Efficiency of techniques for post-translocation monitoring of the Duvaucel's gecko (*Hoplodactylus duvaucelii*) and evidence of native avian predation on lizards

A thesis submitted in partial fulfillment of the requirements for the degree of
Master of Science in Conservation Biology
Massey University, Auckland,
New Zealand.

Dylan van Winkel
2008

Dedicated to

STEVE ROBERT IRWIN
(February 22, 1962 - September 4, 2006)

A true conservation hero

Abstract

Translocation of threatened reptile species to pest-free offshore islands is one of the most important conservation management tools available in New Zealand. However, a limited knowledge of how an animal responds to translocation and what factors threaten their survival prevails. Post-translocation monitoring is crucial and may help explain the reasons for translocation failure, but only if monitoring techniques are effective in detecting animals post-release. This thesis documents the post-release response of two small populations of Duvaucel's geckos (*Hoplodactylus duvaucelii*) using radio-telemetry, translocated to Tiritiri Matangi and Motuora Islands in December 2006. The efficiency of three standard reptile monitoring techniques, including spotlight searching, artificial refuges, and footprint tracking tunnels were tested and the impact of native bird predators on island lizards was investigated.

Following translocation, no mortalities were recorded and the geckos increased in body condition by 22%. Post-release activity was shown by small initial movements within the first week, followed by increasingly large-scale (up to 480 m), non-directional movements thereafter. Range areas were atypically large (up to 7,820 m²) as a result of the large-scale dispersal movements however few geckos did demonstrate small range areas. There were no sexual or island site differences in the dispersal movements or the range area estimates, suggesting that all geckos responded similarly to the translocations and release into a novel environment. Several neonate *H. duvaucelii* were captured on both Tiritiri Matangi and Motuora, and their high body condition scores indicated that they were capable of surviving and securing adequate resources.

All three reptile monitoring techniques were capable of detecting *H. duvaucelii* at low densities these methods however differed significantly in their detection abilities.

Footprint tracking tunnels demonstrated the most consistent detection rates, probably due to the provision of attractive baits. Spotlight searching resulted in the recapture of 21% and 75% of founders on Tiritiri Matangi and Motuora, respectively. However, this method relied heavily on skilled fieldworkers. Artificial refuges (A.R.s) were the least effective for detecting geckos at low densities and A.R.s were only occupied by *H. duvaucelii* on Tiritiri Matangi Island. Environmental conditions significantly influenced the effectiveness of the monitoring methods, with temperature having a highly positive influence on tracking rates and spotlight encounters.

Native birds, including kingfishers, pukekos, moreporks, and Swamp harriers are reportedly known to prey on lizards. Dietary analyses of these species revealed that lizards represented a large proportion of the prey for kingfishers on Tiritiri Matangi (88%) and Motuora (43%), and that kingfishers have the potential to seriously impact on small establishing lizard populations. Lizard remains were not present in the diet of any other bird species sampled and captive feeding experiments were inconclusive in determining if lizard remains could be detected in pukeko faeces.

This research can aid in the further understanding of post-release responses of lizards to translocations and the factors that threaten their establishment. The provision of adequate habitat quality and size, release locations with a reduced number of known bird predators, and the instatement of long-term monitoring programmes will help improve the translocation success of threatened lizard species in the future.

Acknowledgements

Yeeeewwwwww!!! …and now that it’s done, I’m going surfing!

But first…there are so many people to thank and acknowledge for all their help and support throughout the last two and half years of this thesis. First of all I would like to thank my supervisors Weihong Ji and Dianne Brunton. Thanks Weihong for always having time to listen, provide advice, discuss new ideas, volunteer in the field, and supply the most delicious dumplings and food to keep me powered up during writing. You are always positive and I could not have asked for a better supervisor, so thank you again. Thanks Dianne for providing ideas and helping me with my statistics.

To my family, Dad, Mom, Carly, Jason, Gagga and Grandpa, Rex, Sabu, and the geckos, you guys mean the world to me. Your support, encouragement, and positive attitudes have got me through my time of study. Dad, you have taught me that discipline, focus, and hard work pays off and gets you places. Mom, you have always been there for me, cheering me up during the lows, and cracking me up even more during the highs. We share similar passions for the natural world and you inspire me to learn all I can about it. Thanks Carly and Jason for always cheering me up and keeping me amused with questions like “how’s your thesis ‘thingy’ going?” and Jay, how you claim you are so tough…pfffft…you know I’d waste you…haha. Gagga and Grandpa, the most special people in my life, you have given me the strength to be who I want to be and have taught me that life will reward those who mean well and work hard. And to the animals (the hounds Rex and Sabu, and the gecko crew), you are my inspiration for studying animals and every time I get to see you guys you reassure me that I’m doing the right thing.

A big thank you to all those in the ecology lab who have made my time here enjoyable and kept me entertained at the daily coffee breaks. Thanks Weihong Ji, Marleen Baling, Manuela Barry, Chris Wedding, Mike Anderson, Luis Ortiz Catedral, Jo Peace, Monique Jansen van Rensburg, Mark Seabrook-Davidson, Kevin Parker, Karen Stockin, Mark Delaney, Ben Barr, Birgit Ziesemann, Anna Gsell, Cheeho Wong, Jurgen Kolb, Kirsty Denny, Dianne Brunton, Rosemary Barraclough, and David Raubenheimer

A very special thanks to Marleen, Manu, Monique (aka Tony Robbins), Luis, Mike, and Jo for their super support throughout this write-up. Huge thanks to Weihong Ji, Chris Wedding, Marleen Baling, Manu Barry, Mike Anderson, and Luis Ortiz Catedral for reviewing drafts and providing countless comments on my thesis.

To Dave Jenkins, Helen Lindsay, Jennifer Haslem, Ian Price, Deane Williams, Andrea Ravenscroft, Wendy John, Robin Gardner-Gee, Marleen Baling, Weihong Ji, Rose Thorogood, Kevin Hawkins, Liz Norquay, Ray Downing, Kit Brown, Simon and Morag Fordam, Mel and Sonya Galbraith, Megan Wilson, Manu Barry, Bret Sterwart, thank you for volunteering to walk around an island in the dark looking for small inconspicuous geckos!, and thanks to those for helping me troop excessive amounts of gear on and off islands.

Also, thanks to those experts who have provided help and comments on various aspects of this thesis. Thanks to Trent Bell, Tony Whitaker, Dave Towns, Tony Jewell, Jo Hoare, Doug Armstrong, Murray Potter (Muzza Pozza), Brett Gartrell, Brian Gill, Shirley Pledger, Richard Sharp (for abseiling skills), the stats tutor guy, and members of the herpetological society. A special mention goes out to Rachel Summers for her patience and persistence during the many video conference sessions on how to use GIS programs.

Big ups to the naki boys, Gordan, Jeff, P-dog (Preston), and Mogli (Matt) for hassling me to finish studying! And thanks to the flattys and friends for their encouragement.

The research in this thesis was approved by the Massey University Animal Ethics Committee (Protocol 06/98) and the Department of Conservation (permit AK-19734-FAU). Funding was provided by the Society for Research on Amphibians and Reptiles in New Zealand (S.R.A.R.N.Z.) Herpetological Research Award, the Supporters of Tiritiri Matangi Research Fund, and the Motuora Restoration Society (M.R.S.).

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CHAPTER 1

General introduction

Plate 1.1 *Hoplodactylus duvaucelii* appeared from behind coastal flax (*Phormium tenax*). (Photograph by author).

1.1 New Zealand’s biota and their conservation

New Zealand’s unique and archaic biotas are the result of an extensive isolation (ca. 80 million years) from the super continent Gondwana (Stevens *et al.*, 1988; Daugherty *et al.*, 1993; Daugherty *et al.*, 1994; Saunders, 1995). These fauna and flora exhibit unusually high levels of endemism and extensive radiation within some taxonomic categories, such as *Powelliphanta* land snails (Climo, 1975) and *Hoplodactylus* geckos (Hitchmough, 1997). Such characters are rivaled by few other archipelagoes around the world, including similarly isolated islands such as Hawaii and the Galápagos (Daugherty *et al.*, 1993). New Zealand’s native lizard fauna demonstrate these characteristics to the highest extent, exhibiting 100% endemism and comprising more than 80 species (Hickson *et al.*, 2000). In addition, the lizard fauna are considered to comprise the most diverse and speciose genera of all of New Zealand’s terrestrial vertebrates. In comparison, New Zealand’s extant terrestrial birds demonstrate only 32% endemism (Daugherty *et al.*, 1994) and comprise ca. 53 species (Daugherty *et al.*, 1993).

The evolutionary history of New Zealand’s fauna and the isolation from predatory mammals has meant that specialisations such as flightlessness (i.e. some birds and invertebrates), extensive life histories, late onset of sexual maturity, and low rates of reproduction (i.e. reptiles) have evolved (Wilson, 2004). This has meant that they are particularly vulnerable to environmental modifications and stochastic events because they are slow to recover (Daugherty *et al.*, 1993; NZBS, 2000). Recent human colonisation, ca.1000 years ago, had immediate and ongoing detrimental impacts on this unique ecosystem through habitat destruction, fragmentation, and the introduction of mammal predators (Davidson, 1984; Towns, 1994; Craig *et al.*, 2000). Agriculture, exotic forests, and urban landscapes presently comprise 63% of New Zealand's land area and have created a patchwork of isolated fragments from a once continuous range of natural ecosystems (NZBS, 2000). New Zealand accommodates the highest number of introduced predatory mammals of any country in the world (Towns, 2002). As a result, New Zealand's native biodiversity has undergone dramatic declines leaving many species threatened with extinction. Currently, some 2,500 species of native plants, animals, and fungi are considered threatened (NZBS, 2000; Hitchmough *et al.*, 2007), and thirty-two percent of endemic birds, six reptile and amphibian species, one bat, one fish, at least 12 invertebrates, and 22 vascular plants have become extinct (Wilson, 2004).

Many mainland faunas now persist only in small isolated habitats, some of which are too inhospitable for introduced predators. For example, the survival of a recently discovered skink species (*Oligosoma pikitanga*) from Fiordland is partially attributed to the steep cliffs it inhabits and the harsh, rugged surrounding terrain, making it almost impenetrable to predators (Bell & Patterson, in press).Therefore, the persistence of many mainland populations relies on intensive conservation management efforts to provide protection from these continuous threats. Mainland island sanctuaries, including Karori, Mangatautari, and Rotokare have been created by non-governmental organisations (NGO's) for the protection of native flora and fauna. Similarly, predator-proof fencing at Macraes Flat has been considered the last hope for the critically endangered grand and Otago skinks (*Oligosoma grande* and *O. otagense*, respectively). Recent figures of population trends have predicted both of these species to be extinct in the wild by 2010 (Norbury *et al.*, draft).

Pest-free offshore islands also continue to serve as important wildlife refuges, and many are protected with stringent quarantine procedures and restricted public access, such as Little Barrier Island (Hauraki Gulf), Stephen's Island, and Maud Island (Milford sound) (Towns & Robb, 1983; Daugherty *et al.*, 1990a). Codfish Island (*Whenua Hou*), west of Stewart Island, is the focus of recovery efforts for the critically endangered kakapo (*Strigops habroptilus*). This island supports almost the entire breeding population of this species (Lloyd & Powlesland, 1994; Anonymous, 1996). Until recently, half of New Zealand's native leiopelmatid frogs and both species of tuatara (*Sphenodon* spp.) survived only on pest-free offshore islands (Towns, 2002).

In response to the state of declining indigenous biodiversity, the Department of Conservation (DOC) have implemented the "New Zealand Biodiversity Strategy (2000)" with intentions of conserving and sustainably managing New Zealand's biodiversity. Species translocations for the restoration of offshore island and mainland sanctuaries have shown promise in the past (Veitch, 1986; Atkinson, 1990; Craig & Veitch, 1990; Daugherty *et al.*, 1990a; Towns & Atkinson, 1991; Towns & Ballantine, 1993) and therefore feature prominently within this strategy. These programs are aimed at lowering the vulnerability to extinction of rare species, decreasing threats to rare communities, and in the longer-term, re-establishing lost trophic links in ecosystems, thereby restoring natural processes of evolution. This approach is regarded as a practical means of decreasing the rate of global diversity decline (Towns *et al.*, 1990a).

1.2 Translocation

The movement of plants and animals (deliberate or otherwise) has been occurring for thousands of years and under many different circumstances. The ancient Romans have been held responsible for the current discontinuous distribution of the Aesculapian snake (*Elaphe longissima*) as a result of multiple translocations conducted for the purposes of rodent control in their temples, some 2000 years ago (Mehrtens, 1987). More recently, translocations have been applied specifically within conservation management with an ultimate goal of preserving species from extinction.

For the purpose of conservation management, the term ‘translocation’ has been defined as the intentional release of animals at a new location in an attempt to establish a new population, re-establish an extirpated population, or augment a critically small population (Griffith *et al.*, 1989). Some translocations may be classified as ‘re-introductions’. A re-introduction is defined as an attempt to establish a species in an area, within its historical range, from which it has been extirpated or become extinct (Reinert, 1991; Armstrong & Craig, 1995; Wolf *et al.*, 1996; IUCN, 1998). Translocations are driven by many goals and ambitions (Griffith *et al.*, 1989; Dodd & Seigel, 1991; Stuart, 1991). In many instances the primary objective is conservation of rare or threatened species through the establishment of new populations.

Translocations occur frequently around the world, reflecting their significance in conservation management. Nearly 700 programs are estimated to occur annually in North America (Griffith *et al.*, 1989). In New Zealand, over 400 translocations of at least 50 taxa have occurred in the past 60 years (Saunders, 1995). Compelling success stories include those of reintroduced American bison (*Bison bison*), pronghorns (*Antilocapra americana*), Arabian oryx (*Oryx leucoryx*), and black-footed ferrets (*Mustela nigripes*). In New Zealand, translocations have been crucial for the preservation of several New Zealand birds including the Chatham Island black robin (*Petroica traversi*), little spotted kiwi (*Apteryx owenii*), takahe (*Porphyrio mantelli*), South Island saddleback (*Philesturnus carunculatus carunculatus*), and the kakapo (*Strigops habroptilus*) (Armstrong & McLean, 1995). Furthermore, the restoration of *Oligosoma* skink populations has been advocated through the use of translocations to restore populations within their natural geographic range (Towns, 2002).Thus, translocation appears to be an effective tool for conserving at least some species in the face of habitat loss and extinctions (Wolf *et al.*, 1996).

1.2.1 Translocation theory

Despite the widespread use of translocations in conservation management, there is still a poor understanding of the underlying theory behind the success of translocations (Armstrong & McLean, 1995; Stockwell & Leberg, 2002). A lack of theoretical knowledge can have counterproductive and/ or detrimental effects on the success of a translocation. For example, poor management and techniques are highlighted by over 80 failed North Island weka (*Gallirallus australis greyi*) transfers since 1957 (Saunders, 1995). Ruffell (2005) emphasises three important consequences of failing to understand relevant theory, as identified by other authors. These include: a low power to predict the outcome of future releases due to unclear information on factors influencing success or failure (Armstrong & McLean, 1995), an inability to refine transfer protocols due a lack of experimentally testing clear assumptions (Armstrong & McLean, 1995), and a poor understanding of the viability of translocation as a conservation tool (Griffith *et al.*, 1989). These consequences are at least partially due to the lack of information gained by post-release monitoring of the founder population.

In addition, a lack of clear, predetermined research objectives and protocols for post-release monitoring have meant that translocations have been applied as practical tools, borne out of necessity, rather than as scientific conservation strategies (Soulé, 1985; Armstrong & McLean, 1995; Ussher, 1999b; Armstrong *et al.*, 2002). In a review of internationally published papers on animal re-locations, Fischer & Lindenmayer (2000) reported a 26% re-introduction success rate suggesting a need to reduce *ad hoc* approaches and carefully monitor relocations. Increased publication of results from past translocation projects, regardless of outcomes, is crucial for wildlife managers and conservation biologists to make informed decisions regarding future translocations (Griffith *et al.*, 1989; Fischer & Lindenmayer, 2000; Germano, 2006).

1.2.2 Factors influencing translocation success

A translocation may be considered successful if it results in the establishment of a self-sustaining population (Griffith *et al.*, 1989). There are several methodological and biological factors that may affect the outcome of a translocation. These include the number and productivity of founders; the distance of the recipient site from the source population; whether the species was released within its core historical range; the habitat quality; and the removal of all factors threatening the survival of the species (e.g. predation, habitat degradation, resource competition, competitive exclusion) (Griffith *et al.*, 1989; Saunders, 1995; Wolf *et al.*, 1996). The importance of the latter two factors is emphasised by the IUCN, which lists them as crucial criteria to be satisfied in order to justify a translocation (IUCN, 1987).

In addition there are other factors that may significantly impact on the outcome of the translocation, such as the potential for disease transmission (Cunningham, 1996), the social structure of founders (Towns & Ferreira, 2001), long-term genetic viability (Stockwell *et al.*, 1996), and predatory effects (Armstrong & McLean, 1995). A translocation can not be considered successful if it damages the source population (Gaze, 2001). Therefore, the impacts of harvesting source populations and issues described above require consideration (Dimond & Armstrong, 2007). These are briefly discussed below.

1.2.2.1 Disease transmission

Disease transmission may have serious consequences if introduced to novel populations through translocation of infected individuals. For example, the introduction of upper respiratory disease syndrome (URDS) from captive to wild populations of desert tortoises (*Gopherus agassizii*) in the western United States caused significant morbidity and mortality, leading to the federal protection of the species (Dodd & Seigel, 1991). Therefore, strong recommendations are given for the application of disease-screening and quarantine for all animals destined for translocation (Towns *et al.*, 1990b; Dodd & Seigel, 1991; Cunningham, 1996).

1.2.2.2 Founder demographics

The significance of founder demographic characteristics in translocation success is highly debated in literature (Dodd & Seigel, 1991; Towns & Ferreira, 2001; Landers, 1981; Berry, 1986; Burke, 1991). Simulating the demography of a parent population may act to maintain social interactions among released animals (e.g. dominance, hierarchies, and harem formation), but may not render optimised conditions for maximal population growth (Dodd & Seigel, 1991). Conversely, population expansion may be increased by selectively manipulating a release population's demography to maximise productivity (i.e. releasing fecund females, unequal sex ratios). Towns & Ferreira (2001) provide evidence for the latter by computer simulations and field observations of *O. suteri* after manipulation of sex ratios and selection of gravid females for release.

1.2.2.3 Genetic variation

Small founder populations generally have lower genetic variation and therefore may place these populations at a greater risk from environmental stochasticity (Armstrong & McLean, 1995), or increase susceptibility to the potential effects of inbreeding. It has been argued that New Zealand's fauna have undergone unusually high levels of inbreeding due to their long history of small populations and that this has 'purged' deleterious alleles (Armstrong & McLean, 1995; Craig *et al.*, 2000; Jamieson *et al.*, 2006). For these reasons, genetic issues have had little influence on past New Zealand translocation strategies (Armstrong & McLean, 1995; Jamieson *et al.*, 2006). However, in a review of New Zealand inbreeding management, Jamieson *et. al.*(2006) advocated for better integration of genetic considerations into recovery plans and translocation protocols. The addition of further individuals to a translocated population some time after the release may act to compensate for some inbreeding effects (Armstrong & McLean, 1995).

1.2.2.4 Harvesting founder populations

The effects of harvesting source populations have been shown to induce modifications in population demographics and population growth rates (Pullin, 2002; Ruffell, 2005). Theoretically, negative density-dependent regulation should act to recover the source population to pre-harvest equilibrium (Ruffell, 2005). However, recovery is not guaranteed if the effects of over-harvesting upset regulatory mechanisms acting towards population recovery. Therefore, considering the effects of harvesting and applying post-harvest monitoring may ensure the source population recovers to a stable equilibrium (Dimond & Armstrong, 2007).

1.2.2.5 Predation

Removal of all factors threatening the survival of the founder population is crucial for the success of translocation (Griffith *et al.*, 1989; Saunders, 1995; Wolf *et al.*, 1996). Armstrong & McLean (1995) highlighted the importance of understanding whether a translocated species can coexist with predators present at a potential release site. In New Zealand, research has been focused almost entirely on the impacts of introduced mammalian predators on native wildlife and little emphasis has been placed on the role of native predator-prey interactions. Translocating lizards to protected islands has acted to augment highly threatened species and to mitigate the detrimental effects of mammalian predators (Saunders, 1995; Thomas & Whitaker, 1995; Towns & Ferreira, 2001). However, these islands are not completely free of predators and concerns are raised when considering the translocation of low numbers of rare and threatened animals to sites harbouring high abundances of native predators (Armstrong & McLean, 1995). In New Zealand, native birds such as pukeko (*Porphyrio porphyrio melanotus*), weka (*Gallirallus australis*), and morepork (*Ninox novaeseelandiae*) may reach exceptionally high densities on predator-free offshore islands and many are known to prey on lizards (Heather & Robertson, 1996; Beauchamp & Chambers, 2000). Despite largely anecdotal evidence of lizard predation by native birds in New Zealand, little attempt has been made to quantify predation rates.

A lack of understanding of natural-prey dynamics could have significant impacts on the outcome of threatened species translocations. For example, the failure of a translocated population of threatened shore plover (*Thinornis novaeseelandiae*) to establish on a protected offshore island was attributed to unpredicted predation by a native owl species, morepork (*Ninox novaeseelandiae*) (Aikman, 1997; Davis & Aikman, 1997; Aikmen, 1999). Similarly, predation by pukeko and native Swamp harriers (*Circus approximans*) appears to be limiting the population expansion of brown teal (pateke, *Anas chlorotis*) translocated to Tiritiri Matangi Island (Armstrong, 2006).

A suite of complex biological and ecological interactions may impact on the success of a translocation, however estimating the influence of these interactions is inherently difficult.

Appropriate monitoring methodologies may help to determine the effects of these interactions, address possible requirements for further management, and suggest improvements for the success of future translocations, thus providing positive feedback (Dodd & Seigel, 1991; Saunders, 1995).

1.3 Short- and long-term monitoring

In the absence of post-release monitoring, ascertaining the reasons for translocation success or failure becomes difficult (Ussher, 1999b; Fischer & Lindenmayer, 2000). A lack of detailed records on failed re-introductions of tuatara in the early 1900's meant that information for future guidance of transfers was not available. Both short- and long-term monitoring are now regarded as critically important elements within translocation projects (Dodd & Seigel, 1991; Armstrong & McLean, 1995; Fischer & Lindenmayer, 2000). While short-term monitoring may act to determine post-release survival and reproduction, an accurate evaluation of establishment can only be determined with implementation of longer-term monitoring.

Long-term monitoring can also ensure that release sites maintain their biodiversity integrity (Dodd & Seigel, 1991). However, the duration of long-term monitoring depends on the species' life history strategies such as age at sexual maturity, recruitment rate, and reproductive lifespan (Dodd & Seigel, 1991; Towns & Ferreira, 2001). For example, a study on a relocated population on gopher tortoises (*Gopherus polyphemus*) was deemed successful after only two years of monitoring or 10% of the time it takes for the tortoises to reach sexual maturity (Burke, 1991), hardly enough time to conclude re-location success (Dodd & Seigel, 1991). Long-term monitoring may extend more than 20 years for such a long lived species and would involve a substantial commitment of resources that in many cases may not be feasible (Burke, 1991).

Therefore, short-term indicators such as founder recaptures and presence of island born young are typically used for preliminary assessment of translocation success (Towns & Ferreira, 2001; Nelson *et al.*, 2002; Ruffell, 2005). The Tuatara Recovery Group's criteria for judging the progress towards establishment of tuatara populations are that at least 30% of founders are recaptured within three years and that island-born young are captured within 10 years (Nelson *et al.*, 2002). Ruffell (2005) described a translocation of tuatara (*S. punctatus punctatus*) to Tiritiri Matangi Island as 'successful' after two years, based on the first criterion, but lacked data for assessment of the latter. Importantly, it is not recommended that the automatic acceptance of success of one species be substituted for long-term monitoring and experimentation of a related species or premature conclusions on establishment (Dodd & Seigel, 1991). There is little doubt regarding the application of short-term monitoring. However, it should be accepted only as a preliminary step towards the assessment of translocation establishment.

1.3.1 Monitoring tools

Several qualitative and quantitative sampling techniques exist for monitoring reptile populations, including visual encounter surveys (VES) (Doan, 2003; Manley *et al.*, 2005; Grover, 2006), artificial cover objects or refugia (ACOs or ARs) (Engelstoft & Ovaska, 2000; Lettink & Cree, 2007; Lettink & Seddon, 2007), drift fence and pitfall trap arrays (Crosswhite *et al.*, 1999; Ryan *et al.*, 2002), footprint tracking pads (Siyam, 2006), and live traps (Hall, 1967; Jamieson & Neilson, 2007). Deciding on which technique(s) to apply requires consideration of both the logistics of implementation and the appropriateness of the data obtained. For example, ACOs and drift fences with pitfall traps were determined to be ineffective methods for surveying rainforest herpetofauna due to their time-intensive installation and maintenance (Doan, 2003). Corn & Bury (1990) noted that the choice of monitoring method(s) is dependent on the scope of the study, the target taxa, and the particular study objectives. The existence of strong sampling biases means that each method must be explored before its application and interpretation of results (Doan, 2003). Several of these monitoring techniques are used for herpetofaunal conservation within New Zealand. Most, however, are applied with limited knowledge and evidence of their efficiency. This is partially due to a general lack of basic ecological knowledge, such as habitat preferences, life-history strategies, activity patterns, and home-ranges of many native lizard species, which act to confound the ability to monitor them efficiently (Neilson *et al.*, 2004; T. Bell, unpublished data). An accurate assessment of the status of translocated herpetofauna is imperative for their future conservation. Therefore, quantitative examination of monitoring techniques requires further investigation to ensure the data obtained accurately represent the true result of a translocation.

1.4 Herpetofaunal translocations: International and New Zealand perspectives

Traditionally, translocations have been heavily biased towards vertebrates, especially mammals and birds (Seddon *et al.*, 2005). The first recorded translocations in New Zealand were those conducted by Richard Henry in the 1890's in an attempt to establish kakapo and kiwi (*Apteryx* spp.) on islands in Dusky Sound (Atkinson, 1990). More recently, increasing concern of worldwide herpetofaunal declines has prompted initiatives for their inclusion in translocations for conservation (Griffith *et al.*, 1989; Burke, 1991; Gibbons *et al.*, 2000; Towns & Ferreira, 2001; Germano, 2006; Hoare, 2006). Of these, a significant number of reptile re-locations overseas have been initiated in response to mitigation efforts for urban construction (Burke, 1991; Dodd & Seigel, 1991; Germano, 2006), such as the gopher tortoise (Dodd & Seigel, 1991).

In New Zealand, recognition of the significance of herpetofauna in functioning ecosystems has been an important impetus for their translocation to islands undergoing restoration (Whitaker, 1987; Payton *et al.*, 2002). Important roles include plant pollination (Olesen & Valido, 2003), frugivory and seed dispersal (Whitaker, 1987; Lord & Marshall, 2001), honeydew feeding (Eifler, 1995), as well as other important ecosystem functions such as predation (Spencer *et al.*, 1998), and prey for other animals (Walls, 1981).

Despite numerous efforts worldwide, herpetofaunal translocations have demonstrated low success rates in comparison to other vertebrates. A review of herpetofaunal translocations between 1978 and 1990 has established that, of those that could be assessed, only 19% were successful long-term (Dodd & Seigel, 1991). The study concluded that translocations were not effective conservation strategies for herpetofauna. Burke (1991) was in general agreement with Dodd & Seigel (1991) on some issues, but remarked that the evidence was weak and that re-location programs should at least be considered with application of cost/ benefit risk analyses. Similarly, a review by Germano (2006) on herpetofaunal translocations (1991 to 2006) concluded that only 29.4% resulted in long-term success, with uncertainties remaining high (50%). Despite these low reported success rates, an increasing number of herpetofaunal translocations continue to occur worldwide. This may indicate the importance of translocation as a crisis management tool, or that rewards gained from a potentially successful translocation are still great enough to drive conservation motives, despite reported low successes.

In contrast to overseas, New Zealand herpetofaunal translocations show atypically high success rates, with representatives from all six genera having been successfully translocated in the past (Armstrong, 2006; Germano, 2006). Typical life-history traits of New Zealand herpetofauna, such as low productivity (Cree & Guillette Jr., 1995) and late onset of reproduction (Cree, 1994), would be expected to confound assessments of a translocation's success. However, founder populations have exhibited high survivorship and high reproductive success (Towns, 1994; Thomas & Whitaker, 1995; Nelson, 1998; Ruffell, 2005), most likely reflecting high habitat quality and reduced predatory pressures provided by protected offshore islands (Daugherty *et al.*, 1990b; Armstrong & McLean, 1995; Ruffell, 2005).

There is a clear requirement to evaluate the inconsistencies of post-translocation monitoring and success, especially for cryptic lizard species. Ultimately, a better understanding of how a lizard population responds to translocation, identification of factors influencing their success of establishment, and the efficiency of monitoring methods at detecting lizards at low abundance, can enable improved management decisions to be made and contribute greatly to the conservation of threatened lizards.

1.5 Research objectives

This study investigates several important, yet understudied aspects of translocation theory, by documenting an intensive post-release monitoring programme of a translocated population of Duvaucel's geckos (*Hoplodactylus duvaucelii*) to two pest-free islands in New Zealand. The specific aims and associated objectives are outlined below.

1) To monitor the survival, dispersal, and activity of translocated *H. duvaucelii* on Tiritiri Matangi and Motuora Islands.

Questions: How does *H. duvaucelii* respond to an inter-island translocation and are there differences in the response of *H. duvaucelii* between the two island sites? Does translocation to a novel environment induce an initial dispersal phase?

2) Compare the efficiency of three standard reptile monitoring techniques for detecting cryptic geckos. Monitoring techniques include: i) footprint tracking tunnels, ii) night spotlight searching, and iii) artificial refugia.

   Question: With knowledge of founder population sizes, how well do these techniques work for detecting lizards at low density and abundance?

3) Describe habitat selection and artificial refugia preference by *H. duvaucelii* with implications for future monitoring.

   Questions: Do *H. duvaucelii* preferentially select habitat or is their habitat use in proportion to available habitat? Are artificial refuges preferred as refugia compared to natural refugia?

4) Quantify the rate of native avian predation on island lizard populations with implications for future translocation management.

   Questions: At what rate do native avian predators remove individuals from lizard populations? What are the implications for this on rare lizard species released at low densities?

These objectives will be investigated in four separate chapters, with a summary of results and future research directions presented in the final chapter. A single reference section covering all chapters is presented at the end of this thesis.

CHAPTER 2

General methods

Plate 2.1 Author (left) and volunteers (Ben Barr and Nick Lane) attaching a backpack radio-transmitter to a *Hoplodactylus duvaucelii* on Motuora Island. (Photograph by Dave Jenkins)

2.1 Study species

Duvaucel's geckos (*Hoplodactylus duvaucelii* Duméril, 1836) belong to the monophyletic subfamily, the Diplodactyline, of the family Gekkonidae (Bauer, 1990; Hitchmough, 1997). The group is represented by geckos found only in Australia, New Caledonia, and New Zealand (Kluge, 1967a; b; Hitchmough, 1997).

2.1.1 Morphology and biology

Hoplodactylus duvaucelii is New Zealand's largest extant gecko reaching total lengths of 320 mm (160 mm snout-vent length [SVL]) and can weigh up to 118 grams, at the most northern limit of their geographic range where they appear to be larger (Whitaker, 1968; Gill & Whitaker, 1996) (Plate 2.2). They are nocturnal (Gill & Whitaker, 1996) and typically take refuge in crevices during the day. They are recorded as being both terrestrial and arboreal (Barwick, 1982). As with most of New Zealand's herpetofauna, *H. duvaucelii* is long-lived (at least 36 years in the wild and captivity), slow breeding (≤ 2 young per year), and may take 4-7 years to reach sexual maturity (Barwick, 1982; Thompson *et al.*, 1992; Thony, 1994). They may remain active at remarkably low temperatures (< 8°C), possibly explaining the reason for their slowed growth and low recruitment rates (Barwick, 1982; Cree, 1994). Gestation usually lasts 7-8 months and females may have the ability to prolong gestation for extended periods if conditions are deemed suboptimal (Cree, 1994).

2.1.2 Distribution

The present discontinuous distribution and sub-fossil remains provides evidence that *H. duvaucelii* once had a more extensive distribution (Worthy, 1987; 1998). At present, *H.*

duvaucelii are known from 36 islands from the Cook Strait to Northland (Pickard & Towns, 1988; Towns, 1991). The Cook Strait population is spread over seven islands (Thompson *et al.*, 1992) and the northern population is distributed among 29 islands on the north-eastern coast of the North Island.

2.1.3 Threat classification

Hoplodactylus duvaucelii are listed under Category 6 (Sparse) by the Department of Conservation (DOC) New Zealand Threat Classification System (Hitchmough *et al.*, 2007). This category includes all taxa that occur within typically small and widely scattered populations. The discontinuous distribution of *H. duvaucelii* is regarded as human induced (HI) by DOC. The IUCN Red List classifies *H. duvaucelii* as 'Lower Risk'/ subcategory 'Least Concern' (LR/lc) with its history insufficiently known (Groombridge, 1994).

Plate 2.2 The Duvaucel's gecko (*Hoplodactylus duvaucelii*), is a large nocturnal gecko that inhabits coastal vegetation including coastal flax (*Phormium tenax*). (Photograph by author).

2.1.4 Translocation history

Past translocations of *H. duvaucelii* have included two transfers from North Brother Island (Cook Strait) to Mana Island (217 ha) near Wellington. The first transfer occurred in February 1998 involving 21 geckos, followed by a further release of 19 geckos in November 1998. Post-release monitoring included the implementation of pitfall traps, spotlight searching, artificial shelters, and the use of radio-transponders in an attempt to assess *H. duvaucelii* activity and daytime retreat sites. All methods were unsuccessful in detecting translocated geckos, with the exception of spotlight searches which located seven of the 40 *H. duvaucelii* founders (Jones, 2000). This study advocated for a refinement of monitoring techniques and recommended the implementation of long-term monitoring to assess the establishment of the population.

2.2 Study sites

This study was conducted in New Zealand on three offshore islands free of mammalian pests. The islands were Korapuki (Mercury Island Group, Coromandel), Tiritiri Matangi, and Motuora Islands (Hauraki Gulf) (Figure 2.1). A detailed description of each site is provided below.

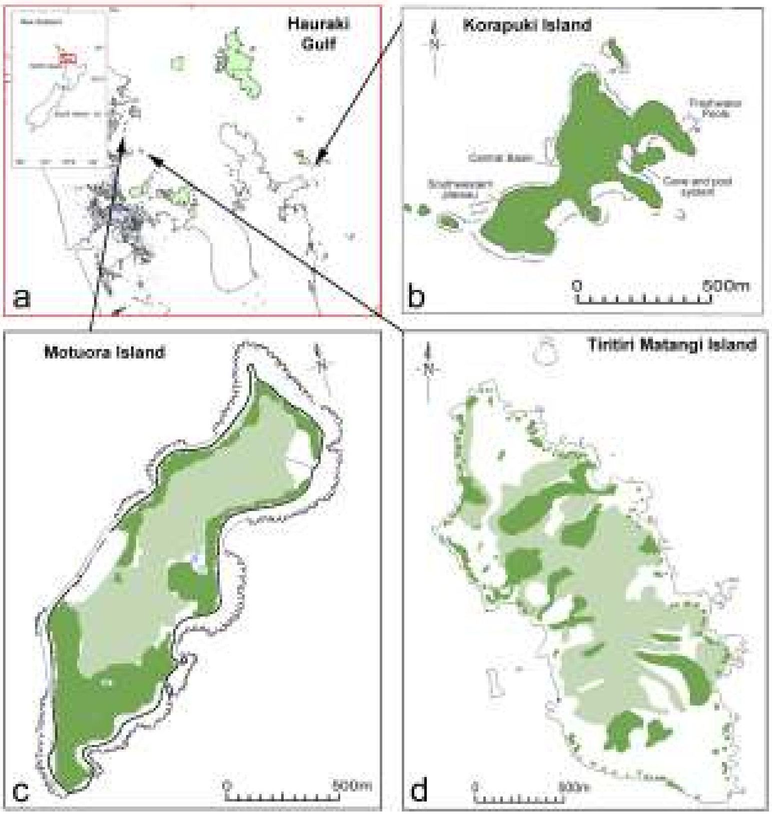


Figure 2.1 Map of New Zealand and the Hauraki Gulf (a). Enlargements showing (b) Korapuki Island, (c) Motuora Island, and (d) Tiritiri Matangi Island. Dark green indicates mature forest and light green indicates re-vegetated forest. (Modified from the Department of Conservation and Towns & Atkinson (2004)).

2.2.1 Korapuki Island

Korapuki Island, hereafter Korapuki, (36° 39.5' S, 175° 51' E, 18 ha) lies approximately 6 km off the eastern Coromandel Peninsula of New Zealand (Plate 2.3). It belongs to a group of islands known as the Mercury Island Group, which were all once connected to the mainland. Korapuki, Middle, and Green Islands remained connected up until about 6,000-7,000 years ago. Historical human occupation on Korapuki resulted in the destruction of forests by burning and the introduction of mammalian pests. After the eradication of kiore (*Rattus exulans*) and rabbits (*Oryctolagus cuniculus*) in 1986 and 1987 respectively, the island was proposed suitable for restoration (McFadden & Towns, 1991). A combination of natural vegetation regeneration through succession, natural re-colonisation, and direct restoration via faunal translocations has created an island refuge for conservation. Korapuki is classified as a Class A ‘Inviolable Reserve’ as part of the Hauraki Gulf Maritime Parks, with restrictions on landing access (Mossman & Millar, 1986). At present, the DOC administers the island as a Scenic Reserve, with secondary use as a wildlife sanctuary (Towns & Atkinson, 2004).

The island’s vegetation is dominated by coastal forest comprising extensive areas of pohutukawa (*Metrosideros excelsa*), mahoe (*Melicytus ramiflorus*), and karo (*Pittosporum crassifolium*) trees. Boulder beaches, fringed with dense flax (*Phormium tenax*), surround much of the island and large ngaio trees (*Myoporum laetum*) are patchily distributed throughout. Ngaio trees provide an important source of refugia for lizards due to their old hollow trunks and branches. Many plants that are beneficial to lizards as a food source are present on the island including flax, pohutukawa, kawakawa (*Macropiper excelsum*), ngaio, taupata (*Coprosma repens*), mahoe, and toetoe (*Cortaderia splendens*).

Although a relatively small fauna of native forest birds (five species), Korapuki hosts a diverse fauna of seabirds (seven species). The ground is littered with seabird burrows, many of which are utilised by resident lizard species. The reptile fauna comprises nine species of lizard, representing three genera, all of which are found at high densities (Towns, 2002; Towns & Atkinson, 2004). *H. duvaucelii* are found throughout the forest, in coastal scrub, and may occupy rocky beaches (Towns, 1996; Towns & Atkinson, 2004; Hoare, 2006).

Hoplodactylus duvaucelii populations translocated in this study were sourced from Korapuki Island for the following reasons: 1) it supports a high density of *H. duvaucelii*, 2) geographically, it is the closest natural population of *H. duvaucelii* to the release islands, 3) Korapuki lies on the same line of longitude as the release islands, thereby exhibiting similar environmental conditions, and 4) it is the most easily accessible island in the Mercury Island Group (D. Towns, *pers. comm*., 2006).

Plate 2.3 Korapuki Island (18 ha) (Mercury Islands, Coromandel) showing a boulder beach fringed with low coastal vegetation and heavily forested central region, comprised of pohutukawa (*Metrosideros excelsa*). Korapuki Island supports a very large abundance of threatened wildlife, including *H. duvaucelii*. (Photograph by author).

2.2.2 Tiritiri Matangi Island

Tiritiri Matangi Island, hereafter Tiritiri Matangi, (36°36' S, 174°53' E, 220 ha) lies in the Hauraki Gulf, 3.5 km east of Whangaparoa Peninsula and 28 km north of Auckland City (Plate 2.4). During the late Quaternary period (some 70,000-12,000 years ago) increasing temperatures resulted in melting ice and flooding of the Hauraki Gulf, subsequently isolating Tiritiri Matangi and surrounding islands from the mainland (Hayward, 1986; Rimmer, 2004). Tiritiri Matangi has had a long history of human occupation, possibly extending from 800 years ago when Maori settled in the Auckland region (Reid, 2007). Maori and European settlers employed burning in order to clear bush for cultivation and farming practices (Rimmer, 2004). Introduced mammals were liberated by both early Maori and Europeans. Farming continued until 1971 (Rimmer, 2004).

In 1970, Tiritiri Matangi was gazetted as a Recreation Reserve and became part of the Hauraki Gulf Maritime Park. The reclassification of the island to an Open Scientific Reserve in 1980 provided the opportunity for the public to become involved alongside scientists in restoring the island to its original pre-human state. Pest removal had already begun in the early 1900's and by 1993 rabbits, cats (*Felis catus*), goats (*Capra hircus*), and kiore had been eradicated from the island (Drey *et al.*, 1982; Mitchell, 1985). An extensive 10-year re-vegetation program began in 1984 and evidence of its success is apparent today with a variety of habitat types present, including open grassland, coastal scrub, regenerating forest, and remnant broadleaf forest (Mitchell, 1985).

A series of faunal translocations has led to the establishment of an island refuge for threatened species (Galbraith & Hayson, 1995). The island now supports a great variety of birds (75 species) including some of New Zealand's most threatened species. The resident reptile fauna is comprised of two species of skink (*Oligosoma moco* and *Cyclodina aenea*), one gecko species (*H. maculatus*), and the northern sub-species of tuatara (*S. punctatus punctatus*). No historical records of *H. duvaucelii* on Tiritiri Matangi exist. However, their present distribution on islands surrounding the Hauraki Gulf suggests they once occupied Tiritiri Matangi (Gill & Whitaker, 1996). The island's invertebrate fauna is diverse and has sufficient resources to support reptile fauna such as tuatara and *H. duvaucelii* (Ussher, 1999b; Ruffell, 2005).

Presently, Tiritiri Matangi is jointly administered by the DOC and The Supporters of Tiritiri Matangi Island (SoTM).

