morphometrics

The median weight and snout-to-vent length (SVL) for males, females and juveniles were determined for each gecko population. Mann-Whitney *U* tests were performed to determine whether the distribution of the two measurements differed significantly between female and male groups within each gecko population, and between gecko populations of the same species.

2.3.2.4 Body condition index

Body condition index (BCI) was calculated by regressing the cube root of weight of the gecko (grams) with its snout-to-vent length (SVL) (millimetres) and obtaining the residuals (Barry *et al.*, 2010). Positive residuals are expected to indicate greater physical health related to increased energy stores, while negative residuals are expected to indicate a less healthy individual due to reduced energy reserves. Any pregnant individuals or those with loss of tails were not included in the body condition analysis in order to prevent biases (Jakob *et al.*, 1996). The distributions and medians of BCIs for each population were compared across years using Kruskal-Wallis tests and post-hoc Mann-Whitney tests if results were significant.

2.3.2.5 Scarring and tail loss

Photos of individual geckos were analysed for scarring and regeneration or loss of tails. Tallies of individuals with scarring were compiled for each sex at each park. Scarring included any healed or fresh wounds, loss of limbs and patches of missing or deformed scales. Fisher’s exact test was used to determine whether there were any significant differences in the number of geckos with scarring or regenerating tails between sexes and populations.

2.3.2.6 Re-sighted geckos

Photos taken of geckos at the same transect during different surveys were compared in order to determine any recaptures of individuals. Photos were compared a second time after initial analysis in order to reduce error from failing to identify a re-captured gecko. Comparisons were made based on patterns. It was assumed that these markings did not vary during the three years of surveys (Knox *et al.*, 2013). Due to the low number of recaptures, changes in the BCI, scarring and reproductive status of individuals at their different times of capture were determined with no statistical analysis.

2.3.2.7 Possible sources of bias

Linear regression analyses were used to determine whether the number of surveyors was related to the CPUE of each gecko species from VESs.

2.3.2.8 Microhabitat use

Independent two sample t-tests were used to test any differences between each of the three gecko species in the average height in a tree a gecko was spotted, the average tree height it was spotted in and the average distance from the path it was spotted. Averages were calculated for each species with available data from all geckos spotted during the three years of monitoring. Data from multiple visits to the same site were compiled regardless of whether the same gecko was seen again and its height measured more than once (Chandler *et al.*, 2009).

2.4 Results

Over the three years of monitoring, 255 geckos were sighted over the entire period of the study (Figure 2.1). 162 of these geckos were caught: 18 Pacific geckos, 68 green geckos and 76 forest geckos. Pacific geckos were sighted at Whakanewha and Shakespear. Forest and green geckos were sighted at Tawharanui and Whakanewha. 109 geckos were photographed: 11 Pacific geckos, 44 green geckos and 54 forest geckos. Out of these photographed geckos, 11 (10.1%) were determined to be re-sightings. Some geckos were photographed multiple times, and there was at least one photograph of each individual that was of appropriate quality to be used in the analysis of body condition and the identification of recaptured individuals. Not all geckos that were caught were measured. Of the geckos caught, five Pacific, four green and eleven forest geckos were excluded from the analysis of body condition on account of missing measurement data. An additional two green geckos were excluded because they were pregnant. Five Pacific and four green geckos were not included in abundance index estimates because they were sighted after survey times. Individuals were also excluded in the analysis of population morphometrics due to missing data. Exact sample numbers that could be used are given.

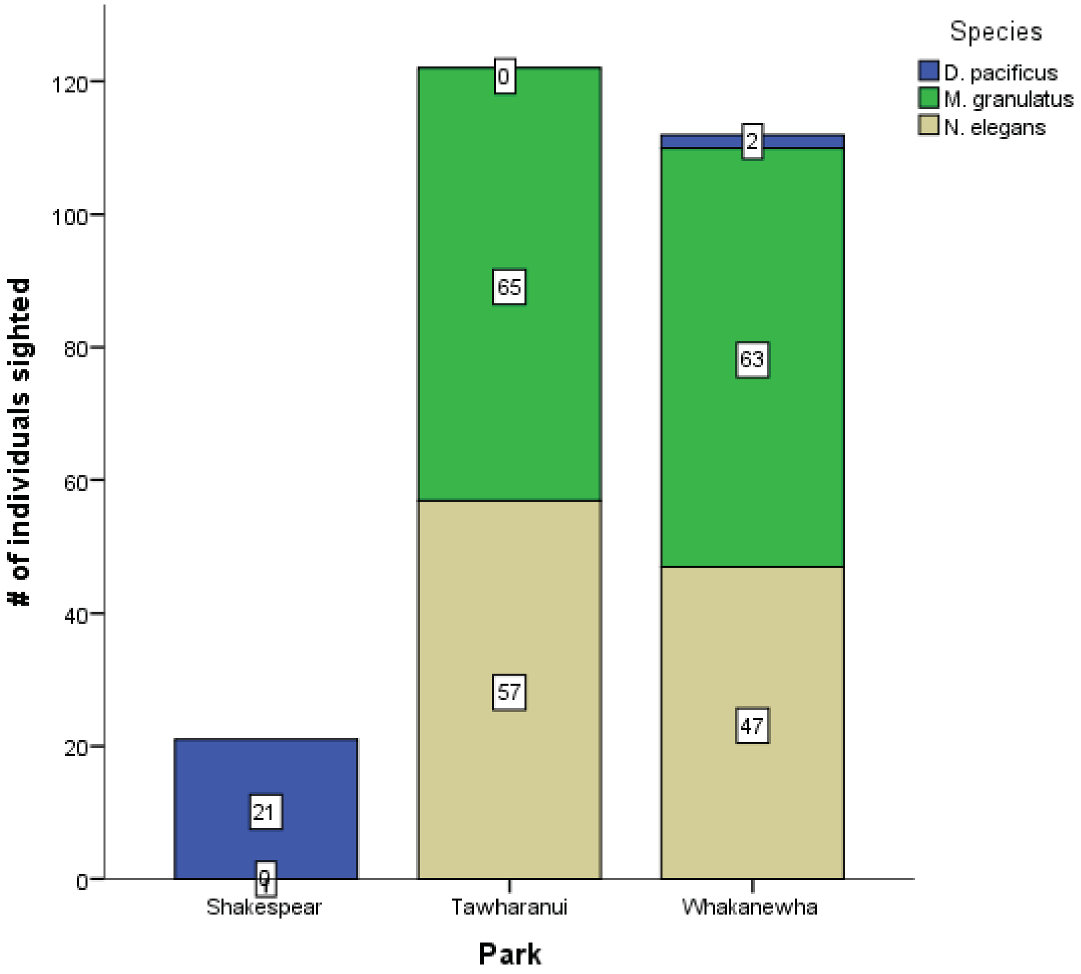

Figure 2.1 Number of geckos sighted at each of the three parks.

2.4.1 Difference in CPUE between years

Based on Friedman's non-parametric test for related samples, there was no significant difference ($\chi^2 = 0.200$, n = 12, df = 2, p = 0.974) in the mean CPUE between any of the years for any of the parks.

2.4.2 Cell foam retreats

CFRs aided in the detection of Pacific geckos at Shakespear and Whakanewha, forest geckos at Tawharanui and Whakanewha and green geckos at Tawharanui (Table 2.1). The only difference between the gecko species detected using CFRs and those detected using VESs was the failure to detect green geckos at Whakanewha.

Table 2.1 Number of geckos of each species found under cell foam retreats (CFRs) at each of the parks during the 2012 and 2013 checks.

	Park					
	Shakespear		Tawharanui		Whakanewha	
	2012	2013	2012	2013	2012	2013
Pacific	3	4	-	-	-	1
Forest	-	-	16	11	9	14
Green	-	-	1	-	-	-

2.4.3 Sex ratios

The sex was determined for 181 of the 255 geckos spotted.

There was no significant deviance ($\alpha = 0.05$) from a one-to-one ratio of sexes for Pacific geckos spotted at Shakespear during any of the years ($\chi^2 = 0.167$, df = 1, p = 0.6831) (Table 2.2).

Table 2.2 Sex ratio (males to females) of Pacific geckos for each of the years of monitoring followed by actual numbers of each sex caught during the monitoring period of that year.

Park	Year	2013	2014
Shakespear	Sex ratio	1.5	1
	(# of males, females, juveniles)	(6,4,4)	(2,2,1)

There was no significant deviance ($\alpha = 0.05$) from a one-to-one ratio of sexes for forest geckos spotted at Tawharanui or Whakanewha during any of the years ($\chi^2 = 0.0067$, df = 1, p = 0.9348) (Table 2.3).

Table 2.3 Sex ratio (males to females) of forest geckos for each of the years of monitoring followed by actual numbers of each sex caught during the monitoring period of that year.

Park	Year	2012	2013	2014
Tawharanui	Sex ratio	1.8	0.8	0.5
	(# of males, females, juveniles)	(18,10,3)	(8,10,1)	(3,6,1)
Whakanewha	Sex ratio	4	1	0.6
	(# of males, females, juveniles)	(8,2,0)	(3,3,3)	(3,5,0)

There was no significant deviance ($\alpha = 0.05$) from a one-to-one ratio of sexes for green geckos spotted at Tawharanui or Whakanewha during any of the years ($\chi^2 = 0.9496$, df = 1, p = 0.3298); non-parametric Kruskal-Wallis test) (Table 2.4).

Table 2.4 Sex ratio (males to females) of green geckos for each of the years of monitoring followed by actual numbers of each sex caught during the monitoring period of that year.

Park	Year	2012	2013	2014
Tawharanui	Sex ratio	0.7	2.3	2.0
	(# of males, females, juveniles)	(8,11,0)	(14,6,0)	(10,5,1)
Whakanewha	Sex ratio	2.5	1.3	1.0
	(# of males, females, juveniles)	(5,2,0)	(5,4,0)	(2,2,0)

2.4.4 Morphometrics

The only significant difference ($\alpha = 0.05$) in SVL or weight between females and males was found for the population of forest geckos at Tawharanui (Table). The females have a higher median SVL than the males (Table 2.5).

Table 2.5 Results of Mann-Whitney *U* tests for differences in distributions of female and male snout-to-vent lengths (SVL) and weights from each of the gecko populations. Significant results ($\alpha = 0.05$) are shown in bold.

		Tawharanui		Whakanewha		Shakespear	
		U	p-value	*U*	p-value	*U*	p-value
SVL	Forest	**473.5**	**0.03278**	46	0.9074	-	-
	Green	380	0.4863	28.5	0.4579	-	-
	Pacific	-	-	-	-	31.5	0.3646
Weight	Forest	256.5	0.3717	40	0.9298	-	-
	Green	341.5	0.1039	13	0.9999	-	-
	Pacific	-	-	-	-	11	0.9143

The populations of forest geckos at Tawharanui and Whakanewha show a significant difference in their distribution of SVLs ($U = 23$ and $p = 0.001587$, $U = 19.5$ and $p < 0.001$, for females and males, respectively). Females and males were tested separately due to the significant difference in their distribution of SVL for the population at Tawharanui. The population at Whakanewha has a higher median for both males and females. The two populations also showed a significant difference in their weights, males and females tested collectively ($U = 43$, $p < 0.001$), with the population at Tawharanui having a higher median.

The populations of green geckos at Tawharanui and Whakanewha also showed a significant difference in their distribution of SVLs ($U = 228.5$, $p = 0.02834$), with the population at Whakanewha having a higher median (Table 2.6). Their weight distributions were not significantly different (U = 199.5, p = 0.1224).

Table 2.6 Median weight(g) and snout-to-vent length, SVL(mm), of geckos captured at Shakespear, Tawharanui and Whakanewha. Sample sizes are listed in parentheses.

