Anchoring techniques for translocated Duvaucel's geckos (*Hoplodactylus duvaucelii*), and the use of cell-foam retreats by lizards and invertebrates

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

Master of Science in Conservation Biology

Massey University, Albany,

New Zealand.

Alaine Holdom

2015

"You cannot get through a single day without having an impact on the world around you. What you do makes a difference, and you have to decide what kind of difference you want to make."

Jane Goodall

Abstract

Conservation management often requires translocations to isolated habitats, and determining the success of such events is reliant on the use of effective post-translocation monitoring (PTM) techniques. Many reptile populations are already difficult to monitor, and post-release dispersal often increases this difficulty. Effective monitoring techniques for nocturnal, semi-arboreal, cryptic lizards are consequently still lacking. Furthermore, very little research has been conducted on the use of anchoring techniques for improving the PTM of lizards by reducing post-release dispersal behaviour. In early 2013, two populations of Duvaucel's geckos (*Hoplodactylus duvaucelii)* were translocated to two offshore islands. This provided an excellent opportunity to investigate several aspects relating to the improvement of PTM techniques for this species. I investigated whether two anchoring techniques, i.e. temporary food provision and release into cell-foam retreats (CFRs), can reduce post-release dispersal and encourage CFR usage. Further, I assessed the usefulness of CFRs for the PTM of *H. duvaucelii*. Additionally, I investigated the usage of CFRs for a range of other lizard species and invertebrates. My research provided evidence that both anchoring techniques can improve the use of CFRs by *H. duvaucelii* in the short term. However, anchoring effects were not maintained beyond two months after release. While anchoring treatments may have delayed post-release dispersal behaviour, they did not affect post-release dispersal distances. The study results suggest that CFRs can be a useful PTM tool for *H. duvaucelii*, particularly shortly after translocation, and also aid in the detection of young. In addition, I demonstrated that CFRs can detect a variety of other lizard and invertebrate species. In conclusion, this research provides valuable information for the improvement of monitoring techniques for cryptic, semi-arboreal lizards, also providing evidence that CFRs can be useful tool for monitoring a range of lizards and invertebrates.

Acknowledgements

Table of Contents

List of Figures

List of Tables

List of Appendices

Chapter 1   Literature Review

1.1 Conservation History in New Zealand

New Zealand was separated from Gondwanaland 65-80 mya and has since split into three main islands and 700 smaller islands (Craig et al. 2000). It was first colonised by Polynesians, who arrived approximately 1000ya with domestic dogs *(Canis lupus familiaris)*, the Pacific rat, (*Rattus exulans*) and various crop plants (Atkinson and Cameron 1993, Craig et al. 2000). There is still some debate around the timing of their arrival, with some research suggesting an earlier date (Wilmshurst et al. 2008). During the time since their arrival, forest cover declined from 78% to 53%, and at least 32% of terrestrial bird species became extinct (Atkinson and Cameron 1993). Europeans arrived in 1840, bringing with them 80 species of exotic birds, fish, and mammals, including cats, rats, mice, and mustelids (Atkinson and Cameron 1993). Forest cover was further reduced to 23%, native wetlands to only 10% of their pre-European cover, and another 8% of terrestrial bird species became extinct (Atkinson and Cameron 1993, Craig et al. 2000). Currently 63% of New Zealand's land area is covered by agriculture, exotic forests and urban landscapes (NZBS 2000), and there are more introduced than native plant species (Craig et al. 2000). New Zealand is now home to eleven species of predatory mammals which, along with habitat reduction and modification, have resulted in many native species, including a large number of New Zealand's native lizard species, being confined to small fragmented predator-free areas on the mainland or offshore islands (Towns et al. 1997, van Winkel 2008). Due to the isolated nature of these available habitats, and the inability for lizards to

disperse to these areas without assistance, translocations are an essential management practise for lizard conservation in New Zealand.