Plate 2.4 Tiritiri Matangi Island (220 ha) lies in the heart of the Hauraki Gulf. This Open Scientific Reserve provides one of the most successful examples of restoration efforts and now acts as a model for other reserves. (Photograph by A. Mitchell)

2.2.3 Motuora Island

Motuora Island, hereafter Motuora, (36°30' S, 174°47' E, 80 ha) lies in the Hauraki Gulf approximately 3 km from the Mahurangi Heads and 38km north of Auckland City (Plate 2.5). The island is long, narrow, and flat-topped with coastal cliffs, sandy beaches, and an extensive inter-tidal shelf (Gardner-Gee *et al.*, 2007). Much of the island's coastal forest was cleared by early Maori and European occupants leaving remnant pohutukawa, karo, mahoe, and scrub on surrounding coastal cliffs. Although considerably affected by human disturbance, Motuora is one of the very few islands that has never had introduced mammalian predators (Gardner-Gee *et al.*, 2007). Farming ceased in 1990 when the Royal Forest and Bird Protection Society initiated a plan with goals to "re-establish a thriving indigenous ecosystem and to create a sanctuary for endangered fauna and flora." (Gardner-Gee *et al.*, 2007).

At present the island is jointly managed by the Motuora Restoration Society (MRS) and the DOC. Invertebrate abundance in naturally regenerating forest is relatively high compared to other modified offshore islands (R. Gardner-Gee, unpublished data; Moeed & Meads, 1984; 1987), indicating the potential to support insectivorous fauna such as birds and reptiles. The resident reptile fauna, comprising only two species of skinks (*O. moco* and *C. aenea*), are found at low densities. Evidence from current species compositions of similar island ecosystems suggests that as many as 13 species of reptile could have been present on Motuora prior to modification, including *H. duvaucelii* (Gardner-Gee *et al.*, 2007).

After 15 years of afforestation efforts the island has entered the second stage of restoration; the implementation of faunal translocations. The first translocations began in 2006 involving Duvaucel's geckos, shore skinks (*O. smithi*), and again in 2007 with northern diving petrels (*Pelecanoides urinatrix urinatrix*).

Plate 2.5 Motuora Island (80 ha) is a predator-free Open Scenic Reserve which lies approximately 3 km from the mainland. Presently a kiwi (*Apteryx owenii*) crèche, the island has potential to harbour many species of native flora and fauna. (Photograph by Motuora Restoration Society)

2.3 Release island reptile surveys and disease-screening

Pre-translocation reptile surveys were conducted on both Tiritiri Matangi (29th October - 2nd November 2006) and Motuora Islands (February-May 2005 and 4th – 8th November 2006) to confirm local absence of *H. duvaucelii* and presence of potential competitive species (Habgood & Baling, 2007; Ussher & Baling, 2007) (Table 2.1).

Cloacal swabs and faceal samples were taken from all reptiles captured during the surveys as part of the disease-screening procedure. Samples were tested for the presence of *Salmonella*, *Cryptosporidium*, and *Giardia*.

Table 2.1 List of reptile species recorded on Tiritiri Matangi and Motuora Islands following translocations in December 2006.

Species	Motuora	Tiritiri Matangi
Hoplodactylus maculatus	Absent	Relict population
Cyclodina aenea	Relict population	Relict population
Oligosoma moco	Relict population	Relict population
Sphenodon punctatus punctatus	Absent	Translocated 2003
Oligosoma smithi	Translocated 2006	Translocated 2006
Hoplodactylus duvaucelii	Translocated 2006	Translocated 2006

2.4 Translocation

2.4.1 Animal collection

Sixty-nine *H. duvaucelii* were collected from Korapuki between the 23rd and 28th November 2006. Geckos were captured via hand searching through day (diurnal refuge sites) and night searches. Morphological information, including: snout to vent length (SVL; to 1 mm), vent to tail length (VTL; to 1 mm), and weight (on 100 g Pesola spring balance to 1 g) were recorded for each gecko captured. The geckos were sexed (i.e. presence of a hemipenal sac and large cloacal spurs indicated males), and the reproductive stage of females assessed by gently palpating the abdomen. The substrate on which they were captured was also recorded (i.e. ground, tree, or rocks). Only adult geckos with SVL's larger than 115 mm were collected as translocation subjects, due to the size limitation for insertion of passive integrated transponder (PIT) tags (*Allflex*®) into the individuals (R. Jakob-Hoff, *pers. comm*., 2006) (Table 2.2 and Table 2.3). Preferential selection of females in late pregnancy was applied with the intention of females giving birth soon after translocation. Geckos were placed in individual 300 mm plastic tubes (50 mm diameter), one end sealed and the other meshed for ventilation. The animals were transported via boat and car to Massey University, Auckland, and quarantined for two weeks.

2.4.2 Quarantine and disease-screening

The quarantine period acted to allow disease-screening, PIT tag insertion, and transmitter attachment trials (see Chapter 4, section 4.2.2). Quarantine also allowed animals to pass any gut contents carried from the source island, thereby eliminating the chance introducing foreign seeds onto other release sites. Animals were housed in compartmented containers and had access to UV lighting. Their condition was assessed daily and animals were fed mealworms (gut-loaded with reptile vitamins) twice a week with water provided *ad libitum*.

Cloacal swabs and faecal samples were collected from each individual for disease-screening. Samples were tested for the presence of *Salmonella*, *Cryptosporidium*, and *Giardia*. Geckos were considered for translocation only if they tested negative for disease. Thirty-nine geckos were selected for translocation. The remaining 40 animals were held at Massey University and used in a captive breeding program. PIT tags were inserted prior to translocation. The tags were inserted subcutaneously on the left flank anterior to the hind leg using a PIT tag applicator gun (*Allflex*®). The procedure, conducted under the supervision of a registered wildlife veterinarian, was quick and did not require anaesthetic (J. Potter, *pers. comm.*, 2006). The tags will enable future individual capture histories to be built (Ruffell, 2005).

2.4.3 Release

All geckos tested negative for *Cryptosporidia*, *Salmonella*, and *Giardia* (Habgood & Baling, 2007; Ussher & Baling, 2007; M. Baling, unpublished data). In late December 2006, 19 geckos were released onto Tiritiri Matangi and 20 geckos onto Motuora. General release locations were decided on the basis of source island habitat similarity and food availability (Habgood & Baling, 2007; Ussher & Baling, 2007).

Both sites presented a mosaic of vegetation dominated by well established pohutukawa, karo, and mahoe canopy. A sparse understorey composed of flax, kawakawa, and few small ngiao trees provided adequate refuge habitat. More extensive information of the vegetation structure of each island is given by Gardner-Gee *et al.*(2007) and Mitchell (1985). Release sites were in close vicinity to coastal cliffs and boulder beaches which provided numerous crevices and other refugia. The release consisted of placing tubes, each housing a gecko, randomly within predetermined areas (25 m²) within monitoring grids (see Chapter 5, section 5.2.2.1) on each island. The tubes were placed out in the early evening with one end of the tube open to allow the geckos to venture out on their own accord. The location of each tube was recorded using a global positioning system (GPS) and represented the start/ focal point of their dispersal. Intensive radio-tracking (see Chapter 4) and monitoring (see Chapter 5) followed the release and continued through till February 2008. Specific details on monitoring methods are described in Chapter 5.

Table 2.2 Summary of translocated *H. duvaucelii* morphometric measurements, PIT tag numbers, and transmitter attachments released onto Tiritiri Matangi Island in December 2006. Sub-A refers to sub-adult. n = 19.

ID	Age	Sex	Reproductive stage	SVL (mm)	Weight (g)	PIT tag number	Transmitter
003F	A	F		122.5	51.0	04511487	Yes
005F	A	F	Gravid	122.5	58.1	04469595	Yes
006F	A	F	Gravid	123.0	53.9	04520065	No
017F	A	F	Gravid	120.0	45.0	04489831	No
020F	A	F		124.0	44.4	04732389	No
027f	A	F	Gravid	120.0	47.9	04511463	No
029f	A	F	Gravid	128.0	58.7	04488613	Yes
033f	A	F	Gravid	123.5	60.3	04697133	Yes
037f	A	F	Gravid	120.0	56.6	04515589	Yes
202jf	sub-A	F		117.0	34.6	04453521	No
002m	A	M		124.0	55.3	04486384	No
007m	A	M		124.5	61.3	04493863	Yes
009m	A	M		122.0	60.2	04459741	Yes
011m	A	M		117.5	36.7	04514537	No
014m	A	M		119.0	53.3	04512432	Yes
016m	A	M		115.5	47.2	04453769	No
030m	A	M		124.0	53.3	04453319	Yes
033m	A	M		118.0	47.9	04486593	No
036m	A	M		124.5	59.1	04730981	Yes

Table 2.3 Summary of translocated *H. duvaucelii* morphometric measurements, PIT tag numbers, and transmitter attachments released onto Motuora Island in December 2006. n = 20.

ID	Age	Sex	Reproductive stage	SVL (mm)	Weight (g)	PIT tag number	Transmitter
002F	A	F	Gravid	120.0	55.7	04473308	Yes
007F	A	F		121.5	40.5	04468498	No
012F	A	F	Gravid	129.0	52.2	04712658	Yes
014F	A	F		118.0	38.0	04464688	No
015F	A	F		116.5	49.6	04489923	Yes
018F	A	F	Gravid	124.5	56.7	04555669	Yes
024F	A	F		120.0	40.7	04709743	No
031F	A	F		115.0	42.6	04495062	No
035F	A	F	Gravid	127.0	62.5	04491127	Yes
118F	A	F		121.0	46.1	04456921	No
005M	A	M		121.5	50.1	04464671	Yes
012M	A	M		124.5	45.6	04459837	No
017M	A	M		120.5	44.9	04462837	No
024M	A	M		122.5	61.8	04698524	Yes
027M	A	M		125.0	48.7	04473625	No
031M	A	M		119.0	45.6	04472402	No
032M	A	M		121.0	56.7	04473468	Yes
035M	A	M		125.5	58.4	04509541	No
037M	A	M		123.5	51.3	04519802	Yes
101M	A	M		122.0	48.2	04700870	Yes

2.5 General Statistics

All statistical tests were conducted in *MINITAB*® version 14 (Minitab Inc. 2003) unless otherwise stated. Data were assessed for normality to determine whether parametric or nonparametric tests were appropriate for final analyses. Hypotheses were tested at a 5% level of significance. Specific tests are described in the methodologies of relevant chapters.

CHAPTER 3

Condition of founder *H. duvaucelii* and post-harvest population size estimates.

Plate 3.1 *Hoplodactylus duvaucelii* re-captured on Tiritiri Matangi Island. (Photograph by author).

3.1 Introduction

3.1.1 Translocation: harvesting source populations

Translocations are frequently conducted with aims of restoring the biodiversity of ecosystems and improving the status of threatened species (Dimond & Armstrong, 2007). However, the harvesting of source populations for translocations has been observed to have a range of effects, including modifications to population demographics and population growth rates (Pullin, 2002; Ruffell, 2005). Therefore, harvesting generally results in destabilising population dynamics and may even increase the probability of extinction (Chau, 2000). Alternatively, recovery from harvesting events may occur if the population is subject to compensation by negative density-dependent regulation (Caughley, 1977; Begon *et al.*, 2006). This means that a release from the effects of high conspecific density may provide greater resource availability, and associated increases in survivorship and fecundity within the source population. Over time, the population may be expected to return to its pre-harvest equilibrium (Cameron & Benton, 2004). It is crucial that post-translocation monitoring extends to cover both the translocated population and the source population to provide information on future sustainable harvest levels (Dimond & Armstrong, 2007).

3.1.2 Translocation: effects on founders

Translocation success is determined by the survival of the founder propogule and persistence of the established population (Dickinson & Fa, 2000). These two requisites are influenced by a range of factors including resource availability (Knapp, 2001), habitat quality (Dodd & Seigel, 1991), and productivity of founders (Thomas & Whitaker, 1995; Letty *et al.*, 2003). High post-release mortality has been documented in numerous studies and in some cases has been the primary cause for the translocation to fail (Brambell, 1977; Dodd & Seigel, 1991; Saunders, 1995; Aikman, 1997; Davis & Aikman, 1997; Aikmen, 1999; Reinert & Rupert, 1999). For example, a study of translocated grey squirrels (*Sciurus carolinensis*) in the U.S. reported a mortality rate of 97% (Adams *et al.*, 2004) and several studies documenting the translocation of European rabbits (*Oryctolagus cuniculus*) have reported mortality rates of over 50% (Letty *et al.*, 2000; Letty *et al.*, 2003). An even more extreme case was shown by several attempts to establish Houston toad (*Bufo houstonensis*) in the U.S., where after the release of half a million individuals, not even one new population has established (Dodd & Seigel, 1991). Post-release mortality may be the result of high predation (Davis & Aikman, 1997), poor habitat quality (Wolf *et al.*, 1996), stochastic events (Armstrong & McLean, 1995), and/ or stress mediated effects (Teixeira *et al.*, 2007).

3.1.2.1 Stress-mediated effects

The adverse effects of stress on an animal’s well-being and survival are well represented in the literature (Sapolsky, 1990; McEwen & Sapolsky, 1995; Moberg *et al.*, 2000). Stress is a symptom resulting from the exposure of an animal to a hostile environment (Stott, 1981) and stress-mediated effects can act on an animal’s physical function and health, cognitive ability, and response mode to novel or important stimuli (Mathews *et al.*, 2005; Teixeira *et al.*, 2007). Translocations and associated procedures including capture, handling, captivity, and transportation, have the ability to exert large amounts of stress on the animals involved. For example, Kock *et. al*. (1990) reported that following a translocation of black rhinoceros (*Diceros bicornis*), 11% of the founders showed signs of stress-related morbidity. Short-term captivity of only a few hours may induce significant levels of stress in frogs (Coddington & Cree, 1995), while only 10 minutes of handling wild tree lizards, *Urosaurus ornatus*, resulted in a 6.6 fold increase in circulating stress hormone levels (Moore *et al.*, 1991). This may present difficulties if translocations over long distance are required to protect endangered animals.

The effects of stress on an animal's cognitive ability may be dramatic following a translocation into a novel environment. Following release, the immediate challenge for an animal is securing food resources and avoiding predation (Teixeira *et al.*, 2007), and therefore a reduced cognitive ability due to stress may inhibit the animal in adapting to the new environment. Additionally, reduced body condition and available energy could increase the animal's susceptibility to mortality. These effects were shown following a translocation of urban raccoons (*Procyon lotor*) that begun to lose weight during a time when they should have been storing fat, in order to survive winter denning (Rosatte & MacInnes, 1989). An animal that lacks sufficient ability to orientate through the environment may also venture into higher risk areas where they are more susceptible to predators (Plummer & Mills, 2000).

3.1.2.2 Founder resilience

If the translocated animals manage to overcome the immediate effects imposed by a translocation and its associated procedures, they may benefit from greater resource availability relative to the source population, under the assumption that there are negligible effects from conspecific competition. Translocated animals released into a new environment of equal or better habitat quality than their original site, may experience higher resource availability as a result of reduced conspecific density (Ruffell, 2005). Tuatara (*Sphenodon guntheri*) translocated to Titi Island showed a 41% increase in body weight following release, despite stable weights for seven years prior to the translocation (Nelson *et al.*, 2002). Similarly, high habitat quality on Korapuki is most likely responsible for the population growth and establishment of several translocated populations of rare New Zealand skinks

(Towns & Ferreira, 2001). High habitat quality is likely to contribute to the overall success of a translocation. However, it is the reproduction of founder individuals and the survival of offspring to breeding age that will ultimately determine the establishment of a translocated population. This may take a long time for New Zealand lizards as they are long-lived K-strategists (Wilson, 2004). Towns & Ferreira (2001) suggest that it may take decades for translocated *Cyclodina* species to expand into available habitat on Korapuki due to their lower than expected reproduction rates. Therefore, the implementation of long-term monitoring is important for evaluating founder survival and on-going assessment of the population status.

3.1.3 Research objectives

Translocations of lizards in New Zealand to protected island sites have acted to expand the current geographic distributions of threatened species and also to restore damaged ecosystems. These translocations are often conducted as *ad hoc* approaches, based on perceived habitat quality and viability of the founder populations. Few studies have documented the initial response of lizards to a new environment, following a translocation event. This study aimed to monitor the response of translocated *H. duvaucelii* populations, sourced from Korapuki and re-located to Tiritiri Matangi and Motuora Islands in December 2006.

The specific objectives of this study were:

1) Describe the survival and condition of founder *H. duvaucelii* populations over time, following translocation. Determine if site specific factors influenced survival and/ or body condition of founders.

2) Provide a preliminary assessment of the success of the two translocated *H. duvaucelii* populations and evaluate the viability of these populations.
3) Estimate the population size of *H. duvaucelii* on Korapuki post-translocation, to infer whether harvesting affected the persistence of the source population.

3.2 Methods

3.2.1 Study sites and species

This study was conducted on two small populations of geckos, *H. duvaucelii*, translocated to Tiritiri Matangi and Motuora (Hauraki Gulf, New Zealand). The effects of founder population harvesting were examined on Korapuki (Mercury Islands, Coromandel, New Zealand). For a more detailed description of *H. duvaucelii* and the study sites refer to Chapter 2.

3.2.2 Founder condition

3.2.2.1 Measurements

Hoplodactylus duvaucelii re-captured during the study period were processed for individual identification, morphological information, sex (gender), and the reproductive stage of females (see Chapter 2, section 2.4.1).

3.2.2.2 Founder survival

Survival was measured by the number of founder *H. duvaucelii* re-captured over time within the monitoring area.

3.2.2.3 Parasite load

External parasitic loads were expressed as the total number of mites on the eyes and body of each individual. Mites that occurred in the ears were not incorporated in the analyses due to the inability to accurately quantify them. The geckos were release at the point of capture after processing.

3.2.3 Post-harvest population estimate on Korapuki Island

The population density of *H. duvaucelii* on Korapuki was investigated using a mark-recapture method. A 3.5-hectare area on the island was searched for *H. duvaucelii*, over four nights from 23 February to 26 February 2008. The search area included the central low lying saddle region and adjacent slopes climbing to the eastern and western plateaus.

Geckos were located via spotlight searches and each night represented an independent capture session. Captured geckos were processed for morphological information and sexed (see Chapter 2, section 2.4.1). Geckos were marked with a temporary silver, xylene-free marker pen (*Sharpie*®). A small dot was placed on one of four positions on the lateral side of a captured animal, for determining re-captured individuals. The four positions included latero-posterior of the two front legs and latero-anterior of the two hind legs. Each position on the body denoted a corresponding capture session. When an individual was re-captured, the date of original and/ or consecutive recaptures was recorded. Geckos were released back to the site of capture following processing.

3.2.4 Statistical analyses

Refer to Chapter 2, section 2.5 for the level of significance tested and statistical program used. None of the data satisfied the assumption of normal distribution. Program *MARK* version 5.0

(Colorado State University; Otis *et al.*, 1978) was used to estimate the density of *H. duvaucelii* on Korapuki.

3.2.4.1 Parasite load

The number of mites per individual was plotted for each island such that temporal patterns could be described. Differences in the mite loads between islands were tested using a Mann-Whitney test.

3.2.4.2 Measurements & body condition index (BCI)

A body condition index (BCI) was determined for each individual by calculating the ratio between their weight (g) and SVL (mm), according to the equation: BCI = weight/ SVL (Floyd & Jenssen, 1983). The mean proportional change in BCI was calculated for individuals on each island, over the study duration. Data were plotted such that sex differences and temporal patterns could be described. The BCI's of all individuals at time of capture (23rd – 28th November 2006) were compared with those at the conclusion of quarantine period (20th December 2006) using a Wilcoxon signed-rank test. The BCI's at release (20th December 2006) and one year after release (December 2007) were plotted, and differences were investigated using a Wilcoxon signed-ranked test. Body condition indices from individuals on each island were combined to increase sample size.

3.2.4.3 Mark recapture

A closed population mark-recapture model was applied using program *CAPTURE*, within program *MARK* version 5.0 (Otis *et al.*, 1978; Lettink & Armstrong, 2003), using the Korapuki mark-recapture data. The assumptions for this model included; 1) the population was closed (no recruitment, mortality, or emigration), 2) all animals retained their marks throughout the entire study, 3) recording was accurate, and 4) each animal had a constant and equal probability of capture on each occasion (Caughley, 1977; Otis *et al.*, 1978). Program *CAPTURE* tests data against eight models that vary in aspects of catchability and selects the one that best fits the mark-recapture history presented (Otis *et al.*, 1978; Flannagan, 2000). Model M_t allows for capture probabilities that vary with time (e.g. each capture occasion), Model M_b allows capture probabilities to vary by behavioural response, and in Model M_h, individual variation is taken into account. In addition, all possible model combinations (M_{tb}, M_{th}, M_{hb}, and M_{tbh}), and a null model (M_o), where capture is constant with respect to all factors, are considered (Otis *et al.*, 1978).

3.3 Results

3.3.1 Founder condition

3.3.1.1 Founder survival

A total of 68.4% (13 of 19) and 80% (16 of 20) of founders on Tiritiri Matangi and Motuora, respectively, were re-captured at some stage during the study. Approximately 70% of the founders on Tiritiri Matangi and Motuora were caught in the monitoring area one month after release (Figure 3.1). A decrease in captures over time was apparent thereafter. At the conclusion of the 12 month study period only 5% (1/19) of founders on Tiritiri Matangi and 20% (4/20) of founders on Motuora were relocated within the monitoring area.

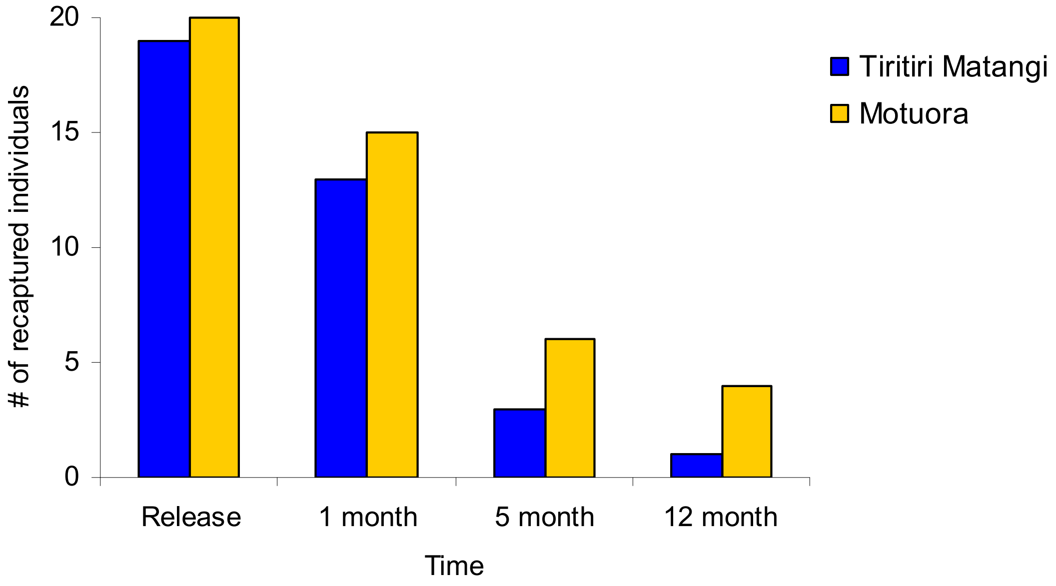


Figure 3.1 Recaptures of translocated *Hoplodactylus duvaucelii* over the study duration (12 months), on Tiritiri Matangi and Motuora Islands.

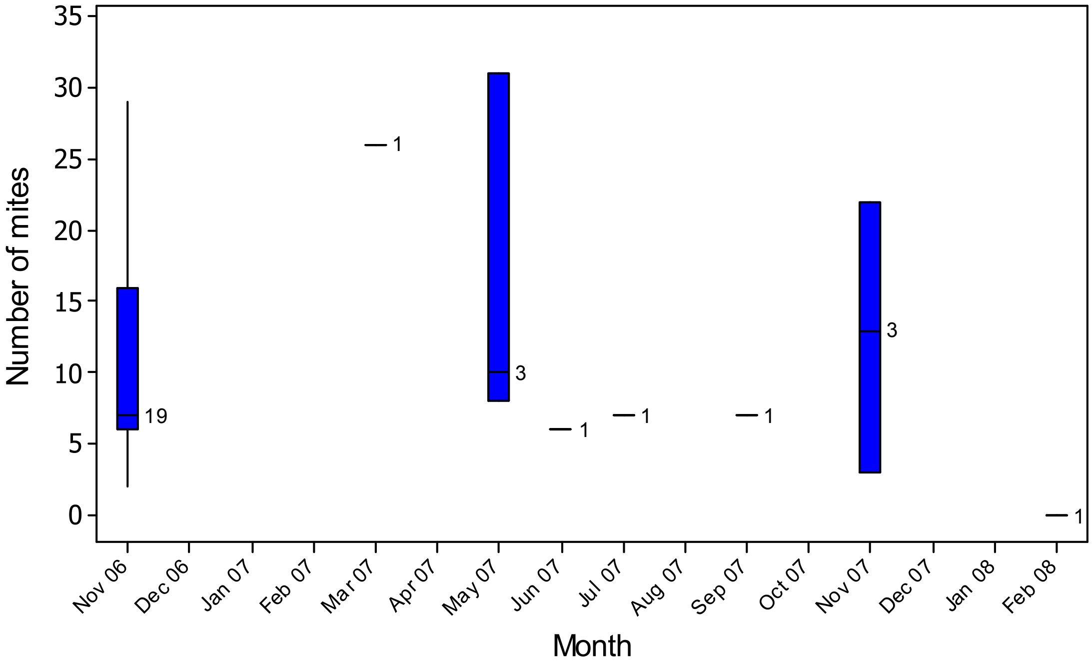
3.3.1.2 Parasite load

Parasitic mites were present on all translocated *H. duvaucelii* and there was no significant difference in the number of mites present on geckos released to Tiritiri Matangi and Motuora ($W_{19,\ 20} = 460$, $p = 0.0999$). Parasite loads peaked during March 2007 (26, n = 1) and November 2007 (13, n = 3) on Tiritiri Matangi and were lowest during June 2007 (6, n = 1) and February 2008 (0, n = 1) (Figure 3.2). On Motuora, parasite loads were highest during February 2007 (25, n = 3) and again in February 2008 (8, n = 1), and lowest in September 2007 (0, n = 1) and January 2008 (2, n = 4).

Parasitic mites were identified as *Geckobia naultina* (A. Heath, *pers. comm*., 2008) (Plate 3.2). This species of mite has only been recorded from a single *Naultinus* spp. (Womersley, 1941). This find represents a new host record for this species (A. Heath, *pers. comm*., 2008; McKenna, 2003).

Plate 3.2 Two large *Geckobia naultina* mites engorged at the edges of the eye of *Hoplodactylus duvaucelii* and a number inside the ear. (Photograph by author).

a) Tiritiri Matangi



b) Motuora

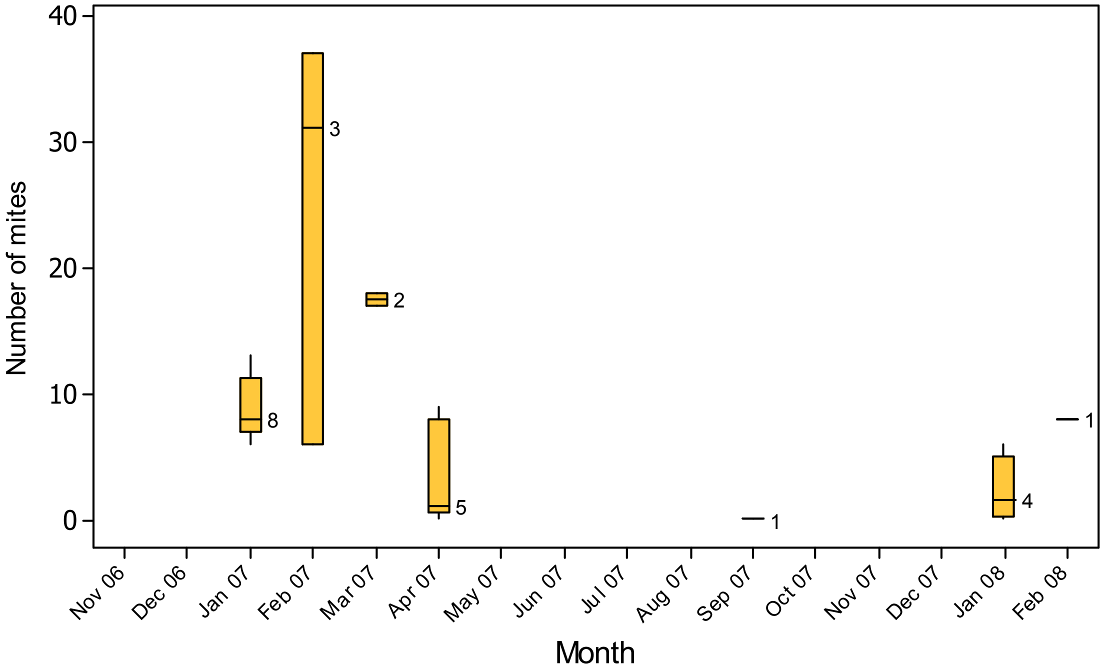
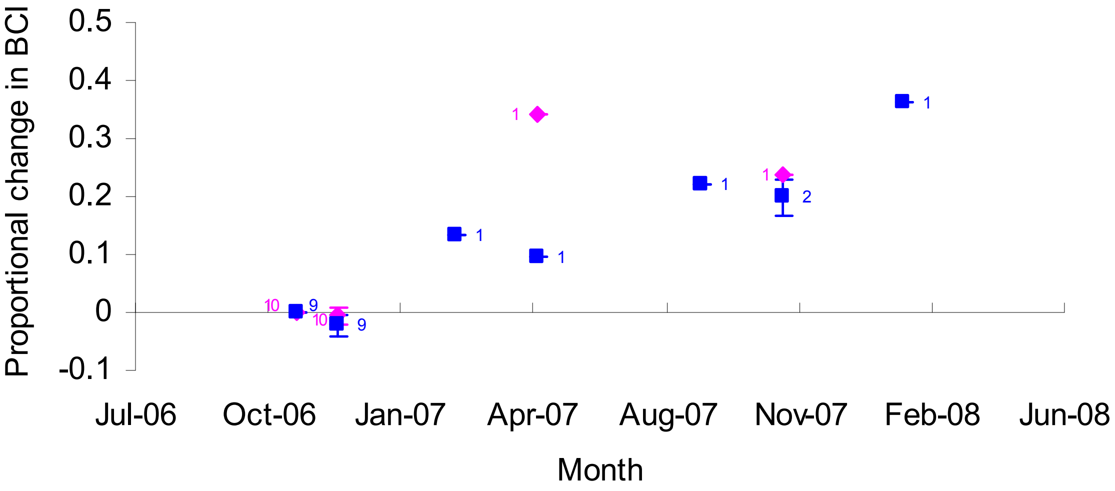


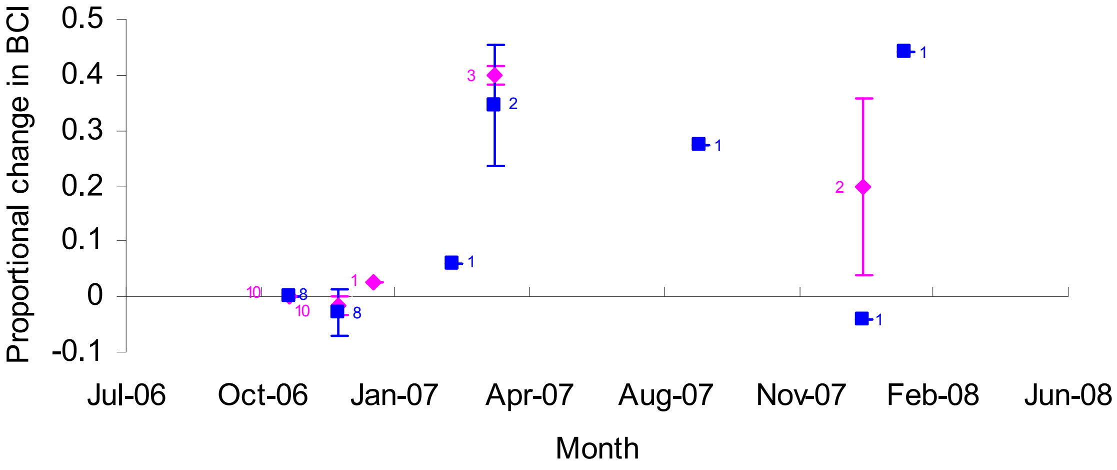
Figure 3.2 Mite load of translocated *Hoplodactylus duvaucelii* on a) Tiritiri Matangi and b) Motuora Islands. Lines within boxes (–) represent medians; boxes represent first and third quartiles; and whiskers represent the non-outlier range. Numbers next to bars indicate the sample size.

3.3.1.3 Body condition index (BCI)

The BCI's decreased during the quarantine period (28th November 2006 – 20th December 2006) for geckos destined for Tiritiri Matangi and Motuora. However, these decreases were not significant (Tiritiri Matangi: $T = 87$, $p > 0.05$; Motuora: $T = 53$, $p > 0.05$) (Figure 3.3). BCI's were only available for 18 geckos released to Motuora Island. Following release, rapid increases in the geckos' BCI were apparent on both islands. Male and female geckos appeared to show similar increasing trends.



a) Tiritiri Matangi



b) Motuora

Figure 3.3 Mean proportional change in body condition index (BCI) of male and female *Hoplodactylus duvaucelii* released on a) Tiritiri Matangi and b) Motuora Islands. Change is relative to condition at first capture (see text). Error bars indicate standard errors. Pink diamonds (◆) indicate females, blue squares (■) indicate males.

The median BCI one year after release (0.50; n = 6) was significantly greater than the median BCI at time of release (0.41; n = 6) (T = 21.0, p = 0.036) (Figure 3.4). This is represented by a 22% increase in body condition.

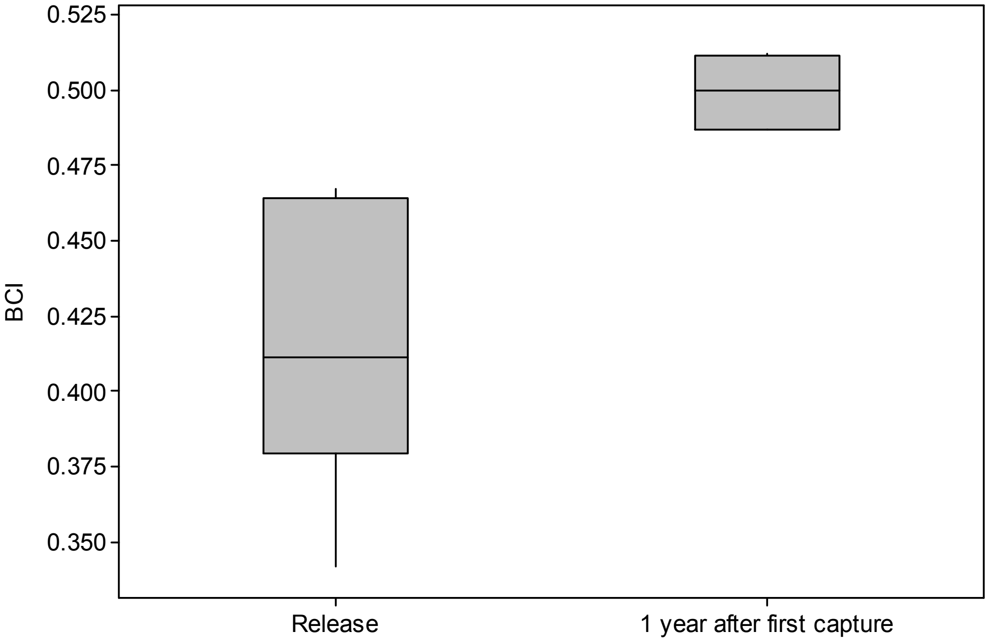


Figure 3.4 Body condition of *Hoplodactylus duvaucelii* at release (n = 6) and one year after release (n = 6). Horizontal lines within each box represent medians; boxes represent first and third quartiles; and whiskers represent the range.

3.3.2 Neonate *H. duvaucelii*

Four neonate *H. duvaucelii* were captured in January and February 2008 on Tiritiri Matangi (n = 1) and Motuora (n = 3). The morphometric measurements of the island born neonate *H. duvaucelii* were comparable to healthy neonates held in captivity (M. Barry, unpublished data) (Table 3.1).

Table 3.1 Morphometric measurements of neonate *Hoplodactylus duvaucelii* captured on Tiritiri Matangi and Motuora Islands, and captive neonate *H. duvaucelii* (n = 13).

Site	Capture date	Weight (g)	[1]SVL (mm)	[2]VTL (mm)
Motuora	14-01-2008	12.5	73.5	85
Motuora	15-01-2008	13.2	77.0	87
Tiritiri Matangi	04-02-2008	16.5	77.0	90
Motuora	14-02-2008	17.0	82.0	90
Captivity (n =13)	15-02-2008	*10.6	*73.0	*81

[1] Snout-vent length; [2] Vent-tail length; * mean values

3.3.3 Post harvest population estimate on Korapuki Island

A total of 197 *H. duvaucelii* were captured during 58 person search hours on Korapuki (23rd – 26th February 2008), indicating a catch rate of 3.4 geckos per person hour. Of those captured, only five were represented by re-captured individuals. The population estimate was 2,852 (SE ± 1,233.8, 95% CI = 1,313 to 6,510) and the estimate was best explained by the null model (M_o), where capture remains constant with respect to all factors (Otis *et al.*, 1978). Based on the 3.5 ha survey area, the population estimate indicated density of 815 *H. duvaucelii* per hectare (CI = 375/ ha to 1,860/ ha).

3.4 Discussion

3.4.1 Founder survival

At the conclusion of the 12 month study, at least 5% of founders on Tiritiri Matangi and 20% on Motuora were still alive and located within the monitoring area. Although these figures are low they are unlikely to represent the true survival rates of the translocated founders.

Difficulties in locating the geckos as a result of cryptic habits and complex habitat structure mean that survival estimates are highly conservative. Similarly, low recapture rates were reported by Jones (2000) with only 17% (7 of 41) of translocated *H. duvaucelii* recaptured during her 13 month study on Mana Island. This population has since become established (T. Whitaker, *pers. comm*., 2008), which seems to indicate that a high number of founders survived the translocation and have bred successfully.

Additionally, dispersal out of the monitoring area may have resulted in reduced encounters therefore lower survival estimates (see Chapter 4). On Motuora, gecko movements out of the monitoring area are likely to have been restricted by large vertical cliffs, which descend down into the ocean, on three sides of the monitoring area. However, Tiritiri Matangi had no such restrictions and geckos were free to disperse out of the monitoring area. This seems a plausible explanation for the much reduced survival estimates on Tiritiri Matangi compared to Motuora.

However, the actual translocation survival rate can not be determined from such short-term studies, unless actual records of mortality are recorded. Studies on tuatara have based the determination of their translocation success on a ≥30% survival of founders over a critical time period (e.g. harsh summers) (Nelson *et al.*, 2002; Ruffell, 2005). Consequently, if mortalities are not recorded, this may only provide a short-term estimate of founder survival. In the present study, monitoring efforts were focused only within the monitoring areas. Therefore, the fate of animals that dispersed out of the survey area could not be determined. Although 50% of founders were radio-tracked (see Chapter 4) and past studies have shown that animals carrying transmitters can be more susceptible to stress and mortality compared to animals without transmitters (Cox *et al.*, 2004; Guthery & Lusk, 2004; Theuerkauf *et al.*, 2007), no predation or mortalities were recorded amoung transmittered *H. duvaucelii* over the time they were tracked. It seems likely that the majority of founders could have survived the duration of the study.

3.4.2 Founder body condition

Body condition decreased during the capture and quarantine period, prior to translocation. Capture, transportation, and captivity are known causes of stress in animals, resulting in decreases in body condition and occasionally mortality (Kock *et al.*, 1990). During the quarantine period, animals were housed separately, provided with free access to water, and were fed twice a week with a balanced diet of invertebrates and fruit mix (Rowlands, 2005). Therefore, it seems probable that stress related factors, such as reduced appetite, may have led to the decrease in body conditions rather than the lack of access to food or conspecific competition.

Following release onto Tiritiri Matangi and Motuora, *H. duvaucelii* body conditions increased rapidly. These increases in body condition resulted from increases in weight, as the SVL's of all the geckos remained stable over the study. Body condition was significantly greater one year after release, representing a 22% increase from time of capture on the source island. Since body growth in lizards varies according to the availability of energy resources (Knapp, 2001), the results from this study suggest that there were sufficient food resources available at the release sites and that founders were capable of foraging successfully in their new environment. At least one *H. duvaucelii* was observed feeding on a large cicada (*Amphipsalta* spp.) on Motuora.

The low density of founders on Tiritiri Matangi and Motuora meant that conspecific competition for resources would have been low. Ruffell (2005) concluded that density-dependent factors were at least partly responsible for increases in post-translocation tuatara body condition. Similarly, translocated cichlid fish (*Pseudotropheus* spp.) increased condition due to greater food availability associated with the release site's superior nutrient quality (Munthali & Ribbink, 1998). The higher growth rates in translocated Alien's Cay iguanas (*Cyclura cyclura inornata*) are most likely attributable to higher food availability due to reduced conspecific density, and thus have contributed to the successful establishment of a new colony (Knapp, 2001). Reduced *H. duvaucelii* densities, coupled with high food availability on both islands (Clarke, 2003; Gardner-Gee *et al.*, 2007) would suggest that conditions are adequate for population expansion, at least in terms of resource availability.

Neonate *H. duvaucelii* may be susceptible to mortality due to a naivety to predators and/ or a poor ability to hunt for prey. These factors may have the strongest effects during the critical survival period following birth. Therefore captive animals, including neonates, are generally regarded to be in better condition than wild animals (Burnham *et al.*, 2006), due to the relatively high availability and access to resources in captivity. This study showed that the body conditions of island born neonates on Tiritiri Matangi and Motuora were comparable to those of captive-born neonate *H. duvaucelii* of the same age, suggesting that the island-born neonates are adequately nourished. Although body condition has been used as an indicator of overall health and energetic adequacy or deficiency in reptiles (Burnham *et al.*, 2006), and this study seems to indicate good population health, the actual proportion of neonates that survived the critical stage following birth is unknown.