Sex	Species	Pacific	Forest		Green	
	Park	Shakespear	Tawharanui	Whakanewha	Tawharanui	Whakanewha
Female	Weight	9.7 (4)	8.2 (21)	15.2 (7)	6.8 (19)	6.3 (3)
	SVL	75.5 (6)	71.5 (24)	83.5 (8)	60 (22)	70 (5)
Male	Weight	8.4 (6)	6.9 (21)	15.3 (11)	5.3 (28)	6.8 (9)
	SVL	70 (8)	65 (27)	82 (12)	59 (31)	61 (9)
Juvenile	Weight	2.7 (3)	1.3 (5)	-	3.1*	-
	SVL	49.5 (4)	38 (5)	-	51*	-

*actual measurement of gecko

2.4.5 Body condition index

Based on Kruskal-Wallis tests, the population of Pacific geckos at Shakespear (χ^2 = 0.0333, d.f. = 1, p = 0.8551), forest geckos at Whakanewha (χ^2 = 0.6471, d.f. = 2, p = 0.7236), and green geckos at Whakanewha (χ^2 = 0.9091, d.f. = 2, p = 0.6347), showed no significant effect of year on body condition index. For the forest gecko population at Tawharanui, a Kruskal-Wallis test revealed a significant effect of year on BCI (χ^2 = 8.6895, d.f. = 2, = 0.01297). A post-hoc test using Mann-Whitney tests showed a significant difference between years 2012 and 2013 (W = 81, p = 0.0406), and the years 2012 and 2014 (W = 34, p = 0.008847). The population had a larger BCI median and spread in 2012 than either 2013 or 2014 (Figure 2.2). Based on a Kruskal-Wallis test there was also a significant effect of year on BCI of the green gecko population at Whakanewha (χ^2 = 12.5442, d.f. = 2, p = 0.001888). Post-hoc Mann-Whitney tests showed a significant difference between years 2012 and 2013 (W = 45, p = 0.001212), and the years 2012 and 2014 (W = 32, p = 0.009447). The green gecko population had a lager BCI median and spread in 2012 than either 2013 or 2014 (Figure 2.3).

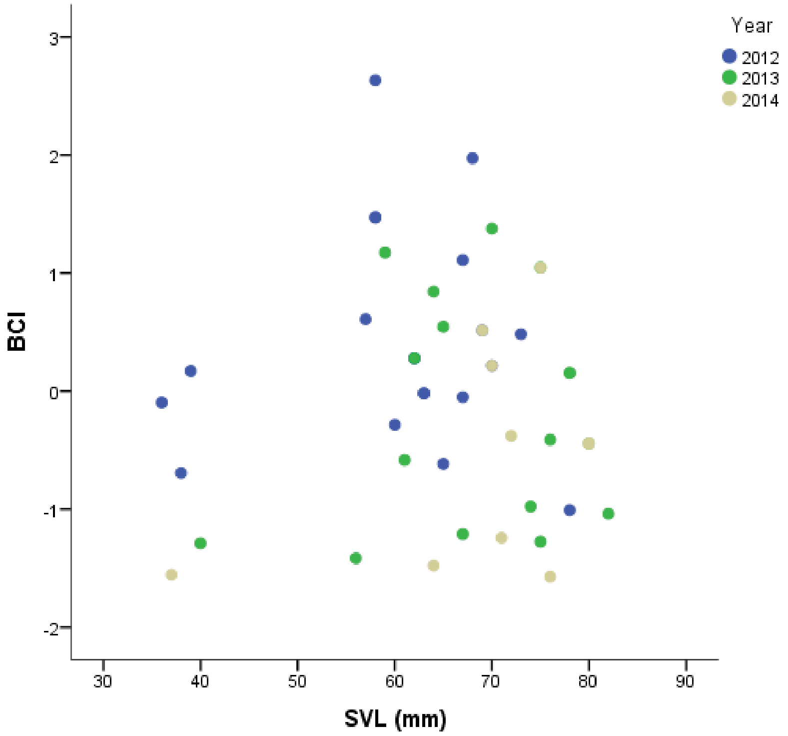

Figure 2.2 Body condition index (BCI) of forest geckos at Tawharanui plotted against snout-to-vent length (SVL).

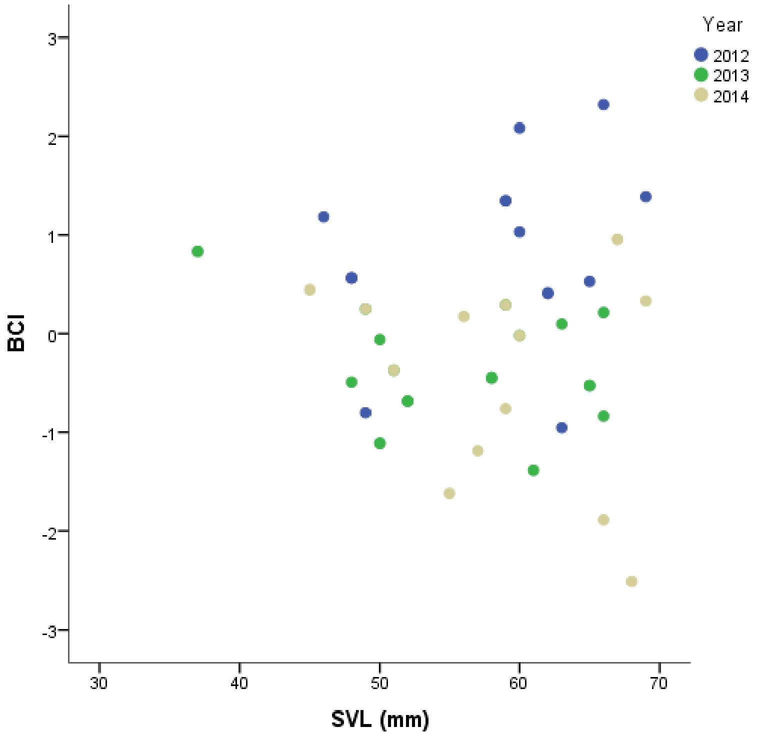

Figure 2.3 Body condition index (BCI) of green geckos at Whakanewha plotted against snout-to-vent length (SVL).

2.4.6 Scarring and tail loss

Fisher's exact tests revealed no significant differences in the number of individuals with scarring or regenerating tails (p = 0.2574, df = 5 and p = 0.9999, df = 5, respectively) between parks or sexes. Owing to the elaborate colouration and patterning of forest and Pacific geckos, it was difficult to determine whether scarring was present based on the photographs (Table 2.7). One juvenile forest and Pacific gecko were photographed at Tawharanui and Shakespear, respectively, both having no scars or a regenerating tail. One of the forest geckos at Tawharanui had a complete loss of a hind limb. One male forest gecko at Whakanewha had complete tail loss with a healed-over stump where it had been severed. Scarring on green geckos was much easier to discern due to their generally monotonous colour apart from white patterning on some which also did not affect the ability to detect scars on the geckos. Six (29 %) female and 10 (34 %) male green geckos at Tawharanui had white patterning. Three (75 %) female and five (56 %) male green geckos at Whakanewha had white patterning.

Table 2.7 Number of geckos with scarring or regenerating tails. Numbers in brackets indicate the total number of geckos photographed.

		Scarring		Regenerating tails	
Park	Species	Females	Males	Females	Males
Tawharanui	Forest	1 (21)	2 (26)	4 (21)	6 (26)
	Green	9 (21)	15 (29)	3 (21)	4 (29)
Whakanewha	Forest	0 (7)	0 (11)	4 (7)	6 (11)
	Green	1 (4)	5 (9)	0 (4)	1 (9)
Shakespear	Pacific	2 (5)	0 (7)	2 (5)	4 (7)

2.4.7 Re-sighted geckos

Ten geckos were positively re-sighted based on photo identification (Table 2.8). All re-sightings were determined from the first analysis of photographs and confirmed with the re-analysis. No scars or wounds were apparent on any of the geckos re-sighted at Shakespear. Both green geckos, male and female, recaptured at Tawharanui within a year did not change in exterior condition to any visible degree. Both geckos moved at least thirty metres from their site of original capture. The green gecko recaptured in consecutive years at Tawharanui displayed no visible changes in appearance: the white markings on this gecko remained visibly consistent between capture times. The gecko was recaptured ten metres from its original site.

The male forest gecko recaptured within the same year at Tawharanui remained the same in both patterning and shading, as was apparent from photographs. The female forest gecko recaptured in consecutive years at Tawharanui remained in the same condition, with no visible scarring or loss of tail. The gecko was recaptured ten metres from its original site. The juvenile forest gecko caught in all three consecutive years at the park showed no visible change in patterning from one year to the next. It moved at least ten metres from its point of recapture.

One green gecko was positively re-sighted at Whakanewha based on photo identification. It had moved at least ten metres from its original site. Faint scars were present in both years of sighting, but they were in different positions. White markings remained visibly similar.

Table 2.8 Date of capture, morphometrics and body condition (BCI) of re-sighted geckos as determined from photo identification.

Park	Species	Sex	Date	SVL(mm)	TL(mm)	Weight(g)	BCI
Shakespear	Pacific	Male	7/03/2013	71	69(15)	-	-
			9/04/2014	83	69(-)	12	-0.83
	Pacific	Female	14/03/2013	78	87	9	-1.41
			26/03/2014	78	94	10.4	-0.31
	Pacific	Juvenile	25/03/2013	40	50	1.3	-0.06
			26/03/2014	56	74	4.3	0.24
Tawharanui	Green	Male	12/03/2012	64	-	-	-
			29/03/2012	63	72	6	-0.95
	Green	Female	29/03/2012	69	80	10	1.38
			12/04/2012	66	80	10.2	2.32
	Green	Male	5/03/2013	50	65	3	-1.11
			3/03/2014	59	78	5.7	0.29
	Forest	Female	12/04/2012	78	60	9.4	-1.0
			5/03/2013	82	65(59)	10.1	-1.04
	Forest	Male	29/03/2012	62	76	5.7	0.28
			12/04/2012	58	65	6.1	1.47
	Forest	Juvenile	12/04/2012	39	40	1.8	0.17
		Female	5/03/2013	67	77	5.5	-1.21
			17/03/2014	71	77	7.4	-1.24
Whakanewha	Green	Female	26/03/2012	71	-	10.1	-
			20/03/2013	70	87	12.6	Gravid

SVL = snout-to-vent length
TL = tail length
BCI = body condition index
Gravid = pregnant and not included in BCI analysis
(#) = length of regenerating portion of tail

2.4.9 Possible sources of bias

Green geckos were the only species for which the number of surveyors significantly predicted the CPUE (Table 2.9).

Table 2.9 Results from linear regression analyses of catch per unit effort of surveys and the number of surveyors conducting the searches. Brackets indicate degrees of freedom for test statistics.

	slope	t-value (62)	p-value	R2	F-statistic (1,62)
Forest	-0.03295	-0.229	0.8198	0.000844	0.05324
Green	**0.21417**	**2.25**	**0.02797**	**0.07552**	**5.065**
Pacific	0.03368	1.115	0.2692	0.01965	1.243

2.4.10 Microhabitat use

Pacific geckos were on average found at a lower height in the tree and in a shorter tree than either forest or green geckos (Tables 2.10 & 2.11).

Table 2.10 Results of two sample t-tests determining whether there is a significant difference (α = 0.05) between each species for each of three variables: the height in the tree a gecko was spotted, the height of the tree the gecko was spotted in and the distance from the path a gecko was spotted. Bold indicates significant differences between two species; t = t-statistic; df = degrees of freedom.

		Pacific			Forest		
		t	df	p-value	t	df	p-value
Height in tree	Forest	**-3.575**	**41.8**	**<0.001**	-	-	-
	Green	**-4.292**	**40.6**	**<0.001**	-0.925	228.4	0.3559
Tree height	Forest	**-2.174**	**30**	**0.0377**	-	-	-
	Green	**-2.925**	**31**	**<0.001**	-1.398	224	0.1637
Distance from path	Forest	-0.565	68	0.5742	-	-	-
	Green	0.331	48.3	0.7418	0.953	110.1	0.3429

Table 2.11 Mean height in tree a gecko was spotted, height of tree a gecko was spotted in and the distance from the path a gecko was spotted, all in metres. One mean was tabulated for each species from all geckos captured during the three years (2012-2014) of monitoring and for which data were recorded. Numbers in brackets indicate total number of geckos.

Species	Height in tree	Tree height	Distance from path
Pacific	2.1 (23)	3.5 (23)	1.9 (23)
Forest	3.6 (128)	5.0 (128)	2.2 (62)
Green	3.9 (104)	5.5 (104)	1.7 (62)

The log heights of trees in which geckos were spotted was significantly different between each of the parks, based on independent samples t-test for differences in means ($p < 0.001$ for all tests). Shakespear has the lowest average tree height and Whakanewha the highest (Table 2.12).

Table 2.12 Mean tree height at each of the parks. n is number of trees sampled.