External parasite loads followed a weak seasonal trend or at least numbers decreased during the winter months. Very little is known about the life cycle of *Geckobia* spp. (A. Heath, *pers. comm.*, 2008) and further research is required to test if they follow seasonal patterns. The effects of these parasites on host body condition are also poorly known (Womersley, 1941; Hardy, 1972; Allison, 1982). Parasitic mites have not been recorded causing harm to wild geckos, but in captivity they can reach excessive numbers and are often removed by keepers (Rowlands, 2005). Martinez-Rivera *et. al*. (2003) suggests that transmission of *Geckobia* spp. between hosts is through sexual contact or other prolonged and direct physical interactions (e.g. diurnal retreats, social interactions). Therefore, the low densities of *H. duvaucelii* on Tiritiri Matangi and Motuora may limit the transmission of mites to conspecifics and other gecko species due to low encounter rates. Transmission of *G. naultina* to resident *H. maculatus* populations on Tiritiri Matangi may not pose a large threat, as other *Geckobia* spp. have been recorded parasitising *H. maculatus* in other locations (Hardy, 1972; Allison, 1982; McKenna, 2003). There is a possibility that translocated *H. duvaucelii* may transfer novel blood and endoparasites to resident *H. maculatus*, via *G. naultina*, however further research is required to explore how blood and endoparasites are transmitted and what affects they have on lizards.

3.4.3 Population viability

Founder group sizes on the Tiritiri Matangi (19 individuals) and Motuora (20 individuals) were low, as a result of the logistical difficulties of translocating larger numbers of animals. There has been much debate regarding the viability of translocated populations as a function of founder propogule size (Griffith *et al.*, 1989; Craig & Veitch, 1990; Simberloff, 1990; Craig, 1991; Dodd & Seigel, 1991; Armstrong & McLean, 1995). Small founder numbers may have negative implications on the viability of the translocated populations. Griffith *et. al*. (1989) showed that translocation success increased with increasing founder group size in birds, with an asymptote at approximately 40 animals. However, numerous examples have suggested that the relationship between founder group size and probability of success does not always hold true (Armstrong & McLean, 1995; Thomas & Whitaker, 1995; Towns & Ferreira, 2001; Armstrong *et al.*, 2002). For example, populations of three species of robins

(*Petroica* spp.) have been established from groups of about five individuals (Flack, 1977). These are R-selected strategists, those with relatively short life spans and high reproductive success, have an increased ability to establish in new environments. Another example is the *Anolis* lizards that are known to colonise areas with only five founder individuals (Losos & Spiller, 1999). These strategies are typical of many invasive species (Lodge, 1993; Veltman *et al.*, 1996; Facon *et al.*, 2006). In contrast, K-strategists like New Zealand's lizards may require extended periods of time to gain population numbers. Towns *et. al*. (2001) predicted that from 30 translocated *Oligosoma suteri*, it may take 12 years or more to reach population numbers of 200 individuals. The more extreme K-selected strategists, like *H. duvaucelii*, may have even lower rates of increase possibly taking centuries to build up to population densities that the islands could support (Towns & Ferreira, 2001).

In addition to reduced population viability, small founder populations are at risk of extinction due to demographic and environmental stochasticities (Goodman, 1987; Armstrong & McLean, 1995). Stochasticity includes irregular chance events, such as a short lived species having a poor breeding season (i.e. demographic stochasticity) or an influx of a highly infectious fatal disease (i.e. environmental stochasticity). Both demographic and environmental stochasticity may act to reduce population numbers (Towns *et al.*, 1990b; Keedwell, 2004). For example, the small founder *H. duvaucelii* populations may be susceptible to high post-release mortality caused by predation, in which case the population size may become too small, thereby jeopardising the viability of the population (Allee, 1938).

The releases of *H. duvaucelii* were deliberately biased towards sexually mature adults, 50:50 sex ratios and presence of gravid females as this was predicted to increase the potential population expansion. Burke (1991) recommended that deliberate sex ratio manipulation can improve success of translocations however others suggest that release groups should reflect the demographic structure of the source population (Dodd & Seigel, 1991). The demographic composition of the *H. duvaucelii* source population was not known and due to the small founder population size, biasing sex ratios would have resulted in a very low number of male founders. Although, a female biased sex ratio may have acted to increase the number of available breeding females, the low number of males would have meant that any mortalities or large-scale dispersals by male *H. duvaucelii* could have potentially reduced the male population size available to females, to such low levels that breeding success became jeopardised (Allee, 1938). For example, one male *H. duvaucelii* was located with telemetry over 220 m away from the monitoring area (see Chapter 4). This individual was subsequently re-located back into the monitoring area, since such a large-scale dispersal would have represented a loss to the breeding population. No interactions or copulations were observed during the study however range analysis indicated animals were sufficiently close enough to encounter one another (see Chapter 4).

The release of gravid females aimed to simulate a first breeding season, and amplify the number of geckos in founder population in a short period of time. *H. duvaucelii* are known to take up to four years to become sexually mature (Thony, 1994). Therefore, the presence of neonates in the first year of release may act to inaugurate the population's expansion. The capture of these neonates confirmed that at least one female on Tiritiri Matangi and two females on Motuora gave birth during the study. The fact that the neonates were able to survive and gain body condition, provides a good indication that once breeding begins the population is likely to become subject to negative density-dependant compensation and expand. Recently, a translocated population of *H. duvaucelii* on Mana Island has begun showing signs of establishment, 10 years after 40 individuals were released (T. Whitaker *pers. comm*., 2008; Jones, 2000).

Concerns regarding compromised long-term genetic viability, as a result of low founder size on both islands, are relevant. Small populations are highly susceptible to inbreeding depression and declines in genetic variation over time (Frankham, 1994; Armstrong & McLean, 1995). It is argued that New Zealand's fauna have naturally high levels of inbreeding and therefore, may be less susceptible to its effects (Craig *et al.*, 2000; Jamieson *et al.*, 2007). For example, populations of 10-20 *H. duvaucelii* have been suggested as a sufficient number to establish a population on Motukaha Island (D. Newman & C. Daugherty *pers. comm*. in Jansen (1991)). In the present study, the release of gravid females was predicted to increase the founder genetic pool if offspring survived to sexual maturity. The offspring may potentially carry half their genetic material from a different father from the source population. This would theoretically increase the genetic variation in the translocated population. However in the longer-term, further management may be required if these populations are to expand greatly. Population integrity can be maintained in small populations through the introduction of further individuals with new genetic variation and/ or via meta-population management; interchanging individuals between separate populations to maintain or increase genetic diversity (Craig, 1994; Ussher, 1999b). At present, these issues require consideration and the implication of long-term post-release monitoring to reveal the extent of management required in the future.

3.4.4 Korapuki population estimates

The effects of harvesting on the source population could not be accurately determined in the present study due to the lack of pre- and post-harvest data. The only pre-harvest data available were catch rates from over a year before harvest (Hoare, 2006). These catch rates (4.64 geckos/ hour) were 30% higher than the catch rates calculated in the present study. However, direct comparisons can not be made due to differences in study methodologies. The mark-recapture study on Korapuki indicated a high population estimate and a density of 815 geckos per hectare. This estimate is much larger than the naturally occurring *H. duvaucelii* population estimates on the Poor Knights Islands of approximately 185-308 geckos per hectare (Whitaker, 1968). During the mark-recapture study, representative individuals from all age classes were captured and four 2008-born neonate *H. duvaucelii* were caught. Evidence of breeding may suggest that the population is capable of recovering from the harvesting event. The Korapuki population was only harvested once for 69 geckos. Considering the mark-recapture population estimate, it would seem unlikely that the removal of such a small proportion of the population would have highly detrimental effects on the source population.

The effects of population harvest may be of greater concern if repetitive harvesting of the same population is required; either because they are the only populations available or because of difficulties accessing other populations (Dimond & Armstrong, 2007). Similarly, translocations of rarer species may mean harvesting significant proportions of the source population, in order to guarantee the viability and establishment of a translocated population. Over harvesting events such as these, are likely to jeopardise the persistence of the source population if negative density-dependent factors destabilise population dynamics and increase the probability of extinction (Chau, 2000).

3.4.5 Conclusion

The small founder populations of *H. duvaucelii* translocated to Tiritiri Matangi and Motuora appear to be capable of surviving the translocation procedures and accessing sufficient resources, resulting in an increase in their body condition post-release. In addition, the survival of island-born neonate *H. duvaucelii* and their high body condition scores provides promise for future population expansion and establishment of the species. Further monitoring is essential to assess the longer-term genetic integrity of the population and may help reveal the extent of management required in the future. It is unlikely that the Korapuki *H. duvaucelii* population was severely affected by the removal of 69 geckos for translocation to Tiritiri Matangi and Motuora. This is based on high population estimates from the mark-recapture study and the fact that the population was only harvested once, to remove a relatively small number of geckos.

CHAPTER 4

Post-translocation movements, range size, and habitat use

Plate 4.1 A male *Hoplodactylus duvaucelii* wearing a backpack harness transmitter and climbing through coastal flax (*Phormium tenax*) on Tiritiri Matangi Island. (Photograph by author).

4.1 Introduction

4.1.1 Animal movement and habitat use

An animal’s ability to move through its environment can ultimately affect its prospects of survival and reproduction (Germano, 2006). These movements are strongly influenced by the landscape structure (McIntyre & Wiens, 1999) and therefore, familiarity with the landscape can assist orientation through the environment in such ways to minimise the time spent in vulnerable habitat and avoid predation. For example, the gecko *Gehyra variegata* was shown to select the shortest distance between tree habitats to move, to limit the distance traveled over open ground and hence reduce their risk of being predated (Gruber & Henle, 2004). In addition, landscape familiarity also enables the animal to minimise the amount of energy spent while moving through the environment in search of resources, such as food, shelter, and mates (Reinert & Rupert, 1999).

The area within which an animal regularly travels for foraging and sheltering purposes is referred to as a home-range (Burt, 1943). A home-range should therefore contain all of an animal’s routine requirements including shelter (Whitaker & Shine, 2003), suitable thermal conditions (Christian *et al.*, 1984; Huey *et al.*, 1989), food resources (Trivers, 1976) and in some cases mates (Stamps, 1983). The size of a home-range may be considered an important indicator of an animal’s behavioural and resource requirements (Perry & Garland Jr., 2002). This is because home-range size is be influenced by many biological factors and resources, including body size, diet, sex, and habitat type (Turner *et al.*, 1969; Perry & Garland Jr., 2002). This has important implications for the management of threatened species, since providing areas of sufficient size and habitat quality is essential for sustaining populations (Shaw, 1994; Johnson, 2000).

4.1.2 Animal's response to translocation

Knowledge of how founder populations respond to a translocation is limited, and consequently, understanding the reasons for a translocation success or failure is difficult. High frequencies of movement and large distance dispersal from release sites have been shown by translocated reptiles (Blanchard & Finster, 1933; Reinert & Rupert, 1999; Plummer & Mills, 2000; Sullivan *et al.*, 2004). These post-release movements may jeopardise the success of a translocation for three reasons. These are, 1) higher activity above normal levels is likely to be energetically inefficient and can lead to decreased body condition (Reinert & Rupert, 1999), 2) increased frequency of movement through unfamiliar habitat may increase the susceptibility of founders to predation (Sullivan *et al.*, 2004), and 3) high initial dispersal distances may reduce the intended population density, thereby exposing the population to Allee effects (Dennis, 1989; Nunney & Campbell, 1993). Therefore, examining how translocated species respond to and utilise their new environment is important for management of the species and improving the design for more successful translocation projects in the future (Germano, 2006). For example, understanding the degree of movement and range area size of translocated populations will allow managers to select sites that provide habitat with suitable resources and of sufficient size to avoid translocated animals moving into sink habitats.

4.1.3 Measuring animal movement

Describing an animal's movements, activities, and habitat selection can be difficult, especially for small and cryptic species (Wone & Beauchamp, 2003). These characteristics are typical of many lizards, however a variety of techniques have been developed in an attempt to measure these behaviours. These include: short-term displacement experiments and movement rules

(Stanley, 1998; Gruber & Henle, 2004), fluorescent powder tracking (Nishikawa & Service, 1988; Germano, 2006), mark-recapture studies (Lettink & Armstrong, 2003; Germano, 2007), and radio-telemetry (Salmon, 2002; Neilson *et al.*, 2006).

4.1.3.1 Radio-telemetry

Radio-telemetry can be an effective tool for investigating the ecology of cryptic reptiles (Greene, 1994) as this method allows for detailed temporal and spatial data to be collected from animals under natural conditions (Fisher & Muth, 1995). Such data includes mortality/ survivorship, movements, home-range, and micro-habitat use (Anonymous, 1998; Warner *et al.*, 2006). In addition, radio-telemetry can provide information on the amount and type of habitat necessary to maintain viable populations (Beauchamp *et al.*, 1998; Fair & Henke, 1999).

In New Zealand, radio-telemetry has been used in research and threatened species management of reptiles (Fair & Henke, 1999; Ussher, 1999b; Ruffell, 2005; Hoare, 2006; Neilson *et al.*, 2006) and amphibians (McAllister *et al.*, 2004; Germano, 2006). The information obtained from these studies has provided insight into the ecology of highly elusive lizards, such as the chevron skink (*Oligosoma homalonotum*) which were shown to occasionally become arboreal and refuge in the crown of tree ferns (*Cyathea* spp.). This has contributed information for the development more efficient management protocols for the species (Neilson *et al.*, 2006). Although, radio-telemetry can be especially important for monitoring the survival and response of reptiles to translocations (Reinert & Rupert, 1999; Ussher, 1999a; Sullivan *et al.*, 2004), very few studies have attempted to investigate these responses in cryptic, nocturnal geckonids (Jones, 2000; Lettink, 2007).

4.1.4 Research objectives

The aim of this study was to investigate temporal and spatial post-release movements of a cryptic gecko *Hoplodactylus duvaucelii*, following translocation to novel environments (Tiritiri Matangi and Motuora Islands) in New Zealand. For the purposes of this study, the term 'range area' has been used in replacement of home-range, for the reason that home-range refers the area in which resident animals undertake their normal behaviours, such as the acquisition of nutritional resources, shelters, and mates (Whitaker & Shine, 2003). This term can not strictly be applied to recently translocated animals since their normal behaviours are likely to be disrupted by release into an unfamiliar environment. Therefore, 'range area' is a more appropriate term and describes the area in which the translocated geckos were active.

The specific objectives are listed below:

1) Determine the performance and effectiveness of an external radio-transmitter attachment on *H. duvaucelii*.
2) To monitor the initial movement and activity of the translocated *H. duvaucelii* on Tiritiri Matangi and Motuora, using radio-telemetry. Measure the distances moved by geckos post-release in order to determine the occurrence of a dispersal stage.
3) Determine the size of the range area of founder *H. duvaucelii* on both islands, during the first year post-release.
4) Describe the habitat use of founder *H. duvaucelii* on Tiritiri Matangi and Motuora during the first year post-release. Describe the differences between habitat used during foraging and the habitat used for refuging by *H. duvaucelii*.

4.2 Methods

4.2.1 Study site and species

This study was conducted on two small populations of geckos, *H. duvaucelii*, translocated to Tiritiri Matangi and Motuora (Hauraki Gulf, New Zealand). For a more detailed description of *H. duvaucelii* and study sites refer to Chapter 2 (section 2.1).

Individual *H. duvaucelii* could be identified by their unique PIT tag identification number upon recapture (see Chapter 2, section 2.4.2 for details on PIT tags).

4.2.2 Radio-transmitters and telemetry

4.2.2.1 Transmitter attachment

Small, single-stage radio transmitters (20 mm x 10 mm, with a 150 mm whip antenna; Sirtrack Ltd., New Zealand) were attached to 20 *H. duvaucelii* (10 geckos per island) for this study. Ten individuals from each island carried transmitters immediately following release. Transmitters were replaced if batteries were reaching the end of their life (within 20% of the total battery life or at 83 days). Transmitters were attached to all re-captured animals throughout the study period, except animals with reduced body condition or signs of previous backpack abrasion.

Transmitters were attached to geckos using a backpack harness design (Plate 4.1) modified from Fisher (1995) and Richmond (1998). At first, rubber tubing was used for creating the harnesses however, later in the study the rubber was replaced with the more flexible *Co-Flex*® material. Captive transmitter attachment trials, prior to release, indicated that geckos moved freely and normally while wearing backpack harnesses.

Harnesses were cut out from the *Co-Flex*® sheet using a cardboard template. The harness consisted of two shoulder straps branching from a central pad. A rubber disc was glued onto the central pad to provide a smoother attachment surface for the transmitter. The transmitters were positioned with the antenna pointing posterior towards the tail and fixed with cyanoacrylate glue (*Superglue*™). The complete harness including transmitter weighed approximately 3.5 g and accounted for less than 5% of *H. duvaucelii* body weight.

The harness was placed across the individual's shoulders with shoulder straps pointing anterior along each side of the head. The straps were wrapped over the shoulders, across the chest in a 'X' pattern, and then back up behind the opposite foreleg. The ends were subsequently attached to the dorsal surface of the transmitter with glue and excess strap material was cut off. The straps crossing the chest were glued together to reduce movement. A further two straps were applied diagonally over the top of the transmitter and crossing the chest to add further rigidity. The backpack harnesses were fitted neatly but did not constrict the chest and interfere with breathing (Plate 4.3). Care was taken to avoid glue coming in to contact with the individual's skin and the procedure was performed in open air to avoid excessive inhalation of vapours that could be harmful to the animals.

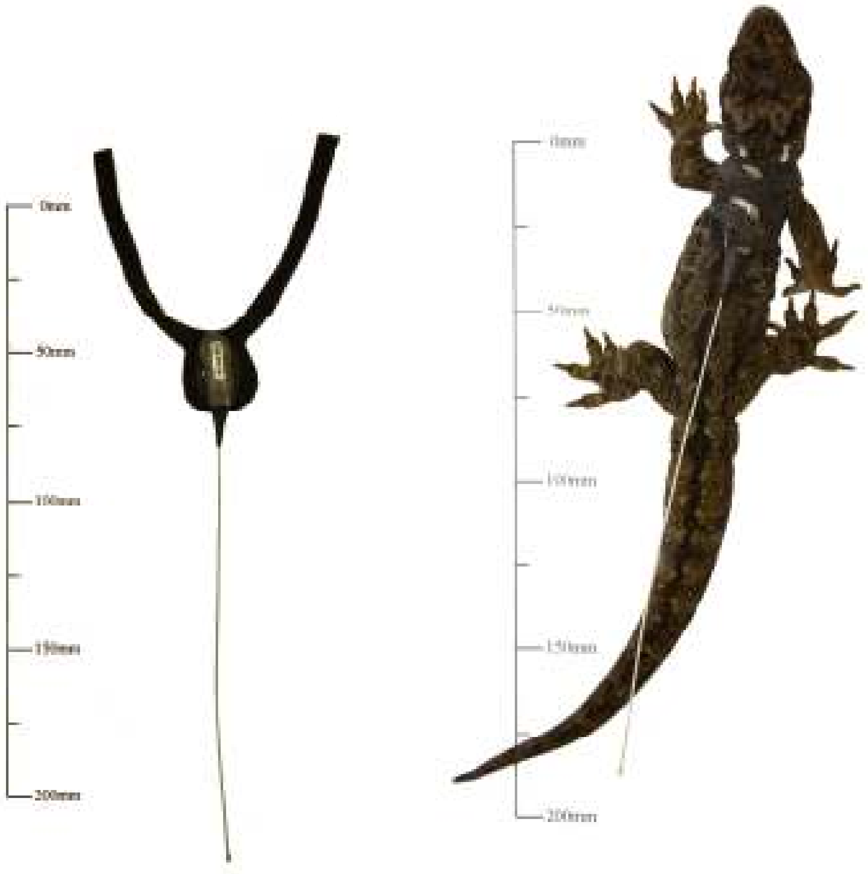


Plate 4.2 Backpack harness made from *Co-Flex*® material, with a radio transmitter attached and ready for mounting (left) and mounted on a gecko (*Hoplodactylus duvaucelii*) (right).

Plate 4.3 Adult female *Hoplodactylus duvaucelii* shown with a *Co-Flex*® transmitter harness attached. (Photograph by author).

4.2.2.2 Movements and activity

4.2.2.2.1 *Radio-tracking*

Radio-tracking was conducted using a hand-held *R-1000* telemetry receiver (Communication Specialists Inc.) and a 3-Element Yagi aerial tuned to 160MHz operating frequency (Sirtrack, Havelock North, New Zealand). Radio-tracking was conducted between December 2006 and February 2008.

Post-release telemetry monitoring occurred in three stages following release.

These included:

1) **Intensive monitoring (first week):** Geckos were located every two hours throughout the night (3-4 fixes per night) and once during the day. This continued for five days on Motuora but only two days on Tiritiri Matangi due to the logistics of concurrent releases. Geckos were located using both triangulation and homing-in methods (both described in sections 4.2.2.2.2 and 4.2.2.2.3).
2) **Weekly monitoring (two months following stage one):** Each gecko was located during the day, twice a week. This continued for approximately two months following release and allowed for both islands to be monitoring concurrently. Efforts were made to visually locate geckos during this stage.
3) **Monthly monitoring (following stage 2):** After two months, the monitoring regime changed and daily locations were recorded for up to five days each month. New transmitters were attached to recaptured individuals and morphometric measurements were recorded.

4.2.2.2.2 Triangulation

Triangulation was used to determine the geckos' positions during the initial dispersal phase to minimise any disturbance to their behaviour. This involved recording the distances and compass bearings from multiple point-locations (i.e. monitoring grid reference points, see Chapter 5, section 5.2.2.1) to each radio-transmittered gecko. More point-locations results in a reduction in size of the error polygon and a higher precision in determining the position of a gecko. In the present study, a minimum of three point-locations were used to calculate the estimated position of each gecko. If the gecko was sighted during the triangulation procedure the position was recorded and triangulation abandoned. Individual gecko locations were recorded on GPS, to an accuracy of five metres.

4.2.2.2.3 Homing-in

This method involves 'homing-in' on a signal until the animal's location is determined. The starting point for each animal was at the site where the gecko was last seen. The antenna was moved from side to side to determine which direction the strongest signal was coming from (i.e. the loudest signal pulse). The size of the movements was decreased while moving in the direction of the strongest signal and slowly decreasing the gain and volume to increase the precision of location. Individual gecko locations were recorded on GPS, to an accuracy of five metres.

4.2.2.3 Morphometric measurement

For details on the procedures for obtaining morphometric measurements, refer to Chapter 2 (section 2.4.1).

4.2.3 Habitat use

Habitat use was described from relocations of *H. duvaucelii* during the study. Night locations were assumed to represent foraging habitat, whereas day locations were assumed to be refuge habitat. Whenever a gecko was located, the habitat immediately surrounding the animal was categorised into one of four habitat types. These habitat types included:

1) Ground (i.e. leaf-litter, soil, or grass)
2) Flax (*Phormium tenax*)
3) Scrub (muehlenbeckia, *Muehlenbeckia complexa*; gorse, *Ulex europaeus*; or any vegetation < 1 m high)
4) Tree (i.e. branch, canopy, and trunk).

Habitat availability was estimated by quantifying the habitat composition within each monitoring grid (see Chapter 5, section 5.2.2.1). Ten quadrats (5 m x 5 m) were selected randomly within the grids and the proportion of habitat type in each quadrat was estimated to the nearest five percentile.

4.2.4 Statistical analyses

4.2.4.1 Movement

The locations of each gecko were transcribed to GPS coordinates and transferred into mapping and spatial analyst programs, *ArcGIS* (Environmental Systems Research Institute, Inc.) and *Ranges7 eXtra v1.7* (Anatrack Ltd.). Initial post-release gecko movements were plotted and analysed for distances travelled away from releases sites over time (e.g. 1st night, 2nd night, 1st week, 2nd month,…, 9th month). Differences in movement were tested across sexes and islands using Mann-Whitney tests. Sexes were combined if differences were not apparent.

4.2.4.2 Activity

Post-release gecko activities, measured as the distance (m) travelled over a 24-hour period were plotted to show variation in individuals and differences between islands. Sex and island differences were tested using Mann-Whitney tests.

4.2.4.3 Range area

Range area was estimated by 95% minimum convex polygons (MCP) using program *Ranges7*. Only individuals with three or more locations were included in range area estimates. Range area estimates were plotted to expose individual variations and range polygons drawn for visual evaluation. Sex and island differences were tested using Mann-Whitney tests. Individual movements were assumed to be in straight lines for movement and range area analyses. The relationships between SVL and estimated range area were examined using correlation coefficients.

Potential shifts in range were examined by plotting cumulative range area (m^2) against the number of locations for each radio-transmittered gecko with greater than three location fixes. A range area yields a simple logistic curve where the plateau of the curve is the area of the range (Rose, 1982). A shift in range area is represented by a series of stepwise logistic curves that rapidly increase in cumulative area (Wone & Beauchamp, 2003), and a new range area becomes apparent when another plateau forms.

Four possible scenarios are apparent when establishing a new range area; 1) establishment of a small stable range area, characterised by low dispersal, 2) continual increase in cumulative area and the complete absence of a stable range area, 3) a rapid expansion in cumulative area followed by the establishment of a large stable range area; characteristic of high dispersal, and 4) a rapid expansion in cumulative area and the establishment of a new larger range, following a small stable range area period. This last scenario is referred to as a 'shift' in range area. The sequential data obtained from radio-tracking geckos post-release allowed us to fit these scenarios to the gecko observations. Attempts to explain the reasons for shifts were made.

4.2.4.4 Habitat use

An estimate of the total available habitat within the monitoring area on each island was determined by calculating the mean of the proportions from the 10 quadrats. The two following definitions were applied (Pledger *et al.*, 2007):

i) Habitat availability: The proportion of the monitoring grid area covered by each habitat type.

ii) Observed habitat use: Measured as the number of geckos found in each type of habitat.

A Bray-Curtis Dissimilarity (BCD) analysis was used to measure the magnitude of discrepancies between expected habitat use (based on habitat availability) and observed habitat use by geckos. Bray-Curtis analyses are used to measure dissimilarity between groups based on continuous variables (Quinn & Keough, 2002; Hoare, 2006). The significance of the BCD value was tested by generating a null distribution of the observed dissimilarity (pseudo-BCD) by assuming no population dissimilarity (Hoare, 2006; Pledger *et al.*, 2007). This statistical methodology was used to test both foraging and refuge habitat use relative to availability by *H. duvaucelii* on Motuora and Tiritiri Matangi.

4.3 Results

4.3.1 Transmitter attachment and performance

On average, the rubber harnesses remained attached for significantly longer periods of time (43 ± 1.6 days; n = 20) than *Co-Flex*® harnesses (12.4 ± 2.4 days; n = 30) ($t = 10.65$, $df = 46$, $p < 0.001$). Rubber harnesses caused abrasive lesions in some geckos after three weeks of attachment. These occurred under the armpits and across the neckline on the dorsal surface, and in some cases the abrasions were severe enough to break the skin surface. The backpacks were removed from these individuals and injuries were treated with Betadine antiseptic ointment. Evidence of injury prompted the abandonment of all the rubber harnesses and the replacement with *Co-Flex*® material harnesses. Replacement harnesses were not attached to any individuals showing abrasive injuries. Recaptured individuals indicated that injuries took up to three months to heal adequately. All transmitters were recovered, with the exception of one transmitter that failed while still attached to a gecko early in the study.

4.3.2 Post- release behaviour and movement

4.3.2.1 Observational activity patterns

Hoplodactylus duvaucelii were observed to be active from dusk and throughout most of the night until dawn. The first few hours after dusk were the best for capturing geckos. Radio-telemetry indicated that animals were less active after 02:00 hrs local time. They were found to retreat into refugia at this time and remain there until the following night. No animals were observed active or basking in sun during the day. On one occasion a gecko was sighted during the day, hanging exposed on a tree trunk approximately one meter above the ground.

4.3.2.2 Movement

A total of 20 *H. duvaucelii* were tracked between December 2006 and February 2008 (Appendix I). There was no significant difference between sexes, in the distances moved from the release sites on either Tiritiri Matangi ($W_{11,\,8} = 101$, p = 0.483) or Motuora ($W_{7,\,5} = 43$, p = 0.745). There was no difference between islands, in the distances geckos travelled from the release sites ($W_{11,\,7} = 107$, p = 0.856). Variation in the distance of each individual's movement from the release sites increased over time, and distance travelled was greatest during the third and fourth month (212 m and 207 m, respectively) on Tiritiri Matangi and during the second month (63 m) on Motuora (Figure 4.1). On both islands, distances travelled remained low during the first month (under 50 m), with a slight increase during the second month.

On Motuora, a male and female *H. duvaucelii* were re-sighted within one meter of each other on four separate and consecutive occasions (22nd January 2007, 23rd January 2007, 30th January 2007, and 26 February 2007). The two geckos moved in unison and occupied refuge sites < 0.5 m from one another (Figure 4.2). On the last occasion, the transmitter harnesses of both geckos were recovered close together.

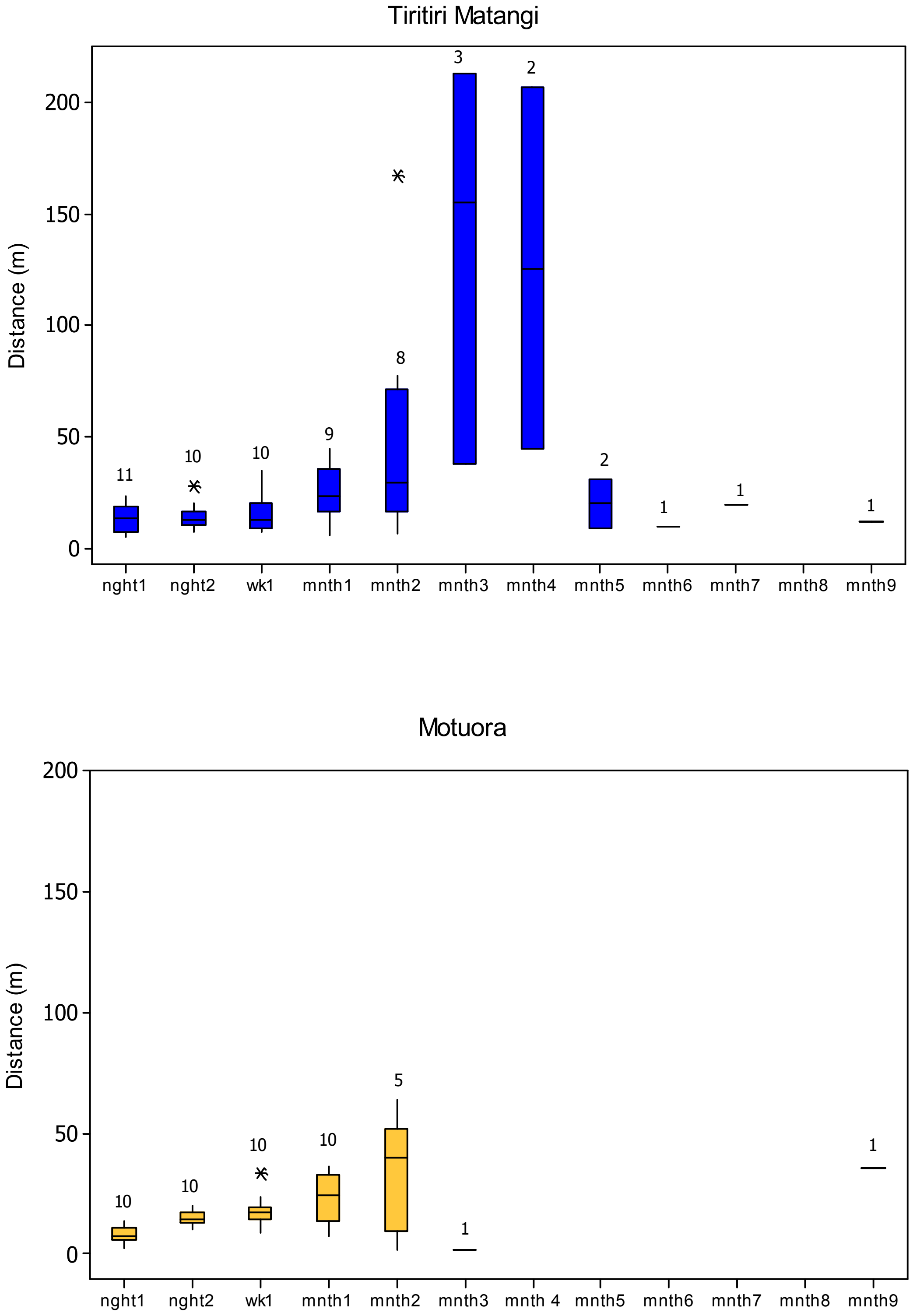


Figure 4.1 Distance moved away from the release site over the study period, by *Hoplodactylus duvaucelii* on a) Tiritiri Matangi and b) Motuora Islands. Release dates were 20 December 2006 and 22 December 2006 for Tiritiri Matangi and Motuora, respectively. Lines within boxes (–) represent medians; boxes represent first and third quartiles; and whiskers represent the non-outlier range. Sample sizes are recorded above each data bar.

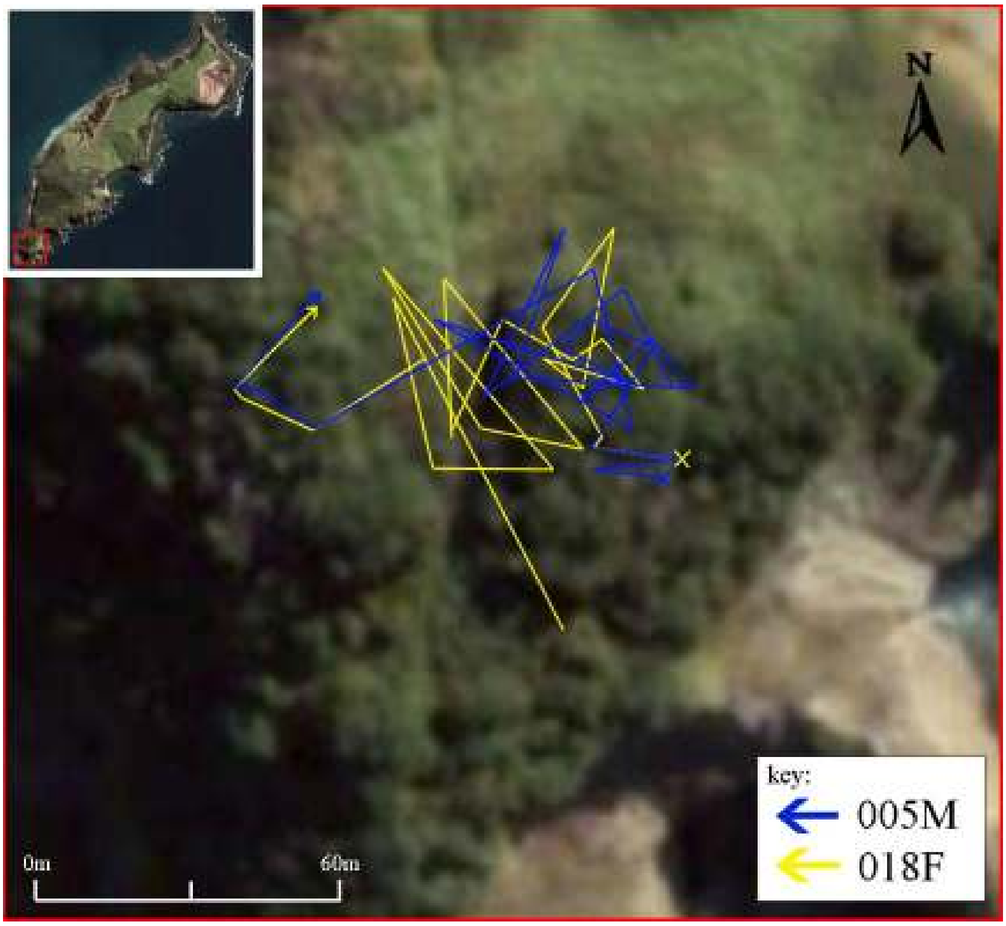


Figure 4.2 Map of Motuora showing the movements of a male (005M) and female (018F) *Hoplodactylus duvaucelii*. Coloured X's indicate the release site of each gecko and arrows indicate the direction of their movement. The last four location points show the paired movements. (Photograph by Google earth).

4.3.2.3 Activity

The median distance moved by individuals per night was 8.2 m (n = 13 individuals) on Tiritiri Matangi (Table 4.1) and 11.5 m (n = 11 individuals) on Motuora (Table 4.2) (Figure 4.3) and there was no significant difference in activity between islands ($W_{72, 33} = 4056.5$, p = 0.097). No sex differences were detected in the activity of *H. duvaucelii* on Tiritiri Matangi ($W_{11, 22} = 188.5$, p = 0.970) and Motuora ($W_{33, 37} = 1318$, p = 0.086).

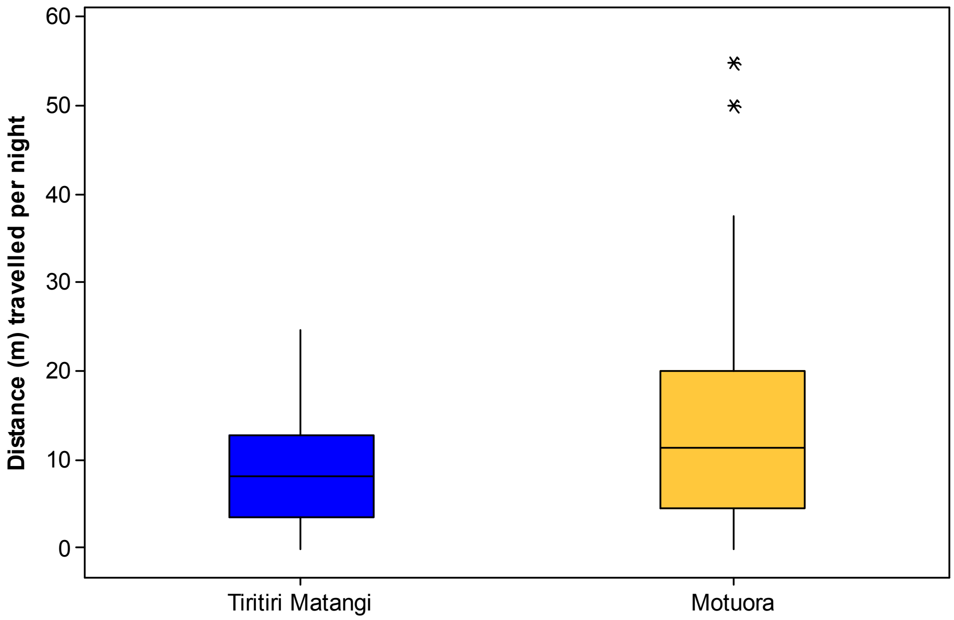


Figure 4.3 Distance traveled by *Hoplodactylus duvaucelii* (metres per night) on Tiritiri Matangi (n = 13) and Motuora (n = 11) Islands. Lines within boxes (–) represent medians; boxes represent first and third quartiles; whiskers represent the non-outlier range; and * indicate outliers.

4.3.2.4 Range area

The median estimated range area for *H. duvaucelii* on Tiritiri Matangi (n = 12) and Motuora (n = 11) was 563 m^2 and 774 m^2, respectively (
Figure 4.4, Appendix II). Estimated range areas varied greatly between individuals on both islands; Tiritiri Matangi varied between 33.0 and 1,634.5 m^2 [Table 4.1] while Motuora was between 256.5 and 2,006 m^2 [Table 4.2] (Figure 4.5), but no significant difference was apparent between islands ($W_{12,11}$ =128, p = 0.340). The number of radio-telemetry fixes per individual ranged from 3 to 33, and averaged 19.9. Range areas overlapped extensively among translocated *H. duvaucelii* on Tiritiri Matangi (Figure 4.6) and Motuora (Figure 4.7). No sex differences were detected in range area on Tiritiri Matangi ($W_{6,6}$ = 48, p = 0.174) and Motuora ($W_{6,5}$ = 38, p = 0.784).

No correlations existed between the SVL of individuals and estimated size of their range area on Tiritiri Matangi (r = 0.377, p = 0.204, n = 13) and Motuora (r = -0.124, p = 0.734, n = 10).

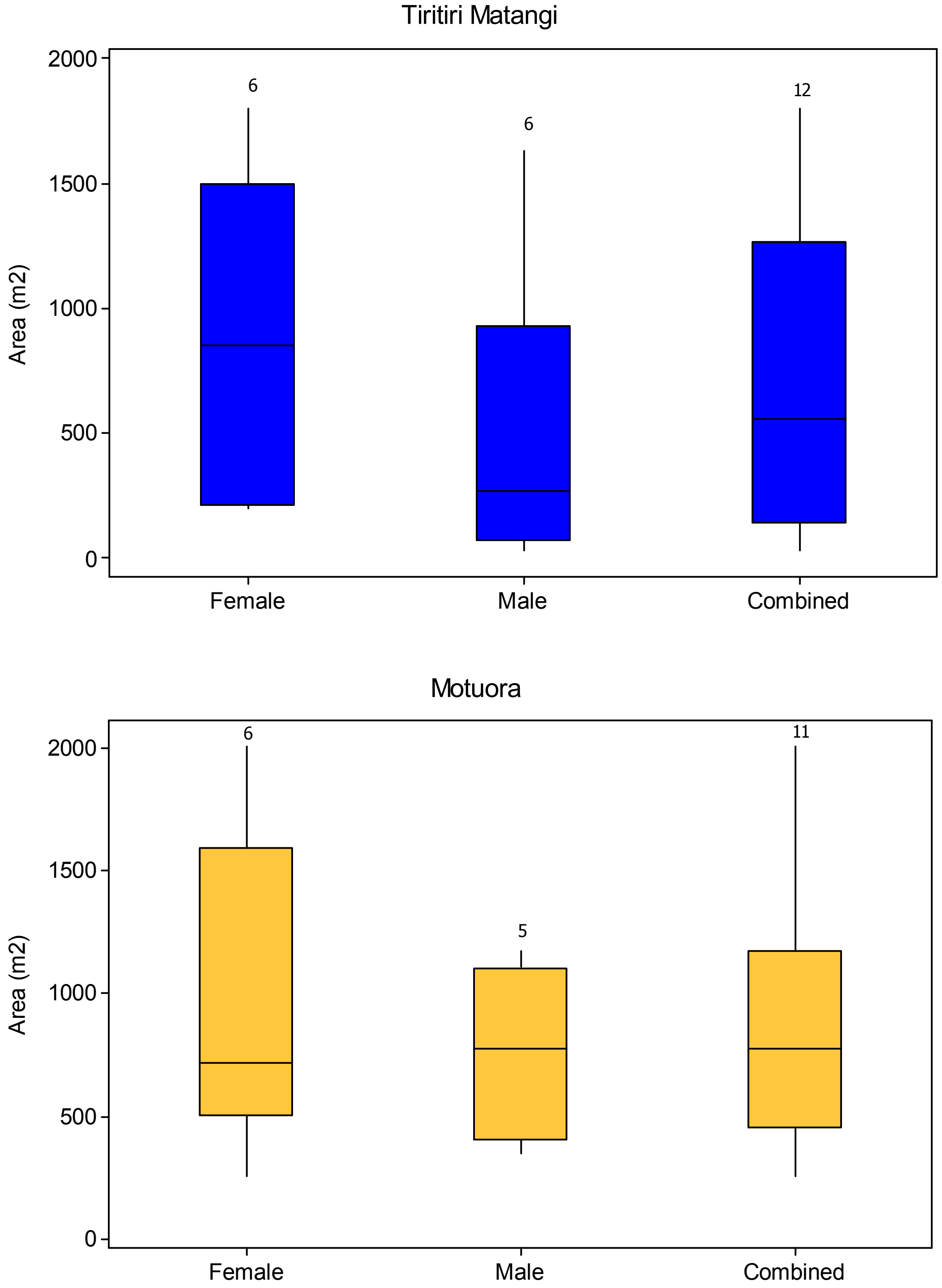
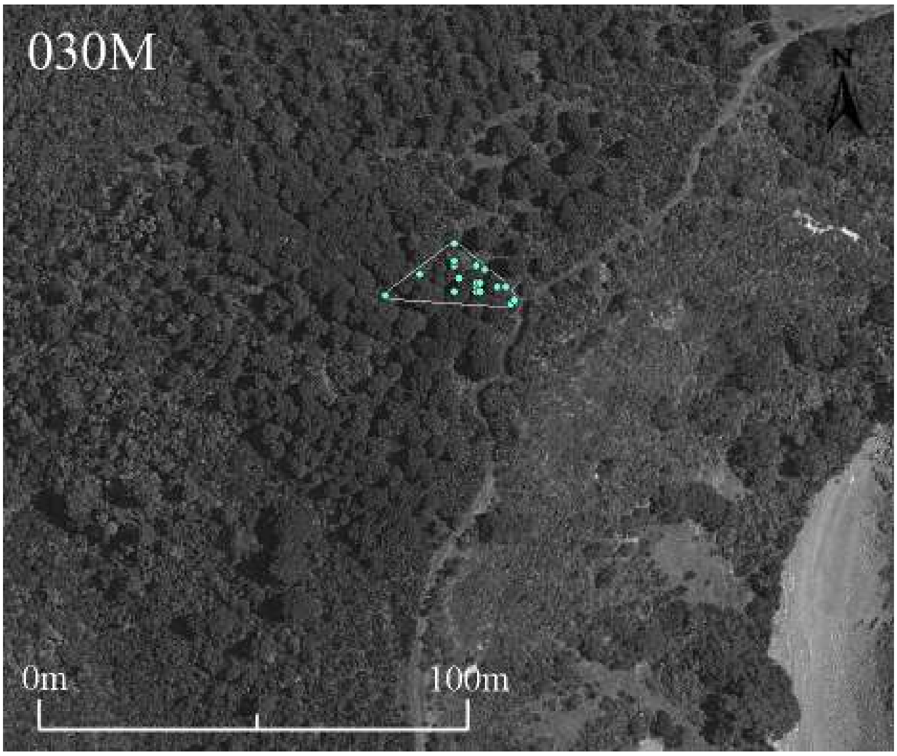


Figure 4.4 Range area of male, female, and combined sexes of *Hoplodactylus duvaucelii* on both islands (Tiritiri Matangi and Motuora). Lines within boxes (–) represent medians; boxes represent first and third quartiles; and whiskers represent the non-outlier range. Sample sizes are recorded above each data bar.



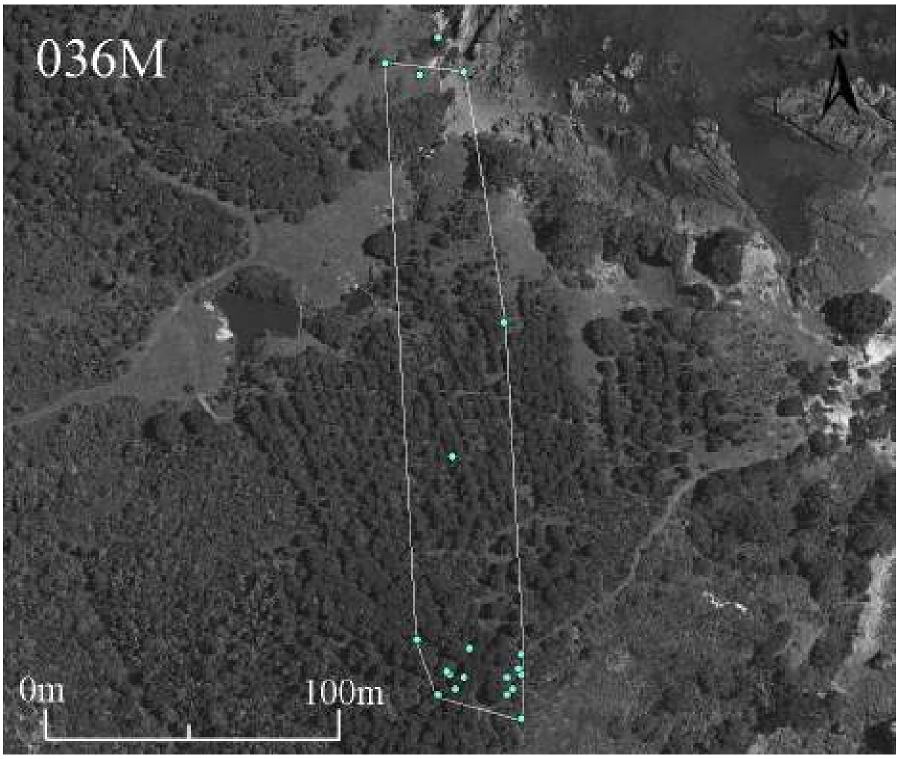


Figure 4.5 Examples of two male *Hoplodactylus duvaucelii* range areas. 95% minimum convex polygons (MCP) are outlined with a white border on Tiritiri Matangi Island. Blue dots indicate actual locations of the geckos.

Table 4.1 Average distance moved per night (m) and range area (m²) of male and female *Hoplodactylus duvaucelii* on Tiritiri Matangi Island bewtween December 2006 and February 2008.

Gecko ID	Sex	No. of locations	Average distance moved per night (m)	Range area (m²)
003f	female	15	11.8	939.5
005f	female	16	18.1	357.5
020f	female	9	3.8	215.5
029f	female	19	11.8	2884.0
033f	female	18	8.1	960.5
037f	female	17	7.7	2319.0
007m	male	18	21.1	772.0
009m	male	18	18.5	2728.5
011m	male	3	24.5	33.0
014m	male	13	8.2	106.5
030m	male	33	4.7	256.5
033m	male	4		423.5
036m	male	24	5.7	7820.5

Table 4.2 Average distance moved per night (m) and range size (m²) of male and female *Hoplodactylus duvaucelii* on Motuora Island between December 2006 and February 2008.

Gecko ID	Sex	No. of locations	Average distance moved per night (m)	Range area (m²)
002f	female	20	27.8	2195.0
012f	female	26	9.4	273.5
015f	female	27	9.8	817.5
018f	female	28	14.2	1126.5
035f	female	25	23.8	1609.0
005m	male	27	13.2	788.0
017m	male	9	9.2	350.0
024m	male	26	8.8	539.5
032m	male	25	18.9	1337.0
037m	male	30	4.5	1187.5
101m	male	27	15.5	589.0

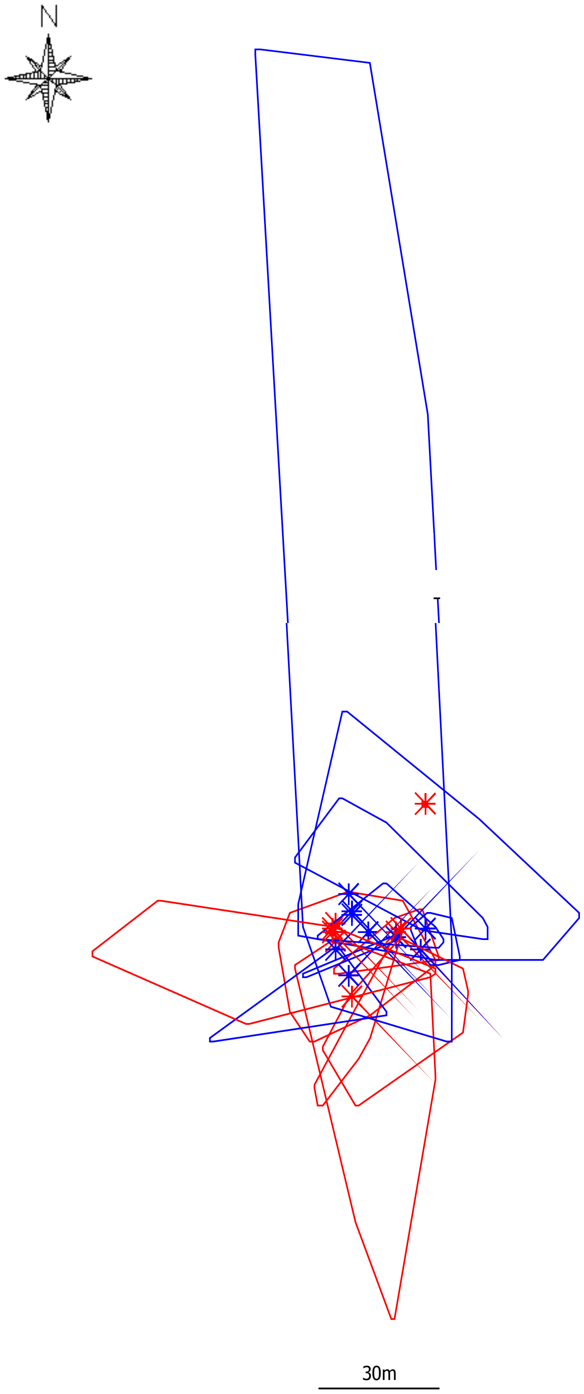


Figure 4.6 Range areas (95% minimum convex polygons) of translocated male (blue) and female (red) *Hoplodactylus duvaucelii* carrying radio-transmitters on Tiritiri Matangi Island. Asterix denotes first recorded location of each gecko.

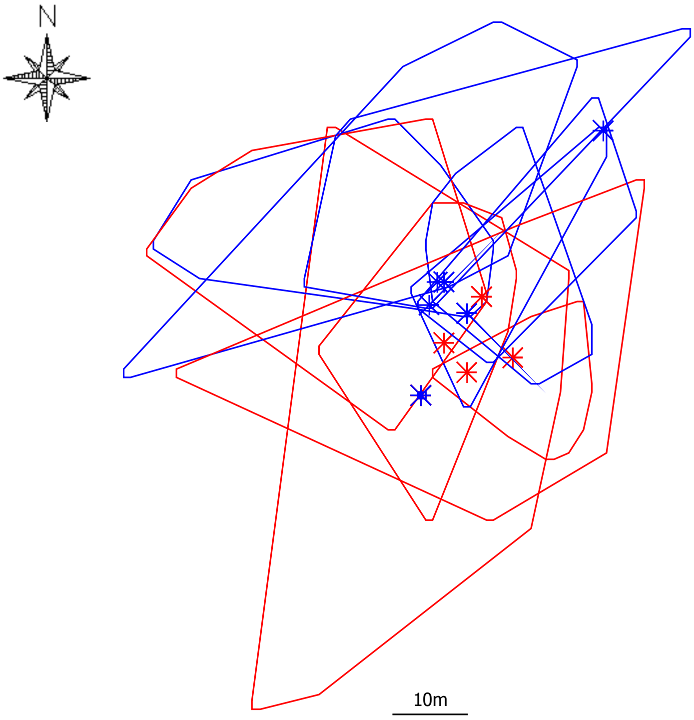


Figure 4.7 Range areas (95% minimum convex polygons) of translocated male (blue) and female (red) *Hoplodactylus duvaucelii* carrying radio-transmitters on Motuora Island. Asterix denotes first recorded location of each gecko.

4.3.2.5 Range area shifts

Translocated geckos displayed all four range scenarios (Table 4.3; Appendix III). Most individual geckos were able to be grouped into a scenario. On some occasions however, geckos demonstrated combinations of scenarios. Two geckos on Tiritiri Matangi (033M and 011M) were excluded from results due to an insufficient number of sample points.

On Motuora, 9% of geckos showed limited dispersal and established relatively small range areas, in comparison with 30% of individuals employing the same scenario on Tiritiri Matangi. A comparable proportion of geckos on Tiritiri Matangi (30%) and Motuora (36%) did not appear to establish stable range areas, but continued to move further away from the release site, constantly increasing cumulative area. The most common scenario displayed by geckos on both Tiritiri Matangi (40%) and Motuora (45%) was that of high initial dispersal followed by a plateau. Small shifts in range area were apparent within scenarios 1 - 3, on both islands. Large pronounced shifts in range area were not displayed by geckos on Tiritiri Matangi, although 9% of individuals on Motuora displayed large shifts in range area.

Table 4.3 Proportion of radio-tracked *Hoplodactylus duvaucelii* displaying each cumulative range area scenarios.

Islands	Cumulative range scenario*			
	1	2	3	4
Tiritiri Matangi Island	0.30	0.30	0.40	0.00
Motuora Island	0.09	0.36	0.45	0.09

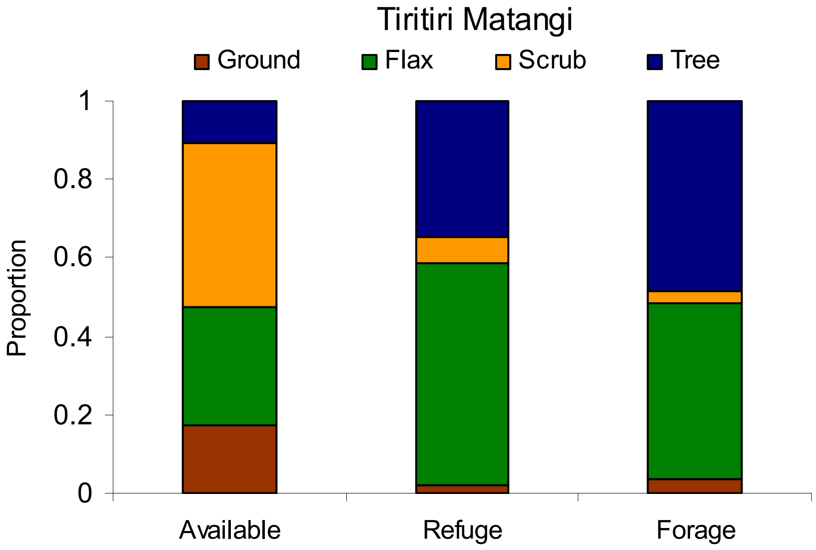
*Cumulative range scenarios

1. Establishment of a small stable range area, characterised by low dispersal.
2. Continual increase in cumulative area and the complete absence of a stable range area.
3. A rapid expansion in cumulative area followed by the establishment of a large stable range area; characteristic of high dispersal.
4. A rapid expansion in cumulative area and the establishment of a new larger range, following a small stable range area period.

4.3.3 Habitat use

All four habitat types were utilised by *H. duvaucelii* on Tiritiri Matangi and Motuora. Observed refuge habitat use (day locations) by *H. duvaucelii* was in proportion to available habitat on both Tiritiri Matangi (BCD = 0.2534436, p = 0.084) and Motuora (BCD = 0.2182403, p = 0.165). Observed foraging habitat use (night locations) was in proportion to available habitat on Tiritiri Matangi (BCD = 0.3117586, p = 0.08) however, this differed significantly on Motuora (BCD = 0.5116087, $p < 0.01$), showing a greater amount of time spent foraging in trees.

Habitat use by *H. duvaucelii* differed across refuging and foraging activities on both islands (Figure 4.8). Scrub and flax habitat were used in higher proportions as refuges than during foraging activity. Tree and ground habitat were used in higher proportions during foraging than refuging activity.



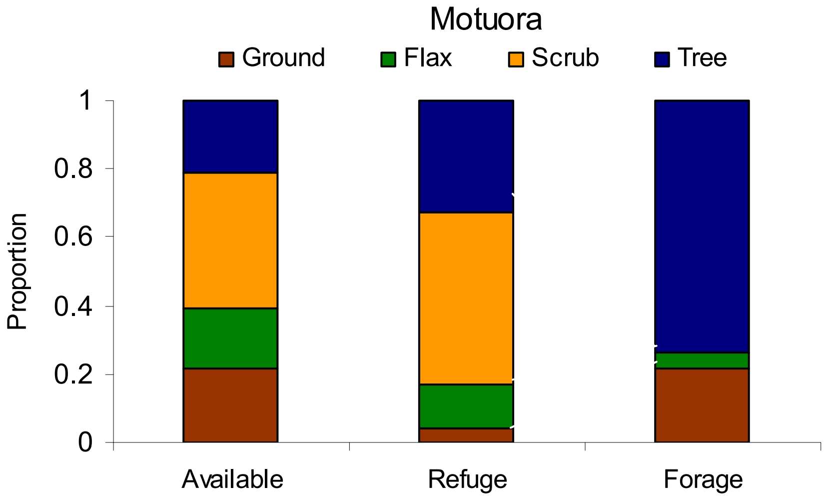


Figure 4.8 Available habitat and observed habitat use for refuging and foraging activity by *Hoplodactylus duvaucelii* on Tiritiri Matangi (n = 14) and Motuora (n = 20) Islands.

4.4 Discussion

4.4.1 Transmitter attachment and performance

The backpack harness method was successful for monitoring the movements and habitat use of *H. duvaucelii* in the present study. Rubber harnesses remained attached to the geckos for significantly longer periods of time compared to the *Co-Flex*® material harnesses. This was probably due to the highly inelastic properties of the rubber material, which prevented the geckos from squeezing their way out of the harnesses. In comparison, the high elasticity of the *Co-Flex*® material meant that dislodging the harnesses may have been relatively easy. In addition, the *Co-Flex*® was more susceptible to the effects of long exposure to environmental conditions than the rubber material, and therefore over time the *Co-Flex*® lost its elasticity and the harnesses were discarded by the geckos. However, despite the extended length of attachment time, the rubber harnesses caused abrasions to the skin of many geckos (van Winkel, 2007). These abrasions were often sufficient to break the skin surface and appear highly likely to have caused pain and discomfort to the geckos. For this reason, rubber harnesses were abandoned and replaced with *Co-Flex*® harnesses.

The body condition, movement, and behaviour of translocated *H. duvaucelii* did not appear to be negatively affected by radio-transmitter attachment. All geckos carrying transmitters gained body condition and were frequently observed climbing, sprinting at speed, and squeezing through tight vegetation to evade capture. No entanglements in vegetation were recorded. The weight of the backpack harnesses never exceeded 5% of an individual's body weight in the present study. Previous studies have suggested that transmitter packages weighing up to 25% of an animal's body weight are suitable and do not adversely affect their behaviour (Fisher & Muth, 1995; Wone & Beauchamp, 2003). These estimates are based on the proportional weight of a clutch of eggs carried by a gravid female. Miles (2000) showed that weight gained by gravid females led to reduced locomotor performance and survival in lizards as a result of increased susceptibility to predation. Since an individual lizard weight can fluctuate over 5% within a normal seasonal cycle (Telford, 1970), it appears that backpack harnesses used in this study are of a more acceptable weight.

4.4.2 Post-release behaviour and movements

4.4.2.1 Activity patterns

In this study, most *H. duvaucelii* were encountered in the first three hours after dusk and a significant decrease in sightings was apparent after midnight. These observations are in accordance with previous studies on the *H. duvaucelii* (Whitaker, 1968; Christmas, 1995; Jones, 2000). *H. duvaucelii* emerge from their day refuge sites just after dark to forage while retaining warmth from day-time temperatures. In the hours after midnight the geckos reduce their activity greatly as they search for or return to refuge sites.

4.4.2.2 Movement

Differences in the movement distances from the releases sites between sexes and between islands were not supported statistically. This suggests that there may be some common factor(s) determining the movements of *H. duvaucelii* following their release, irrespective of sex and site differences.

Some animals rely on familiar cues within their environment to navigate through it, in such ways as to avoid predation, or encounter important resources (Slip & Shine, 1988; Plummer, 1990; Koenig *et al.*, 2001). Therefore, translocating animals into unfamiliar environments has the potential to disrupt normal movement patterns and behaviours (Plummer & Mills, 2000).

These unusual behaviour patterns are shown in some reptiles displaying increased frequency of movements and large dispersal distances moved away from release sites following translocation (Blanchard & Finster, 1933; Reinert & Rupert, 1999; Plummer & Mills, 2000; Sullivan *et al.*, 2004).

Hoplodactylus duvaucelii translocated to Tiritiri Matangi and Motuora showed large dispersal distances (up to 220 m) during the post-release monitoring period. In addition, some geckos in this study travelled large distances overnight (> 50 m). By comparison, *H. duvaucelii* released onto Mana Island dispersed a maximum of 64.5 m (Jones, 2000) during the first year following release, and Whitaker (1968) reported movements of up to 250 feet (76 m) by resident *H. duvaucelii* over three nights (c. 25 m/ night) on the Poor Knights Islands. The greater movements observed in this study may be the result of the motivated exploration of a novel environment, although these observations are not consistent with the translocated Mana Island geckos. It is possible that an absence of radio-tracking data, the low gecko recapture rates, and searches confined only to the forest valley and shoreline may have meant that geckos moving large dispersal distances were not recorded on Mana Island. Translocated timber rattle snakes (*Crotalus horridus*) were shown to display frequent and extensive movements in their new environment. These patterns of movement suggest that either snakes were searching for familiar environmental features, or they were exploring the new environment in order to become familiar with it (Reinert & Rupert, 1999).

In the present study, translocated *H. duvaucelii* displayed non-directional movements away from release sites. Post-translocation movements are often aberrant and involve either random wandering or unidirectional movements (Reinert & Rupert, 1999). In comparison, resident animals have been shown to move in a predictable manner due to familiarity with their environment (Slip & Shine, 1988; Shine & Fitzgerald, 1996; Plummer & Mills, 2000).

Aberrant movements can result in a translocated animal moving constantly farther away from the release site. For example, studies have described aberrant, long-distance movements by various species of translocated snakes and have suggested that translocations are responsible for these rapid, wide ranging dispersals (Fitch & Shirer, 1971; Galligan & Dunson, 1979; Reinert & Rupert, 1999). Similarly, in the present study, one gecko on Tiritiri Matangi was calculated to have moved a distance of 480 m, in a straight line between fixes, during a two week period (036M; Appendix I).

Alternatively, some reptiles and amphibians appear capable of accurate directional homing movements following translocation (Stanley, 1998; Gruber & Henle, 2004; Germano, 2006). However, a clear lack of directional movement patterns shown by *H. duvaucelii* suggests that homing did not occur, at least during this study period, and that the hypothesis of exploration of a novel environment and/ or the disorientation effects of the translocation procedure better explain the reasons for their large-scale, aberrant movements.

Large increases in daily activity levels have been reported in lizards post-translocation. For example, Gila monsters (*Heloderma suspectum*) increased their activity five times higher following translocation, compared to those of resident animals (Sullivan *et al.*, 2004). An increase in activity and frequency of movement through unfamiliar habitat may ultimately affect the survival of translocated animals, as a result of reduced energetic or thermoregulatory inefficiency and increased risk of predation (Rose, 1981; Reinert & Rupert, 1999; Plummer & Mills, 2000). The nightly activity (m/ night) of translocated *H. duvaucelii* was comparatively similar to that of resident non-translocated geckos (Christmas, 1995). However, the range area seen in this present study is larger than what was described in Christmas (1995), suggesting a larger distance travelled by the former despite similar activity levels to the latter. Therefore, translocataed geckos must have moved more frequently to accomplish these large range areas.

Hoplodactylus duvaucelii were released in close proximity to each other, i.e. within 25 m² areas on each island. Therefore there is a possibility that the effects of high conspecific density and interactions immediately following release may have caused geckos to disperse away in search of vacant habitat. However, this seems unlikely since *H. duvaucelii* are not known to show aggressive territorial behaviour and often display high inter- and intra-species tolerance (Whitaker, 1968; Christmas, 1995; Flannagan, 2000; Jones, 2000; Rowlands, 2000). Only direct observations of intra-species interactions will further elucidate if *H. duvaucelii* defend or exclude conspecifics from particular habitats.

An alternative explanation is that habitat quality at the release sites was sub-optimal and therefore, geckos were dispersing away in search of more preferred habitat (Brown & Orians, 1970). Ruffell (2005) suggested that sub-optimal habitat (i.e. absence of natural refuge burrows) may have induced high emigration rates by translocated tuatara (*S. punctatus punctatus*) on Tiritiri Matangi. Although, habitat structure and availability differed between Tiritiri Matangi and Motuora, translocated geckos demonstrated similar movement responses following release. This may suggest that either both islands provided sub-optimal habitat, with respect to habitat structure and availability of refuges, within the release areas or that dispersal occurred due to some other factor(s), irrespective of habitat features. Further research is required regarding the factors involved in initiating post-translocation dispersal phases in lizards.

On Tiritiri Matangi, *H. duvaucelii* dispersal out of the monitoring area occurred frequently, after the second month following release. Distances moved by some *H. duvaucelii* on Tiritiri

Matangi were up to three times greater than the movement distances of geckos on Motuora. This may be explained by differences in the geography of the release sites on the two islands. The release site on Motuora resides on the most southern peninsula of the island. Large vertical sea cliffs border three side of the peninsula while the third side forms an arm that connects to peninsula to the rest of the island's landmass. These geographical features are likely to have limited *H. duvaucelii* dispersal out of the monitoring area. In comparison, the release site on Tiritiri Matangi was not bordered by cliffs and is contiguous with the rest of bush on the island. Therefore, *H. duvaucelii* were able to disperse out from all four sides of the monitoring area.

4.4.2.3 Additional observation

The two geckos (005M and 018F) that were re-sighted within one metre of each other appeared to remain together for the at least eight days before their transmitters were recovered 0.5 m from each other (35 days after the pair were first observed) Both transmitters had sloughed skin attached to them and were found under wood and debris. It is unclear why these geckos appeared to pair, at least temporarily, as monogamous pairing is very rarely demonstrated in lizards (Bull, 2000) and has never been documented in geckonids. The pairing is unlikely to be related to courtship or mating as the observations occurred outside of the known *H. duvaucelii* breeding season which occurs in September to October (Rowlands, 2005). However, it is possible that the individuals were attracted to each other via chemical stimuli (Regalado, 2003), as the ability to recognise individual conspecifics has been documented in many reptiles, including geckonids (Dial *et al.*, 1989; Yeager & Burghardt, 1991; Shah, 2002). Conspecific attraction has been associated with aggregation behaviour in geckos and although the two *H. duvaucelii* individuals were never observed in the same refuge, they were seen very close to one another. If conspecific attraction through chemical stimuli was occurring, then this may be important for mate finding and reproduction in low density translocated populations. Further research confirming the presence of chemical communication in *Hoplodactylus* geckos and its role in social interactions is required.

4.4.3 Range area

Range areas of *H. duvaucelii* varied greatly between individuals in this study, and were much larger than reported for non-translocated resident geckos. Resident *H. duvaucelii* on Ruamahua-iti Island reportedly utilised areas of up to 210 m² over three nights of radio-tracking (Christmas, 1995). A similar sized nocturnal gecko, *Phelsuma guentheri*, occupied home-ranges (100% MCP) varying in size from 6 m² (number of fixes = 17) to 116 m² (fixes = 16) (Gerner, 2008). Translocated *H. duvaucelii* range areas were six times larger than this in size. The large range areas demonstrated in this study are probably a function of the effects of translocation on the movement and activity of the geckos (see section 4.4.2.2). The range areas on Tiritiri Matangi and Motuora did not appear to be influenced by individual body size (i.e. SVL) as reported by a number of other authors (Turner *et al.*, 1969; Christian & Waldschmidt, 1984; Perry & Garland Jr., 2002; Sullivan *et al.*, 2004). The selection of only adult geckos for release may have contributed to the small differences in SVL measurements and therefore was insufficient to detect any body size effects on the size of range areas.

Home-range size can often be used to reflect reproductive strategies, since males often display large home-range areas in order to increase encounters with females and increase reproductive success (Turner *et al.*, 1969; Fleming & Hooker., 1975; Rose, 1982). This strategy is commonly exhibited among polygamous lizards (Rose, 1982; Eifler & Eifler, 1999; Melville & Swain, 1999; Schneyer, 2001). In the present study, no differences were shown between male and female range areas of *H. duvaucelii*, despite the high occurrence of polygny and promiscuity amongst New Zealand geckos (Todd, 2005; Todd, 2008). However, these results were not conclusive since range area data was not available over the entire year or across seasonal cycles, nor were the estimated range areas accepted as truly representative of normal *H. duvaucelii* home-range. Further research across all seasons is required on the ranges of resident *H. duvaucelii* before the actual relationships between home-range size and reproductive strategies can be described.

Home-range size and site fidelity are a function of resource availability (i.e. access to food, shelter, and mates) (Rose, 1982). In an environment with high resource availability, a small home-range may be sufficient to sustain an individual. Once resources become scarce, the animal may need to expand the home-range to acquire these resources. High site fidelity has been reported in a number of New Zealand geckos (Flannagan, 2000; Salmon, 2002; Lettink, 2007). For example, 92% of adult *H. maculatus* reportedly remained within five meters of previous sightings, over an eight year study period (Whitaker, 1982). *H. duvaucelii* have shown similar behaviours, with Barwick (1982) and Thompson (1992) both reporting tenacious site fidelity by one *H. duvaucelii* recaptured 29 years later, five meters from its original capture site. However, translocated *H. duvaucelii* in this study demonstrated large range areas and showed low site fidelity; very rarely re-captured in the same areas on subsequent occasions. Although this may again suggest a lack of resource availability at the release sites induced dispersal by the geckos, it is more likely that the large ranges were a result of increased activity and movement associated with the translocation and release into an unfamiliar environment (see section 4.4.2.2).

4.4.4 Range area shifts

At end of the monitoring period of this present study, the translocated *H. duvaucelii* demonstrated all four range scenarios, which may suggest that individual variation plays a role in deployment of different strategies for obtaining resources and responding to their availability in the environment. The scenario that was most commonly displayed by translocated *H. duvaucelii* on both Tiritiri Matangi and Motuora are associated with exploration and familiarisation behaviour to a new environment. This can result in large increases in cumulative range area, where this animal's range area is likely to stabilise once suitable habitat is found (Rose, 1982; Ussher, 2002; Ruffell, 2005).

However, there was also a high proportion of *H. duvaucelii* that did not appear to form stable range areas. This second scenario can be expected if the geckos failed to find adequate resources within a specific area, or they acted as 'floaters' and preferred to wander through the environment to take advantage of resources as they became available (Rose, 1982; Gruber & Henle, 2004; Gerner, 2008).

A smaller proportion of geckos did not disperse far distances and had established stable range areas immediately surrounding the release site. There may be many unmeasured factors that influence the lack of dispersal in these individuals such as stress, physical restrictions, or even that they were the first to secure the most suitable habitat in these areas, and subsequently excluded/ caused other founders to disperse to other vacant habitats. However, territoriality has been previously discussed and discarded as a limiting factor for this population's movement (see section 4.4.2.2).

Moreover, some geckos (Motuora) even displayed large shifts in range area following a period of stability. Again, there are many possible explanations for such behavioural shifts, including a change in the levels of conspecific interactions, resource availability/ inavailabilty, or floaters (Stebbins, 1948; Satrawaha & Bull, 1981; Rose, 1982). More detailed experimental research is required to measure these potential factors to determine the actual cause(s) of the range area shifts.

4.4.5 Habitat use

Habitat used for refuging, by *H. duvaucelii*, was most often characterised by dense, complex vegetations, such as flax on Tiritiri Matangi and scrub (e.g. gorse and muehlenbeckia) on Motuora. The observed use of these habitat types was proportional to their availability implying that *H. duvaucelii* did not preferentially select refuge habitat but rather utilised what was available to them. Nevertheless, dense flax thickets and thick low-lying vegetation are likely to provide safe refuge sites for *H. duvaucelii*. Many radio-tracked geckos were located deep within the base of flax and occasionally it was not possible to retrieve the individuals due the impenetrability of the vegetation. The high frequency of geckos found in dense vegetation is similar to the study by Heaphy (1998), where observed *H. duvaucelii* on Motukahakaha Island utilised dense boxthorn (*Lycium* spp.) and taupata (*Coprosma repens*). The thick, dense structure of these vegetations may be important for geckos as they provide safe refuge sites that are difficult for predators, such as birds, to penetrate. In the present study, *H. duvaucelii* were occasionally located up in the tree canopy during the day, where they clung tightly to branches and became very difficult to see.

At night, *H. duvaucelii* were most often recorded on trees, flax, and on the ground. The tree species most commonly used by *H. duvaucelii* were karo, pohutukawa**,** and mahoe however, these trees were also the most common species found in the monitoring areas on both islands. Past observations of *H. duvaucelii* at night suggest that they emerge from their day refuge locations and descend from tree tops to forage amongst the leaf litter for invertebrates (Whitaker, 1968; Jones, 2000; Hoare, 2006). Large numbers of invertebrates, including beetles, weta, moths, and earwigs, were observed on the ground and on trunks of trees at night during this study on Tiritiri Matangi and Motuora. Geckos were also observed foraging on trees on Motuora in significantly greater proportions than the availability of tree habitat on in the monitoring area. On two occasions, a number of karo trees began to exude sap from areas on the trunk and invertebrates congregated in large numbers at these areas to consume the sap. Geckos appeared to be attracted to these locations, as it was common to observe at least two *H. duvaucelii* on a sapping tree in one night. On one occasion, five individuals were observed within a one-metre area of a tree trunk. Although geckos were never directly observed licking sap or predating on invertebrates, it is likely that they were attracted to these trees by the invertebrate activity. The infrequent observation of high numbers of *H. duvaucelii* within an area, are probably the reason for the calculated disproportionate use of tree habitat compared to their availability on Motuora.

Habitat utilisation by translocated *H. duvaucelii* was comparable to that of resident radio-tracked geckos on Korapuki Island (Hoare, 2006). However, *H. duvaucelii* seemed to forage less on the ground on Tiritiri Matangi and were only occasionally located in flax on Motuora, compared to the high use of both these habitats on Korapuki Island. These differences may be explained by the availability of habitat in monitoring areas, on the release islands. On Motuora, a very small proportion of the available habitat was comprised of flax vegetation, and similarly on Tiritiri Matangi, the proportion of habitat comprising open ground is relatively low. Similarities of habitat use source and translocated *H. duvaucelii* may suggest that translocation does not have large scale effects on the ability of *H. duvaucelii* to adapt to their new environment. This is important for future translocations as it provides evidence that geckos released into a novel environment have the ability to successfully adapt and exploit resources provided by a new environment.

4.4.6 Limitations

4.4.6.1 Range area

Minimum convex polygons (MCP) are arguably the most useful estimate for reptile home-range analysis (Rose, 1982; Thompson *et al.*, 1999; Perry & Garland Jr., 2002; Row & Blouin-Demers, 2006; Nilsen *et al.*, 2007). Accuracy in home-range estimates are governed by the number of locations obtained from an animal, with more locations over time yielding more accurate estimates (Howell, 1954; Rose, 1982; Alterio, 1994). Additionally, the sampling frequency is likely to affect the accuracy of the area to be estimated (Waldschmidt & Tracy, 1983). For example, mean home-range estimates for *Uta stansburiana* in Western Colorado were three times larger after three months of data collection, compared to one month (Waldschmidt & Tracy, 1983). Sampling across seasons is also important as many animals alter their behaviour or increase their range during the breeding season (Hitchmough, 1982; Rose, 1982; Gerner, 2008).

In the present study, the average number of location fixes obtained for *H. duvaucelii* was 19.9 (ranged from 3 to 33). Although this was comparable to other studies on lizard home-ranges (Salmon, 2002; Wone & Beauchamp, 2003; Gerner, 2008), radio-tracking was not conducted across all seasons. Gaining an accurate assessment of home-range will require a longer-term study that incorporates all of the animal’s seasonal activities. The interval between sampling points is also important as sporadic and/ or long intervals between samples may result in the measurement of floaters, rather than a resident animal within an established range area. Monthly sampling of *H. duvaucelii* fixes may have been too infrequent to accurately estimate range area, especially since individuals were capable of moving over 200m in two weeks (Appendix I). However, there is a cost/ benefit between obtaining more accurate fixes and higher disturbance to the animal. A further limitation of MCP home-range estimation is that it does not incorporate three-dimensional space use. This may not affect range estimates of terrestrial species, however range areas may be dramatically underestimated in arboreal species that incorporate large vertical components in their spatial use (Milstead, 1972; Perry & Garland Jr., 2002).

4.4.6.2 Radio-telemetry

Radio-telemetry studies are often limited to small sample sizes, due to the logistics of tracking multiple animals and the cost of the equipment. This may affect the results of a study by reducing its statistical power. Radio-telemetry acts to provide vast information on few individuals and inferences on their movements and behaviour are generally applied across the population. However, in the present study, half the founder population on each island carried radio-transmitters. It is likely that these individuals provided a sufficient representation of the entire translocated population for describing trends in post-release movement, range area, and habitat use.

4.4.6.3 Habitat use

Observations of *H. duvaucelii* habitat use at night were subject to high observer bias as a result of vegetation structure. Sighting geckos in dense vegetation (i.e. flax and muehlenbeckia) was often more difficult compared to sighting them on tree trunks or on the ground. Caution needs to be taken when describing habitat utilization from observation data and observations should be taken as conservative estimates of actual habitat use. Radio-telemetry has acted to reduce some of this observer bias by providing more accurate data on small scale habitat use (Hoare, 2006).

4.4.7 Conclusion

Ultimately, the relevance of the *H. duvaucelii* range areas estimated in the present study may only become apparent once detailed home-range analyses have been conducted on resident non-translocated *H. duvaucelii*. Without a comparative study it is difficult to make conclusions on how translocations affect the movement and behaviour of *H. duvaucelii*. However, the ability of *H. duvaucelii* to move large distances in response to translocation needs to be considered when assessing habitat suitability for translocations to reduce the chance of translocated individuals moving into sub-optimal habitats.

CHAPTER 5

Efficiency of reptile monitoring techniques

Plate 5.1 Footprint tracking tunnel showing *Hoplodactylus duvaucelii* footprints remaining on the tracking card and leaflitter. (Photograph by author).

5.1 Herpetofaunal monitoring

Amphibian and reptile population monitoring has become increasingly important due to recent documentation of global herpetofauna declines (Gibbons *et al.*, 2000). Herpetofauna, particularly amphibians, are recognised as bioindicators of ecosystem health and documentation of recent declines are particularly alarming (Gibbons & Stangel, 1999; Gibbons *et al.*, 2000; Hilty & Merenlender, 2000). Around the world, biological monitoring strategies are implemented to assess the health of ecosystems and often focus on overall herpetofaunal assemblages (Ryan *et al.*, 2002).

New Zealand's herpetofaunal monitoring differs in that it is born out of species management and research rather than biodiversity-based species inventories. This is due in part to deficiencies in data (Hitchmough *et al.*, 2007) and the vulnerable status of many of New Zealand's herpetofauna. However, the Department of Conservation (DOC), as well as some Regional Councils, has implemented long-term herpetological monitoring for both species management and ecological monitoring. For example, the critically endangered grand (*Oligosoma grande*) and Otago (*O. otagense*) skinks (Norbury *et al.*, draft) and the jeweled gecko (*Naultinus gemmeus*) have long-term monitoring programmes in place. Similarly, the Auckland Regional Council (ARC) monitors shore skinks (*O. smithi*) and ornate skinks (*Cyclodina ornata*) at Tawharanui Regional Park, as well as moko (*O. moco*), ornate and copper skinks (*C. aenea*) at Shakespear Regional Park. These long-term monitoring programmes form an important part of the ecological restoration of these conservation parks.

In comparison, herpetological surveys in more isolated areas occur infrequently. Sampling methods in such areas need to be more effective in order to provide reliable results. However, New Zealand's herpetofauna are highly elusive and currently, difficulties associated with reliable survey methods mean that it is difficult to assess species vulnerability. The recent discoveries of new species, such as *H. cryptozoicus* from the Takitimu Mountains (Jewell & Leschan, 2004) and the recently described skink, *O. pikitanga* (Bell & Patterson, in press) highlight the need to develop improved monitoring techniques so that effective and appropriate management decisions can be made.

Regardless of the monitoring objectives, surveying herpetofauna is inherently difficult for the following reasons: 1) they are highly cryptic due to their small size, camouflage colouration, and arboreal and/ or nocturnal habits, 2) they are often found in spatially clumped distributions, 3) their activity is governed by both immediate environmental and seasonal variables, and 4) they inhabit complex three-dimensional structured habitats (T. Bell, unpublished data). Furthermore, factors such as home-range size, trap and/ or observer avoidance (Crosswhite *et al.*, 1999), and behavioural shifts in response to predators may affect the ability to detect an animal (Hoare, 2006).

5.1.1 Monitoring techniques

Traditionally, herpetofaunal inventories implement broad scale non-selective sampling techniques to ensure representation of an entire herpetofaunal community. These sampling techniques include pitfall traps (Hobbs *et al.*, 1994; Read & Moseby, 2001), double and single ended funnel traps (Crosswhite *et al.*, 1999; Thompson &

Thompson, 2007), artificial cover objects (ACOs) (Monti *et al.*, 2000; Hampton, 2007), drift fence arrays (Friend *et al.*, 1989), and visual searching (Doan, 2003; Flint & Harris., 2005). A large number of comparative studies have described the effectiveness of different sampling techniques for monitoring herpetofauna in varying habitats (Ryan *et al.*, 2002; Donnelly *et al.*, 2004; Manley *et al.*, 2005). Such studies reveal that a key attribute of an effective sampling technique is the ability to increase the detectability of a rare or cryptic species (T. Bell, unpublished data; Sutton *et al.*, 1999). For example, drift fence arrays are efficient for capturing small, surface dwelling species (Greenburg *et al.*, 1994). However, they become relatively ineffective for capturing more arboreal herpetofauna, such as cryptic tree frogs (Gibbons & Semlitsch, 1981; Dodd, 1991; Enge, 2001).

Successful monitoring techniques include those that provide some benefit to the animal (i.e. refuge sites, bait as food rewards) and do not induce avoidance behaviour due to bad experiences (e.g. stress). Experimental studies on the retreat site selection of a nocturnal gecko, *Oedura lesueurii*, have shown that they preferentially select sites with more suitable characteristics, such as warmth and crevice shape (Schlesinger & Shine, 1994). Therefore, designing monitoring techniques to exploit an animal's preferences may lead to the development of more effective monitoring tools. (Lettink & Cree, 2007) reported successful results after testing '*Onduline*' retreat stacks to monitor lizard populations. *Onduline* material is a type of roofing material (*Onduline*, France) made from a bitumen and organic material, which is waterproof and has the ability to absorb and retain heat for long periods. Therefore, it is likely lizards will utilise these refuges not only for cover but also for thermoregulation.