Park	n	Mean tree height(m)	Standard error
Shakespear	21	2.7	± 0.4
Tawharanui	122	3.5	± 0.13
Whakanewha	112	7.2	± 0.3

2.5 Discussion

2.5.1 Difference in CPUE between years

Stable populations and consistency in survey efforts are indicated in the failure to detect any significant differences in the CPUE between any of the parks. However, results may be a consequence of Type II errors due to a low effect size or small survey effort (Gerrodette, 1987; Cohen, 1992). For example, only two Pacific geckos were recorded at Whakanewha over the three years. With low sample sizes, the effect size, in this case the difference in CPUE between years, may have been too small to allow a significant result and the rejection of the null hypothesis that the CPUE of geckos did not change between the years. Another possibility is the survey effort was too small. The statistical power, or the probability an analysis will correctly reject a null hypothesis, of these tests can be increased by either increasing survey effort or by an increase in the effect size (Gerrodette, 1987). This will reduce the risk of Type II errors. Greater survey effort can be achieved by performing more replicate VESs on the same transect during the monitoring period each year (Gerrodette, 1987). Seavy & Reynolds (2007) suggest complementing increased statistical power with increases in precision, achieved through incorporating monitoring standards into sampling design. This includes standardising procedures that will control for biases and preserve constant detection probability. It can be achieved by maintaining the same period of data collection and surveying the same transects over time.

2.5.2 Detection success of monitoring devices

CFRs may best be used as a complementary monitoring device of arboreal geckos to VESs. CFRs were the most successful in detecting forest geckos, as this species was found under the covers the most. Green geckos were less liable to use the covers; only one green gecko was found using one at Tawharanui and no green geckos were found under CFRs at Whakanewha despite encountering several during VESs. Pacific geckos used the CFRs at Whakanewha and Shakespear where they had also been detected by VESs. VESs returned a greater number of individual geckos for each year of monitoring, compared to CFRs, which agrees with other studies that have found

VESs to have the highest rate of gecko detection (Doan, 2003). The one disparity between the monitoring techniques, the detection of green geckos at Tawharanui, suggests that CFRs should not be used alone for monitoring the three gecko species.

2.5.3 Sex ratios

There were no significant differences in the number of males or females captured for any of the gecko populations. The equal proportion of male and female geckos caught for all populations is in agreement with most lizard species, including many gecko species, which have a sex ratio of one to one (Turner, 1977; How *et al.*, 1986). The fact that all of the populations do not vary from this ratio agrees with other studies that population sex ratios are tightly controlled (Greenwood, 1980). These studies have found that the numbers of each sex are balanced by mortality and emigration of the more frequent sex as a result of intrasexual competition (Greenwood, 1980). While the capture rate of geckos of each sex may not be truly representative of the ratio in the population as the ability to detect and capture geckos may vary with their sex and age, VESs have been used to determine the sex ratio of other lizard populations (Rose, 1982; Perry, 1996; Nelson *et al.*, 2002).

Higher incidences or more elaborate patterns of males compared to females can indicate a role of the patterns in sexual dimorphism (Johnston & Bouskila, 2007). Green geckos are the only of the three gecko species in this study that have either the presence or complete absence of distinct visual patterns. The fact that they are diurnal also brings credence to the theory that their patterning may play a role in mate selection. However, in this study, it was found that both female and male green geckos possessed white spots or patterning with similar frequencies. Therefore, there is no evidence that it plays a role in sexual dimorphism in this species. The white spots could have a role in camouflage. The green geckos are most often seen on manuka (*Leptospermum scoparium*) or kanuka (*Kunzea ericoides*) (Thoresen, 2012). These scrub trees have bright to dark green leaves and flower profusely for several months a year with a white bloom (Wardle, 1991). The white flowers may give green geckos that possess white spots or patterning an advantage in avoiding predators through camouflage.

2.5.4 Population health

The most likely source of scarring on the geckos is from predators or conspecifics. Apart from small invasion events, Tawharanui and Shakespear are free from all mammalian predators except mice. The gecko species at these parks are mainly subject to avian predators (Reardon *et al.*, 2012), whereas geckos at Whakanewha have the added pressure of rats, stoats and ferrets (Maitland, 2011). With the different predator pressures between the parks, differences in the frequencies of bodily harm between sites may be expected if external damages were caused by predators. However, no significant differences in scarring frequency were found. The varying predator pressures at the parks may explain the significant difference in the distribution of SVLs and weights of the populations of forest and green geckos at Tawharanui when opposed to their conspecifics at Whakanewha, with the geckos at Whakanewha having a larger median SVL and weight than their conspecifics at Tawharanui. Greater predator pressures at Whakanewha may select against smaller geckos that have less chance of surviving attack by large mammalian predators (Whiting *et al.*, 2003). While smaller geckos have the ability to avoid predators through escape into small crevices, they have a lower absolute running speed, making them more vulnerable to predation (Martin & Lopez, 2003; Whiting *et al.*, 2003). It is also possible size differences are a result of differences in food availability at the two parks, or based on genetic differences of the populations (Dunham, 1978; Ellegren & Sheldon, 2008). There is no difference in the distribution of the BCI of either forest or green geckos between their populations at the two parks. Despite the smaller size of forest geckos, on average, at Tawharanui, compared to Whakanewha, the two forest gecko populations are still in similar health.

Scarring due to agonistic intraspecific interactions is common for lizard species. Male-male aggression through competition for mates has been witnessed in several species of geckos (Vervust *et al.*, 2009). However, no significant difference in the frequency of male and female scarring rates was found in this study. Injuries may also have been inflicted by other lizard species, especially as all three gecko species are arboreal and insectivorous to some degree, which, together with their sympatric distributions, may lead to resource competition. The incidence of interspecific competition between lizard species can vary through time because of changes in resource availability with increases in densities amplifying interactions (Dunham, 1980). Continued monitoring of the frequency of scarring and tail loss may provide indications of pressures to the species, although determining its source may be difficult. Different scarring results may be found over a short time frame as wounds have been shown to heal scar-free on the leopard gecko (*Eublepharis macularius*) within a two-month period (Peacock, 2014). Scarring results should also be corroborated with other health indicators as they can be difficult to detect on forest and Pacific geckos and may be missed.

In geckos, the frequency of tail loss within a population does not necessarily correlate with the pressures of predation (Jaksic & Greene, 1984). In experimental studies, the frequency of tail loss in a population has been found to correlate with the inefficiency of predators and the ability of lizards to escape them through autotomy (Medel *et al.*, 1988). Therefore, tail loss frequency or scarring may merely be a measure of a species' ability to escape predators. The tendency of a species to lose their tails has also been found to have evolutionary origins. Genes are selected for depending on whether they increase the fitness of a species for their environment (Vitt *et al.*, 1977). Green geckos are less prone to losing their tails because they use it as a fifth limb. However, no significant difference in tail loss frequencies between green and forest geckos was found in this study. Rates of tail loss are expected to be less for lizards that use their tail for purposes other than just predator escape (Vitt *et al.*, 1977).

Whatever the reason for tail regeneration or body scars, there is an associated cost to individuals because of the energy needed for regrowth or healing. Regeneration can increase the fitness of an individual as it prolongs its life through escape from predators; however, tail regeneration and scar healing will reduce the resources available for an individual's reproduction. A greater frequency of scarring and tail loss in a population may affect its growth or stability. Therefore, despite not knowing their causes, monitoring of injuries can still provide important information regarding the health of a population.

The downward shift in the distribution of the BCI for the forest gecko population at Tawharanui and for the green gecko population at Whakanewha from 2012 to 2014 may have been caused by increases in outside pressures. These include resource pressures brought about by a decrease in invertebrate populations or the number of flowering plants, or an increase in the abundance of mice and other resource competitors (Toft, 1985). Increases in predator abundance may force the geckos to use more energy in predator avoidance tactics, spend more time being vigilant and increase stress levels (Downes, 2001). All of these activities equate to greater energy consumption and less time spent foraging (Downes, 2001). Another explanation is the difference in the climate from one year to the next. In 2012 and 2013 one month of spotting was unusually dry and warm, while the other month was unusually wet and had a below average temperature (NIWA, 2014). In 2014 the months of spotting overall had below average rainfall and just above average temperature (NIWA, 2014). The changes in climatic conditions may have affected the availability of resources or daily energy expenditure of the geckos due to varying activity levels (Walls, 1983).

Another possibility is the population distributions of the BCI were biased by the low number of individual geckos sampled, with a smaller sample size decreasing the likelihood it is representative of a population (Gerrodette, 1987). The BCI population distributions may also have been negatively biased if the likelihood of detection was influenced by individual BCIs. Poor health can make animals less liable to seek cover and avoid detection by predators which can make them more easily visible to observers than their healthy conspecifics (Rose, 1981). On the other hand, BCI can positively bias results with good health promoting movement of individuals away from relative places of safety and increasing their likelihood of detection (Rose, 1981). Monitoring the BCI of these populations over the next few years will help ascertain whether the downward trend is a cause for concern.

It was no surprise that only those geckos that were re-sighted in different years changed in physical condition to any significant degree. The male Pacific gecko only increased in its SVL and the female Pacific gecko only increased in tail length which may be a result of measurement error. The green and forest geckos that were recaptured generally grew in both tail length and SVL. Only the juvenile forest gecko experienced a significant decrease in its BCI between its first and second year of capture. This may be expected as juveniles use the majority of their resources to grow and mature. The male and female green geckos recaptured traveled the greatest distance, with one having moved at least 30m. *Naultinus* species, both male and female individuals, have shown territorial tendencies (Hitchmough, 1979). However, some home ranges are spatio-temporal in nature and *Naultinus* species have been recorded traveling an average of 0.6 metres each day (Hare *et al.*, 2007; Hitchmough, 1979). Both male and female forest geckos tended to stay closer to their first point of capture having been found within ten metres. *Mokopirirakau* species have been recorded moving five metres per day (Hoare *et al.,* 2013). While the locations of the two capture events were close for the forest geckos, it is possible that their total travel distance between times of capture was much greater.

The low number of recaptured individuals compared to the number of green and forest geckos captured and photographed (4 out of 44 and 3 out of 54, respectively) for analysis may be indicative of low detectability of these gecko species and their presence at a large density. This poses a problem for uncovering trends in abundance estimates. Although it may be expected that a decrease in the density of a population will also equate to a decrease in its detectability, when detection probabilities are less than 0.5 then abundance indices can be unstable (Couturier *et al.*, 2013). Therefore, population changes can be hard to detect, especially when they are slow, due to a large statistical variation in abundance estimates (Couturier *et al.*, 2013). In order to increase statistical power in such cases, when detection probability is low or density high, it is best to increase the number of visits to sites (Field *et al.*, 2005; MacKenzie & Royle, 2005). Increasing the number of visits will decrease variation in abundance estimates and allow the detection of smaller changes in abundance (Gerrodette, 1987). Pacific geckos had a higher relative rate of recapture compared to green and forest geckos, with three geckos re-sighted from 11 observations. This may be indicative of lower population densities or the greater difficulty in detecting the species. While it is possible not all recaptures were identified from the photographs, the identification procedure was performed twice, and one hundred percent accurate identification of individuals has been achieved with the jewelled gecko *N. gemmeus* in first-time analyses (Knox *et al.*, 2013).

2.5.5 Potential sources of bias

There were consecutive captures of the same individuals within a two-month period, with three geckos captured at least twice in this time. If there is no evidence for capture avoidance, the CPUE results can be assumed to be representative of the population over time (Towns, 1991). The rate of recaptures was low compared with total gecko encounters analysed (109 geckos photographed) and is not sufficient to confirm that the capture of a gecko does not induce it to employ capture avoidance tactics in the future. However, there are enough individual geckos at each location VESs are undertaken to allow CPUE to remain stable despite any avoidance behaviour that may be employed by geckos.

Sample sizes were too small to show any significant difference in the CPUE for the number of surveyors. Nevertheless, surveys conducted by three observers resulted in the greatest average CPUE, suggesting that the addition of a fourth observer is superfluous. Moreover, there are indications that having too many observers may create bias in results. When species are cryptic and/or in low abundance biases can occur when VESs are performed by too many observers. In such situations it may only require a minimum number of observers before all possible animals will be easily detected. Too many observers may also create a lot of noise, a potential gecko deterrent, causing them to seek cover (Bowles, 1995).