Since monitoring techniques vary widely in their ability to sample herpetofauna, considerations need to be given to which method(s) will be most appropriate for the intended outcomes. Ultimately, the specific aims and objectives of the monitoring programme will govern which technique(s) are the most appropriate to apply. Irrespective of the method however, the sample obtained should be representative of the population (Kjoss & Litvaitis., 2001; Marsh & Goicochea, 2003).

Herpetofaunal monitoring within New Zealand has traditionally been based on three methods: pitfall traps (Siyam, 2006; Lettink & Cree, 2007), active searching (Jones, 2000; Hoare, 2006) and ACOs or refuges (Wakelin *et al.*, 2003; Lettink & Cree, 2007); T. Bell, unpublished data). More recently, footprint tracking tunnels have been trialed for detecting reptiles and estimating abundance (Siyam, 2006).

5.1.1.1 Active searching

Active searching methods include hand-searching, litter plots (Donnelly *et al.*, 2004), diurnal visual encounter surveys (Doan, 2003), and nocturnal spotlight searching (Whitaker & Shaw, 1999; Tocher & Marshall, 2001). These are probably the simplest and most intuitive methods used by field herpetologists (Flint & Harris., 2005) and are regarded as standard and effective techniques for terrestrial and arboreal herpetofaunal surveillance (Corn & Bury, 1990; Heyer *et al.*, 1994; Crosswhite *et al.*, 1999; Doan, 2003; Manley *et al.*, 2005; Grover, 2006). These methods involve counting the number of individuals present in a given survey area or over a specific time period (Flint & Harris, 2005). These data are then used to generate a catch per unit effort (CPUE) number, which can be used for comparisons over time or across sites of similar habitat quality, if the surveyor remains the same or similarly experienced. Active searching is relatively inexpensive to perform and can cause little disturbance to the environment (Flint & Harris, 2005). However, active searches do not necessarily result in the capture of an animal (Heyer *et al.*, 1994) and inaccurate identification of species can reduce the survey integrity. Nocturnal spotlight searching has been used extensively in New Zealand for surveying tuatara, *Sphenodon* spp. (Ussher, 1999b; Ruffell, 2005), lizards (Whitaker, 1991; Whitaker & Shaw, 1999; Tocher & Marshall, 2001; T. Bell, unpublished data) and frogs (Germano, 2006; Haigh *et al.*, 2007).

5.1.1.2 Artificial refuges (A.R.s)

Artificial refuges (A.R.s) are commonly used to survey and monitor reptile (Engelstoft & Ovaska, 2000; Hampton, 2007; Lettink & Cree, 2007), amphibian (Ryan *et al.*, 2002; Wakelin *et al.*, 2003), and invertebrate communities (Green, 2005; Bleakley *et al.*, 2006). Artificial refuges may be highly complex or very simple in terms of design, ranging from intricately designed artificial retreats involving crevices and holes, to simple foam-cover refuges (T. Bell, unpublished data) or plain corrugated iron ground cover objects (i.e. ACOs) (Lettink & Cree, 2007).

These designs can vary according to their application to the target taxa. For example, ACOs (e.g. corrugated iron, *Onduline*, or plywood) placed flat on the ground, are commonly used for detecting and assessing populations of terrestrial amphibians, such as salamanders (Monti *et al.*, 2000; Marsh & Goicochea, 2003). In other studies, A.R.s are preferred as they can be mounted up trees to provide refuge for arboreal species. For example, the use of polyvinylchloride (PVC) pipes for detecting hylid frogs (*Hyla* spp.) is widely accepted as a successful sampling technique (Moulton *et al.*, 1996; Borg *et al.*, 2004).

Despite their high application in the field, it is still unclear whether A.R.s can be used for estimating population densities. Bleakley (2006) suggested that weta (*Hemideina thoracica*) numbers in A.R.s are likely to reflect the number of weta in the immediate surrounding area. However, results were tentative as they were based on only six samples.

5.1.1.3 Footprint tracking tunnels

Footprint tracking tunnels have been used extensively in New Zealand pest monitoring programs to detect presence and index the density of small introduced mammals (King & Edgar, 1977; Brown *et al.*, 1996; Blackwell *et al.*, 2002). Tracking tunnels consist of a pre-inked wet strength tracking card inserted within a waterproof polypropylene tunnel (*Black Trakka*™). The central ink strip consists of non-drying, water resistant, and non-toxic ink derived from vegetable dye. The tracking tunnels can be set either unbaited or baited, by placing bait on the central inked strip. An animal passes over the ink and leaves its footprints on the non-inked outer portions of the card on exiting. Footprints from non-target species are often also recorded in tracking tunnels.

In recognition of their effectiveness as monitoring tools, tracking tunnels have recently been applied within invertebrate and reptile conservation with very successful results. Watts *et. al*. (2008) suggest that tracking tunnels are useful for detecting and monitoring large weta species (*Deinacrida* spp.) and could potentially be used for other sized weta species. Research into the application of tracking tunnels in lizard conservation has indicated that species discrimination from footprints is possible and that tracking tunnels are capable of estimating absolute density (Siyam, 2006). As animals are attracted by different lures, the opportunity to selectively monitor certain species becomes possible (e.g. peanut butter attracts rodents, while honey attracts invertebrates and lizards).

Additionally, there is potential for tracking tunnels to be used as a highly effective method for detecting cryptic lizard species. For example, a small population of geckos on Tiritiri Matangi Island went unnoticed for many years until the discovery of their footprints in rodent monitoring tracking tunnels in 2004. Subsequent searches confirmed the presence of a remnant population of *H. maculatus* (G. Ussher, *pers. comm.*, 2007).

5.1.2 Efficiency of monitoring techniques

Monitoring programs are often limited by financial and labour constraints and therefore efficient sampling methods are imperative to maximise the validity and usefulness of the data collected (Brathwaite, 1991; Burbidge, 1991). Assumptions that methods are efficient based on past studies alone can be misleading and inaccurate when it comes to interpreting results. Additionally, the extrinsic effects of the environment may influence reptile activity (van Damme *et al.*, 1987; Read & Moseby, 2001), and therefore significantly affect the ability of the monitoring tool to detect an animal.

5.1.3 Research objectives

Testing the efficiency of monitoring methods requires either knowledge of a population's size, or experimental manipulation of population densities. Very few studies have managed to achieve this, and none in New Zealand has compared these monitoring methods against known population sizes in the wild. The translocation of two small populations of *H. duvaucelii* from Korapuki to Tiritiri Matangi and Motuora provided the opportunity to test the efficiency of various monitoring techniques for cryptic, nocturnal reptiles. Three standard New Zealand reptile monitoring techniques were tested, between February 2007 and February 2008, in areas surrounding the release sites on both islands.

The specific objectives of the study were:

1) Compare the efficiency of three standard reptile monitoring techniques: i) spotlight searching, ii)A.R.s, and iii) footprint tracking tunnels for detecting cryptic geckos at low densities.
2) Compare the differences in monitoring techniques across the two island sites to expose inconsistencies and potential effects of habitat structure on detecting cryptic geckos.
3) Determine the influence of environmental variables on the effectiveness of the three reptile monitoring techniques.

5.2 Methods

5.2.1 Study sites and species

This study was conducted on two small populations of geckos, *H. duvaucelii*, translocated to Tiritiri Matangi and Motuora Islands (Hauraki Gulf, New Zealand). Refer to Chapter 2 for a detailed description of *H. duvaucelii* and study sites.

5.2.2 Monitoring techniques

5.2.2.1 Release site setup

A 50 m x 80 m grid was set up surrounding the predetermined gecko release sites on Tiritiri Matangi and Motuora Islands (Plate 5.2). The monitoring grid consisted of 40 monitoring stations on Tiritiri Matangi and 38 stations on Motuora (due to the release area terrain), positioned evenly at 10 m intervals (Figure 5.1). Each station consisted of one tracking tunnel and one of four A.R. (see below & Plate 5.3). Monitoring stations were placed out two weeks prior to the gecko release, in November 2006, to avoid problems of neophobia. All A.R.s were positioned between zero metres (i.e. at ground level) and 2.5 m above the ground and most of the tracking tunnels were placed at ground level. All A.R.s were positioned in areas that were most likely to be encountered by a gecko, such on the main trunk and in the crown of trees.

The four different A.R. designs were tested and these were randomly assigned to each of the 40 monitoring stations. Designs are described below:

1) Rope retreat (RP) (Plate 5.4a, b)

The rope retreat refuge was designed specifically for use by arboreal species. It consisted of a piece of two-inch natural fibre rope coiled around a tree branch or mounted to a trunk to create numerous crevices, and finally covered with a *Corflute*® cover. *Corflute*® (Corex Plastics Australia Pty Ltd) is a double-layer corrugated plastic material that is lightweight and highly durable. The material was trialled due to its ability to absorb solar heat rapidly and retain heat over the short-term due to its double-layered structure.

The coiled design meant that a gecko travelling along a branch would encounter the rope and follow its spiral into the refuge. Similarly, a gecko ascending or descending a tree trunk would be likely to encounter the refuge. The *Corflute*® cover could be removed to check for occupants.

2) *Corflute*® plastic zigzag (ZZ) (Plate 5.4c)

The design of the *Corflute*® plastic zigzag refuge incorporated various sized compartments and surface textures within a single box. The *Corflute*® box (250 mm x 250 mm x 50 mm height) was divided into two sides with a zigzag partition and each side contained three wedge-shaped compartments of differing sizes (i.e. small, medium, & large). Three compartments were lined with a rough textured “sandpaper” type material while the other three remained un-textured. The refuge could be placed either horizontally on the ground or vertically in a tree, and a hinged lid allowed easy checks.

3) Wooden wedge (WW) (Plate 5.4d)

The wooden wedge refuge was based on a design previously used by (Francke, 2005) for monitoring *H. maculatus* on Stephens Island and *H. granulatus* at Karori Sanctuary (R. Empson, *pers. comm.* 2007). It consisted of a wedge-shaped plywood box (250 mm x 200 mm x 50 mm height at the high end) with a small opening at one end and a removal lid for checking the refuge. The wedge shape provided a gradually narrowing crevice allowing the geckos to select the preferred width.

4) *Corflute*® plastic wedge (PW)

The *Corflute*® plastic wedge design was identical in dimension to the wooden wedge design. However, it differed in that it was constructed out of *Corflute*® material.

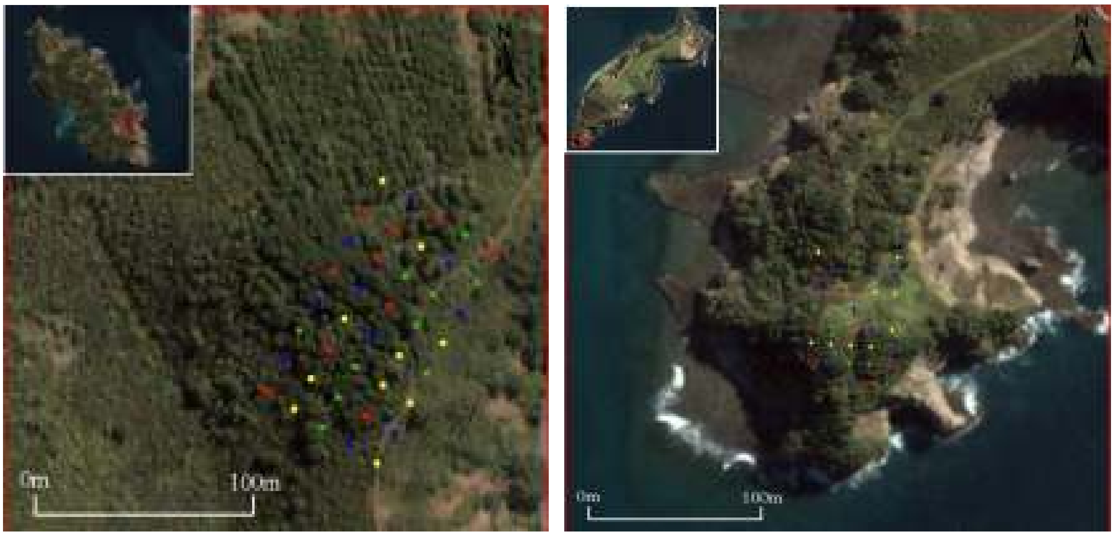


Plate 5.2 Position of the monitoring grids on Tiritiri Matangi (left) and Motuora (right) Islands. Translocated *Hoplodactylus duvaucelii* were released in the centre of each monitoring grid in December 2006. Coloured dots represent randomised placement of different artificial refuge designs within each grid (see figure 5.1).

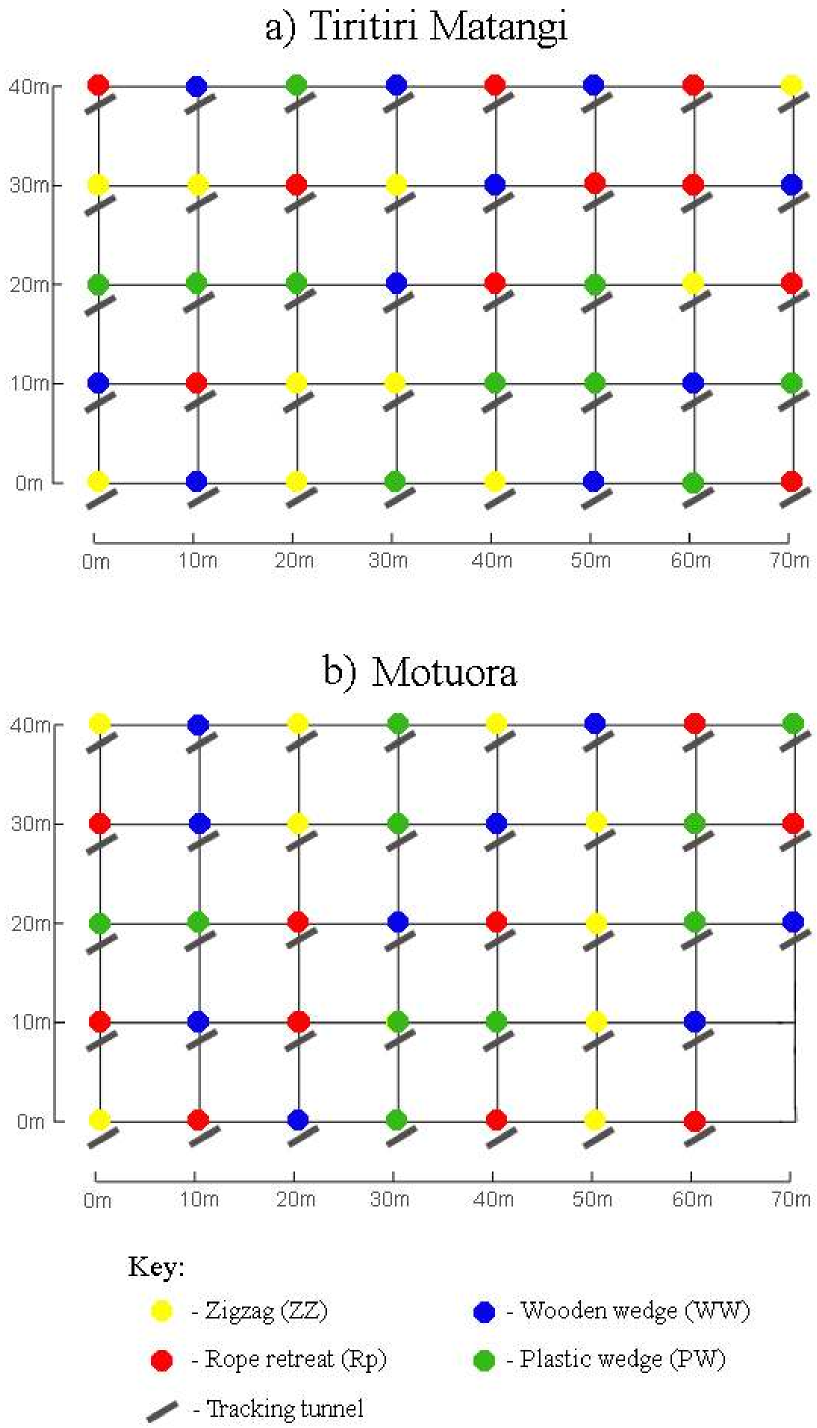


Figure 5.1 Diagrammatic layout of monitoring grids, showing the placement of four artificial refuge (A.R.) designs and tracking tunnels, on a) Tiritiri Matangi and b) Motuora Islands.

Plate 5.3 Monitoring stations showing a) wooden wedge in the crown of a pohutukawa tree (*Metrosideros excelsa*) and tracking tunnel at base of tree, and b) zigzag refuge and tracking tunnel on the ground. (Photographs by author).

Plate 5.4 Artificial refuge (A.R.) designs tested in this study, a) & b) rope retreats, b) *Corflute*® zigzag, c) wooden wedge. Plastic wedge not pictured, but is similar in design to wooden wedge and made of *Corflute*®. (Photographs by author).

5.2.2.2 Monitoring methods

Each monthly monitoring session ran for five consecutive days from February 2007 to February 2008. Monitoring stations (A.R.s and tracking tunnels) were checked every day, in mid-morning and spotlight searches were conducted on all possible nights from dusk onwards. Details of each procedure are described below.

5.2.2.2.1 *<u>Spotlight Searches</u>*

Spotlight searches were conducted on four nights each month during the five-day monitoring session, except during inclement weather. All searches were confined within the monitoring grids. Searches began just after dusk and continued for at least one hour. Torches (6V *Dolphin*, Eveready) and headlamps were used to search for geckos on the ground and in vegetation in all accessible areas within the grid every night. However, some areas (i.e. cliff vegetation, gorse [*Ulex europaeus*], and flax [*Phormium tenax*] thickets) were searched at a safe distance due to dangerous terrain and to reduce noise disturbance while moving through thick vegetation. The start point on each consecutive search night was randomised to avoid searchers following biased routes. Captured geckos were scanned with a PIT tag gun to identify them by their individual PIT tag number (refer to Table 2.2 & 2.3). The location of sighted geckos was recorded on a GPS unit (*Garmin 60CTM*, Garmin Ltd.).

5.2.2.2.2 *<u>Artificial refuge (A.R.s) checks</u>*

Artificial refuges were checked daily over the duration of the monitoring sessions. Checks involved ‘opening’ each A.R., recording the presence of any occupants, and replacing the covers. Occupiers were categorised as invertebrate, skink, or gecko. Therefore, if any evidence of previous occupancy was found (e.g. lizard faeces, sloughed skin, or footprints) the A.R. was recorded as having an occupant for that particular day. This evidence was removed before closing the A.R. to avoid re-sampling the following day.

5.2.2.2.3 Tracking tunnel checks

Inked tracking cards were placed in tunnels on the first day of each monthly monitoring session. These were baited in the centre with a slice of banana. Tracking cards were checked every morning during each monitoring session for footprints and recorded as invertebrate, skink, or gecko. Tracking cards were replaced only if gecko prints were present; otherwise cards were re-baited and left in the tunnels.

5.2.3 Environmental variables

Environmental variables, including daily ambient temperature (°C; collected at 22:00 hrs), relative humidity (% RH), and precipitation (mm) were collected from the National Institute of Water & Atmospheric Research (NIWA) weather station based at Warkworth (ca. 22 km north of Tiritiri Matangi and Motuora).

5.2.4 Statistical analyses

None of the analysed data were normally distributed. Refer to Chapter 2, section 2.5, for details of level of significance tested and general statistical program used.

5.2.4.1 Spotlight searches

Search effort varied with the number of searchers and the duration of each search occasion (hours). Therefore, the number of person search hours was calculated by multiplying the number of search hours by the number of searchers. Gecko encounters each night were then corrected to provide a gecko encounter rate (i.e. CPUE, gecko/person/hour). Median monthly encounter rates were plotted for each island and monthly differences tested using a Kruskal-Wallis median equality test. A Mann-Whitney test was used to describe the differences in gecko encounter rates between the island sites.

5.2.4.2 Artificial refuges (A.R.s)

Artificial refuge occupancy rates were expressed as the proportion of total refuges occupied by a gecko, skink, and invertebrate. The proportion of the total founder population occupying A.R.s was calculated for each month. Monthly occupancy rates on each island were calculated for each category and plotted. Kruskal-Wallis median equality tests were applied to describe differences in monthly gecko occupancies. The frequency of occupancy of different A.R. designs was plotted, although sample sizes were too small to statistically test for refugia preference.

5.2.4.3 Tracking tunnels

For each island, nightly tracking rates were expressed as the proportion of tunnels tracked by a given category (i.e. invertebrate, skink, & gecko) during that particular night. An average monthly tracking rate was calculated for each category and monthly tracking rates were plotted for each island. Differences in monthly tracking rates were tested using Kruskal-Wallis median equality tests. Island differences were described using Mann-Whitney tests.

5.2.5 Environmental variables

The influence of environmental variables on each of the three monitoring techniques was determined using multiple regression analysis. Seasonal differences were tested by combining months into seasons (i.e. Dec/Jan/Feb = summer, etc.) and applying Kruskal-Wallis median equality tests.

5.3 Results

5.3.1 Spotlight searches

A total of nine gecko encounters on Tiritiri Matangi and 19 gecko encounters on Motuora were recorded from 2,100 and 2,211 person search hours, respectively. These included multiple sightings of the same individuals. On Tiritiri Matangi, four (21%) of 19 founders were re-sighted, while 15 (75%) of 20 founders were re-sighted on Motuora.

The highest gecko encounter rates occurred during May 2007 on Tiritiri Matangi (1.0 geckos/ person hour) and during April 2007 on Motuora (1.3 geckos/ person hour) (Figure 5.2). Encounter rates did not differ significantly across islands ($W_{27, 25}$ = 625.5, p = 0.068) and although large variations in monthly encounter rates were apparent for both islands, these were differences were not significant (Tiritiri Matangi: H = 20.30, df = 12, p = 0.062; Motuora: H = 13.13, df = 10, p = 0.216). Gecko encounter rates were highest in the first four months following release, after which encounter rates decreased. An increase in encounters occurred again later in the year during the months of November (Tiritiri Matangi), and January and February (Motuora). Geckos were still being encountered within the study grid on Motuora, 14 months following release however, no geckos were encountered after November 2007 on Tiritiri Matangi (11 months after release).

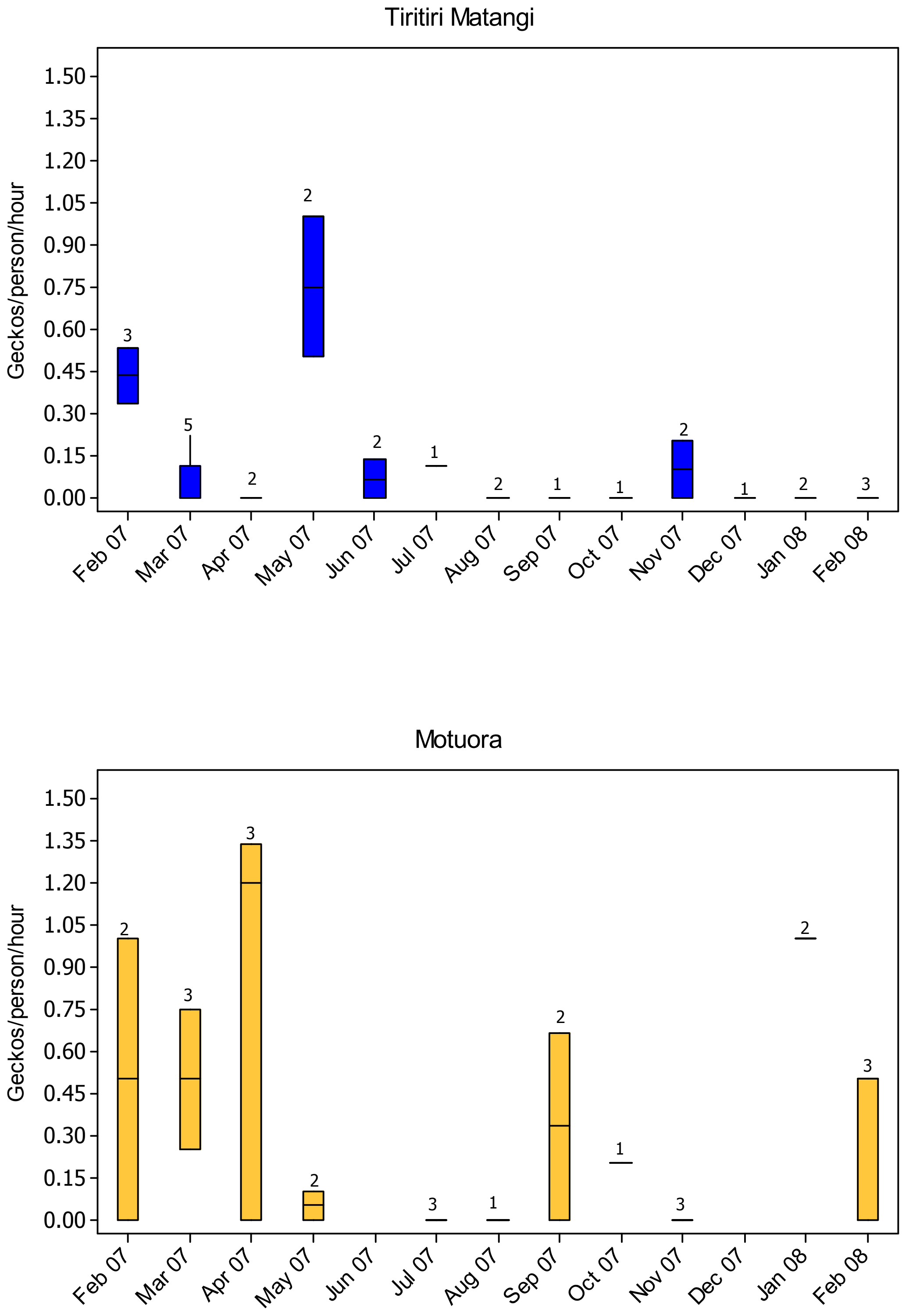


Figure 5.2 *Hoplodactylus duvaucelii* encounter rates on Tiritiri Matangi and Motuora Islands, over a 12 month study period. Lines within boxes (–) represent medians; boxes represent first and third quartiles; and whiskers represent the non-outlier range. Numbers above bars indicate the number of nights spotlight searching occurred.

5.3.2 Artificial refuges (A.R.)

5.3.2.1 Hoplodactylus duvaucelii occupancy

Artificial refuges were occupied or showed signs of occupancy by *H. duvaucelii* on six occasions on Tiritiri Matangi, and were never occupied on Motuora (Figure 5.3). The proportion of the total A.R.s occupied by *H. duvaucelii* each month on Tiritiri Matangi was low (≤ 5%), with no more than 10.5% (2 of 19 geckos) of the total founder population occupying refuges over the study period (Table 5.1). The highest occupancy rates occurred in April 2007 (5%) while no occupancy was recorded between June 2007 and January 2008. Artificial refuge occupancy was indicated on three occasions, through the presence of a complete sloughed skin, large faecal pellet, and blue ink footprints in the A.R.

Three of four A.R. designs were occupied by *H. duvaucelii* on Tiritiri Matangi (Figure 5.4). One individual (030M) occupied two A.R. designs and the same refuge twice (Table 5.2). The two different refuges were located approximately 15 m from each other (Figure 5.1). All occupancy by geckos was observed in refuges positioned above the ground (> 0.3 m).

5.3.2.2 Skinks and Invertebrates

Invertebrates and skinks regularly occupied A.R.s on both islands and throughout the study (Figure 5.5). On Tiritiri Matangi, invertebrate occupancy gradual increased from March through to a peak in September (19%), gradually declined again. An unusual peak in invertebrate occupancy occurred in April (19.2%). On Motuora, peaks in invertebrate occupancy occurred in February (57.4%) and April (44.7%) and a trough on occupancy occurred in July (23.2%). Monthly invertebrate occupancy rates were generally higher on Motuora than on Tiritiri Matangi throughout the study.

Skink occupancy of A.R.s was higher than that of *H. duvaucelii* throughout the study and they were found in A.R.s almost every month. Occupancy by skinks was highest in July (3%) on Tiritiri Matangi and in March (4.4%) and May (4.4%) on Motuora. Peaks in skink occupancy appeared in general to coincide with peaks in invertebrate occupancy on Tiritiri Matangi (Figure 5.5).

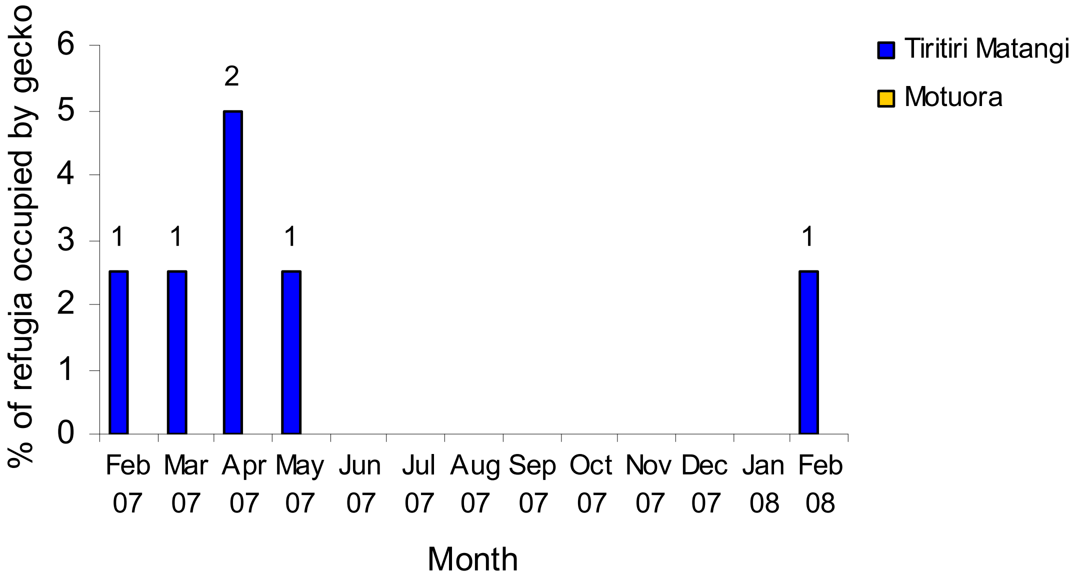


Figure 5.3 The proportion of total artificial refuges (A.R.s) occupied by *Hoplodactylus duvaucelii* over a monthly period from February 2007 to February 2008, on Tiritiri Matangi and Motuora Islands. No occupancy was recorded on Motuora Island. Sample size (n) recorded above each bar.

Table 5.1 Monthly artificial refuge (A.R.) occupancy by *Hoplodactylus duvaucelii* described as a proportion of the total founder population, on Tiritiri Matangi and Motuora Islands between February 2007 and February 2008. Months from June 2007 to January 2008 were excluded due to lack of geckos encountered during those times.

Islands	n	Feb '07	Mar '07	Apr '07	May '07	Feb '08
Tiritiri Matangi	19	5.3%	5.3%	10.5%	5.3%	5.3%
Motuora	20	0%	0%	0%	0%	0%

* n = total founder population size

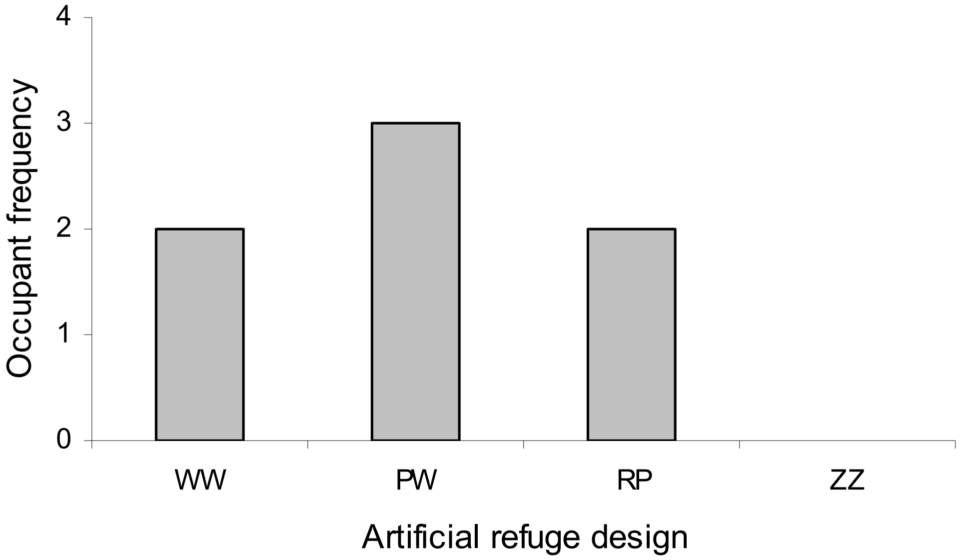
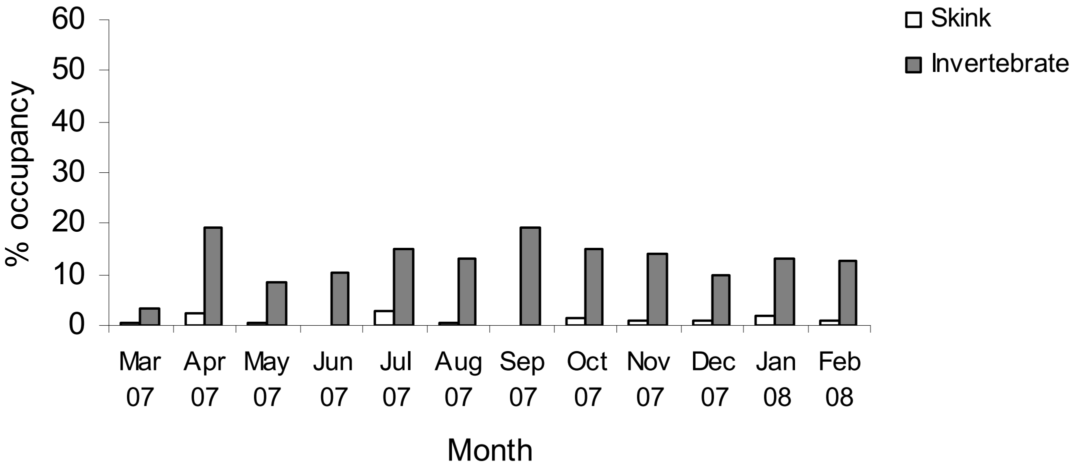


Figure 5.4 Frequency of *Hoplodactylus duvaucelii* occupancy of different artificial refuge designs on Tiritiri Matangi Island (n = 7). WW = wood wedge, PW = plastic wedge, RP = rope, and ZZ = zigzag. Artificial refuges were never occupied by *H. duvaucelii* on Motuora Island.

Table 5.2 The presence of *Hoplodactylus duvaucelii* in different artificial refuge (A.R.) types and individual identified by positive identification or signs of lizard occupancy on Tiritiri Matangi and Motuora Islands during the study (20 December 2006 – 31 February 2008).

Date	Gecko ID/ sign	Refuge type
28-12-2006	030M	plastic wedge
17-02-2007	Faecal pellet	plastic wedge
08-03-2007	030M	plastic wedge
11-04-2007	030M	wood wedge
11-04-2007	sloughed skin	rope retreat
06-05-2007	020F	rope retreat
03-02-2008	ink foot prints	wood wedge

a) Tiritiri Matangi



b) Motuora Island

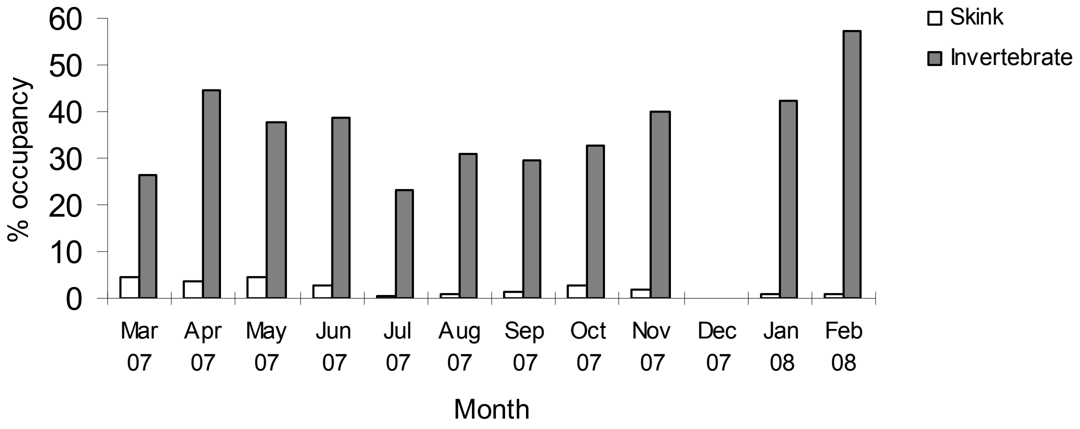


Figure 5.5 Artificial refuge (A.R.) occupancy by skinks and invertebrates on a) Tiritiri Matangi and b) Motuora Islands, over time between March 2007 and February 2008. Measured as the percentage of total A.R.s occupied by each category.

5.3.3 Tracking tunnels

5.3.3.1 Hoplodactylus duvaucelii tracking

The presence of *H. duvaucelii* were able to be detected with tracking tunnels throughout the study period on Tiritiri Matangi, but mostly during the warmer months on Motuora (Figure 5.6). Tracking rates were significantly higher on Tiritiri Matangi than Motuora ($W_{47,\ 39} = 2370.5$, $p = 0.005$). Monthly tracking rates differed significantly on both Tiritiri Matangi ($H = 28.81$, $df = 11$, $p = 0.002$) and Motuora ($H = 26.93$, $df = 10$, $p = 0.003$). Tracking rates peaked in May 2007 (10.6%) and February 2008 (11.9%) on Tiritiri Matangi and in March 2007 (4.4%) and January 2008 (6.6%) on Motuora. Tracking rates were lowest from June 2007 to August 2007 on both islands. Average monthly temperature matched *H. duvaucelii* tracking rates well, with increased tracking rates associated with higher temperature spikes (Figure 5.6). Similarly, decreasing temperatures associated with the onset of winter are matched by decreasing tracking rates. Tracking rates were highest at temperatures above 12°C on both islands.

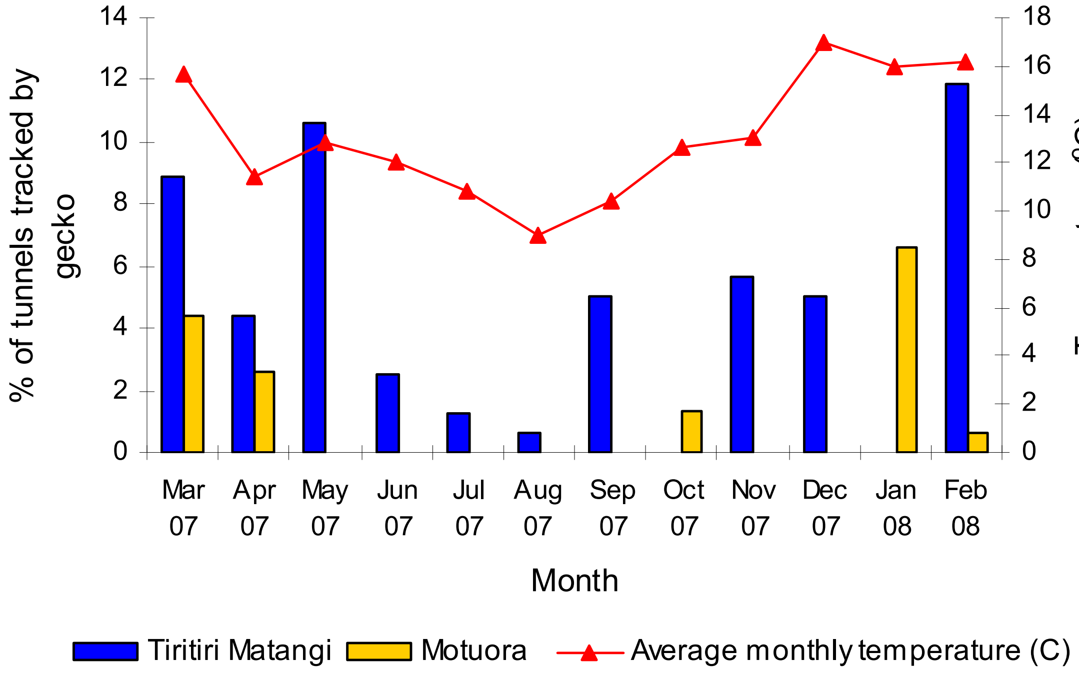
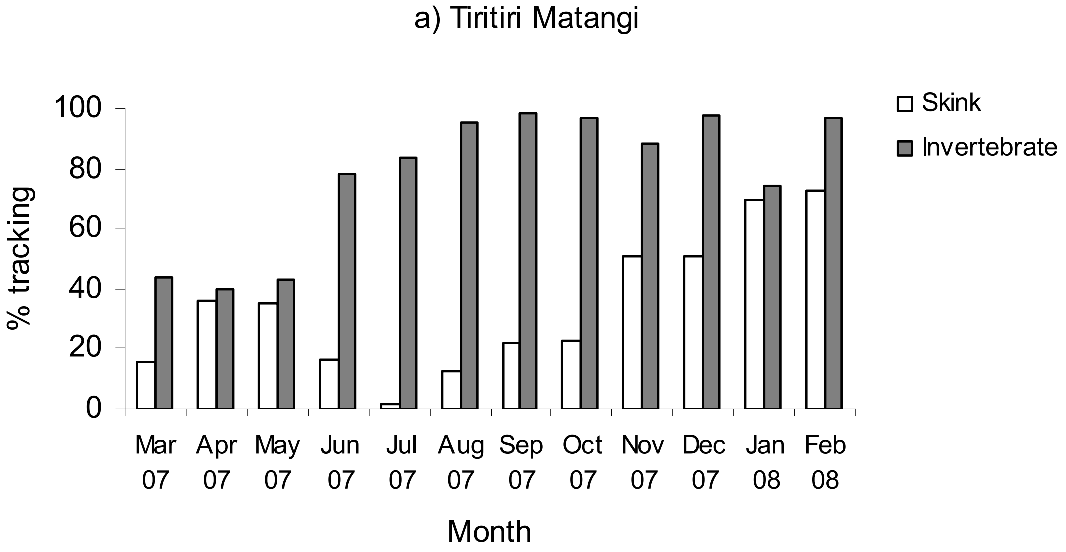


Figure 5.6 Tracking rates of *Hoplodactylus duvaucelii* on Tiritiri Matangi and Motuora Islands and average monthly temperature (° C), using tracking tunnels.

5.3.3.2 Skinks and Invertebrates

On Tiritiri Matangi invertebrate tracking rates remained around 50% from March 2007 to May 2007 (Figure 5.7). From June 2007 to February 2008, invertebrate tracking rates remained consistently high, at above 70%. On Motuora invertebrate tracking rates remained above 50% over the entire study duration.

Skink tracking rates on Tiritiri Matangi showed peaks in April 2007 (36.3%) and February 2008 (72.5%) and the lowest tracking rates were recorded from June 2007 to August 2007. On Motuora, skink tracking rates showed peaks in May 2007 (24.6%) and January 2007 (40.8%), and were lowest from June 2007 to August 2007.



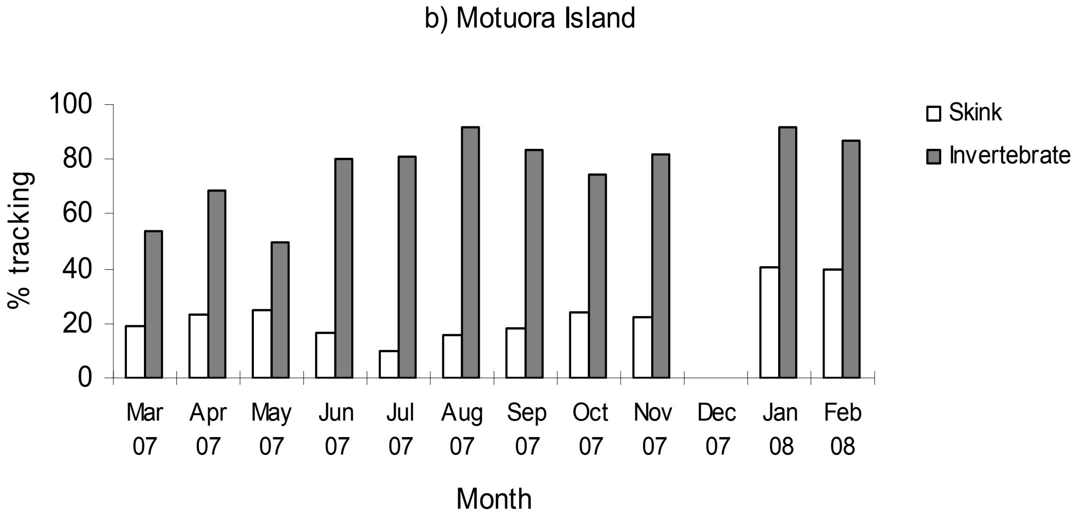


Figure 5.7 Tracking rates of skinks and invertebrates on a) Tiritiri Matangi and b) Motuora Islands, using tracking tunnels.

5.3.4 Influence of environmental variables

Hoplodactylus duvaucelii activity appeared to be influenced by environmental variables, with temperature having the greatest negative influence on tracking rates (i.e. tracking tunnel method) (Tiritiri Matangi: $r^2 = 51.7$, $p = 0.027$; Motuora: $r^2 = 31.5$, $p = 0.001$) (Table 5.3). Artificial refuge use was excluded in final analyses due to low occupancy rates. Encounter rates (i.e. spotlight searching method) did not appear to be influenced by temperature, relative humidity, or precipitation (rainfall) on both islands.

Relative humidity had no apparent influence on tracking rates on Tiritiri Matangi ($r^2 = 51.7$, $p = 0.114$) however, tracking rates on Motuora were influenced by relative humidity ($r^2 = 31.5$, $p = 0.031$). Precipitation had a significant negative influence on tracking rates on Tiritiri Matangi ($r^2 = 51.7$, $p < 0.001$) but had no apparent influence on tracking rates on Motuora ($r^2 = 31.5$, $p = 0.159$).

Combining months into the four seasons exposed significant differences in tracking rates between seasons (Tiritiri Matangi: $H = 13.15$, df = 3, $p = 0.004$; Motuora: $H = 11.44$, df = 3, $p = 0.01$).

Table 5.3 Influence of environmental variables on monitoring method indices, tracking rate and encounter rates of *Hoplodactylus duvaucelii* on Tiritiri Matangi and Motuora Islands. Relationships were calculated using multiple regressions. Note that the third monitoring method, A.R. use, was excluded due to low occupancy rates.

		Temperature	Relative humidity	Precipitation	r^2
Tiritiri Matangi	Tracking rate	*p = 0.027	p = 0.114	*p < 0.001	51.7 %
	Encounter rate	p = 0.458	p = 0.924	p = 0.403	5.1 %
Motuora	Tracking rate	*p = 0.001	*p = 0.031	p = 0.159	31.5 %
	Encounter rate	p = 0.065	p = 0.437	p = 0.091	29.8 %

* significant results

5.4 Discussion

This study indicates that detecting cryptic reptiles in complex environments is inherently difficult, in accordance with other research (Neilson *et al.*, 2004; Jamieson & Neilson, 2007; T. Bell, unpublished data). This is especially true for nocturnal and arboreal species, as well as those that exist at low densities. Nevertheless, this study indicated that all of the three monitoring techniques tested were capable of detecting *H. duvaucelii* post-translocation, and that these techniques differed significantly in their detection abilities. Their strengths and weaknesses are explored below.

5.4.1 Spotlight searching

Spotlight searches on Motuora resulted in a higher number of *H. duvaucelii* encounters and recaptures than on Tiritiri Matangi, despite implementation of similar search efforts. This difference may be due differences in the availability and structure of the habitat between the two islands. Whitaker (1991) noted that habitat structure had a significant effect on the ability to encounter cryptic *H. stephensi* via spotlight searching. The habitat on Tiritiri Matangi is dominated by complex thickets of coastal flax and this was particularly preferred by *H. duvaucelii* for refuging and foraging (see Chapter 4, section 4.3.3), however this dense cover is likely to have reduced the ability to observe geckos on Tiritiri Matangi. In addition, disturbance created by noise and vibrations as a result of moving through flax would have been sufficient to initiate geckos to flee early and/ or seek refuge deep within the vegetation. In comparison, the habitat on Motuora was comprised of tall trees and a less dense understorey, making it easier for observers to move with fewer disturbances and thereby increasing the ability to locate geckos at distance. *Hoplodactylus duvaucelii* sightings on Korapuki were reported to be influenced by vegetation height and structure (Hoare, 2006). Similarly, Jones (2000) noted that the location of only a small proportion of translocated *H. duvaucelii* on Mana Island was partially due to the difficulties of moving quietly through the forest valley.

There are other geographical features of the release sites that may have influenced the probability of detecting *H. duvaucelii* on the two islands. The large vertical cliffs that bordered the monitoring area on Motuora may have reduced or restricted the number and distances of geckos dispersing from the release site (see Chapter 4, section 4.4.2.2). These may have resulted in a higher gecko density during the monitoring period, resulting in increased encounter rates. In comparison, Tiritiri Matangi lacked these geographical limits, and geckos were able to move large distances away from the release site and out of the monitoring grid, therefore suggesting a possible explanation for the decrease in encounter rates over time.

One other possible explanation for the reduced encounter rates on Tiritiri Matangi is that the geckos suffered higher mortality rates on Tiritiri Matangi compared to the population on Motuora. Tiritiri Matangi supports a greater abundance of potential predators than Motuora, including morepork (*Ninox novaeseelandiae*) and tuatara. Consequently, there was a higher risk of predation on *H. duvaucelii*. However, a lack of evidence of predation (see Chapter 6), as well as the high survival and increased body conditions of geckos carrying transmitters (Chapter 3, section 3.3.1), suggests that this is a less plausible explanation for the reduced encounters during the study period.

Environmental factors have been shown to influence gecko activity on Tiritiri Matangi and Motuora, particularly temperature and precipitation. Seasonally low temperatures are generally known to reduce the activity levels in many reptiles (Walls, 1983; Cree, 1994; Read & Moseby, 2001; Salmon, 2002) and it has been suggested that this is a function of their ectothermic physiology (Walls, 1983). Therefore, reduced encounter rates over winter were expected in this study if the geckos were emerging less often to forage due to suboptimal temperatures. Gecko activity on Tiritiri Matangi also showed a negative relationship with rainfall. This corresponds to other studies that illustrated negative affects between catch rates of some reptiles and precipitation (Read & Moseby, 2001), and where precipitation was associated with drops in ambient temperatures (Sound & Veith, 2000). On Tiritiri Matangi, low gecko encounter rates did not allow for a robust enough analysis to determine whether environmental variables were affecting their conspicuousness. It should also be noted that in the present study reduced gecko encounters may have been an artifact of observer bias, since searching for geckos in unfavourable conditions (e.g. wet, cold rain) may have affected search efforts.

A range of other variables has been shown to influence nocturnal reptile catch rates, including: moon phase and cloud cover (Read & Moseby, 2001), optimum foraging conditions (Francke, 2005), and microhabitat differences (Doan, 2003; Lettink & Seddon, 2007), and should also be considered when conducting spotlight searches for lizards.

5.4.2 Artificial refuges

The A.R.s tested in this study were inefficient in detecting cryptic geckos at low densities. *H. duvaucelii* occupancy rates were less than 5% on Tiritiri Matangi and no occupancy was recorded on Motuora. Artificial refuges have been described as an effective technique for monitoring herpetofaunal populations by other authors (Engelstoft & Ovaska, 2000; Hampton, 2007; Lettink & Cree, 2007). However, these conclusions have arisen from studies conducted in areas with comparatively high reptile densities. Francke (2005) reportedly found 30 *H. maculatus* from 22 gecko houses on Mana Island where geckos are known to reach extremely high densities. Application of the same gecko houses at the Karori Wildlife Sanctuary yielded only one gecko in 290 checks over the past three years (R. Empson *pers. comm*., 2006; T. Bell, unpublished data). At similarly low lizard density sites, such as Matiu/ Somes Island Reserve (Wellington, NZ), gecko houses revealed low occupancy rates with four *H. granulatus* recorded in the total of nine boxes, after one year of placement (A. Morrison *pers. comm*., 2006). Lizard densities on mainland sites are usually lower than islands (Whitaker, 1968; Towns & Daugherty, 1994), and A.R. trials have indicated poor success rates. For example, only 17 geckos were detected in refuges at Boundary Stream Mainland Island after 1235 checks (Ward-Smith *et al.*, 2005; T. Bell, unpublished data). Bell (unpublished data) trialled a novel refuge technique using closed-cell foam covers and indicated that although the covers proved successful in high lizard density areas, they failed to meet assigned thresholds for effectiveness in low density areas.

The effects of intra- and inter-species competition may explain differences in A.R. occupancy rates between areas of similar habitat type (Harwood *et al.*, 2002). At high population densities, more natural refuge sites are likely to become occupied or saturated, causing less dominant animals to search for alternative and typically less preferable, refuge sites. At low population densities, unoccupied natural refuge sites may be more common and/ or preferred over A.R.s.

At high population density it may also be that A.R.s are encountered more often by many individuals and therefore show higher occupancy rates. The effects of lizard density on A.R. occupancy may be apparent in the present study as the majority of occupied A.R.s were recorded on Tiritiri Matangi in the few months following the release, when the density of *H. duvaucelii* in the monitoring area was theoretically highest. Dispersal out of the monitoring area, as indicated by large movements during the third and fourth month (see Chapter 4, section 4.3.2), coincided with a decrease in A.R. occupancy (June 2007). However, unfamiliarity with the new habitat and sites for refuging may have encouraged initial A.R. occupancy by the geckos during the first four months post-release, and prior to further exploration within and outside the monitoring area.

None of the A.R.s on Motuora Island were found to be occupied by *H. duvaucelii* at any time during the study. Therefore, the hypothesis of initial post-release density and habitat unfamiliarity on patterns of occupancy on Tiritiri Matangi do not appear to stand for the Motuora release. Additionally, potential dispersal restrictions imposed by surrounding cliffs on Motuora, also meant that geckos should have been more likely to encounter refuges than Tiritiri Matangi geckos, due to higher densities in the release area.

Habitat structure in the monitoring areas differed between the two islands with Motuora composed of a mosaic of different vegetation types with a less dense ground cover, compared to flax thickets and open scrublands on Tiritiri Matangi (see Chapter 3, section 4.3.3). The variety of habitat types on Motuora may have been more preferential as refuge habitat and selected over A.R.s throughout the entire study.

Although, A.R.s are capable of detecting lizards at low densities, previous studies have not tested for possible relationships between A.R. occupancy rate and population size. Understanding what proportion of a sampled population occupies A.R.s is important for describing the efficiency of A.R.s as a survey or monitoring technique. In the present study, no more than 10.5% (2/19) of the founder population on Tiritiri Matangi utilised A.R.s during the study. In most of the months where occupancy was recorded, only 5.3% (1/19) of founders utilised A.R.s. These figures are based on the assumption that all geckos remained within the confines of the monitoring area at the time of sampling. This assumption is likely to hold true, at least during the initial two months following release. During this time, the distances radio-tracked geckos moved from the release site were too small for geckos to move out of the monitoring area (see Chapter 4, section 4.3.2).

The application of these figures to other situations, where founder numbers are known, was tested using an example of a gecko translocation to Matiu/ Somes Island. In 2006, 25 *H. granulatus* were translocated to the island following the instalment of A.R.s. Four *H. granulatus* were recorded utilising refuges after one year of irregular checks. Figures from the present study suggest a population of geckos may generally occupy 5-10% of A.R.s. Therefore, by applying these figures to the Matui/ Somes Island example, the population can be estimated to be between 40-80 *H. granulatus*. This would indicate an overestimation of the population size on Matiu/ Somes Island by 60-220%. Obviously these figures can not be directly applied to the Matiu/ Somes Island example due to a vast number of unknown variables, including species differences, habitat structure, study array, A.R. design, and search effort. However, this illustrates the point that standardisation for application across site and species will be very difficult. Further research is required before A.R.s can be used for accurately indexing low density lizard populations and reliably estimating population densities.

A sign of gecko occupancy (e.g. faeces) was used in three occasions to determine refuge occupancy on Tiritiri Matangi. It was assumed that no other geckos species were present in the monitoring area, based on results of a reptile survey conducted on the island in November 2005 (Ussher & Baling, 2007). A large slough (ca. 240 mm in length) and the large size of faecal pellets were definitive evidence of *H. duvaucelii* occupation. Sloughed skin has been used to determine the occupancy of *H. pacificus* in closed-cell foam covers (T. Bell, unpublished data). However, the geckos may have passed through the refuges without actively taking refuge therefore an underestimate of the actual occupancy rate is assumed for the data collected.

Artificial refuge occupancy by skinks was substantially higher than gecko occupancy on both islands, although skinks were found predominantly inside ground-level refuges. Lettink & Cree (2007) suggested the opposite trend, whereby skinks, as diurnal heliotherms, openly expose themselves to solar radiation to gain heat while geckos, as nocturnal thigmotherms, tend to thermoregulate by day under warm, dry substrates. Therefore, skinks would not be expected to occur in refuges by day as often as they did. It seems unlikely that skinks were disturbed from surrounding areas, causing them to take refuge in A.R.s as researchers approached, because dry faecal pellets from skinks were frequently present in the refuges indicating occupancy some time before A.R. checks. The reason for higher skink occupancy may simply be that the skink population occurred at much higher densities than geckos on both Tiritiri Matangi (Habgood, 2003) and Motuora.

The effect of A.R. design on gecko occupancy rates was not investigated statistically due to the low number of occupant records. However, low occupancy rates may have been the result of poor A.R. design. Although the *Corflute*® material absorbed solar heat rapidly, it failed to retain the heat for any length of time. Additionally, many of the refuges failed to remain waterproof and became completely saturated inside during heavy rainfall. These issues may only partially explain low occupancy since Francke (2005) deployed A.R.s of the same design on Mana and Stephens Island with high occupancy from resident geckos. It would seem more probable that the A.R.s were inferior to the availability of natural refuges. In addition, densely structured vegetation (e.g. flax) may prove more waterproof, have higher humidity, and have better insulation properties thereby providing superior quality refuge sites than the A.R.s.

The number of occupants (skinks and invertebrates) reduced over the five consecutive day monitoring periods. Disturbance effects caused by frequent sampling of A.R.s have shown to reduce the numbers of animals using refuges (Marsh & Goicochea, 2003, Bell, 1996; C. Wedding, unpublished data). Therefore, the sampling intensity requires consideration when using A.R.s for reptile monitoring.

5.4.3 Tracking tunnels

Tracking tunnels proved a successful method for detecting the presence of *H. duvaucelii* at very low abundance. In comparison to the previous two methods, tracking rates provided regular and reliable presence/ absence data of geckos within the release sites throughout the entire study period.

The tracking tunnel method has been successful in detecting animals possibly due to the provision of attractive bait and the avoidance of 'trap shyness' since animals are free to approach and leave the station at will, without disturbance. Since the animal is not harmed and the bait has a high palatability, they will continue to be attracted and detected on the inked card. However, this also means that it is possible that one gecko could track multiple tunnels within the monitoring area in one night, especially since stations were only 10 m apart. The inability to distinguish individuals from the tracked cards means that the accuracy to estimate the density of geckos in an area is greatly reduced. Calibration of tracking tunnels, via the removal of animals from the population, can provide an accurate index for estimating relative population density (King & Edgar, 1977; Brown *et al.*, 1996; Blackwell *et al.*, 2002) and this method has been successfully applied to lizard populations (Siyam, 2006). However, these methods can not be applied to wild populations without experimental manipulation. The use of tracking tunnels as a post-translocation monitoring tool may be limited to detection of presence, monitoring activity, and potentially providing an index of relative abundance.

Placement of bait in the tracking tunnels plays an important role in attracting the animal and in the absence of bait, lizards very rarely track tunnels (Siyam, 2006). Banana was effective in the present study due to its presumably high palatability, strong odour, ease of application, and low expense.

The effectiveness of tracking tunnels as a monitoring tool was demonstrated by the detection of neonate *H. duvaucelii* on both islands. Small gecko footprints were discovered on tracking cards approximately 10 months after the expected birthing time for *H. duvaucelii* (February/May) (Rowlands, 2005). The prints were confirmed as *H. duvaucelii* comparing them to footprints of two existing gecko species on Tiritiri Matangi, *H. duvaucelii* and *H. maculatus*. *Hoplodactylus maculatus* prints were disregarded based on the species foot morphology described by Siyam (2006). There are no other known species of geckos on Motuora. Neonates were much more cryptic and difficult to detect by spotlight searches due to their small size, and none were found occupying A.R.s. In response to the detection of neonates in tracking tunnels, intensive spotlight searches in areas immediately surrounding the tracking tunnels, resulted in the eventual capture of four juveniles. This further emphasises the capability of tracking tunnels to detect highly cryptic geckos in complex habitats.

Gecko and skink tracking rates showed correlations with environmental variables on both islands. Warmer temperatures and lower rainfall were good predictors of increased tracking rates, as fluctuations in both of these environmental variables were paralleled by fluctuations in gecko and skink tracking rates. The explanation for these correlations may be similar to those of the gecko encounter rates via spotlight searching (see section 5.4.1), i.e. ectothermic requirements for reptile activity (Shine & Koenig, 2001; Salmon, 2002). This suggests that tracking tunnels may provide a relative index of reptile activity. In contrast, Walls (1983) suggested that precipitation may have increased the observed abundance of tuatara and geckos on Stephens Island, Cook Strait, particularly after extended dry periods of time. A further possible explanation for the negative correlation between tracking rates and precipitation may be that rainfall and damp air could dilute the odour of the banana lure, thereby reducing the attractiveness of the bait within the tracking tunnel.

Understanding the effects of environmental conditions on the effectiveness of tracking tunnels has important implications for interpreting information collected from monitoring programmes. Deploying tracking tunnels during the summer when temperatures are warm and on rainless nights when reptiles are most active will increase the chances of detection. However, further research should be invested into determining the behavioural responses of native lizards to different environmental variables to better understand and interpret monitoring data.

5.4.4 Study limitations

5.4.4.1 Monitoring techniques

There are several biases that are apparent among all monitoring methods. Some of the more important include observer, habitat, and environmental biases (Towns, 1991; Marsh & Goicochea, 2003; T. Bell, unpublished data). The most efficient method is one that limits these biases, is low cost, time efficient, and provides accurate and useful data.

Spotlight searching relies on the ability to detect and accurately identify small animals at night, often in complex environments and usually at distance. This often requires highly experienced surveyors to ensure consistent and reliable results. Out of all the geckos encountered in the present study, only one *H. duvaucelii* was sighted by an inexperienced volunteer. Similarly, lower numbers of *H. duvaucelii* than expected were encountered on Mana Island by a group of DOC volunteers, possibly due to their inexperience in field techniques (T. Whitaker *pers. comm*., 2008). Additionally, the detection probability is likely to be affected by an animal's avoidance response to light and noise disturbance during spotlight searches (T. Bell, unpublished data).

In comparison, A.R.s and tracking tunnels are less influenced by observer variation due to the presence/ absence data that is collected by simple checks. Only a basic knowledge of ideal installation placement concerning predicted habitat use by an animal is required and can be quickly learned.

Tracking tunnels may be less susceptible to disturbance effects due to the provision of attractive baits. Prints, however, can be obscured when footprint ‘traffic’ is high. This may reduce the ability to distinguish a particular print, and confirm a species presence. For example, in a study of shore skink (*O. smithi*) visitation rates to rodent bait stations in a pest-managed area their presence was often confirmed by a single small footprint whereby the rest of the card was almost entirely covered by mouse prints (Wedding, 2007).

Artificial refuges may be useful for describing relative abundances but do not allow for extrapolation to actual population densities from census data, due to the impossibility of knowing the actual proportion of the population is using the A.R.s (Monti *et al.*, 2000).

A better understanding of lizard species movements, home-range size, and habitat use is crucial for the development of efficient monitoring techniques. The spacing between monitoring units (i.e. tracking tunnels, or A.R.s) and their placement in the environment can ultimately affect their ability to detect an animal. For example, Hoare (2006) showed daily movements of *Naultinus manukanus* averaged 0.59 m ± 0.10 m. Therefore, spacing monitoring units at intervals greater than one meter may have resulted it non-detection. Similarly, non-detection can result if monitoring units are placed in habitat not unsuitable for the target animal.

5.4.4.2 Environmental influences

Herpetological monitoring methods are inherently influenced by environmental variables, such as habitat structure and temperature. Strong correlations between temperature and lizard activity means that spotlight searches and tracking tunnels may only be efficient during optimum foraging conditions (Francke, 2005; T. Bell, unpublished data). Furthermore, nocturnal reptiles are affected significantly more by environmental conditions than diurnal ones (Read & Moseby, 2001).

Artificial refuges may be less influenced by environmental conditions, as the animal is usually detected during an inactivity period. However, the efficiency of an A.R. over different weather conditions should still be considered as foam covers on trees resulted in low occupancy rates during heavy rainfall, due potentially to water flowing down trunks and into refuges thereby driving out lizards (T. Bell, unpublished data). Microhabitat factors, such as the proximity for A.R.s to natural refugia have been shown to increase detection rates as they offer greater protection from predators (i.e. via reduced visibility and escape distances) (Martin & López., 1995; Lettink & Seddon, 2007). These factors were not tested in the present study and require further investigation.

5.4.5 Conclusion

The specific aims and objectives, target species, financial resources, and logistics of the study will govern which monitoring methods are most suitable in a reptile survey (Corn & Bury, 1990). No single monitoring technique is likely to equally detect presence of lizards and provide accurate estimates of population density across species and sites, due to the unknown effects of extrinsic variables. In order to maximise monitoring efficiency, the detection of both active and inactive animals is essential; a task unlikely to be achieved with the application of only one monitoring method.

Monitoring post-translocation success relies on both the detection of released individuals and an assessment of population growth over time. Tracking tunnels, in comparison with other methods, appear to be the most successful and least labour-intensive method for detecting the presence of cryptic lizards at low density. However, additional methods such as spotlight searching and/ or A.R.s may need to be implemented in order to measure relative population change over time.

In addition, A.R.s have the potential to provide information on population demographics (Moller, 1985; Francke, 2005; T. Bell, unpublished data) which is essential for determining the survivorship and breeding success of translocated animals. Presently, spotlight searching and AR's are insufficient in providing an accurate index of population density and therefore, are inefficient in describing population change in low-density lizard populations. Improving these techniques by training searchers in species identification and improving A.R. designs to better reflect natural refugia is required.

CHAPTER 6

Predation on island lizards

Plate 6.1 New Zealand kingfisher (*Halycon sancta vagans*) with unidentified skink in its bill. (Photograph by Geoff Moon)

6.1 Introduction

6.1.1 Reptile predation

Predation is a significant component in population dynamics, trophic networks, and community ecology (Poulin *et al.*, 2001). It plays an important role in regulating reptile and amphibian populations, as well as maintaining balance in ecosystem processes (Martín & López, 1996; Zug *et al.*, 2001). However, despite its importance, few studies have examined the role of predation in reptile populations (Jaksic *et al.*, 1982; McLaughlin & Roughgarden, 1989). Understanding predator-prey dynamics is an essential component of understanding the ecology, behaviour, and evolution of lizards (Martín & López, 1996). Worldwide, lizards fulfill important ecosystem functions, particularly as prey items for many predatory animal groups including mammals, birds, other reptiles, and some invertebrates (Jaksic *et al.*, 1982). Birds however, are regarded as the most important predators of lizards (Wright, 1981; Waide & Reagan, 1983; Greene, 1988; Martin & López, 1990). Jaksic *et. al.* (1982) suggests that reptiles may be extremely important to a predator even if their overall representation in the diet is low. For example, Fitzgerald *et. al.* (1986) noted that although kingfishers preyed on very few lizards, these were important prey in terms of biomass and represented 46% of the weight of prey consumed.

6.1.2 New Zealand reptile predation

Studies addressing the impacts of predation on New Zealand's herpetofauna have focused almost entirely on introduced mammalian predators. This is in response to the large-scale impacts of mammalian predators on reptile and amphibian populations, causing significant population declines and extinctions (Whitaker, 1973; 1978; Towns, 1991; Wedding, 2007).

Although the impact of mammalian predators on native herpetofauna is relatively well understood, it is much less so for the role of predation by native animals on reptile populations. A variety of native fauna, including invertebrates (Lettink & Patrick, 2006), fish (Anonymous, 2003; T. Whitaker, *pers. comm.*, 2008), tuatara (*Sphenodon* spp.) (Sharell, 1966; Whitaker, 1994), and birds (Marples, 1942; Fitzgerald *et al.*, 1986; Ball & Parrish, 2005) have been recorded preying upon reptiles and amphibians. Of these, birds are the greatest consumers of lizard prey and many species have been recorded predating upon them including fernbird (*Bowdleria punctata*; Ball & Parrish, 2005), long-tailed cuckoo (*Eudynamys taitensis*; Oliver, 1955), banded rail (*Rallus philippensis*; Whitaker, 1968), takahe (*Porphyrio mantelli*; Whitaker, 1991), weka (*Gallirallus australis*; Coleman *et al.*, 1983), pukeko (*Porphyrio porphyrio melanotus*; Carroll, 1966), New Zealand falcon (*Falco novaeseelandiae*; Fox, 1977; Worthy, 1997; Morris & Ballance, 2008), New Zealand kingfishers (*Halcyon sancta vagans*; Fitzgerald *et al.*, 1986), and morepork (*Ninox novaeseelandiae*, Ramsay & Watt, 1971).

However many of these reports are largely based on anecdotal accounts and the few studies that have explored the predator-prey relationships between native birds and lizards, have done so with limited success (Schneyer, 2001; Jordan, 2005). Preliminary studies attempting to measure the effects of weka and kiwi (*Apteryx owenii*) on lizard populations on Kapiti Island used exclusion fences but failed to detect any measurable differences in the lizard numbers within and outside the fences (D. Towns, *pers. comm.*, 2008). It is important that the interactions between bird-predator and lizard-prey are described and understood so that more informed decisions regarding threatened lizard management can be made.

6.1.3 Translocation and predation risk

Pest-free offshore islands have been considered ‘safe havens’ for many threatened wildlife species in New Zealand including reptiles (Towns & Robb, 1983; Craig, 1990) and as a result translocation of threatened lizards to islands has shown recent increases with island restoration (Towns & Ferreira, 2001). However, these islands are not entirely free of predators. Native bird populations have been known to reach considerable densities on offshore islands. Such is the case for weka on Kawau Island and Kapiti Island (Beauchamp, 1987; Beauchamp & Chambers, 2000) where they are known to prey upon lizards (Coleman *et al.*, 1983).

Although lizards may provide an especially important food resource to predators in some island ecosystems (Schoener & Schoener, 1978; Wunderle, 1981; Adolph & Roughgarden, 1983), such predator-prey relationships have typically evolved within balanced ecological communities. In addition, established prey populations are generally robust enough to withstand the pressures from natural predators. However, translocated populations typically represent a small sample of a source population. Therefore, even a small loss to the founder population via natural predation, could significantly impact on the populations establishment. This presents an example of the small population paradigm whereby small populations are particularly vulnerable to stochastic events, such as unforeseen predation, which can ultimately have greater effects on population sex ratios, genetic diversity, and the viability of the founder population (Caughley, 1994). Martín & López (1996) note that even a small proportion of a bird’s diet consisting of lizards, may be sufficient enough to impact significantly on a small lizard population. Towns (1999) recognized the need for research and insight into lizard predation by birds, in the *Cyclodina* spp. Skink Recovery Plan (1999-2004), noting the importance of understanding the impact of birds on lizard populations, prior to further translocations of threatened lizards.

6.1.4 Assessing avian diet

There are several methods for assessing the dietary intake of birds, including direct field observations (Marti, 1987; Redpath *et al.*, 2001), regurgitated pellet and faecal analysis (Coulson & Coulson, 1993, Calver & Wooller, 1982; Haw *et al.*, 2001), crop expulsion and gut analysis (Errington, 1932), and isotope analysis (Geurts, 2006). Each method is subject to some form of bias, and gaining an accurate insight into the diet of a bird is best achieved through a combination of sampling techniques (Errington, 1930; McLaughlin & Roughgarden, 1989; Rosenberg & Cooper, 1990; Redpath *et al.*, 2001).

The efficiency of many of these sampling techniques has not been explored experimentally. For example, it is not known whether the composition of faecal samples accurately represents the true diet of a bird (Errington, 1930). In order to accurately assess the diet of birds in the field it is important to know which particular prey items will and will not be represented in the sample. Captive feeding experiments will provide an indication of this and may help improve the knowledge of sampling techniques for assessing bird diets in the field.

6.1.5 Research objectives

The aim of this study was to quantify the rate of predation by native bird species on Tiritiri Matangi and Motuora Island's lizard fauna. Birds are the dominant predators of lizards in both of these island ecosystems, as no terrestrial mammals are present. This study represents the first attempt to quantify this predator-prey relationship on an island system in New Zealand. Tiritiri Matangi supports an abundance of bird predators, including morepork, kingfishers, pukeko, and Swamp harriers (*Circus approximans*). On Motuora, these birds are present at far lower abundances. In addition, both islands support healthy populations of native lizards including copper skinks (*Cyclodina aenea*), moko skinks (*Oligosoma moco*), common geckos (*Hoplodactylus maculatus*; Tiritiri Matangi only), and two recently translocated species, shore skinks (*O. smithi*) and Duvaucel's geckos (*H. duvaucelii*). This provided an ideal opportunity to measure the rate of lizard predation by native birds.

6.1.5.1 Objectives

1) Determine if lizard remains can be detected in faecal and regurgitated pellets by undertaking captive feeding experiments on pukeko and moreporks.
2) Quantify the amount of lizards consumed by native birds, including pukekos, morepork, kingfishers, and Swamp harriers, on Tiritiri Matangi and Motuora Islands, using a variety of techniques for assessing avian diet.
3) Examine the potential influence of avian predators on small translocated lizard populations.

6.2 Methods

6.2.1 Study sites

This study was conducted on Tiritiri Matangi and Motuora Islands (Hauraki Gulf, New Zealand). For a more detailed description of study sites refer to Chapter 2 (section 2.2).

6.2.2 Study species

6.2.2.1 Birds

6.2.2.1.1 Pukeko (Porphyrio porphyrio melanotus)

Pukekos are a highly abundant, partially protected native species. They inhabit a wide variety of habitats and are regarded as opportunistic omnivores (Jordan, 2005) but are primarily herbivorous. Their diet may include: pasture vegetation, seeds, invertebrates, eggs, frogs, and lizards (Muggeridge & Cottier, 1931; Carroll, 1966; Heather & Robertson, 1996; Jordan, 2005)

6.2.2.1.2 Kingfisher (Halcyon sancta vagans)

The New Zealand or sacred kingfisher (kotare) is New Zealand's only native kingfisher. They are a common and widespread species especially in coastal areas, where they build their nest holes in the coastal clay banks. Diet varies depending on their habitat and may include cicadas, stick insects, crabs, fish, lizards, frogs, mice, and small birds (Lewis, 1959; O'Donnell, 1981; Heather & Robertson, 1996). On Tiritiri Matangi they are commonly observed eating skinks (Reid, 2007).

6.2.2.1.3 Morepork (Ninox novaeseelandiae)

Moreporks (ruru) are New Zealand's only extant native owl species. They are commonly found throughout the country and roost by day in thick vegetation, especially in tree ferns and in gullies. After dusk they leave their roosts to hunt for food, including insects, nocturnal lizards, rodents, and birds (Imboden, 1975; Heather & Robertson, 1996; Haw & Clout, 1999).

6.2.2.1.4 Swamp harrier (Circus approximans)

The Swamp harrier (kahu) is New Zealand's largest (55cm; 650g-850g) and most common extant raptor species. They are usually solitary birds and hunt by soaring above the ground searching for prey followed by a dive attack. They have a varied diet, including carrion, other birds, mammals, lizards, frogs, and large invertebrates (Pierce & Maloney, 1989; Heather & Robertson, 1996).

6.2.3 Captive Feeding Experiment

Birds held at registered wildlife rehabilitation centers were offered dead lizards in three feeding trials so that faecal pellets and regurgitates could be described. The birds examined were two pukekos and one morepork.

The two species of lizards including the introduced rainbow skink (*Lampropholis delicata*) and the native copper skink collected for feeding trials were already dead and obtained opportunistically so that none had to be euthanased. No lizards were collected from poison-controlled areas. All lizards were stored in the freezer and thawed before being presented to the birds.

Each bird was presented with a dead lizard in addition to any other food offered at feeding times. If lizards were not eaten voluntarily, the lizards were hidden inside a large bean sprout or rolled up in mince meat. Once consumed, faecal and regurgitated pellets were collected from each bird over the following two days and examined for lizard remains.

6.2.4 Avian dietary analyses

Avian diet was assessed by analysing nest material, faecal pellets, regurgitated pellets, and stomach content (when available). *Ad hoc* observations of birds predating lizards were also noted.

6.2.4.1 Regurgitated pellets

Regurgitated pellets were collected from below roost and nest sites of both kingfishers and moreporks throughout the study. Nest and roost sites were returned to every month and samples were collected if available. Regurgitates from Swamp harriers were also collected opportunistically. Pellets were stored separately in plastic vials and labeled with the corresponding species and nest/ roost site number. The samples were then frozen to prevent decay and invertebrates damaging the pellets. The weight and dimensions (length x width in mm) of each pellet was recorded prior to dissection.

Pellets were examined individually under a dissecting microscope. For kingfishers, the presence/ absence of food items were categorised as follows: insect, crustacean, fish, and lizards. For morepork, categories included: weta, other insect, lizard, and bird bone. The proportion of pellets containing each food item were plotted to show comparisons between island sites. The number of individual lizards per pellet was estimated by counting the number of brain cases, jaw bones (2 dentaries and 2 maxilla per animal), frontal bones, and pelvic girdles (Plate 6.2). Lizard remains were identified to Family (i.e. Gekkonidae or Scincidae) by their morphological characteristics (Worthy, 1987) and comparisons with voucher specimens.

Braincases were used to estimate the number of lizards per pellet, as they can be identified easily.

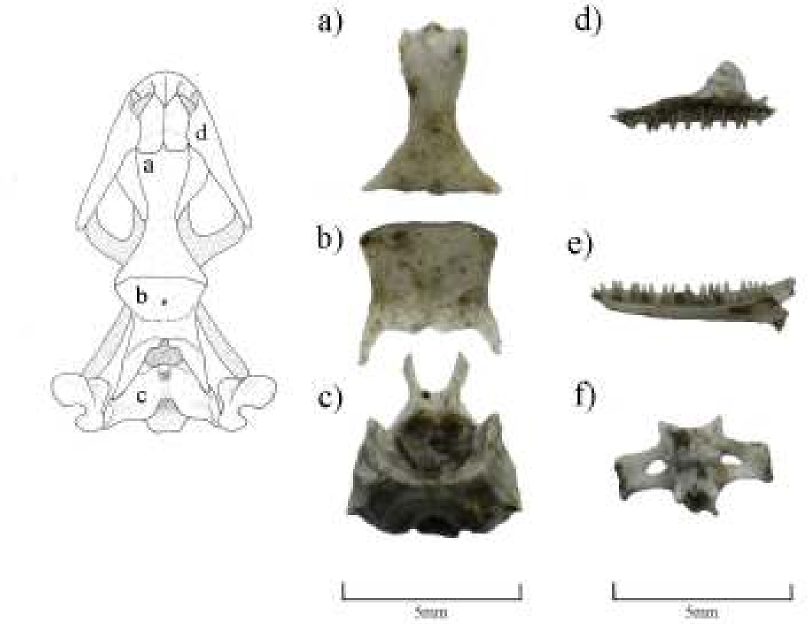


Plate 6.2 Diagrammatic representation of the dorsal view of a skink skull, showing positions of the a) frontal bone, b) parietal bone, C) brain case (occipital capsule), and d) maxilla. (e) shows the right dentary and f) shows the pelvis girdle. Diagram altered from Worthy (1987). (Photographs by author).

6.2.4.2 Nest sampling

Nests and roosts were located primarily through searching forested patches for evidence of nestling calls or unintentional disturbances of adult birds from roost sites and nest holes. Nest and roost searches were conducted once a month, from February 2007 to February 2008, and the entire island was searched.

All accessible nests of both kingfishers and moreporks were scraped of all material after chicks had fledged. As nests of kingfishers are often used more than once within a breeding season (Heather & Robertson, 1996), nest material was collected after each successive fledging to avoid disturbance. Material from each nest and breeding attempt was bagged individually and taken to the lab for analysis. Nest material was examined for the presence/ absence of food items. For kingfishers, food items were categorised as follows: insect, crustacean, fish, and lizards. For morepork, categories included: weta, other insect, lizard, and bird remains.

Lizard remains from nest samples were not quantified as some remains may have been deposited during the previous nesting season.

6.2.4.3 Faecal samples

Faecal samples from pukeko were collected in the field every month during the study. Although collection was *ad hoc*, some samples were selectively collected from known high-density lizard habitats (Habgood, 2003). The objective was to collect a minimum of 50 pukeko faecal samples from each island. These were examined individually in the laboratory under a dissecting microscope. The presence/ absence of food items in each faecal pellet were recorded. These were categorized as grass, seeds, invertebrates, and lizards.

6.2.4.4 Stomach content

Dead birds were collected opportunistically as they became available, and stored in a freezer until examination. Birds that were examined included one pukeko, and one Swamp harrier. For each bird, the entire alimentary tract (i.e. oesophagus, gizzard, stomach, and intestines) was removed from the body cavity. The presence/ absence of lizard remains were determined and the number of lizards consumed per bird was estimated based on occurrence of body parts or bones.

6.2.4.5 Bird observations

Chance observations of hunting and foraging behaviour by potential predatory birds were noted over the duration of the study. Prey were identified using binoculars.

6.2.5 Statistical analyses

Data were not analysed statistically due to insufficient sample sizes.

6.3 Results

6.3.1 Captive feeding experiment results

One morepork and two pukekos were available for captive feeding experiments and each bird was fed a single skink. The morepork failed to regurgitate any pellets after consuming the lizard and faecal samples revealed the absence of any lizard remains.

The faecal samples collected from pukekos showed no evidence of lizard remains.

6.3.2 Dietary analyses

6.3.2.1 Pellet analysis

6.3.2.1.1 Kingfisher

Lizard remains were present in 88% of kingfisher pellets (n = 100) sampled from nine birds on Tiritiri Matangi (Figure 6.1). On Motuora, lizard remains were present in 43% (n = 7) of kingfisher pellets sampled from three birds. Invertebrates were present in 75% of pellets on Tiritiri Matangi and 57% of pellets on Motuora. The remains of crustaceans were present in

71% of pellets on Motuora but only 16% of pellets from Tiritiri Matangi. Fish were present only in 3% of pellets from Tiritiri Matangi and was absent in Motuora pellets.

Other prey items that were recorded in pellets included the remains of: beetles (Coleoptera), grasshoppers (Orthoptera), cicadas (Hemiptera), crabs (Crustacea), and fish (Osteichthyes) (Plate 6.3). Conservative estimates of the number of lizards per pellet were two lizards per pellet on Tiritiri Matangi and one lizard per pellet on Motuora (Table 6.1).

Plate 6.3 Examples of regurgitated pellets from kingfishers showing the remains of (a) crustaceans (b) invertebrates, and (c) lizard bones removed from a kingfisher pellet. (Photographs by author)

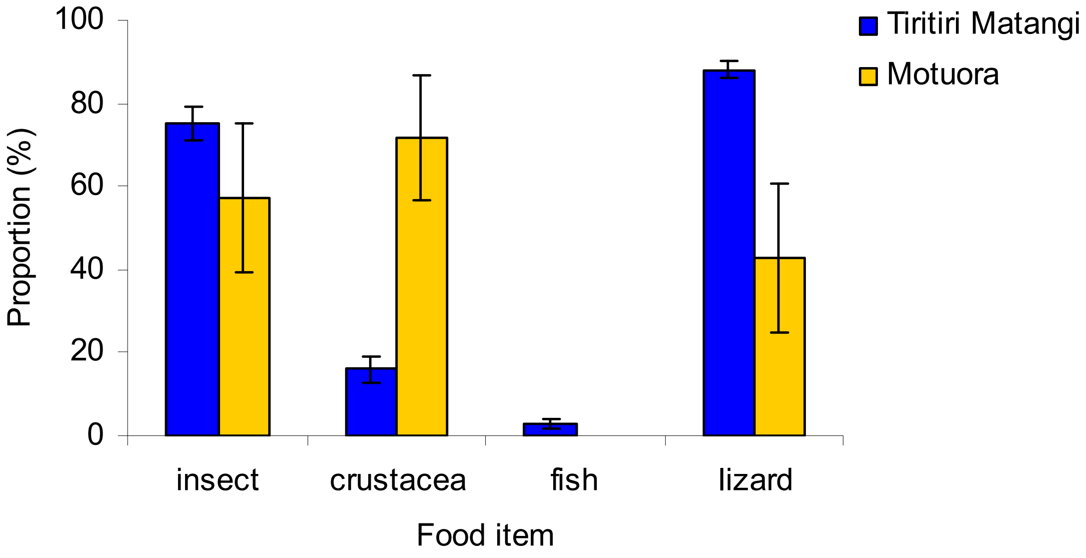


Figure 6.1 Proportion (%) (±95% CI) of overall kingfisher pellets containing food items from Tiritiri Matangi (n = 100) and Motuora (n = 7) Islands.