As all results were pooled to find the average CPUE for each number of surveyors, it could not be determined whether the optimum number of observers was different for differing habitat types. This is highly likely as visual surveys can vary in difficulty for various habitats (Towns, 1991). As long as the number of observers does not reach saturation, or the point where an addition of another observer does not equate to an increase in the number of geckos detected, then results will not be biased by this variable. Below saturation levels, the number of observers will correlate linearly with the number of geckos spotted and the CPUE will remain the same regardless of how many observers conduct the survey. When saturation levels are surpassed the CPUE will drop off as the addition of more observers will not equate to the capture of more geckos.

2.5.6 Microhabitat use by species

The significantly lower height in the tree the gecko was found for Pacific geckos than for forest or green geckos is consistent with other studies. Pacific geckos have been found to favour the lower canopy areas, as opposed to forest and green geckos that have both been found more often in higher zones (Hare *et al.*, 2007; Romijn *et al.*, 2013). Pacific geckos are only semi-arboreal, spending much of their time amongst understorey vegetation. When they do venture amongst trees, their height is relatively low to the ground. Green geckos are much stricter in their arboreal tendencies. Forest geckos have shown tendencies to utilise both lower and higher vegetation. The detection probability of geckos is expected to decrease with distance, which means differences between gecko species in the use of canopy height may be even greater than reported here (Graham & Bell, 1989).

On average, green and forest geckos were found in taller trees than Pacific geckos, possibly a result of a search for higher canopy areas to occupy by the two former species. However, it may also be a consequence of the park the gecko species were spotted in, as geckos were spotted on average in taller trees at Tawharanui and

Whakanewha where only two Pacific geckos were found. The height of trees at these parks may be on average larger than those at Shakespear. Other microhabitat features that the gecko species may have preferences for include distance to cover and tree species present, which have been found to effect the detection of other herpetofauna (Hadden & Westbrooke, 1996). None of these variables were recorded during VESs. Due to the differences in tree height positions of geckos, to avoid biases when surveying Pacific, forest and green gecko populations, all vegetation levels should be searched with the same effort.

2.5.7 Management implications

There is no strong evidence from this study that the threat status of the gecko species should be altered. All gecko populations appear to be stable but this must be confirmed with more years of monitoring before they are determined to be no longer at risk (Hitchmough *et al.*, 2013). The relict status of the Pacific geckos has been confirmed as they were only found at two of the three parks and in relatively low numbers compared to the other species (Hitchmough *et al.*, 2013). Increasing the intensity of sampling can increase the accuracy of abundance indices and decrease the amount of noise. Such a change will not compromise the integrity of the long-term data and comparisons can still be made with previous data. Data collection methods should remain consistent and if possible the number of surveyors should not exceed four in order to reduce any potentially negative effects brought about by large numbers of observers. A population must be monitored for an appropriate length of time in order to help distinguish between population declines that are due to temporal variation and those that are cause for concern (Pechmann & Wilbur, 1994). Once natural population variations become apparent, variations due to human perturbations can be more readily identified.

CHAPTER 3

Vegetation characteristics and gecko encounter rate

3.1 Introduction

3.1.1 Habitat effect on encounter rate

The ability to detect reptiles during visual encounter surveys varies with the type of habitat the surveys are conducted in. The encounter rate during active searches has varied with habitat type in several studies (Pollock *et al.,* 2002; Bailey *et al.,* 2004). For example, when conducting bird counts Pollock *et al.* (2002) found that dense vegetation hinders sight and hence, the identification of birds. Bailey *et al.* (2004) found large scale habitat characteristics including vegetation type varied directly with the encounter rate of salamanders. Not accounting for differences in encounter rate in different vegetation types may result in Type I errors in abundance estimates at different locations (de Solla *et al.,* 2005).

In order to understand the encounter rate of geckos in varying vegetation types the vegetation must first be analysed and grouped into categories. Categorising vegetation into discrete categories can aid in determining in which type of vegetation geckos are most easily detected. Jellinek *et al.* (2004) found that the type and structure of vegetation affects the structure of reptile communities. Vegetation variables including species richness and community composition showed a significant relationship with the number of lizard species (Jellinek *et al.,* 2004). For example, areas with a large ratio of exotic to native plant species have fewer species of lizards present (Jellinek *et al.*, 2004). Lizard species that require native plant species were found less often in such habitats (Jellink *et al.*, 2004). Categorising vegetation and correlating it with where geckos are found can aid in determining their most likely whereabouts in other areas.

3.1.2 Management implications

Data describing vegetation types in which species are detected can aid in the conservation of the species. Information on the most likely places to detect geckos can direct future searches for the animals and which areas of habitat are best to retrieve abundance estimates from (Hare *et al.,* 2007). Although successful conservation management includes the ability to detect animals and determine their distribution, abundance estimates are also important (see Chapter 1) (Whitaker & Gaze, 1999; Guisan & Thuiller, 2005). The estimate of population abundance can be made difficult due to inadequate survey techniques or limited ability to account for environmental variables (Pearce & Ferrier, 2001).

Due to low detection rates of geckos in surveys, not finding the animals in some vegetation types will not equate to the certainty of their absence in such habitats. False absences can occur when there is a failure to detect a species in an area when in fact it is present (Reese *et al.*, 2005). On the other hand, failure to detect a species in an area may in fact mean that it is not present (Hirzel *et al.,* 2002). This is the main difficulty in animal surveys conducted to determine the spatial distribution of a species (Gu & Swihart, 2004). Numerous resources and time are required to determine the exact distribution of populations (Margules & Austin, 1990). However, once a species is detected in an area, the population can be monitored over time with abundance indices. While large errors in true population size estimates are associated with differences in the ability to detect individuals, using an abundance index can allow the comparison of population sizes through time (Koper & Brooks, 1998).

Knowledge of the detectability of geckos in different types of vegetation is important for understanding the limits of data analysis and may allow comparisons between different areas. If the percentage of animals detected in two distinct vegetation types differs then data collected in surveys should not be compared between them (MacKenzie *et al.,* 2005). For example, Hare *et al.* (2007) found that *Naultinus manukanus* was spotted mostly on the coastal shrub *Ozothamnus leptophyllus* but this was thought to be due to a bias in the visual acuity of the geckos on different shrubs. The contrast of the brightly coloured geckos on the comparatively dark-shaded shrub made the geckos more prominent on these tree species than others during searches. It is best to compare abundance estimates over time only in similar vegetation as different characteristics can have differing encounter rates (MacKanzie *et al.,* 2002). Exact detection probabilities for surveys of all individuals in a population can only be determined if total population numbers are known. Only with such knowledge can the proportion of animals detected be discerned. When this is not the case and the number of animals detected in surveys differs between vegetation types then it cannot be determined whether they differ based on different detection probabilities or because there are differing numbers of individuals in each type.

Surveys of a population can provide important information despite not knowing the detection probability of the animals. In most situations it is not possible or practical to determine total population numbers (Frankham, 1995). However, knowing the number of individuals encountered differs between vegetation types can also have important applications for management. If time and resources are scarce, they can be spared by directing searches in habitats most likely to contain or enable spotting of the target species (Whitaker & Gaze, 1999). Other methods can be used for detecting individuals in vegetation types where visual encounters are difficult to attain confirmation of species presence.

3.1.3 Analysing vegetation structure

When analysing vegetation to compare with species distribution models it is not practical to include all plant species or their characteristics (Atkinson, 1962). Instead, variables most appropriate to the study, with the greatest influence over the community aspects that are being investigated are chosen (Austin, 2002). The characteristics of the forest canopy have a large effect on the sub-canopy and ground layers. Canopy layer plants contribute the most to the structure of vegetation and are the main controllers of the light, moisture and nutrients available to lower level plants (Atkinson, 1962). These environmental variables influence the understory species' richness and seedling densities (Parrotta, 1995). Litter-fall from the canopy trees can also influence understory vegetation (Barbier *et al.*, 2008). Litter alters the physical and chemical environment of the soil directly and indirectly (Facelli & Pickett, 1991). Ludwig *et al.* (2004) found that the effect of canopy trees on nutrient composition of the soil is the main factor causing differences in species composition. Understanding canopy composition and structure will give insight into the lower level aspects of vegetation.

3.1.4 Microhabitat use by geckos

Microhabitat and behavioural studies have found geckos utilise several layers of the forest canopy. *Naultinus* species are known to spend the majority of their time in the foliage layers of trees and shrubs (Hare *et al.*, 2007). They make use of lower vegetation and grasses only when moving between trees and shrubs (Hare *et al.*, 2007). *Dactylocnemis* species are found towards the lower levels of forest and shrubland, including clay banks and scrubby vegetation such as flax (*Phormium tenax*) (Hitchmough, 1997; Jewell, 2008). *Mokopirirakau* species are known to spend a lot of their time on trunks and branches of trees and shrubs and have also been found on the ground and among lower levels of vegetation (Romijn *et al.*, 2013). During visual encounter surveys, geckos in the upper story of vegetation may provide the best means of sighting individuals compared to those in the understory. Exposure is expected to be greater when geckos are at or above eye level due to the greater density of understory plants (Bawa, 1990). Greater density of foliage will create more obstructions for observers.

3.1.5 Boundary selection

A degree of subjectivity in vegetation analysis is unavoidable. When determining boundaries for different vegetation categories, the researcher must make a decision as to where one type of vegetation stops and another begins (Atkinson, 1985). Mitchell's (2001) point-centred quarter method provides a means of attaining quantitative data from a section of vegetation once it has been characterised. By collecting data on tree species present, distance between trees and the diameter of trees, several summary statistics of a strand of vegetation can be determined. These include: species composition, relative density, relative cover or dominance and frequency. These characteristics of the upper canopy can influence the understorey species composition and characteristics (Parrotta, 1995; Barbier *et al.*, 1998). An estimate of absolute density of all trees in a vegetation strand and average distance between trees can also be determined from the data. Mitchell’s (2001) method works on the premises that the vegetation strand is homogenous and selecting points randomly along a transect of the strand will provide representative data of the entire section of vegetation. Subjectivity in separating vegetation into homogenous units may be required and will be ideally guided by the objectives of the study (Kuchler, 1973).

When the objective is to determine the encounter rate of geckos in different vegetation types, the characteristics of the vegetation that contribute to differing visual awareness of the geckos are used to separate the vegetation into different categories. Visual cues used in visual surveys include contrasts between the target animals and the background vegetation. For example, the dark-green bodies of *N. manukanus* blend in with darker vegetation and are harder to detect than when on lighter vegetation (Hare *et al.*, 2007). Height of the vegetation can also play a role. A greater canopy height will mean that animals have the ability to move out of range of observer vision. The structure of vegetation can also influence detectability of animals when it encourages individuals to move out into areas where they are more easily detected by observers (Gu & Swihart, 2004). The density of vegetation has been found to cause differences in the ability to see animals in several studies. For example, Pollock *et al.* (2002) found that the denser the vegetation the less likely one is to see birds.

3.1.6 Auckland Council monitoring programme

Understanding how vegetation structure affects the encounter rate of geckos can enable surveyors to conduct VESs in vegetation that offers the greatest ability to encounter geckos. With the assumption that the portion of the population sampled represents the entire population, reducing the area searched can reduce the use of resources if the objectives of the study concern monitoring the abundance index through time. It will not only increase the CPUE and, thereby, statistical power of tests with the abundance index, but will also allow tentative comparisons of CPUE between locations when VESs are conducted within vegetation of similar structure at the different sites. For such comparisons, it may be possible to exclude with confidence different encounter rates in various vegetation types as an explanation for any differences in CPUE.

CHAPTER 4

The effect of moon phase on gecko encounter rate

4.1 Introduction

4.1.1 The effect of moonlight on animal activity

Nocturnal activity of some species of small rodents and reptiles is affected by the amount of light. Although conducted in captivity and simulated moonlight, Clarke *et al.* (1996) found that prairie rattlesnake (*Crotalus viridis*) activity increased significantly from the new moon to the full moon, or to an increase in illumination. Experiments conducted in laboratories found that deermice (*Peromyscus maniculatus*) reduce their activity by a significant degree during nights of brighter moon illumination (Clarke, 1983; Brillhart & Kaufman, 1991). Merriam's kangaroo rats (*Dipodomys merriami*), radio tracked in the wild, were found to reduce their activity during the full moon (Daly *et al.*, 1992). Cloud cover also affects results as it reduces the moon's illumination. The kangaroo rat *Dipodomys ordii* showed greater activity when the moon's illumination was partially dimmed by cloud cover than during a clear moonlit night (Kaufman & Kaufman, 1982).