Table 6.1 Measurements and weights of regurgitated kingfisher pellets and the average number of lizard items per pellet on Tiritiri Matangi and Motuora Islands. Figures in parentheses indicate the standard errors and the range of food items found in the pellets

Islands	n*	Pellet measurements			Lizard remains/ pellet			
		Length (mm)	Width (mm)	Weight (g)	Braincase	Jaw	Frontal bone	Pelvic girdle
Tiritiri Matangi	88	**19.9** (± 1.0 SE)	**11.3** (± 0.3 SE)	**0.8** (± 0.1 SE)	**1.8** (± 0.2 SE) (0-6)	**13.2** (± 1.6 SE) (0-29)	**3.6** (± 0.3 SE) (0-8)	**2.1** (± 0.3 SE) (0-7)
Motuora	3	**20** (± 0.0 SE)	**9.5** (± 0.0 SE)	**0.8** (± 0.2 SE)	**0.5** (± 0.5 SE) (0-2)	**0.7** (± 0.7 SE) (0-2)	**0.5** (± 0.5 SE) (0-2)	**0.3** (± 0.3 SE) (0-1)

* number of kingfisher pellets containing lizard remains

(± SE) standard error

(#-#) range

6.3.2.1.2 Morepork

No lizard remains were identified from any of the pellets collected from Tiritiri Matangi (n = 67, 12 birds) or Motuora (n = 107, 9 birds). Prey consumption consisted almost entirely of invertebrates and included the remains of weta (Orthoptera: Anostostomatidae), earwigs (Dermaptera), huhu beetles (Coleoptera: Cermabicidae), and click-beetles (Coleoptera: Elateridae). Of these, weta (Tiritiri Matangi 85.1%; Motuora 89.5%) were the most important prey item. Other insects (Tiritiri Matangi 53.7%; Motuora 45.7%) were also very common in pellets (Figure 6.2). Bird remains were occasionally apparent in pellets from owls on both islands.

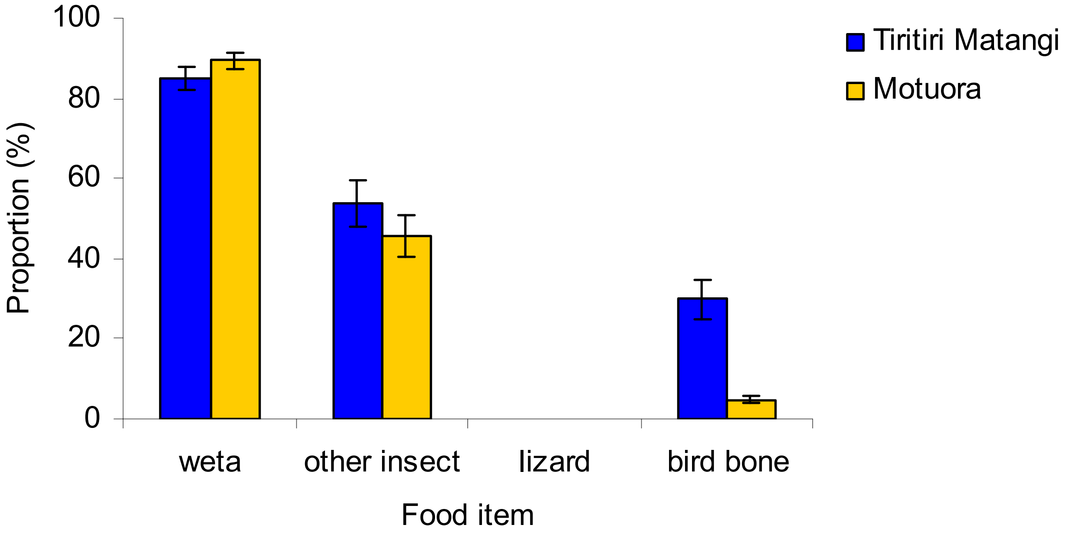


Figure 6.2 Proportion (%) (±95% CI) of prey type in morepork pellets on Tiritiri Matangi (n = 67) and Motuora (n = 105) Islands.

6.3.2.1.3 Swamp harrier

Two Swamp harrier pellets were collected on Motuora, one in June 2007 and the other in September 2007. The pellets measured 60 mm x 26.5 mm and weighed 10 g on average. The pellets were comprised entirely of bird remains including down feathers, vaned feathers, and various bones. No lizard remains were present in these pellets.

6.3.2.2 Nest samples

6.3.2.2.1 Kingfisher

Lizard remains were found in the majority (60%, n = 10) of kingfisher nests on Tiritiri Matangi, but were less often present in nests on Motuora (23.8%, n = 21) (Table 6.2). Both insect and crustacean (i.e. crab) remains were present in nest holes on both islands.

Table 6.2 Proportion (%) of kingfisher nests containing different prey types on Tiritiri Matangi and Motuora Islands.

Islands	n*	Proportion (%) of kingfisher nests containing prey types			
		Insect	Crustacea	Fish	Lizard
Tiritiri Matangi	10	40	10	0	60
Motuora	21	33	14	0	24

* total number of nests sampled

6.3.2.2.2 Morepork

No lizard remains were found at any nest or roost sites on Tiritiri Matangi (Table 6.3). Ten of 11 sample sites (91%) contained bird remains, including claws, plastic colour bands, vertebrae, and beaks. Weta were found at 36% (n = 4) of the nest and roost sites. No nests were found on Motuora.

Table 6.3 Proportion (%) of morepork nests and roost sites containing different prey types on Tiritiri Matangi and Motuora Islands.

Islands	n*	Proportion (%) of owl nest/ roost sites containing prey types			
		Weta	Other insect	Lizard	Bird remains
Tiritiri Matangi	11	36	0	0	91
Motuora	0	-	-	-	-

* total number of nests sampled

6.3.2.3 Faecal analysis

6.3.2.3.1 Pukeko

No lizard remains were present in pukeko faecal samples from Tiritiri Matangi (n = 50) and Motuora (n = 50). Grass comprised the majority of faecal material with occasional seed heads and invertebrate remains present. Broken pieces of shell were present in two of the faecal pellets.

6.3.2.4 Gut content

Two birds were available for gut content analysis during the study. A partially decomposed pukeko was found on Tiritiri Matangi and dissection revealed a completely empty gut. The gut content of a recently deceased Swamp harrier on Tiritiri Matangi was examined revealing a large number of kakariki (*Cyanoramphus novaezelandiae*) feathers only.

6.3.2.4.1 Invasive rat

Towards the end of the study an invasive Norway rat (*Rattus norvegicus*) was trapped on Motuora Island and the opportunity was taken to examine its gut for lizard remains. Lizard remains comprised 52% of the rat's gut content, while invertebrate remains comprised only 25% (van Winkel, 2008).

6.3.2.5 Observational accounts

A number of feeding observations of kingfishers, pukekos, and one morepork were made during the study. Kingfishers were observed catching insects on a number of occasions on both islands, and one kingfisher on Tiritiri Matangi was seen with a skink in its beak on at least three occasions. These skinks were identified as *O. moco* from their distinctive pale dorso-lateral stripes that can be recognised at distance. On Motuora, a kingfisher was seen repeatedly recovering prey after diving into rockpools. One morepork was observed at dusk catching a huhu beetle (*Prionoplus reticularis*) in mid-flight. Numerous pukeko were observed feeding on grass and seeds, but were never observed eating lizards.

6.4 Discussion

6.4.1 Kingfishers

Of the birds sampled, kingfishers consumed the greatest number of lizards during the study. On Tiritiri Matangi, approximately 88% of pellets contained lizard remains and each pellet included the remains of approximately two lizards. This study emphasises the importance of kingfishers as predators of lizards. The overall impact of kingfishers on island lizard populations could not be determined in this study due to lack of data on the lizard populations (i.e. absolute population size, reproductive rates, sex ratios, populations demographics). However, extrapolating the rate of predation may provide a rough estimate of how many lizards kingfishers are likely to prey upon over time. For example, most of the kingfisher pellets collected in the study came from below nests during the breeding season (October – February; Heather & Robertson, 1996). Kingfishers are known to produce several pellets a day (Hayes, 1989) and the results from this study indicated that on average each pellet contained the remains of approximately two lizards. Therefore, it is possible that a single kingfisher and/ or its nestlings may consume as many as 300 lizards over a single nesting season and depending on the number of resident birds on an island and the lizard abundance, these figures may quickly reach excess of 1000 lizards preyed upon in a single season. However, during less demanding times (non-breeding season) lizard predation rates may fall to lower levels, due to reduced demand for food and the difficulties in locating lizards during more inactive periods.

The diet of kingfishers on Tiritiri Matangi contained a much higher proportion of lizards compared to that of Motuora birds. This may reflect either a specialisation or preference of Tiritiri Matangi kingfishers for lizard prey, differences in habitat allowing skinks to be more vulnerable to capture, or simply because of higher densities of skinks on Tiritiri Matangi. Lizards have been recorded in high numbers in the diet of kingfishers throughout the country (Edwards, 1952; Roberts, 1952; O'Donnell, 1981; Fitzgerald *et al.*, 1986), including on Motuora. Therefore, it seems unlikely that Tiritiri Matangi kingfishers are showing specialisations for predating on lizards.

Habitat differences between the two islands may explain why lizards were predated more frequently on Tiritiri Matangi. Large patches of low open grassland, surrounded by bush vegetation with overhanging perches, are abundant on Tiritiri Matangi. These are ideal sites for kingfishers to hunt lizards from as they can perch relatively unnoticed in the edge vegetation and scan for lizards that emerge from the grass to bask. In addition, Habgood (2003) found that *O. moco* appeared to favour grassland habitat on Tiritiri Matangi. Such habitat may expose skinks to higher levels of predation. On Motuora, although large open grasslands are present, a lack of vantage points exists since re-vegetation is fairly recent. On occasions where rogue fence posts were available, kingfishers were very regularly observed hunting from them.

Lizard density on islands is likely to have a major influence on the rate of kingfisher predation. Estimates of skink population size on Tiritiri Matangi indicate densities of up to 4,617 *O. moco*/ ha and 16,562 *C. aenea*/ ha in grassland habitats (Habgood, 2003). On Motuora, density estimates were not available. However, skink captures during a 2005 lizard survey on Motuora indicated that the abundance of *O. moco* and *C. aenea* were relatively low (M. Habgood, unpublished data). It is possible that the differences in the proportion of lizard prey in the diet of kingfishers on the two islands are reflected by lizard densities. However, these differences are based on small sample sizes, particularly from Motuora kingfishers, and conclusions based on density can not be made. Further research incorporating a strict experimental design is required to describe this relationship.

Observational data from Tiritiri Matangi seemed to indicate that *O. moco* was the most frequently predated lizard species on Tiritiri Matangi, although skink remains in pellets were not identified to species level due to difficulty and time constraints. Kingfishers are diurnal predators and it seems likely that the majority of lizards predated may have represented *O. moco* since they are considered to be strongly diurnal and an avid sun-basker (Gill & Whitaker, 1996). In comparison, *C. aenea*, is recorded as being crepuscular as well as diurnal, though rarely emerges from cover (Hudson & Thornton, 1994; Gill & Whitaker, 1996). Although, diurnal blackbirds have been reported eating *C. aenea* after searching under logs (Bell, 1996), kingfishers are not ground/litter foragers, preferring to hunt from elevated positions or catch prey on the wing (Heather & Robertson, 1996). Therefore, predation of *C. aenea* is likely to be lower than *O. moco*.

The frequency distribution of prey items in kingfisher pellets on Tiritiri Matangi was skewed compared to that of Motuora. Birds on Tiritiri Matangi appeared to feed mainly on lizards and invertebrates while the diet of Motuora birds was represented by a more even variety of prey items. This is possibly the result of a small sample size and prey bias by individual kingfishers, or may reflect differences in prey availability on each island.

No remains of gecko were detected in the kingfisher pellets in the present study. Tiritiri Matangi Island supports a small population of resident geckos (*H. maculatus*). However, due to their isolated cliff location and low density it is unlikely that bird predators would pose a threat to them at this present population status. Similarly, recently translocated *H. duvaucelii* are unlikely to be at risk of predation by kingfishers due to their large body size. However, juvenile *H. duvaucelii* could potentially be vulnerable since they fall within the kingfisher's prey size range and nocturnal geckos have been recorded in the diet of kingfishers (Fitzgerald *et al.*, 1986).

No lizard remains were recorded in any other potential avian predator diets sampled on the Tiritiri Matangi and Motuora.

6.4.2 Morepork

Morepork pellets were comprised mainly of large invertebrates, such as tree weta (*Hemideina thoracica*) and occasionally contained bird remains. Many reports of owls preying on lizards are available. For example, stomach content analyses of a little owl (*Athene noctua*) from the South Island, indicated the bird had consumed four lizards (Marples, 1942). Similarly, nocturnal geckos (*Hoplodactylus* spp.) have been found in the nests of moreporks (Chambers & Sibson, 1955; Ramsay & Watt, 1971). The very low abundance and isolated locations of resident and translocated geckos on Tiritiri Matangi and Motuora may have meant that owls did not encounter them or that low predation rates were not detected at the time of the study. Evidence of lizard predation from past studies (Marples, 1942; Chambers & Sibson, 1955; Ramsay & Watt, 1971) indicates that predation rates may increase once gecko populations begin to expand.

Results from the morepork captive feeding trial were inconclusive as the bird did not regurgitate pellets, possibly due to the low fibre supplementary diet it was being fed at the time. Further feeding experiments are required to resolve these issues.

6.4.3 Pukeko

Pukekos have been described as opportunistic omnivores (Heather & Robertson, 1996; Jordan, 2005), their diet comprising primarily vegetation and partially invertebrates (Muggeridge & Cottier, 1931). However, they have been recorded eating a variety of foods including frogs and lizards (Heather & Robertson, 1996). No lizard remains were reported in faecal samples in the present study, despite sampling birds inhabiting areas which supported high skink abundance. A study of pukeko diet at Shakespear Regional Park failed to indicate lizard predation following 242 feeding observations over the summer and 32 pukeko gut content analyses, despite half the pukekos sampled originating from high abundance skink colony areas (Jordan, 2005).

It is possible that the sampling methods (faecal analysis) may have been insufficient to detect all prey items. Lizard remains were absent in faecal samples from captive feeding trials despite birds having eaten the lizards. Trewick (1996) sampled 93 pukeko faecal pellets and 188 takahe faecal pellets from Mana and Kapiti Islands, which are known to support high lizard abundances. They reported high vegetation and invertebrate components but no lizard remains were present. Therefore, faecal pellets may be an inappropriate method for sampling pukeko diet. The gizzard of pukeko is large and built for grinding vegetation (Suttie & Fennessy, 1992), therefore lizard remains may be completely digested or become very hard to distinguish once passed in faecal pellets. The gut contents of five pukeko on Motuora were examined with no evidence of lizard remains (P. Kealing, *pers. comm.*, 2007). However, examination of 298 pukeko gizzards from areas in the South Island revealed that three gizzards contained lizard remains (Carroll, 1966).

It appears that lizard predation by pukekos is highly opportunistic and may be the resultant of their foraging style. Pukekos feed by using their powerful beak to pull and uproot various types of vegetation (Jordan, 2005). This feeding behaviour is likely to disturb lizards taking refuge amongst the vegetation and cause them to flee, thereby exposing them the risk of predation.

6.4.4 Swamp harrier

Swamp harriers have been reported preying on skinks (*O. nigriplantare*, formerly *Leiolopisma nigriplantare*; Pierce & Maloney, 1989), and Whitaker (1968) suggested a harrier was probably hunting basking lizards on the Poor Knights although harrier roosts were checked and no lizard remains were found. Despite these reports, no lizard remains were found in the regurgitated pellets examined in the present study. A sample size of only two pellets is insufficient to provide conclusive evidence for determining if Swamp harriers prey on lizards on islands.

6.4.5 Implications for translocation

The present study compliments previous reports indicating that some birds are important predators of native lizards and have the potential to seriously impact on small populations of translocated lizards. Birds are often present at high densities on mammal-free offshore islands and a great number of species have been recorded preying on lizards. The incidence of lizard predation is likely to be positively correlated with predator abundance (Jaksic *et al.*, 1982), including generalist or opportunistic predators. For example, high numbers of weka on Kapiti Island seem to be limiting the population growth of establishing lizard populations (D. Towns, *pers. comm.*, 2008).

Aberrant movements and unfamiliarity with a new environment may cause translocated lizards to venture into areas where the risk of predation may be higher (Reinert & Rupert, 1999; Plummer & Mills, 2000) (see Chapter 4, section 4.3.2). Furthermore, if translocations are to involve the release of captive bred lizards, consideration needs to be given regarding the lizards' naivety to natural predators and the possible increased risk of predation (Connolly & Cree, 2008). Translocated lizard populations are often small, due to the limitations imposed by harvesting source populations. Although predator-prey theory indicates that low prey density can often result in low predation rates in some cases (Sinclair & Pech, 1996; Sinclair *et al.*, 1998), opportunistic predators may still maintain the same predation rates on small populations of prey, if the prey was taken as by-catch. This is particularly relevant for many New Zealand birds, which are also opportunistic predators, such as pukeko and weka. Furthermore, even low predation rates on small founder populations could exacerbate the effects associated with K-strategist species. For example, following the translocation of highly threatened *C. whitakeri* to Korapuki Island, the population became highly vulnerable to population collapse if predation of adults exceeded 5% per annum (Towns, 1994). In comparison, predation may have less impact on small populations of r-strategist species as they are often subject to negative density-dependent regulation, causing them to reach high densities quickly in favourable habitat (Caughley, 1977). For example, a translocated population of Fiordland skinks (*O. arcinasum*) managed to increase by 400% in less than five years and are now successfully established (Thomas & Whitaker, 1995). Despite this, K-strategist species tend to be the focus of translocations as a consequence of their higher conservation priority.

The effects of avian predators need to be considered when selecting suitable island sites for threatened lizard translocations. Further research is required to elucidate the relationships between high and low predator and lizard abundances, and future studies need to focus on quantifying the effects of other ground feeding birds, such as kiwi and weka, on island lizard populations.

CHAPTER 7

General summary and future research directions

Plate 7.1 Neonate *Hoplodactylus duvaucelii* captured on Motuora Island in February 2008. (Photograph by author).

7.1 Condition of founder *H. duvaucelii* and post-harvest population size estimates (Chapter 3)

All *Hoplodactylus duvaucelii* translocated from Korapuki to Tiritiri Matangi and Motuora Islands survived the translocation procedure. During the quarantine period, all geckos showed significant decreases in weight. However, steady increases in body condition were later shown post-release and *H. duvaucelii* body conditions were significantly higher one year after release compared to that at the release. Parasitic mites (*Geckobia naultina*) did not appear to have an effect on the condition of the translocated geckos and mite loads indicated a weak seasonal fluctuation. Island-born neonates captured one year after release had high body condition and were comparable to those of captive-born geckos of similar age. One year after release, the geckos had no record of post-release mortalities and low re-capture rates within the monitoring areas. This is more likely the result of dispersal or non-detection by observers, rather than mortality. Population estimates of *H. duvaucelii* from the translocation source island, Korapuki, indicated a very large and dense population of 815 geckos/ ha. An accurate assessment of the effects of harvest on the source population was not possible due to a lack of pre-harvest data, however evidence of recent breeding suggests that the population is capable of expanding to pre-harvest levels.

The survival and high body condition of both adult and neonate *H. duvaucelii*, on Tiritiri Matangi and Motuora, suggests that sufficient resources were available at both release sites and that *H. duvaucelii* are capable of securing these resources and adapting to the new environment.

7.2 Post-translocation movements, range size, and habitat use (Chapter 4)

Backpack transmitter harnesses were successful for monitoring the movements and habitat use of translocated *H. duvaucelii.* Although the rubber harnesses remained attached for longer periods of time, they are not recommended for studies on soft-scaled geckos, due to the abrasive characteristics of the inelastic rubber. *Co-Flex* ® harnesses did not cause injuries to the geckos but they remained attached for a significantly reduced amount of time.

In the first week following release, *H. duvaucelii* did not move far from the release site although, a large increase in the dispersal distance away from the release site was apparent thereafter. No differences were apparent between sexes or island sites, suggesting that all translocated *H. duvaucelii* responded to the translocations in a similar way. Post-release movements were non-directional, varied between individuals, and in some instances were relatively large-scale (i.e. dispersal up to 220 m).

Range areas were very large (i.e. medians of 563 m^2 on Tiritiri Matangi and 774 m^2 on Motuora) and no differences were apparent between sexes or island sites. Range area is a function of an animal's movement. Therefore, it is likely that these range estimates are not truly representative of the geckos' normal home-ranges, but are the result of aberrant movements following translocation.

Translocated geckos utilised their habitat according to its availability on each island. On Motuora however, a relatively high proportion of the population was sighted on trees, possibly due to the availability of invertebrates feeding on tree sap. The geckos utilised different habitat types for foraging (i.e. trees and flax) and refuging (i.e. flax and scrub) activities. In general, habitat use by translocated geckos was comparable to that of resident geckos on Korapuki (Hoare, 2006).

The results from this study have important implications for the management of translocated lizards. The observed large dispersal distances moved from the release site in this study provide important inferences for the habitat requirements of translocated *H. duvaucelii*. An insufficiently sized area of habitat at the release site may increase the potential for founders to move into sub-optimal habitat (i.e. low food or refuge resources) or habitat where the risk of predation is higher. In addition, insufficient habitat quality may result in large dispersal movements, exposing the population to Allee effects and jeopardising the establishment of the population.

7.3 Efficiency of reptile monitoring techniques (Chapter 5)

Detecting cryptic geckos in complex environments is inherently difficult, especially when they are nocturnal, arboreal, and occur at low densities. The efficiency of three standard lizard monitoring techniques including spotlight searching, artificial refuges (A.R.), and footprint tracking tunnels were tested against low density populations of *H. duvaucelii* on Tiritiri Matangi and Motuora. All three methods were capable of detecting *H. duvaucelii*, but tracking tunnels proved to be the most successful method for detecting the presence of cryptic lizards at low densities. This is most likely due to the provision of attractive bait within the tunnel and that the method is passive, thereby avoiding issues associated with ‘trap shyness.’

Spotlight searching also provided an effective method for detecting cryptic nocturnal lizards, but this method was highly influenced by observer and habitat bias. Inexperienced volunteers successfully detected only one *H. duvaucelii* during the study and disturbances (i.e. noise, light, and vibration) caused by searching through structurally complex habitats were likely to have instigated early escape or avoidance responses in the geckos.

Artificial refuges were the least effective method for detecting *H. duvaucelii* at low densities and apparently were occupied only on Tiritiri Matangi Island. Natural refuges may be preferred over A.R.s if the quality of the habitat is high, providing a sufficient number of natural refugia. At higher population densities, A.R.s may be utilised more often since conspecific competition for natural refuges will increase.

Irrespective of the monitoring method, environmental variables such as temperature and precipitation are likely to affect the ability of the method(s) to detect lizards. Temperature was shown to have the greatest effect on *H. duvaucelii* tracking rates, with lower detections occurring at reduced temperatures, probably as a result of reduced activity levels in the ectothermic geckos (Cree, 1994; Read & Moseby, 2001).

No single monitoring technique is likely to equally detect presence of lizards and provide accurate estimates of population density across species and sites. Each method is subject to the effects of extrinsic environmental variables and a range of biases, including observer, habitat, and environmental bias. Therefore, the application of multiple monitoring methods may significantly increase the probability of detecting cryptic lizards at low densities following translocation. The results from this study favour the use of tracking tunnels and spotlight searching, especially by trained fieldworkers, and suggest that A.R.s are an ineffective technique for detecting arboreal geckos in low population densities.

7.4 Avian lizard predation (Chapter 6)

Birds are often present at high densities on mammal-free offshore islands (Beauchamp & Chambers, 1987) and many have been recorded preying on native lizards. The present study emphasises the importance of kingfishers as predators of lizards, as a high proportion (88%) of regurgitated pellets contained the remains of lizards on Tiritiri Matangi Island. Similarly, kingfishers on Motuora also consumed a high proportion of skinks although sample sizes were too small for conclusive results. No lizard remains were present in the diets of other native birds, including pukeko, morepork, and Swamp harriers sampled on Tiritiri Matangi and Motuora Islands. The latter three species represent more opportunistic predators of lizards. Therefore, the failure to detect lizards in their diet may have been the result of the method (i.e. faecal analysis) used to detect lizard prey items. When the same method was used in captive feeding trials, lizard remains could not be detected in pukeko faeces.

Avian predators have the potential to negatively impact small translocated lizard populations, especially if the lizards are K-strategist species and show slow rates of population increase. A lack of understanding of predator-prey dynamics between birds and lizards and the influence of lizard prey density on predation rates can have significant consequences on the outcome of threatened species translocations. The assessment of the future release sites for translocated lizards should include considerations of the resident bird species and population densities, as these could jeopardise the success of the translocation.

7.5 Conclusion

The translocation of lizards to protected off-shore islands in New Zealand has proved to be a highly successful conservation tool. This research can aid in the further understanding of post-release responses of lizards to translocations and the factors threatening their establishment (i.e. native bird predation). Provision of adequate habitat quality and size, releases locations limited in the number of known bird predators, and the instatement of long-term monitoring programmes will help improve the translocation success of more threatened lizard species in the future.

7.6 Future research directions

Futher research is required to address the many more questions developed as a consequence of the present study. Future research directions are summarised below.

1) Further test the efficiency of monitoring methods against known population sizes, both experimentally and in the field. This may improve the understanding of monitoring tools as an index for population density.
2) Develop more efficient monitoring techniques that target species biological requirements for increasing detection and can be standardised for across species and site comparisons.
3) Undertake further research on the predator-prey dynamics between lizards and native birds, including other opportunistic ground feeding birds such as weka and kiwi, under different densities. This may allow the influence of native avian predators on lizard population growth rates to be described
4) Describe the small-scale movements and ‘home-ranges’ of resident non-translocated *H. duvaucelii*, using a methodology similar to that in the present study. This will provide a direct comparison with translocated geckos, to determine if the responses in the current study were truly induced by translocations into novel environments.

5) Undertake further research regarding the effects of founder population size and demographics on the viability of translocated lizard populations.

6) Extend post-translocation monitoring to include source population assessment and determine the effects of translocation harvesting.

7) Review the methods for attaching radio-transmitters to geckos and conduct further trials, both in captivity and the wild, on the effectiveness of new techniques that minimise adverse effects to the animals.

8) Investigate the role of chemical stimuli in attraction and communication of conspecific *H. duvaucelii*, with implications for increased breeding potential in low density translocated populations.

Appendix I

Individual movement paths of *H. duvaucelii* following release on a) Tiritiri Matangi and b) Motuora Islands.

Numbers above graphs indicate individual gecko ID numbers. (F = female, M = male), (X = release site).

a) Tiritiri Matangi Island

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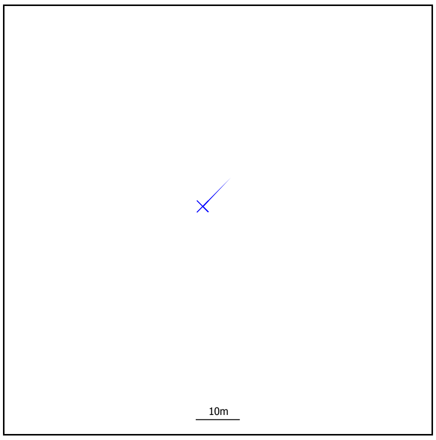

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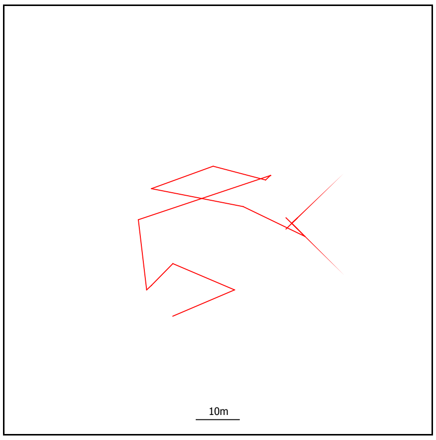

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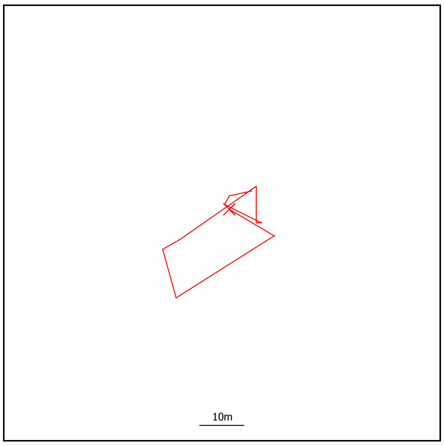

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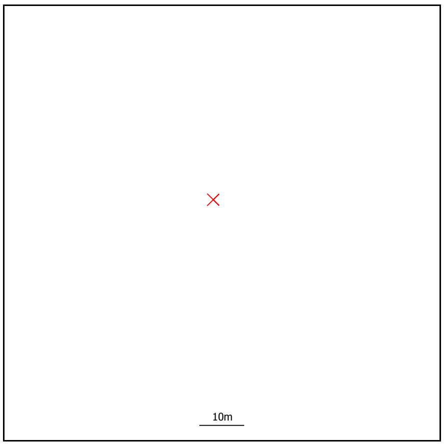

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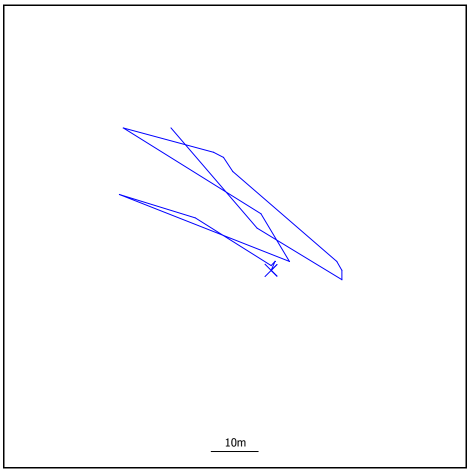

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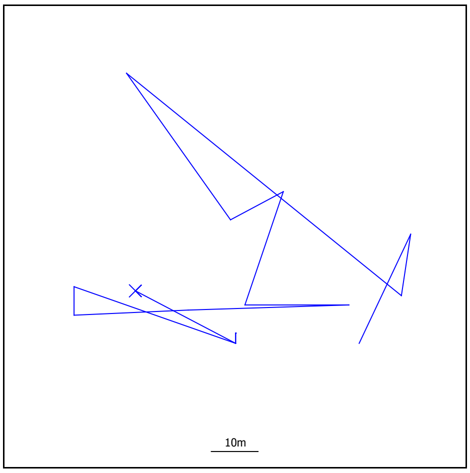

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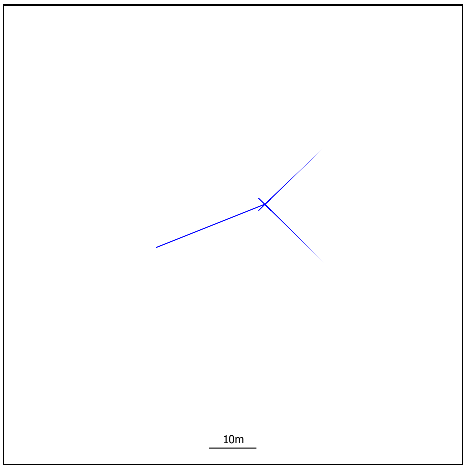

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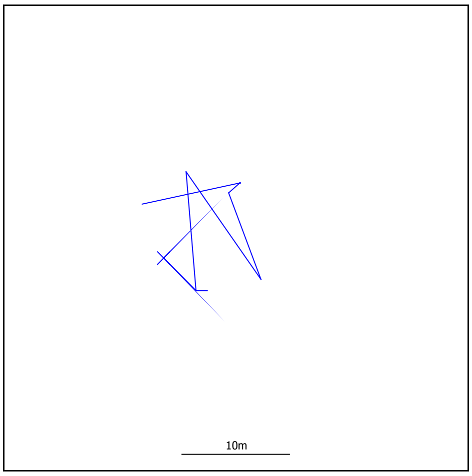

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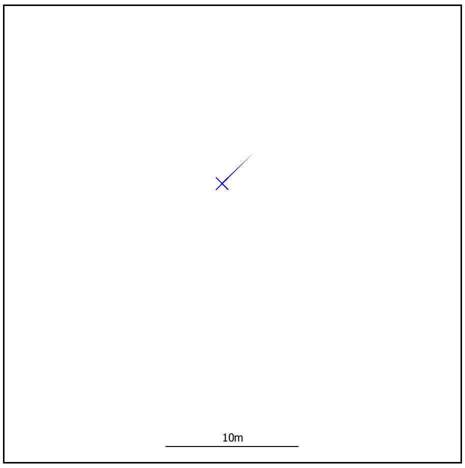

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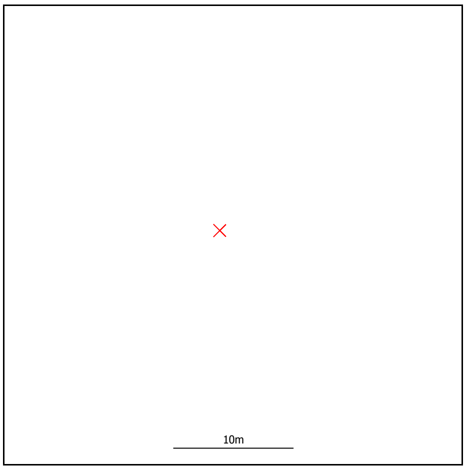

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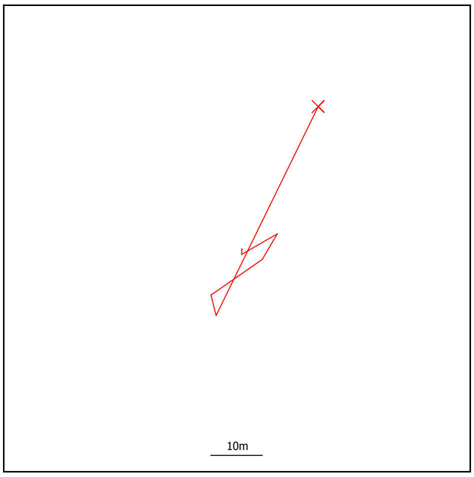

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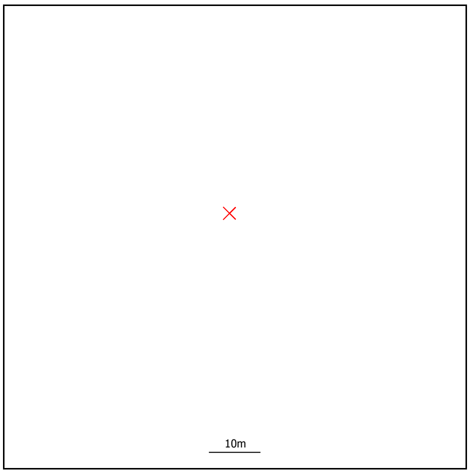

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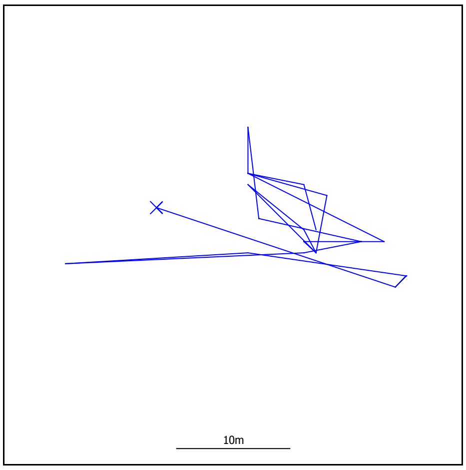

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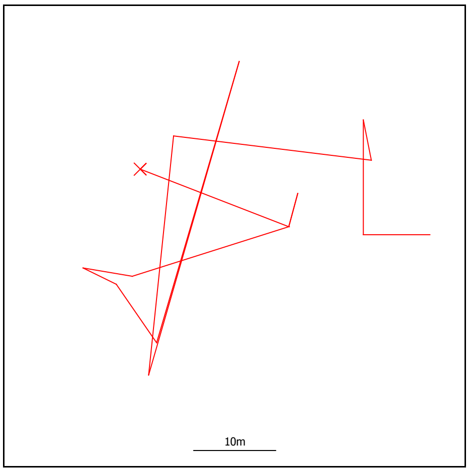

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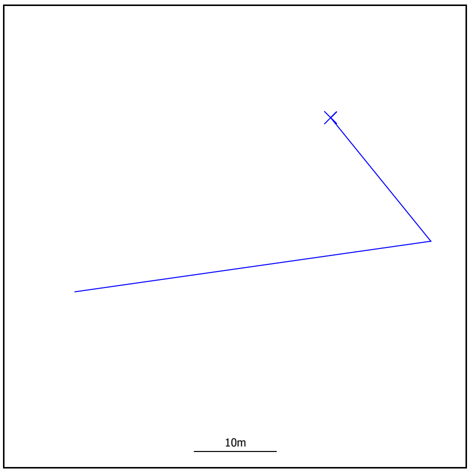

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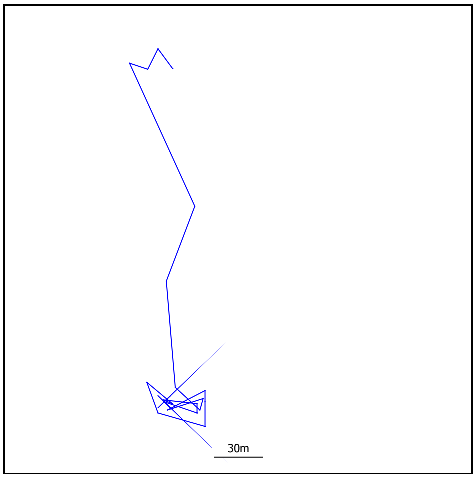

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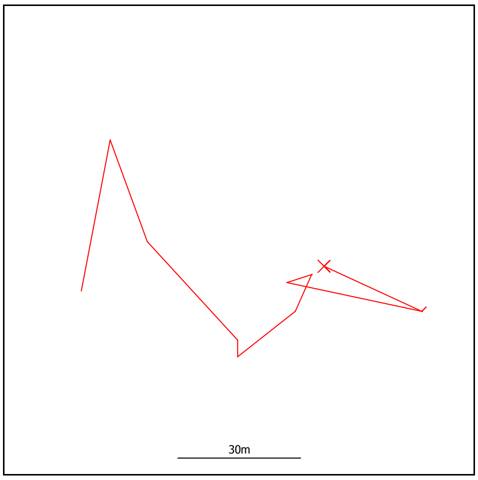
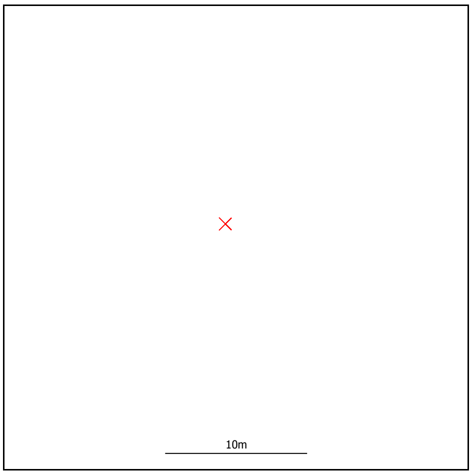
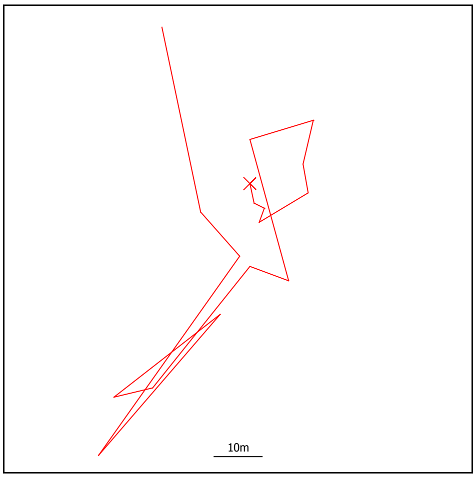


202JF



b) Motuora Island

002F



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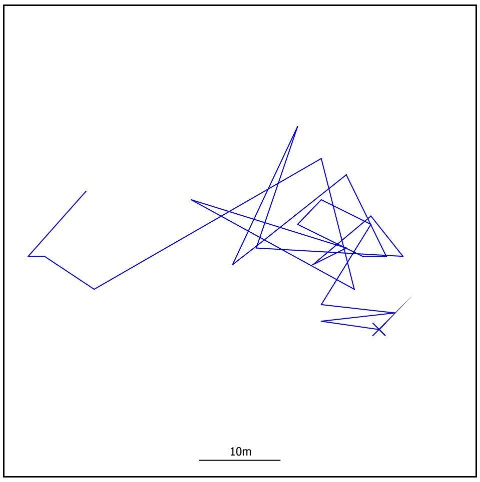

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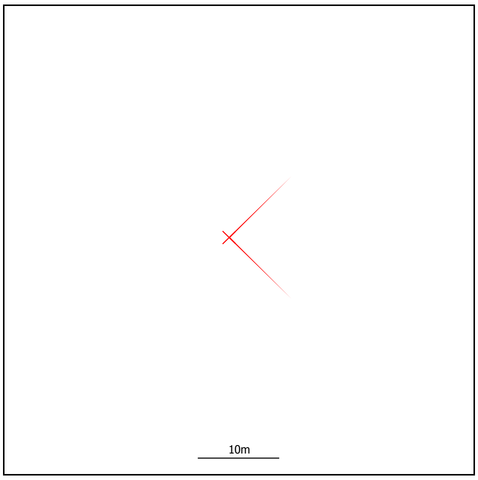

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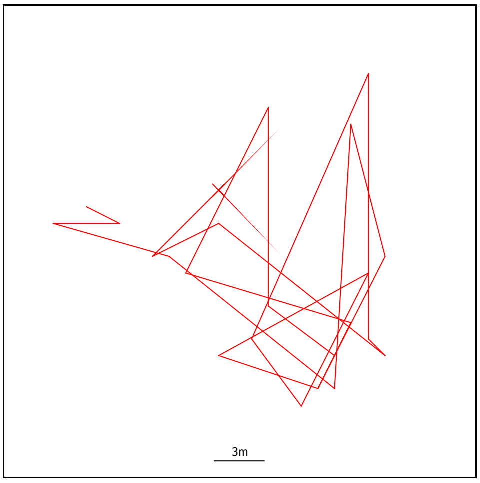