Although studied less extensively, lizard species have also shown evidence for an increase and decrease in activity levels from the new to the full moon. Some lizards including *Stenodactylus doria* and *Ptyodactylus guttatus* increase their activity during the full moon (Sleigmann *et al.*, 2007). However, the lizard *Teratosincus sincus'* locomotive activity decreased in the presence of moonlight (Seligmann *et al.*, 2007). Therefore, effects of moonlight on lizards may be species-specific and dependent on predator avoidance tactics and prey capture. These dependencies may be explained by morphological characteristics of a species (Sleigmann *et al.*, 2007). *T. sincus* is a larger species than the previous two lizards which may help explain their different responses to moonlight (Sleigmann *et al.*, 2007). *T. sincus* being larger, also has larger eyes which may allow it to see its prey better, especially on moonlit nights, and hence it will not need to travel far from its burrow to find enough food (Sleigmann *et al.*, 2007).

One of the explanations for the effect of the moon's illumination on nocturnal animal activity is its influence on predator-prey relationships. For all animals, foraging is an activity in which benefits must outweigh costs. This conforms to the optimal behaviour theory in which an activity will be reduced if the costs outweigh the benefits (Griffin *et al.*, 2005). Foraging will still be necessary for survival, but adjustments in behaviour can reduce the vulnerability to predators. When faced with a predator, an animal may either adjust its movements to avoid it or reduce its time in an open or vulnerable habitat, or it may become more alert and spend more time surveying its surroundings while foraging (Brown *et al.*, 1999). The moon creates another variable that can influence the decisions of the prey or predator, based on the advantages or disadvantages it affords to either.

The amount of illumination can affect the success of predators. Clarke's (1983) experiment on deermice found that their main predators, short-eared owls' (*Asio flammeus*) hunting success was increased as illumination increased, requiring less time to search for and capture prey. Metzgar (1967) found that increased activity of mice can lead to a greater rate of owl predation. Therefore, less movement will reduce predation, especially during nights of greater illumination, when visual cues can aid auditory signals from prey movements and increase hunting success. Daly *et al.* (1992) found a direct relationship between the moon's illumination and the rates of predation by nocturnal and diurnal predators on kangaroo rats. Predation by nocturnal predators was greatest during the new moon and smallest during the full moon. The reverse pattern was seen for diurnal predators, while gross predation rates on the kangaroo rats remained the same. This suggests kangaroo rats change their activity times when the moon is full to daylight hours in order to avoid nighttime predators (Daly *et al.*, 1992). Seasons can affect the degree of influence of the moonlight on predator success. Snowshoe hares are 2.5 and 1.8 times more likely to suffer fatality from predation during the full moon than the new moon during the snowy months and snow-free months, respectively (Griffin *et al.*, 2005).

Although the study of the same effect for reptiles are lacking, the effect of moonlight on lizards may also be explained by predator-prey relationships. Basking and, often, foraging forces lizards to expose themselves to visually hunting predators (Schwarzkopf & Shine, 1992). This is especially true for lizards whose own prey are flying insects or fruit on the periphery of trees. To avoid the complications of basking requirements Seligmann *et al.* (2007) have suggested using nocturnal, lizard species when studying the effect of illumination on the activity of the taxa. This reduces the number of variables that may affect activity levels of lizards (Seligmann *et al.,* 2007). Nocturnal, insectivorous lizards are under pressures from predators and their mobile prey (Seligmann *et al.*, 2007). In theory, if an individual's risk of predation is increased with moonlight and its benefits from foraging remain the same, then the benefit cost ratio will decrease and the individual will be expected to decrease its activity (Daly *et al.*, 1992). However, when the moon's illumination also affects the benefits from activity, or the foraging success of the animal, then the ratio may not in fact decrease and activity levels may remain the same. Some insects have been found to increase their activity during nights of greater illumination (Bidlingmeyer, 1964; Bowden & Church, 1973). Thus, it is this interplay of two variables which determines the effect of moonlight on a lizard's activity and may also explain species-specific differences.

4.1.2 The effect of moonlight on microhabitat use

For several species, the use of cover also changes significantly from the new moon to the full moon. Not only did Clarke's (1983) deermice reduce their activity during the full moon, but when they were active during nights of illumination they chose habitat with greater cover. Longland and Price (1991) found that desert rodents were more vulnerable to great-horned owl predation in the open than under cover. Bush creates greater obstacles for the owls and creates greater opportunities for small rodents to avert predators. When owls did see a rodent their capture success was reduced in the bush (Longland & Price, 1991). Cover offers a greater ability for lizards to escape predators, and lizards will spend longer under cover when the risk of predation is high (Martin & Lopez, 2000). Moonlight may also influence a predators' use of cover. The brown tree snake (*Boiga irregularis*) hunts its prey in the forest canopy during periods of increased moonlight and on the open ground during low illuminations (Campbell *et al.*, 2008). This may be an indirect effect of the snake's prey changing its habitat use.

4.1.3 Seasonal differences in the effect of the moon

Seasonal differences in the effect of moon illumination on animal activity and cover seeking behaviour have been discovered for some species. The difference in illumination between the new and full moon phases is greatest during winter when the moon's path is most directly over the Earth's surface. Seasonal differences in food availability may also affect the moon's influence over the activity of animals. Bannertail kangaroo rats (*Dipodomys spectabilis*) are not active during moonlit nights during autumn and winter but are active anytime during spring (Lockard & Owings, 1974). Snowshoe hares (*Lepus americanus*) were studied in the wild for 2.5 years and were found to have significantly greater activity during the full moon than the new but this difference was markedly greater during winter than in summer (Griffin *et al.,* 2005).

4.1.4 Confounding variables

It is difficult to place a direct cause and effect relationship on the amount of illumination and changes in animal activity or microhabitat choices. Several other variables may play a role. These confounding variables include abiotic factors such as temperature, humidity and precipitation, and biotic factors such as prey availability that is independent of the moon. Temperature has a major affect on the movements of reptiles. Temperature determines the times of activity of terrestrial lizards (Barlett & Gates, 1967). Due to specific temperature tolerance ranges, often temperature will influence reptile’s thermoregulartory behaviour including the choice between activity and non-activity (Brattstrom, 1965). In some cases temperature is superseded by other variables. For example, the distance and frequency of the Malayan pit viper's (*Calloselasma rhodostoma*) movements is highly correlated with the relative humidity (Daltry *et al.,* 1998).

Despite these other explanatory variables for reptile activity the importance of moonlight should not be overlooked. Its effect can have an overpowering influence on an animal's behaviour despite changes in other factors. This was seen for the brown tree snake (*Boiga irregularis*) which altered its microhabitat use based solely on the moon and independently of the availability of prey (Campbell *et al.,* 2008). Understanding the effect of moonlight on the activity of animals can have important management implications for species.

4.1.5 Management implications

The ability to predict the behaviour of lizards under certain environmental conditions will aid in efforts to undertake surveys on populations. If the moon deters the target species from exposing themselves to the open environment they will be less likely to be detected by an observer. This will greatly bias results, including indices of abundance, if such an effect is not taken into account. Lizards in New Zealand are prone to predators that make use of visual cues during hunting such as possums and rats. Therefore, it was hypothesised that the moon's illumination, increasing visual acuity of predators, would cause the lizards to seek refuge in microhabitat that provided cover. The number of individuals spotted, or the catch per unit effort (CPUE), was used as a surrogate for determining the degree to which animals sought cover in the new and full moon. The more lizards spotted, the less likely they were actively seeking cover. It was assumed that an observer's ability to visually detect a lizard was positively correlated with a predator's ability to detect the animals, and the same visual cues were used.

4.2 Objectives

Determine whether there is a significant difference in the collective catch per unit effort (CPUE) of Pacific, green and forest geckos between the new and full moon phases and whether monitoring protocols should be adjusted to account for differences.

4.3 Methods

4.3.1 Location

Separate VESs from that performed for the monitoring programme were conducted at Tawharanui and Whakanewha. The transects chosen were based on the high CPUE rate during VESs performed by the Auckland Council and anecdotal evidence. These were the site F and site H transects at Tawharanui (see Chapter 2), which were the transects at the park with the greatest CPUE from VESs, and two new transects at Whakanewha where at least four geckos had been sighted in one night. A higher CPUE creates a test of greater power with results. The transects ranged in length from 800 to 1200 metres. Three of these transects consisted of a clear path that cut through a section of bush with vegetation on the left and right. The remaining transect was on the bush edge, open to grassland. Transects were also chosen, based on a dominant vegetation of scrub, either manuka or knauka, covering over half the visual aspect. The density of the vegetation only allowed observers to spot geckos on the periphery of vegetation.

4.3.2 Data collection

VESs were conducted within two nights either side of the new and full moons from September 2013 to March 2014 (Appendix 2). Surveys started at least half an hour after sunset and were performed by one to three observers, with at least one experienced observer, having taken part in the monitoring surveys (see Chapter 2). The experienced observer used the same torch for each survey. The surveys during the full moon were not conducted until after the moon had risen. Surveys were not performed on days with heavy rainfall or complete cloud cover during the full moon, owing to the reduction in illumination. The walking pace was kept constant at a leisurely speed and both sides of a transect were scanned. Transects were scanned vertically to include all visible vegetation from the bottom understory to the top of the canopy based on previous sightings of geckos (see Chapter 2 Results).

4.3.3 Data Analysis

The statistical package SPSS was used for data analysis. The Friedman non-parametric pairwise exact test was used to compare CPUE in the new and full moon, based on each transect. The new and full moon VESs were paired within two months to ensure weather differences or other seasonal variations in environmental factors did not bias results.

4.4 Results

4.4.1 Differences in the encounter rate of geckos in the new and full moon

The mean CPUE of geckos for any species was similar in the new and full moon phases (Table 4.1).

Table 4.1 Mean catch per unit effort (CPUE) ± 1 standard error (SE) of geckos for each of the moon phases. n is number of visual encounter surveys (VESs).

		New moon			Full moon		
		n	# of geckos	mean CPUE	n	# of geckos	mean CPUE
Tawharanui	Forest	6	5	0.27±0.2SE	10	5	0.24±0.13SE
	Green	6	9	0.65±0.2SE	10	5	0.22±0.14SE
	All geckos	6	14	0.92±0.3SE	10	10	0.46±0.2SE
Whakanewha	Forest	8	9	1.0±0.4SE	12	13	1.0±0.5SE
	Green	8	34	2.3±0.8SE	12	42	2.34±0.4SE
	All geckos	8	43	3.28±0.8SE	12	55	3.34±0.7SE

There were no significant differences in the mean CPUE between the new and full moon phase for forest geckos (Friedman test: $n = 14$, $\chi^2 = 0.091$, $p = 0.763$) or green geckos (Friedman test: $n = 14$, $\chi^2 = 1.333$, $p = 0.388$).

4.5 Discussion

4.5.1 The effect of the moon phase on gecko activity

No significant difference in the detection rate of geckos by observers in the new moon and full moon phase suggests that geckos do not change their exposure behaviour based on the moon's illumination. Previous studies have shown that the most likely cause of changes in animal activity based on moonlight is linked to predator-prey relationships. However, this might not be the case for green and forest geckos. While Tawharanui may experience re-invasions of introduced mammals, generally the area is free of non-avian lizard predators, apart from mice (Maitland, 2011). Whakanewha is free of possums but geckos are under pressure from stoats, ferrets and rats at the park. These nocturnal, mammalian predators typically use scent when hunting and rely secondarily on sight (Berry, 2002). However, morepork (*Ninox novaeseelandiae*), a nocturnal owl, have been known to prey on lizards despite insects predominating in their diets (Worthy & Holdaway, 1994). Some prey animals do not change their activity patterns in moonlight because they also use visual cues for detecting predators (Beier, 2006). This may negate the advantage the gecko’s predators gain in detecting their prey as the geckos themselves gain an advantage through defensive tactics. Geckos use visual cues during foraging and may use the same visual cues in observing their surroundings for predators. Lizards have also been known to select slender perches possibly for the reason that they prevent larger predators from reaching them (Greene *et al.*, 1978). This may negate the need to avoid detection by non-avian predators such as possums or mustelids.

The possibility that behavioural responses to moonlight are species-specific, or population-specific, in closely related taxa should be considered. Disparities in behaviour may be in consequence of abiotic and biotic differences in the regional environment. There are many examples of intraspecific differences in behaviour as a consequence of a varying biotic or abiotic environment. Separate populations of greater earless lizards (*Cophosaurus texanus*) display different degrees of anti-predator behaviour based on the amount of cover (Bulova, 1994). Downes & Adams (2001) found that populations of rock-dwelling velvet geckos (*Oedura lesueurii*) living with and without snake predation displayed differences in behaviour when exposed to snake scent. Geckos that had not been subject to snake predation did not display all the anti-predator responses typical of the species when exposed to the scent. Different local pressures can cause the same species to behave in ways contrary to the behaviour of conspecifics. While the two populations of geckos in this study showed no behavioural response to the moon, effects on other populations may be different due to varying environmental pressures. If a habitat offers minimal cover, geckos may lessen their activity during nights of greater illumination to reduce exposure to visually hunting prey. They may also reduce their activity on moonlit nights if the area they occupy has a large population of cats; a nocturnal predator that makes use of visual cues (Turner, 2000).

The effect of moonlight on gecko's prey must also be considered when explaining the moon's effect on the behaviour of the geckos themselves. Green geckos are diurnal and sedentary hunters, while forest geckos actively seek out prey. Arboreal geckos include mobile prey in their diet. Despite green gecko’s sit-and-wait hunting approach, they still rely largely on mobile insects. However, because green geckos are diurnal any activity changes of insects at night will likely not affect them. The major influence on their visibility in varying light levels will likely be the effect of moonlight on the activity of their nocturnal predators, dictating the safest resting sites and thereby their exposure at night. Forest geckos, on the other hand, may be affected by nocturnal insect movements. Insects are known to be affected by the amount of illumination at night. A study, in which a non-attractant trapping technique was used, found that the number of mosquitos of the *Aedes* genus captured at night significantly increased from the new to the full moon (Bidlingmayer, 1964). The same study also found the greatest activity of the insects was shown at twilight, during which light levels are similar to those at the full moon. Not all night-active insects show similar patterns. Insects of the order Isoptera and Bostrychide show increased number of catches with increasing illumination but Pyralidae and Formicidae order insects show the opposite pattern (Bowden & Church, 1973).

The potential increase in predation risk of the geckos when they are active at night may have been offset by the increased availability of prey. This would explain the failure to find a significant difference in the number of geckos spotted in the new and full moon. But whether the gecko's prey follows a similar pattern of increased activity on moonlit nights is uncertain until further studies are performed. Other factors also play a role in insect activity. Temperature and wind were found to be the first and second most important factors affecting insect activity, respectively (Persson, 1976). Moonlight was found to be the third most important variable explaining about 10 % in the variation of number of insect captures (Persson, 1976). Factors affecting activity are also prone to correlation. When there is cloud cover reducing illumination, the temperature is often higher and the wind is accompanied by a chill factor that reduces temperature (Williams *et al.*, 1956).

4.5.2 Management implications

The main concern for this study and the purposes of management was to determine the effect of the moonlight on the species where abundance surveys are undertaken. In this way, it will be possible to determine any stratified sampling that may need to occur in conjunction with the phases of the lunar cycle. Nevertheless, from the results of this study, no stratified sampling, according to the moon, is required due to the absence of a significant difference in the number of geckos spotted in the new and full moon.

Seasonal differences in the response of geckos to moonlight should also be considered. Data was collected from late autumn through to late summer. The effect of moonlight on the activity of geckos may influence them to a greater extent during other times of the year, especially during winter when the contrast of the new and full moon is at its greatest. Seasonal differences in the biotic and abiotic environment must also be considered. Temperature and rainfall change throughout the year. Geckos may respond to predators that are known to change their diurnal and nocturnal activity patterns during the seasons. Stoats, cats and ferrets all show a high degree of night activity, but ferrets show the greatest nocturnal activity in spring when compared with autumn (Alterio & Moller, 1997). For management purposes, data is not collected during winter months and, therefore, from the results determined, moonlight should not have an effect on visual encounter surveys and abundance indices.

Biases in data collection must also be considered in explaining the results. Many geckos were spotted at a height above eye level, at which their white under bellies could be seen. It is uncertain whether predators maintain the same vantage point when searching for prey. Predators may also use other search cues such as scent. It is not possible to replicate predator search tactics exactly. Searching for geckos earlier in the night may have masked any change in later night activity during the moon phases because of possible crepuscular activity of the animals. Green geckos may still have been in the process of finding resting places for the night, and forest geckos not fully emerged from daytime refuges. However, as long as the time surveys are undertaken remains consistent it will not prove an issue for acquiring data for abundance indices. While one observer used the same torch for every VES, torch brightness and its light spread were not consistent for other observers. It is a possibility the ability to detect geckos was affected along with the CPUE of results, and it is recommended survey equipment remain consistent for each VES to avoid changes in detectability brought about by different torch aspects (Lardner *et al.*, 2009).

CHAPTER 5

The use of tracking tunnels to determine the distribution of arboreal geckos

5.1 Introduction

5.1.1 Monitoring devices for lizards

There are several common techniques for monitoring lizards. Pitfall traps and visual survey methods have shown the greatest success at detecting reptiles (Garden *et al.*, 2007). Pitfall traps, a small hole made in the ground from which an animal cannot escape once it is in, can be used for species inventory, long-term monitoring and estimation of abundance (Greenberg *et al.*, 1994). Pitfall traps are recommended for ground dwelling reptiles and do not work well for arboreal geckos that spend a large amount of time in trees (Greenberg *et al.*, 1994). Pitfall traps are also known to cause high mortality rates for trapped fauna (Enge, 2001). Visual searches are recommended more for larger reptile species as they are generally easier to find than small cryptic animals (Garden *et al.*, 2007). Visual encounter surveys are best used for determining the presence or absence of species but not abundance (Rodel & Ernst, 2004). However, visual surveys have shown to effectively estimate species abundance when compared with mark-recapture estimates (Flint & Harris, 2005). Funnel traps, where an animal crawls through an inverted funnel and is unable to retreat, have also been used for monitoring lizards, and in some situations are more appropriate than pitfall traps for terrestrial species (Greenberg *et al.*, 1994; Jenkins *et al.*, 2003). Differences in the success of various methods for different species have been attributed to variations in species behaviour and morphology (Greenberg *et al.*, 1994; Jenkins *et al.*, 2003).

No single monitoring technique is sufficient for monitoring all lizard species in a community. Multiple monitoring methods are recommended when monitoring or surveying for the presence of more than one species with different ecologies (Ryan *et al.*, 2002). Differences in species behaviour are responsible for the appropriateness of some monitoring techniques for a species and the inappropriateness of others.

Behavioural tendencies of the species affecting probability of detection include: use of microhabitat, vigilance against predators and foraging techniques. For example, baited or bait-free pitfall traps are likely ineffective at detecting green geckos because the species is strictly arboreal and employs a sit-and-wait foraging technique (Hare *et al.*, 2007; Nielsen *et al.*, 2011). Pitfall traps are known to be biased towards smaller herpetofauna and those species spending a large majority of their time on the ground (Greenberg *et al.*, 1994). The likelihood that an individual will enter a tracking tunnel is dependent on the animal's movements and wariness or gravitation towards the tunnel (Williams *et al.*, 2002). Cryptic tendencies, which can be a result of predator vigilance, reduce the probability of detecting species in visual surveys (Williams *et al.*, 2002; Stuart-Fox *et al.*, 2003). Rare species can make the task more difficult as less individuals equates to a reduced likelihood of detection (Mackenzie *et al.*, 2005). When direct observational surveys are undertaken, size and vocalisations of a species can also affect the chances of detectability (Williams *et al.*, 2002).

Artificial retreats are another tool for surveying lizards. Bell (2009) found that cell foam covers were the most effective method for indexing arboreal gecko populations (Duvaucel's (*Hoplodactylus duvaucelii*), forest and Pacific geckos) when compared to lizard houses, pitfall traps and spotlighting, and in some cases, when Pacific and forest geckos were at low densities, were the only method able to detect them. It is possible a tracking tunnel design tailored for arboreal geckos can provide another method of population inventory and monitoring to complement covers and include the detection success of green geckos. The testing of such a design is the focus of this chapter. Tracking tunnels hold advantages over DOC's current toolbox for monitoring as they are less intrusive for the animals, inexpensive, and relatively easy to set up, the main drawbacks of other monitoring devices (Department of Conservation, 2014). The use of a tracking tunnel prevents possible disruption of a lizard's natural behaviour which is common for other monitoring techniques such as VESs, if geckos are caught for measurements, and pitfall traps that require handling of animals (Russell *et al.*, 2010).

Cryptic species or species in low densities require different monitoring techniques than those of more abundant or easily detected species. Monitoring techniques for any species would ideally require minimal effort. If the effort put into monitoring can be reduced, then the rate of return, in terms of survey counts or the ability to detect the presence of a species, can be increased per unit of effort. Rare or cryptic species will almost always offer low counts in surveys, therefore, minimising effort is the main solution to increasing efficiency of monitoring (Mackenzie *et al.*, 2005). Cryptic or rare species will also mean that they are likely to be either data deficient or have low abundances (Hitchmough *et al.*, 2010). Thereby, a passive, non-destructive method of monitoring the species, such as tracking tunnels, will prevent harmful, even lethal, consequences for individuals, essential to the good health of a population (Watts *et al.*, 2011).

Tracking tunnels have worked successfully for a range of species in New Zealand. Tracking tunnels have been used extensively for indexing introduced mammalian pests. Rats and mice have been indexed using tracking devices in order to help explain stoat diets (Murphy *et al.*, 2008). Tracking tunnels are effective at detecting the presence of rodents at low abundance (Gillies & Williams, 2002). King & Edgar (1977) advise the use of tracking tunnels as a preliminary study of the activity of rats, mice and stoats. They have also been trialled successfully with the native giant weta (*Deinacrida heteracantha*) (Watts *et al.*, 2008). Like the current study species, giant weta are cryptic, arboreal and forest dwelling (Watts *et al.*, 2008). Tunnels were placed on the ground and in trees with clear weta prints in both positions. Tracking tunnels are especially useful for species that are endangered to prevent death from other methods such as pitfall traps (Watts *et al.*, 2011).

Tracking tunnels are still being trialled for the effective use with herpetofauna. The ability to identify gecko species by their footprints has proven successful in one study in which the *Naultinus gemmeus* gecko and the *Hoplodactylus maculatus* gecko were discriminated from their footprints (Jarvie & Monks, 2014). The best characteristics of the prints for distinguishing between the species were footprint measurements and ratios. Pattern recognition may also play a role in species identification (Russell *et al*., 2010). These two geckos are from two different genera and are found in different habitat types, which may make their prints relatively different from one another as opposed to two geckos of the same genera (Jarvie & Monks, 2014). This may not be a problem when most gecko species from a single genus do not exhibit sympatric distributions (Jarvie & Monks, 2014). There is also the potential for automatic recognition of a species through the use of developing imagery technology that has already shown a high success rate at recognising the footprints of small cryptic mammal species (Russell *et al.*, 2009). Authors of this study suggest it will be possible to tailor the technology to recognise species from other taxa.

Tracking tunnels are best suited for long-term monitoring. Tracking tunnels do not provide the total number of animals in a population but rather estimate a relative abundance. Therefore, they should only be used to compare the relative abundance of animals over time at one site or between a control and treatment site with similar habitat (Gillies & Williams, 2002). Their cost effective implementation makes them duly suited for use over a long period. Uusing tracking tunnels instead of alternative monitoring methods also allows the study of a larger area or, for the same area, allows the researcher to gather more detailed information (King & Edgar, 1977). Local activity may be determined at specific sites and changes to this activity may also be monitored.

Tracking tunnels do not work well if animals are present in high densities with the excessive footprints that result (Gillies & Williams, 2002). In such cases, saturation occurs in which the linear relationship assumed between the relative abundance estimated from tracking tunnels and the absolute abundance of a population is lost (Brown *et al.*, 1996). When this occurs, absolute abundance of the population may have altered from one time point to another, but the abundance index will not indicate any change. Another variable altering the linear relationship is the effect of other animals on the use of the tracking tunnels by the target species. Brown *et al.* (1996) found the use of tracking tunnels by mice increased as rats used them less often, following a decrease in the numbers of rats from an extermination operation. Learned avoidance or attraction to tracking tunnels can become a problem as the monitoring technique is no longer random when animals actively avoid or seek out tracking tunnels, which can bias distribution models (Bertram & Cogger, 1971; Phillips *et al.*, 2009).