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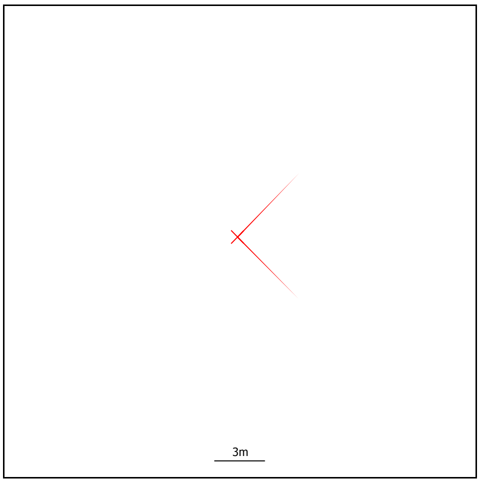

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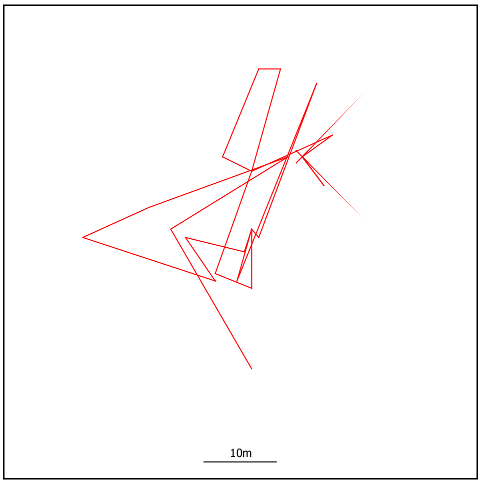

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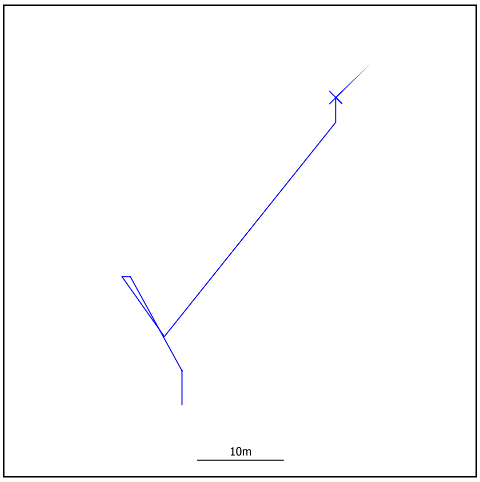

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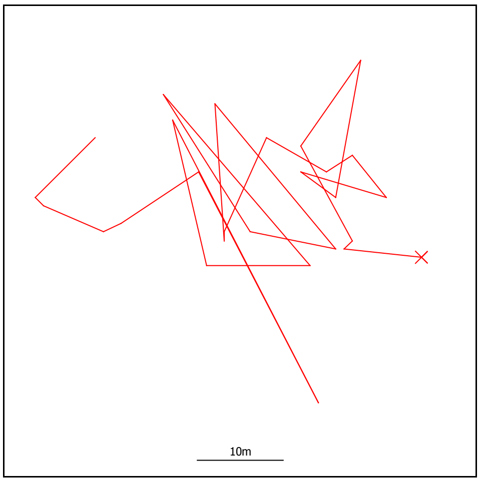

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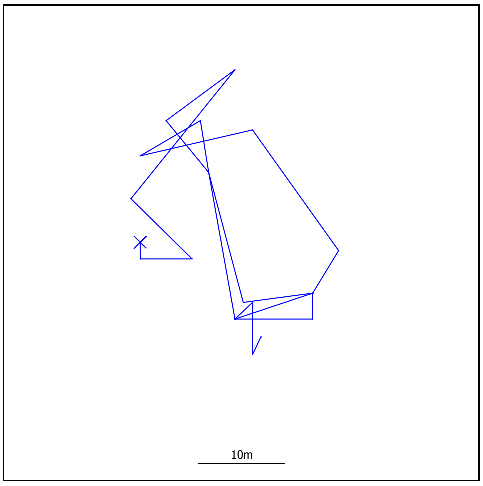

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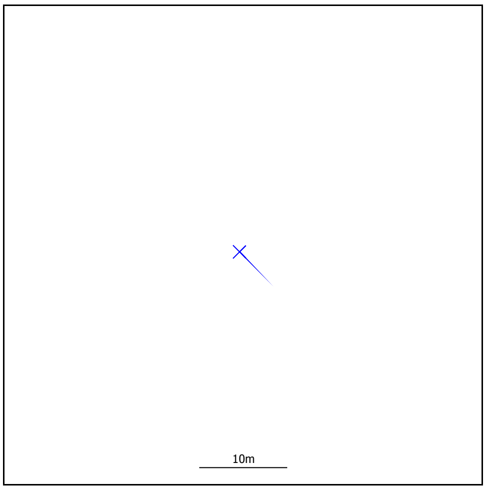

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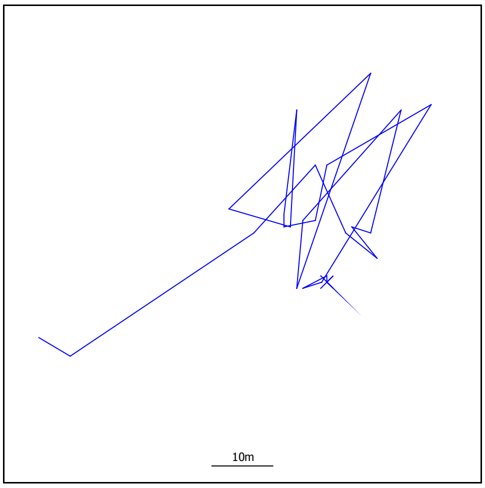

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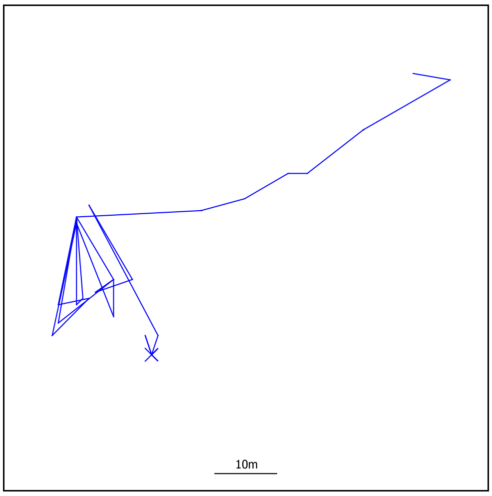

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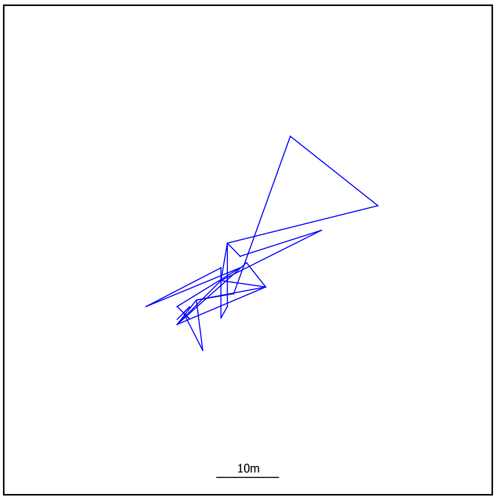
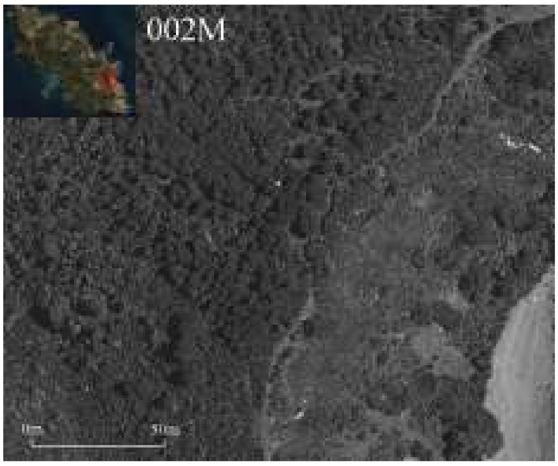


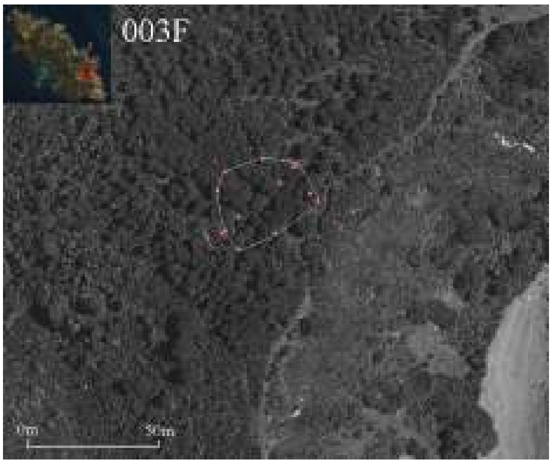
Appendix II

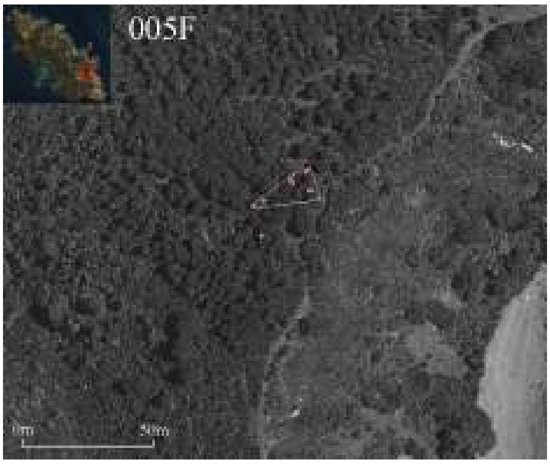
Individual locations and 95% MCP range estimates of *H. duvaucelii* released on a) Tiritiri Matangi and b) Motuora Islands.

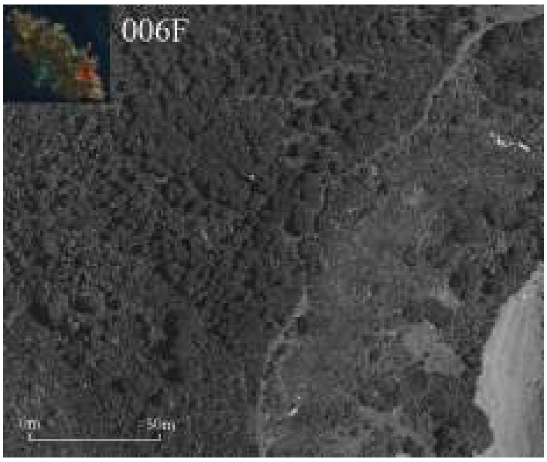
Numbers within figures indicate individual gecko ID numbers. (F = female, M = male), (X = release site).

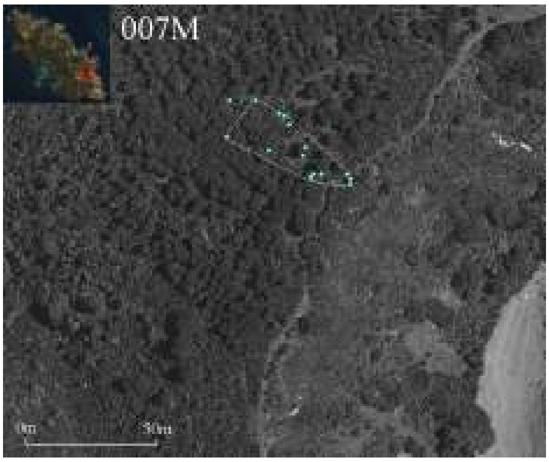
a) Tiritiri Matangi Island

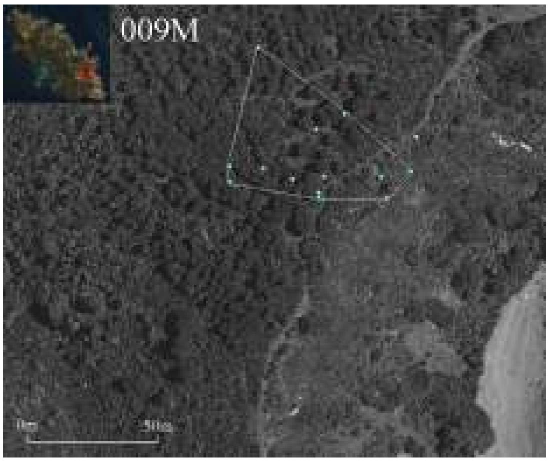









007M
0m
50m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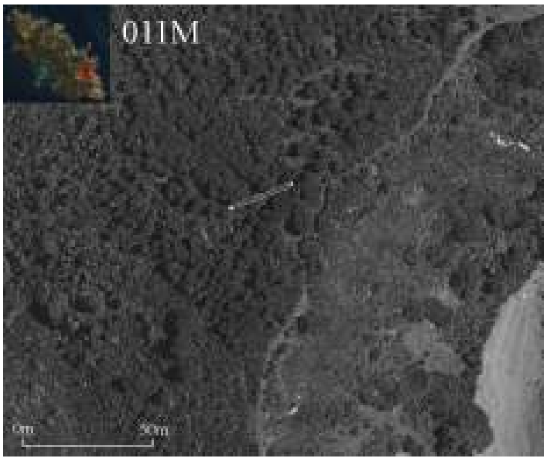
0m
50m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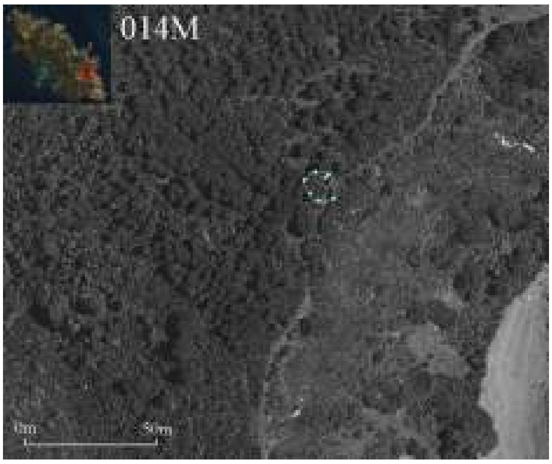
0m
50m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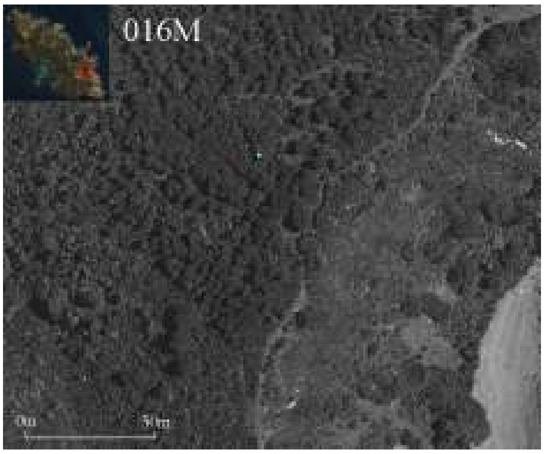
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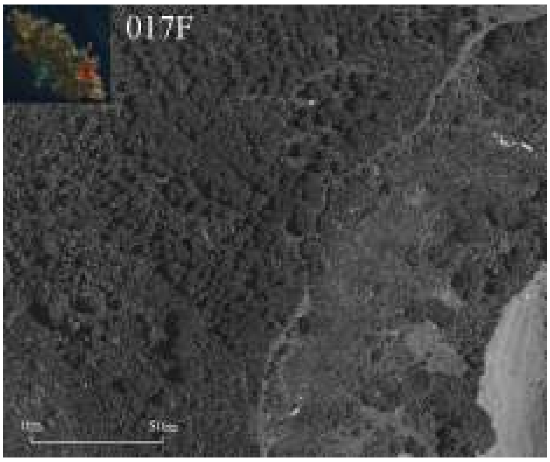
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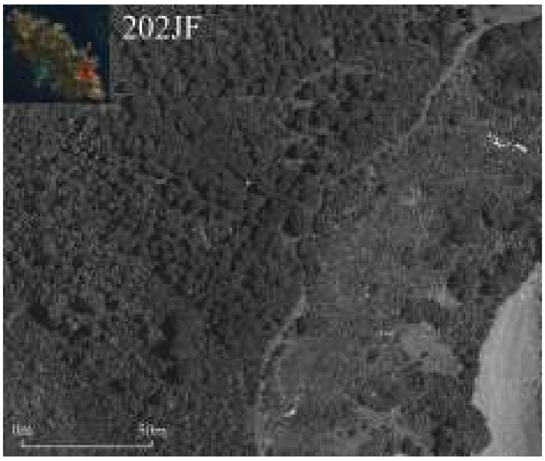
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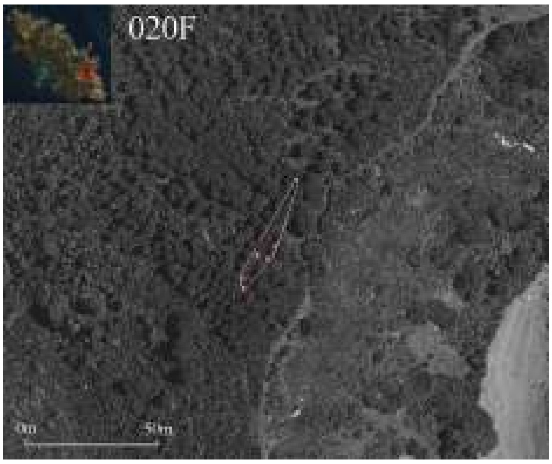
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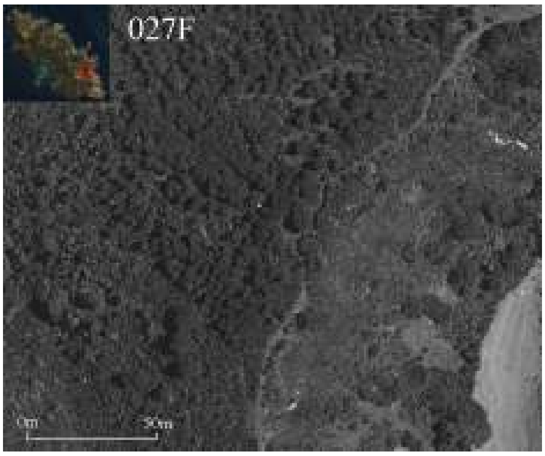
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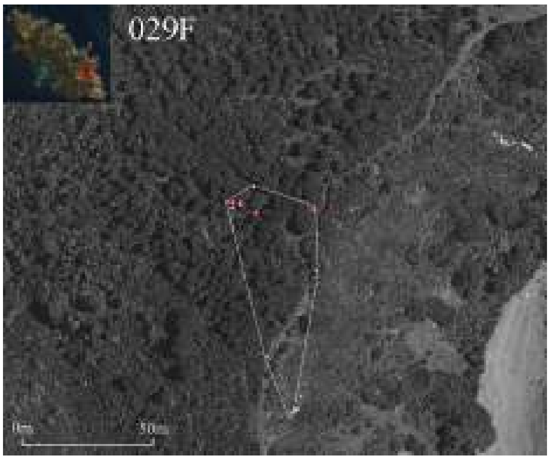
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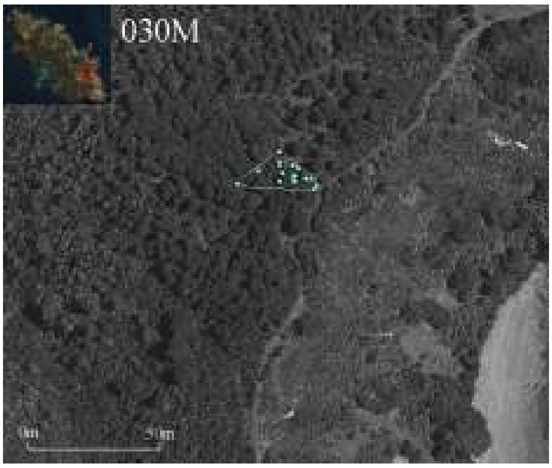
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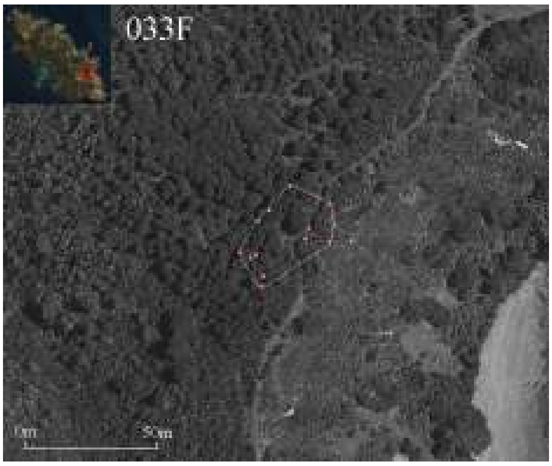
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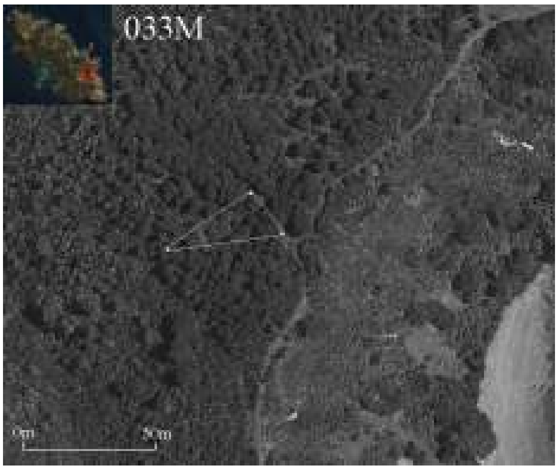
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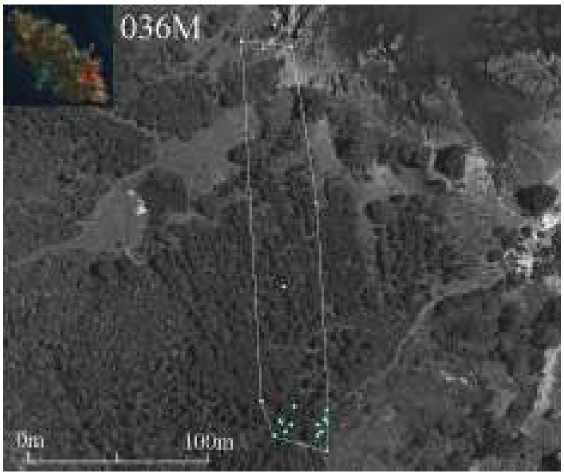
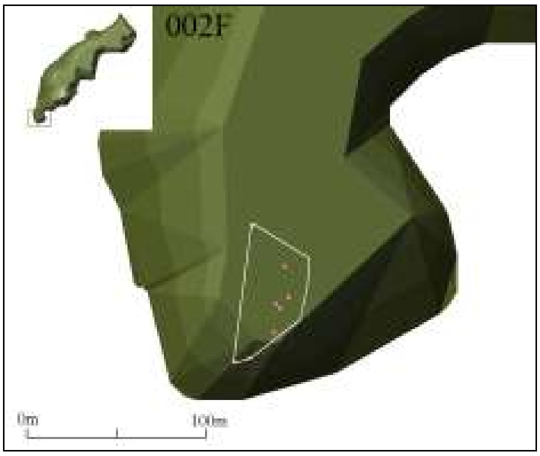
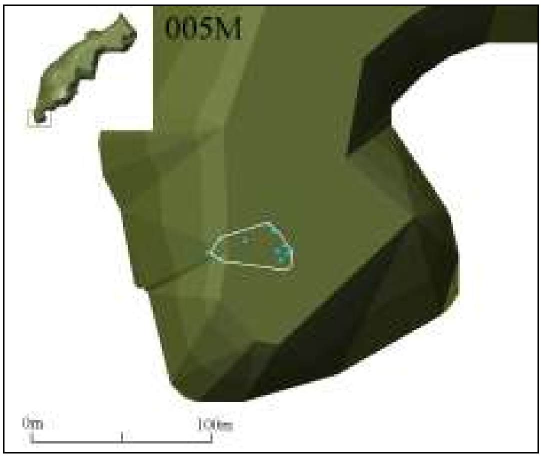
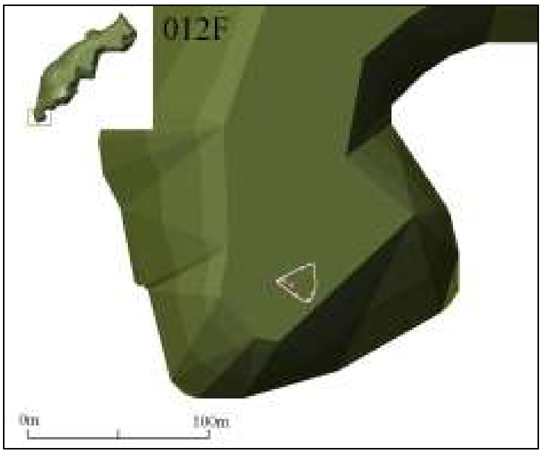

036M
0m
100m

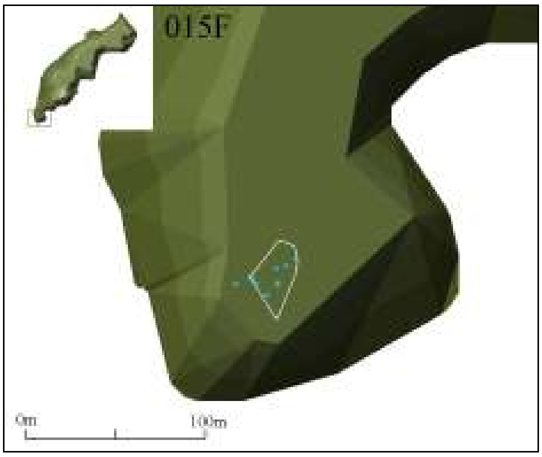

037F
0m
50m

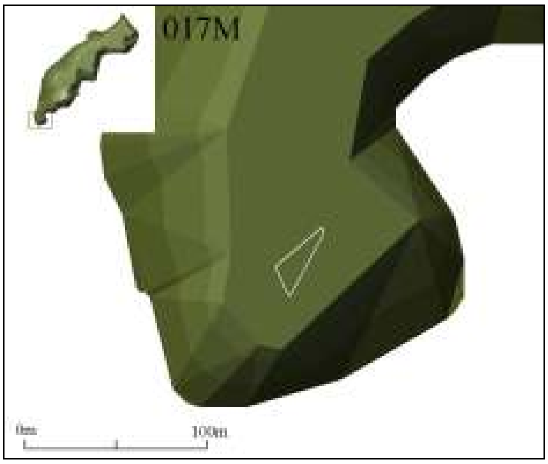
b) Motuora Island

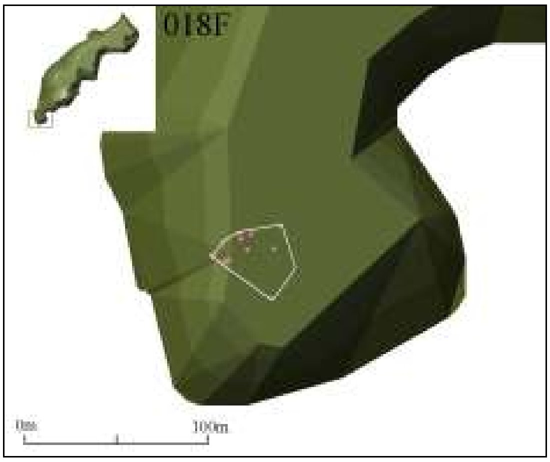


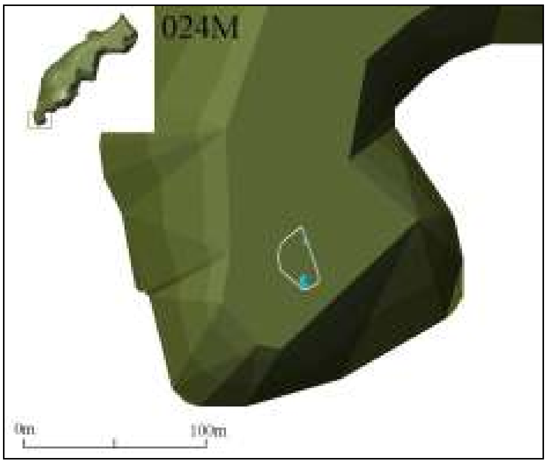








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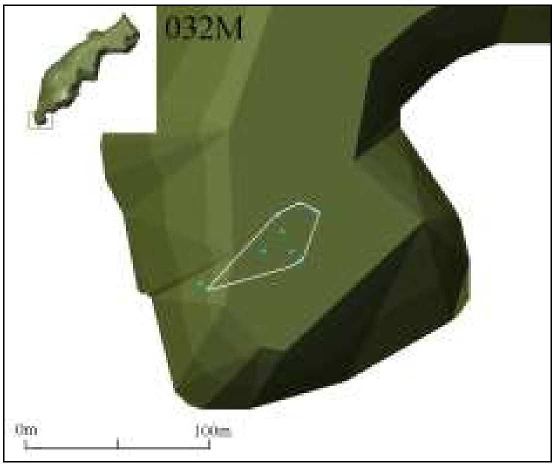
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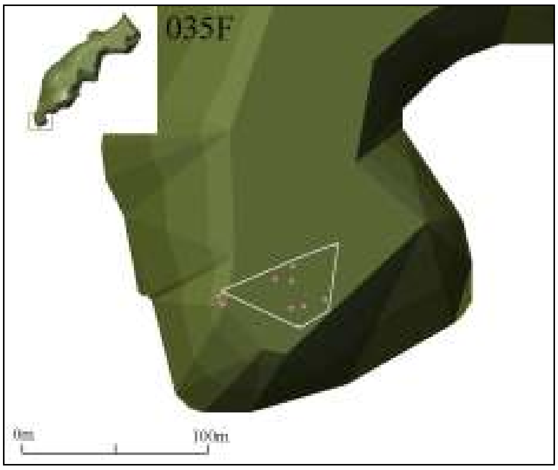
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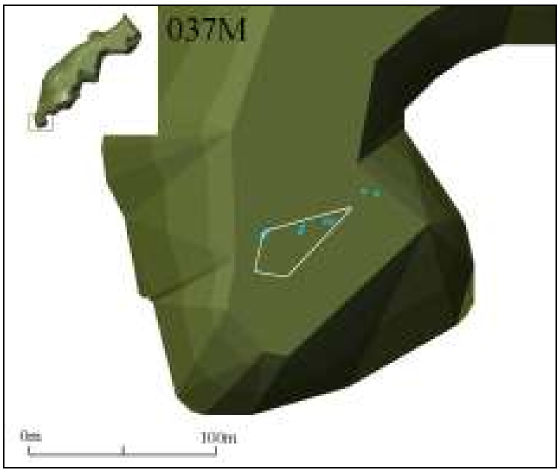
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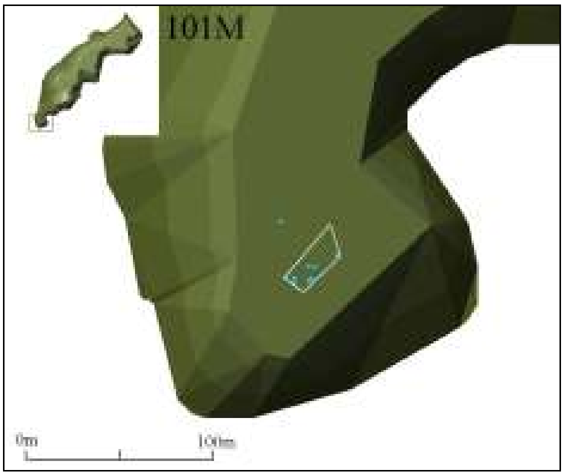

101M
0m
100m

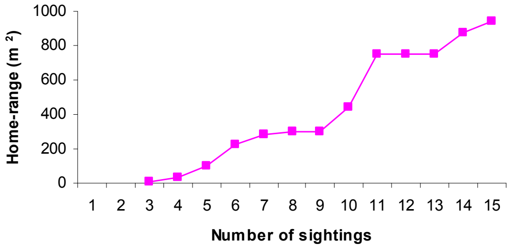
Appendix III

Relationship between cumulative range area (metres) and the number of sightings of individual *H. duvaucelii* on a) Tiritiri Matangi and b) Motuora Islands.

Numbers above graphs indicate individual gecko ID numbers. (F = female, M = male)

a) Tiritiri Matangi Island

003F



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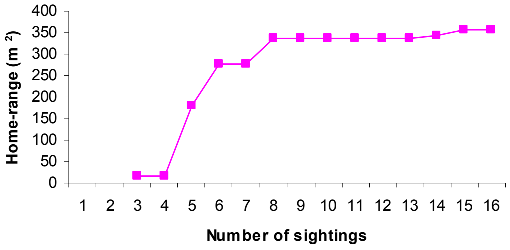

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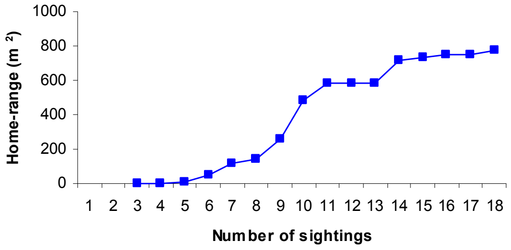

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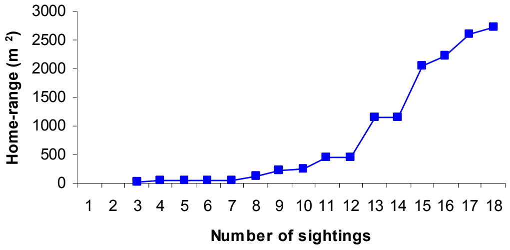

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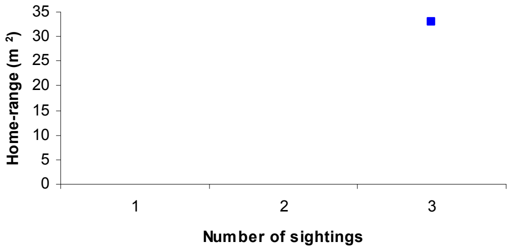

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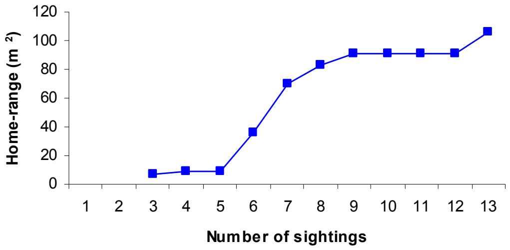

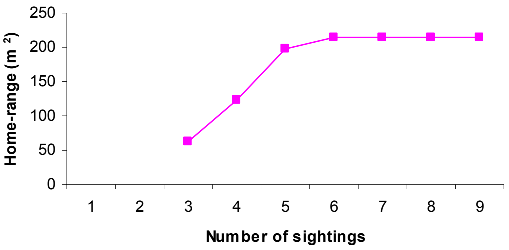

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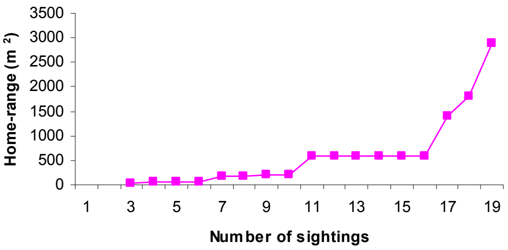

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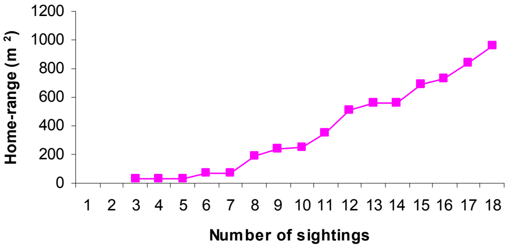

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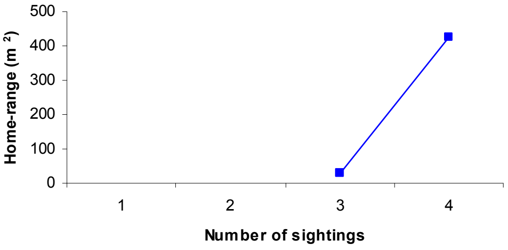

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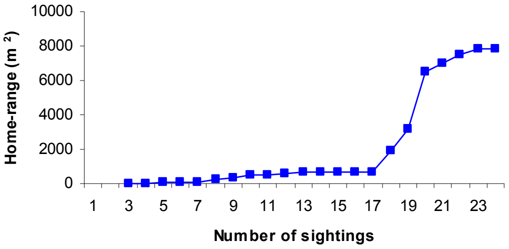

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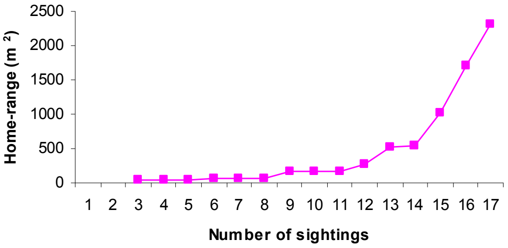
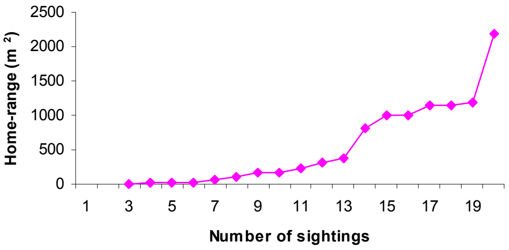


037F

b) Motuora Island

002F



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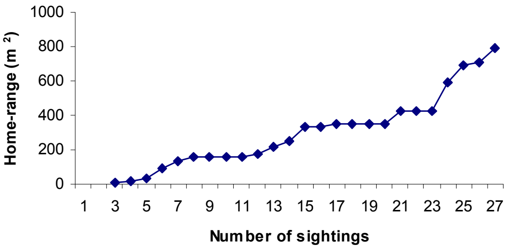
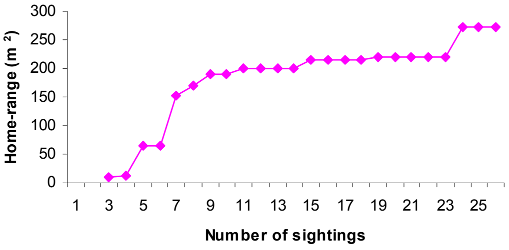
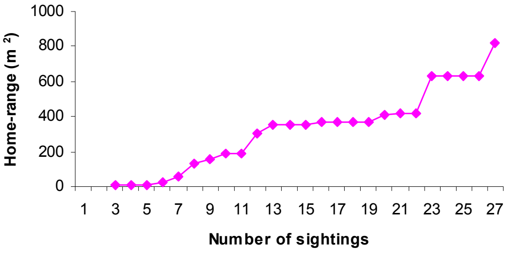


012F



015F



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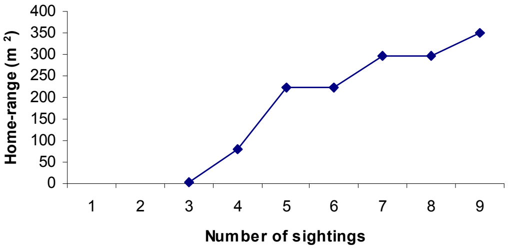
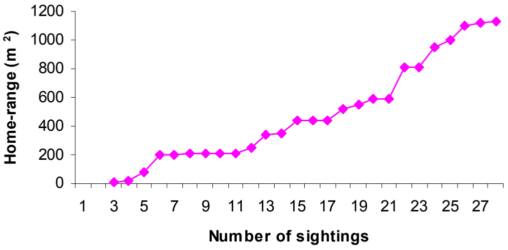
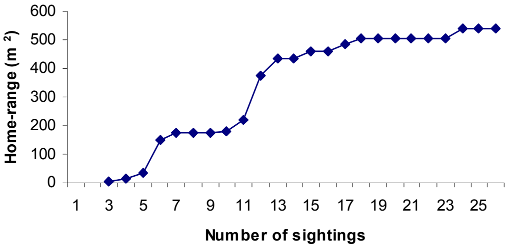


018F



024M



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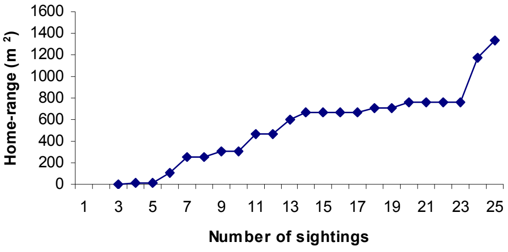

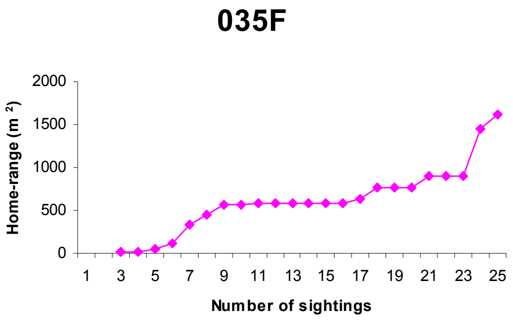
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Home-range (m ²)
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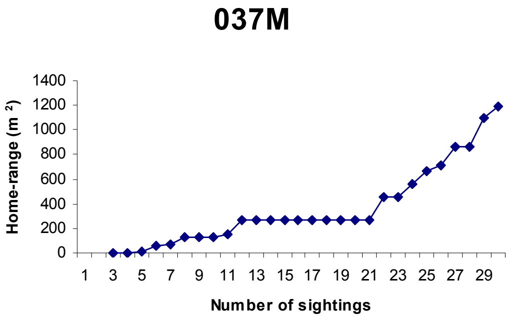
Number of sightings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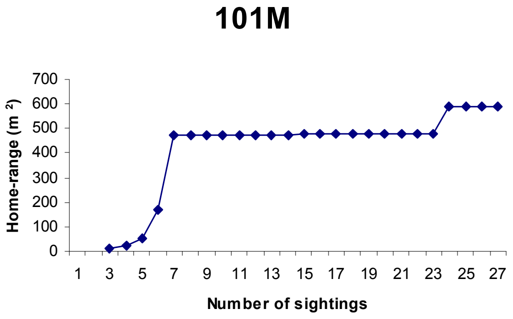
Number of sightings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Home-range (m ²)
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27
Number of sightings

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