5.1.2 Site occupancy

Site occupancy rates can be especially useful for monitoring programmes that cover a number of species over a wide area (Bailey *et al.*, 2004). Tracking tunnels' low maintenance and ease of dispersal over a large area of habitat make them an efficient way of determining site occupancy rates. If designed appropriately, they may also offer the ability to detect the presence of geckos over a greater variety of habitat as opposed to foam covers that have only be used in areas providing trees with large girth for attachment (Bell, 2009). The ability to bait the tunnels has the potential to increase the number of animals detected due to the increased use. This will decrease the possibility of failing to detect at least one target animal when they are present in an area. Decreasing the occurrence of such errors will increase the accuracy of site occupation models (Gu & Swihart, 2004).

This study investigated the efficacy of a new tracking tunnel design for its ability to determine the presence of arboreal geckos in areas of both relatively low and high abundance. Tunnels were trialled in areas where geckos were known to reside as determined from Chapter 2 results. This study only focused on the arboreal tendencies of the geckos, as this is the microhabitat used by all three gecko species, and is expected to present the greatest difficulty in creating a successful tracking tunnel design. A tracking tunnel made for placement on the ground would also have different attributes than one used in trees and require adjustments in design, a process beyond the scope of this study. It was hopped this investigation would provide the first step in tailoring a new technique that, in theory shows great potential for monitoring arboreal geckos over a long period of time with minimal effort.

5.2 Objectives

1. Trial a tracking tunnel design for its effectiveness in determining the presence of arboreal geckos in an area of relatively high and low abundance.
2. Investigate the use of tree tracking tunnels by three species of arboreal gecko (Pacific, forest and green) in relation to its position in terms of its height in the tree and distance from the tree trunk.

5.3 Methods

5.3.1 Captive study

Tunnel designs were trialled with captive Duvaucel's geckos (*H. duvaucelii*), kept in naturalistic outdoor enclosures at the Massey University Reptile Facility. These geckos are semi-arboreal and have nocturnal habits (Hoare *et al.*, 2007). Duvaucel's are insectivores but also feature fruit and seeds in their diet like many other New Zealand native gecko species, including Pacific, forest and green geckos (Barwick, 1982). Duvaucel's geckos make an ideal candidate to trial tracking tunnel designs as they readily eat banana, common bait in tracking tunnels.

Three tunnel designs were trialled. The design consisted of a 1.5 L clear plastic water bottle with a 92mm diameter and both ends cut off to create a tube-like tunnel, about 30cm in length. The tracking card was trimmed to fit horizontally along the bottle. Ink was applied to the middle of the card to create a strip. Non-toxic Black Track ink (Pest Control Research Ltd; Christchurch, NZ) was used, especially adapted to resist drying over long periods of time. Banana was placed in a bottle cap and stuck to the middle of the ink strip. The length of the strip was important, ensuring it was long enough for the gecko to have to step on it, in order to get to the banana. The card with the ink and bait was then attached with bull clips at either end to the water bottle cylinder. Enclosures included at least two geckos, and had a length of about two metres, and width and height of one metre. The tracking tunnel was attached securely to a tree branch, within the cage, with malleable garden wire. This design was the only one to work effectively with footprints clearly visible on the tracking card. One of the failed tunnel designs also consisted of a 1.5 L water bottle. The only difference was the position of the ink which was placed at either end of the tracking card instead of the middle. The process was deemed too untidy to be completed repeatedly in the field. The third tunnel design used carbon paper in place of the ink, but the geckos were too light to leave any impression. Tunnels were placed in the gecko cages and baited with fresh banana. They were left overnight and checked for footprints the next day, and were kept in for three days. These trials were completed in May of 2014.

The field trial used the same design as the successful tunnel but a more cost effective design (750 ml cup) was used (Figure 5.1). As the study species were smaller than Duvaucel’s geckos, it was expected that it would work just as well on them. A margin of plastic tape, approximately four centimetres long was also added to the centre of the card, where the ink would be applied. This way, the ink remained moist for a longer period of time as it was not absorbed by the cardboard material of the tracking card.

Figure 5.1 Gecko tunnel with a tracking card inside attached with bull clips. The tunnel is attached to the tree with malleable garden wire. Photo: Brigid Chamberlain

5.3.2 Field trial

Tunnels were set up without ink a week in advance to allow the geckos to acclimatise to the structures (Gordon, 2010). Tunnels were then set up as outlined above with tracking cards and ink. The tunnels were checked three days in a row to assess the condition of the bait and the tracking cards over time (from 28/05/14 to 31/05/14). Checking determined whether footprints were not excessive on the tracking cards and whether bait remained in good condition, in order to be confident in leaving both out for an extended period without checking. If footprints are excessive from a high density of animals or great activity in the area, then cards must be inspected and replaced more often (King & Edgar, 1977). Otherwise, the same cards can be left out for as long as the ink stays moist (King & Edgar, 1977).

After initial checks, tunnels were left out for a longer time period, with checks completed every four to six days, in order to increase the likelihood they would be used by the gecko species. They were left out with tracking cards and bait for two weeks, re-baiting and renewing tracking cards twice during this time (from 31/05/14 to 17/06/14).

Temperature ranges and rainfall information for the tracking period was taken from MetService as weather is known to influence the activity and movement of geckos and may aid in explaining results (Huey & Pianka, 1977).

5.3.2.1 Tunnel set-up at Tawharanui

The site H VES transect (see Chapter 2), having had previous encounters with a large number of geckos (56 forest geckos and 57 green geckos over three years), was used. Tracking tunnels were set up along the transect where lower vegetation foliage was accessible. This section of the transect was set up by marking 30 points 20 m apart. Thirty tunnels were set up within two metres of each of these 30 points (total of 90 tunnels). DOC (2014) recommends the placement of traps 20 m apart for use in general inventories. The use of a transect will provide greater coverage of an area, which is important for inventories that aim to elucidate the range of populations (Department of Conservation, 2014). Ideal microhabitat took precedence over distance apart when placing tunnels, as microhabitat characteristics can influence the use of the tunnels by the geckos, a technique known as 'micro-siting' (Lettink, 2007).

At each point, tunnels were placed in one of three positions and on different trees in order to avoid unknown interaction effects and to prevent a high intensity of habitat manipulation which may influence natural behaviour (Department of Conservation, 2014). Thirty tunnels were placed between one and four metres high on the outer foliage of the tree. Thirty tunnels were placed on the trunk of the tree or on a branch no more than 50 cm from the trunk of the tree and between two and four metres in height. Thirty tunnels were placed two metres or lower in height on a branch of the tree. Distance from the path was zero to five metres for all tunnels. The tunnels and tracking cards were attached to the tree with malleable wire and bull clips, respectively.

5.3.2.2 Tunnel set-up at Shakespear

The tracking tunnels were set up at Shakespear in the same manner as at Tawharanui using the site C VES transect (see Chapter 2) which had a lower number of gecko encounters (two Pacific geckos over three years) than the site H transect. Trialling the tracking tunnels at Shakespear tested whether they were successful at detecting geckos in low abundance. The overall VES CPUE's have been consistently lower at Shakespear than at Tawharanui (see Chapter 2).

5.4 Results

5.4.1 Gecko footprints

A single gecko print was found on a tracking card on the 7/6/2014. The tracking tunnel was at Shakespear Regional Park on a *Coprosma* species in the foliage. The species could not be determined from counting the lamellae as they were not clear (Jarvie & Monks, 2014). The print was assumed to be a Pacific gecko's, based on the results of VESs at the park (see Chapter 2) and from the width of the toe pads that were larger toward the periphery of the toes, which is in contrast to the sympatric green and forest gecko species (see Chapter 2). The green gecko's footpad print has a larger toe width in the middle of the toe, and the forest gecko's footpad print has a consistent toe width along the length of the toe pad (Agnew, 2009). No gecko prints were found on any of the tracking cards at Tawharanui. The majority of cards with no prints visible on them still had banana intact when checked after five days, and ink was still moist.

5.4.2 Environmental variables

Temperatures ranged from 6.8 ^{O}C to 18.7 ^{O}C over the period of data collection. A maximum temperature of 16.0 ^{O}C was averaged during the day and a minimum temperature of 11.1 ^{O}C was averaged during the night. Most twenty-four hour periods before checks had no, or minimal rain (less than four millimetres), except for the period before the third check of the short trial of print density on cards, during which 8.8 millimetres of rain fell, and two periods before the second check of the full length trial, during which 23.4 and 37.8 millimetres of rain fell in less than twenty-four hours. All periods before checks included at least one twenty-four hour period in which no or minimal rain fell.

5.4.3 Mice and weta footprints

Of the 282 cards with tracks on them, only 10 had both mice and weta footprints, the other cards had weta or mice prints only (Table 5.1; Figure 5.2).

Table 5.1 Number of tracking cards with weta or mice prints from the 90 tunnels put out at each of the two parks. The figures in brackets indicate the percentage of the 90 cards with prints on them during each check.

		Number of cards with prints	
Park	Time between checks	Weta prints	Mice prints
Shakespear	1 night	0	2 (2 %)
		3 (3 %)	5 (6 %)
		9 (10 %)	14 (16 %)
	4-6 nights	20 (22 %)	20 (22 %)
		30 (33 %)	20 (22 %)
		16 (18 %)	24 (27 %)
Tawharanui	1 night	0	0
		3 (3 %)	1 (1 %)
		8 (9 %)	3 (3 %)
	4-6 nights	27 (30 %)	20 (22 %)
		23 (26 %)	12 (13 %)
		15 (17 %)	11 (12 %)

The bait was still in good condition on the majority of cards, without evidence of animal activity, and the ink was still moist.

Figure 5.2 Samples of tracking cards with mice prints (left picture) and weta prints (right picture). Photo: Brigid Chamberlain

5.5 Discussion

5.5.1 Seasonal differences

The low tracking rate of geckos found for this study may be partly due to the season in which it was conducted. Lizards are known to change their activity levels seasonally, dependent largely on their thermoregulatory needs. Thermoregulation allows lizards to maintain an optimal body temperature, allowing high levels of activity. It also maintains other necessary physiological processes (Adolph, 1990). Many lizard species are most active during the summer months (Huey & Pianka, 1977). The tracking rates of geckos can be positively correlated with temperature because of the subsequent changes in their activity levels (van Winkel, 2008). The current study was conducted during late autumn, when tracking rates of geckos can be low (van Winkel, 2008).

Included in seasonal differences are variations in day to day weather such as temperature, rainfall and wind. Daily weather conditions during the time of the study may have influenced the low number of geckos tracked. Lizards can delay their activity times if temperatures are not ideal (Huey, 1974). During the data collection phase, very low temperatures were recorded which may have reduced, if not stopped, lizard activity all together. Wind chill and rain can exacerbate heat loss from a lizard and thereby increase the problem faced with low temperatures (Huey, 1991). There were some periods of high rainfall during the data collection period which may have negatively affected gecko movements.

Tracking rates of the geckos may have been further disrupted by behavioural mechanisms for thermoregulation that lead to changes in microhabitat use. One of the main reasons for changes in microhabitat use through the seasons has been attributed to alterations in the thermal qualities and sun exposure of potential habitat for lizards (Paulissen, 1988). Seasonal adjustments in behaviour of lizards for thermoregulation are performed in order to maintain a constant temperature throughout the day (Christian *et al.*, 1983).

5.5.2 Competing species

The presence of mice, as evidenced from their prints, in a large proportion of tunnels may have dissuaded geckos from using them. The dissuasion of other species in the use of tracking devices has been witnessed for other species. The presence of rats around tunnels is known to cause a decrease in the use of tracking tunnels by mice (Brown *et al.*, 1996). The presence of mice may have a similar effect on the use of monitoring devices for lizards. Mice are attracted to baited pitfall traps as evidenced by captures, scats and partially eaten lizards in and around traps, and eyewitness accounts (Newman, 1994). Therefore, the presence of mice may bias results when analysing the distribution of geckos. Other animals found to increase their use of pitfall traps after mice eradication are native snails and weta (Newman, 1994). It may be possible to use unbaited tunnels in order to decrease the incidence of unwanted animals such as mice. Unbaited tunnels have worked well for other species (Watts *et al.*, 2011).

Mice are known to negatively affect biodiversity and fauna and may affect the actual abundance of lizards. House mice (*Mus muculus*) have been seen actively attacking lizards (Norbury *et al.*, 2014). They seem to pose the greatest risk to unestablished lizards such as those that have recently been translocated to a new habitat (Norbury *et al.*, 2014). But once lizards are established, the effect of mice is not as detrimental (Norbury *et al.*, 2014). On Mana Island, the capture rate of McGregor's skink (*Cyclodina macgregori*) in pitfall traps was significantly reduced and it was thought to be caused by an increase in mice numbers, resulting from land-use change (Newman, 1994). Mice are the only introduced mammal to establish itself on the island.

After a mouse eradication operation was initiated, the numbers of McGregor skink, common gecko (*Woodworthia maculatus*) and the Cook Strait giant weta (*Deinacrida rugosa*) caught in pitfall traps increased significantly (Newman, 1994). Although not as harmful as other introduced rodents, mice may still threaten lizard populations, especially those under stress.

CHAPTER 6

Conclusions

6.1 Baseline data

The data gathered so far from the Auckland Council's monitoring programme provides the initial baseline information on the populations of Pacific, forest and green geckos at three of its regional parks. The current model of the populations is one of unchanging abundance for all populations. This may be a result of low statistical power of tests either because the survey effort was too low, the change in abundance was too small to be detected, or a combination of both (Gerrodette, 1987). The monitoring programme is still in its infancy, but, as more data is collected, major changes in population parameters can be distinguished from cyclical changes. If the gecko populations do show signs of stress, through other means such as their collective BCI, survey effort can be increased in order to ensure changes in abundance indices are detected (Seavy & Reynolds, 2007). The effect of human induced pressures such as predator invasion events or increased developmental pressures can also be determined. Due to the differing predation pressures of the park, information on the benefits of different predator control regimes can be elucidated. This information will help ascertain whether a control regime is performing better at ensuring the health of the gecko populations are maintained and whether all parks should adapt it.

Improved knowledge of the behaviour of the gecko species gained from the monitoring programme can aid in the data collection process. Green and forest geckos make use of the upper canopy levels. While search tactics should not change from one year to the next, observers may be more liable to detect a gecko in the upper reaches of the canopy layers. As behavioural tendencies of the species are determined through continued monitoring, their use as an indicator of the health of ecosystems will become possible. All three gecko species show relatively good health. But whether the BCI is an accurate measure of the health of the geckos would need to be determined with an indepth study showing a correlation between the BCI and a direct measure of the health of individuals. Direct measure of health can include the reproductive success of individuals. Such a study includes many difficulties. It would need to be conducted in captivity or by continual tracking individual in the wild for re-capture analyses (Jakob *et al.*, 1996).

6.2 Standardisation of survey methods

One major bias, affecting the accuracy of monitoring data, is the change in personnel. Records of survey protocols should be kept up to date and in adequate detail for accurate replication. The value of the long-term data will be compromised if drastic changes in methods occur. The only way long-term data can be compared is by consistent methodology. Presently, the abundance indices should only be compared across a temporal scale from the same transect owing to the possibility of varying encounter rates in different vegetation categories. If abundance estimates are to be compared across parks the vegetation searched should be as similar as possible. It may also be justified to exclude transects with vegetation that has offered little or no detection success with geckos. So far the VESs are standardised for seasonal differences in weather and day-to-day changes in weather, such as rainfall. This study has confirmed that the necessity of stratifying sampling to avoid detection probability bias brought on by different phases of the moon is not necessary.

It may be possible to improve the collection of data. Not all geckos that were captured were measured or photographed. While it is not always possible to capture geckos, the importance of collecting all gecko measurements should be reiterated to field teams. Since diagnosing the physical condition of geckos is difficult when analysing photos, notes about the presence of scarring should be made when in the field.

More important variables that can be noted when out in the field and will provide important information for data analyses include distance to cover of gecko and tree species it was spotted on. Consistency in the use of torch manufacturers may also prevent differences in the detectability of geckos for each VES.

6.3 Site occupancy survey tools

Tracking tunnels were not effective at detecting the presence of arboreal geckos. However, more research should be conducted in this area as the potential to determine site occupancy for cryptic or rare species allows the opportunity to efficiently and effectively map their distributions in habitat not yet studied. CFRs have had success at detecting all three gecko species: Pacific, forest and green. They have, however, failed to detect the presence of green geckos where VESs have been successful. CFRs should be used as a tool complementing other survey techniques, rather than a stand-alone monitoring technique.

6.4 Future threats

One of the greatest threats to lizard species and their ecosystems may be an increase in extreme weather events. Thermoregulatory species are particularly sensitive to a changing climate, due to their difficulty in maintaining a constant body temperature. With temperatures on the rise and extreme weather events increasing, it is important to continue the monitoring of the gecko populations on an annual basis. Changes in the abundances of the gecko populations or to the measures of their health such as BCI, may also advocate the disruption of other ecosystem components. Not all species can be monitored, but surveillance of a key species can provide some insight into how other species within the ecosystem, with similar threats are coping.

Introduced predators are a constant threat. Their populations are difficult to control and eradication operations are often followed by re-invasions. Developmental pressures are especially relevant for the geckos at Whakanewha. It is the only park of the three that does not have definite physical boundaries. It is also the closest to residential development. Significant increases in the Auckland population over the next thirty years may threaten the lizard populations with continued residential development. Comparing changes in the survey data from Whakanewha to the two mainland islands will aid in understanding the effect of increases in human settlement. Even if the park maintains its borders, sections of suitable gecko habitat merging with the park are owned privately. These areas can easily be turned into residential developments, especially with the current housing shortage. Introduced predators are known to thrive in disturbed habitat as they have adapted to living alongside human settlements. With a greater density in humans, the traffic to the park and the rate of human disturbance will also increase.

6.5 Recommendations

The monitoring of the gecko populations at Shakespear, Tawharanui and Whakanewha would ideally be continued on a yearly basis. Consistency in survey efforts can help ascertain whether there are declines in population numbers. The number of surveyors would ideally remain consistent across surveys in order to reduce the potential bias. If comparisons of CPUE are to be made between parks, it would be best to ensure the type of vegetation in which VESs are undertaken is more similar in structure across the parks. Comparing trends in data between the gecko populations at Whakanewha with Shakespear and Tawharanui will allow an analysis of the effectiveness of poison based as opposed to predator-free fencing predator control regimes at the parks. There are benefits and disadvantages with both regimes, such as failure to fully eradicate pests with poison bait, or constant reinvasions through predator-free fencing (de Tores & Marlow, 2012). Which predator control regime is best suited for a management scheme is dependent on its objectives, and it is suggested that long-term monitoring be performed to determined the effectiveness of whichever approach is adopted (de Tores & Marlow, 2012). Continued monitoring of the gecko populations will ensure this is achieved. Increasing the number of visits to sites will increase the power of statistical tests and aid in uncovering slow changes in the gecko populations. The continued trial of tracking tunnels for arboreal geckos is recommended as they have been used successfully for mapping the distribution of other animal species.

It is important that objectives of the monitoring programme are clear. Ideally time-related goals should be considered. This will force managers to re-analyse the objectives of the monitoring programme, once the goals have been reached, and decide whether any more information can be gathered from continuing monitoring efforts (Gibbs *et al.*, 1999; Platt, 1964). Considerations should be made as to acquiring data that can be compared across the parks, allowing for the comparisons of management schemes (Nichols & Williams, 2006). This will enable managers to determine whether changes to the schemes can increase the welfare of the gecko populations or reduce costs, without compromising population health.

It is important and more beneficial if the collection of data is driven by a problem. Referred to as a targeted monitoring approach, having a goal to work toward while monitoring, such as determining the extent of the effect of pests in the parks, can increase the effectiveness of data collection (Nichols & Williams, 2006). Now that the collection of the baseline data for the gecko populations has been initiated and partly completed, the next stage in managing the gecko populations should be considered. The parks are popular destinations for tourists and experience a lot of foot traffic. Negative consequences for the gecko populations include soil erosion and compaction that can impact vegetation, direct damage to vegetation, and noise pollution (Buckley & Pannell, 1990). Measuring these impacts along with continued monitoring of the gecko populations can help determine whether they are affecting them negatively.

6.6 Overall study outcomes

This study been useful in determining the current status of the gecko populations at Shakespear, Tawharanui and Whakanewha. It has helped ascertain that, while populations appear to be stable, an increase in sampling intensity can increase the sensitivity of tests for changes in population abundance indices. This study has also highlighted the need to maintain consistent, monitoring protocols, with special regards to the number of observers. The vegetation discussion in the context of available literature suggested population abundance indices should not be compared between parks because of the possibility of large variations in habitat variables affecting the proportion of geckos detected. The study has negated the need to adjust monitoring times in accordance with different phases of the moon.

Appendix I

Transect identification and the date visual encounter surveys were conducted on each.

			Date	
Park	Transect ID	2012	2013	2014
Shakespear	Site A	8/3	14/3	11/3
	Site B	27/3	7/3-14/3-25/3	11/3-26/3-9/4
	Site C	15/3	4/4	23/4
	Site D	15/3	25/3	9/4
	Site E	8/3-15/3-27/3	7/3	26/3
Tawharanui	Site F	12/3	5/3	17/3
	Site G	12/4	18/3	3/3
	Site H	12/3-29/3-12/4	5/3-18/3-27/3	3/3-17/3-1/4
	Site I	-	27/3	-
Whakanewha	Site J	10/4	13/3	15/4
	Site K	13/3-26/3-18/4	13/3-20/3-2/4	19/3-2/4-15/4
	Site L	18/4	9/4	30/4
	Site M	13/3	2/4	5/3
	Site N	26/3	20/3	2/4

#/# = day/month

Appendix II

Date, location and time of visual encounter surveys during the new and full moon.

Date	Park	Transect ID	Moonphase	Start time	End time
17/9/2013	Whakanewha	Site O	Full	19:00	20:35
17/9/2013	Whakanewha	Site P	Full	20:42	22:12
5/10/2013	Whakanewha	Site P	New	20:05	21:39
7/10/2013	Whakanewha	Site O	New	20:04	21:26
17/10/2013	Whakanewha	Site P	Full	20:14	21:55
18/10/2013	Whakanewha	Site O	Full	20:13	21:32
19/10/2013	Tawharanui	Site H	Full	20:12	21:25
20/10/2013	Tawharanui	Site F	Full	20:57	21:39
2/11/2013	Whakanewha	Site P	New	20:27	22:00
3/11/2013	Tawharanui	Site H	New	20:39	22:00
4/11/2013	Whakanewha	Site O	New	20:27	21:29
16/11/2013	Tawharanui	Site H	Full	20:40	22:45
17/11/2013	Tawharanui	Site F	Full	20:41	21:31
18/11/2013	Whakanewha	Site P	Full	20:41	21:47
19/11/2013	Whakanewha	Site O	Full	20:48	21:56
1/12/2013	Tawharanui	Site H	New	21:02	22:47
15/12/2013	Tawharanui	Site H	Full	21:07	22:57
15/12/2013	Tawharanui	Site F	Full	23:13	23:58
16/12/2013	Whakanewha	Site P	Full	21:08	22:50
17/12/2013	Whakanewha	Site O	Full	21:08	22:01
14/01/2014	Whakanewha	Site P	Full	21:13	22:45
15/01/2014	Whakanewha	Site O	Full	21:12	21:54
16/01/2014	Tawharanui	Site F	Full	21:12	21:53
16/01/2014	Tawharanui	Site H	Full	22:07	23:23
29/01/2014	Tawharanui	Site H	New	21:05	22:51
29/01/2014	Tawharanui	Site F	New	23:08	23:42
30/01/2014	Whakanewha	Site P	New	21:05	22:22
31/01/2014	Whakanewha	Site O	New	21:04	21:47
13/02/2014	Whakanewha	Site P	Full	20:50	21:52
13/02/2014	Whakanewha	Site O	Full	21:55	22:32
14/02/2014	Tawharanui	Site H	Full	20:57	22:17
14/02/2014	Tawharanui	Site F	Full	22:31	23:01
28/02/2014	Tawharanui	Site F	New	20:40	21:15
28/02/2014	Tawharanui	Site H	New	21:32	22:48
1/03/2014	Whakanewha	Site O	New	20:41	21:37
1/03/2014	Whakanewha	Site P	New	21:39	22:59

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