The high degree of habitat fragmentation on the mainland has meant that offshore islands have become a central focus for conservation. Islands can often provide predator-free refugia for many plant and animal species struggling to persist on the mainland, with some protected by restricted access and strict biosecurity enforcement (Towns and Ballantine 1993, van Winkel 2008). Approximately 300 of New Zealand's offshore islands are protected in some way (Towns and Ballantine 1993). Rats have been completely eradicated from over 65 offshore islands, the largest of which was Campbell Island, measuring 11,200ha (Bellingham et al. 2010). The development of more effective pest control programs has led to increased opportunities for restoration of habitats on the mainland (Craig et al. 2000, Saunders and Norton 2001). Consequently, mainland islands or areas of natural habitat on the NZ mainland selected for permanent, intensive pest control and ecological restoration (Saunders 1998), have become more of a focus for conservation in recent years (Craig et al. 2000, Saunders and Norton 2001).

1.2 Translocations

1.2.1 Translocation theory

Translocation is defined as the human-mediated movement of living organisms from one area with release into another (IUCN/SSC 2013). They are essential components of conservation programs as they allow opportunities such as re-introductions to islands and other isolated areas (Towns and Ferreira 2001), which are beyond the natural dispersal capabilities of a species (Towns and Atkinson 2004). The translocation of species back into previously inhabited areas has been a large focus for global conservation in recent years. Translocations involving thousands of separate releases of at

least 100 animal species have been documented (Sherley et al. 2010, Miskelly and Powlesland 2013). The majority of translocations in New Zealand are conducted for conservation purposes. For example, 94% of the 85 reptile translocations conducted between 1988 and 2010 served ecological restoration and/or species conservation purposes (Sherley et al. 2010). Initially, there was a large focus on avian species in translocation events. However, this has recently shifted to accommodate a larger diversity of animals including invertebrates, frogs, and reptiles, partially due to the increasing awareness of their ecological importance (Craig et al. 2000).

1.2.2   Translocation success

A translocation is generally considered successful when the population has established, is stable, self-sustaining and has a high probability of persistence without any further human involvement (Dodd and Seigel 1991, Seddon 1999). Criteria for successful population establishment include the survival of the founding population, and reproduction by the founder individuals as well as their progeny (Seddon et al. 2012). The length of time necessary to determine success varies significantly with the species released (Dodd and Seigel 1991). In New Zealand, many species are characterised by delayed maturity, extreme longevity, and low reproductive rates. Therefore longer periods of monitoring are required to determine successful population establishment, in some instances several decades (Jones 2000, Towns and Ferreira 2001). Effective post-translocation monitoring (PTM) is essential to evaluate whether a translocation has been successful (Bell 2009).

1.2.3   Importance of post-translocation monitoring

Effective PTM should provide information on survival, condition, breeding, dispersal, and behaviour, all of which are essential for determining the success of a translocation event, and consequently also making future management decisions. In the past, many translocations were not followed up by adequate PTM, and success remained uncertain (Seddon et al. 2012). For instance, in New

Zealand, PTM was carried out for only 56% of the 85 reptile translocations conducted until 2010 (Sherley et al. 2010). The World Conservation Union (IUCN) Reintroduction Specialist Group (RSG) was formed in 1998, and their production of the "Guidelines for Reintroductions" led to improvements in post-release monitoring standards and a consequent increase in short-term success rates of translocations (Seddon et al. 2012).

PTM is also essential for increasing the chances of success for future translocation events. In many instances, the post translocation responses and subsequent behaviour of the species of concern are unknown (termed structural uncertainty) (van Winkel 2008, Nichols and Armstrong 2012). Baseline information on survival, dispersal, and population health following release are needed to improve future translocation methodologies (Sherley et al. 2010, Nichols and Armstrong 2012).

1.2.4   Reasons for translocation uncertainty or failure

Insufficient PTM regimes or inadequate monitoring methods are some of the main reasons why the success of translocations remain uncertain (Fischer and Lindenmayer 2000). Once released into a new environment, it can be very difficult to detect and therefore collect information from founder animals. This is the case for many New Zealand lizard species that are particularly cryptic (secretive and camouflaged) and elusive. Development and ongoing improvement of species specific monitoring methods can help to improve translocation success.

Translocations can fail due to high mortality rates caused by predation, stress (Parker et al. 2012), and poor or unsuitable habitat conditions (Germano and Bishop 2009). These issues are generally mitigated by preparing release sites through pest control, and release protocols aimed at reducing stress both during and following translocations (Parker et al. 2012). Various supportive measures have been implemented in translocation programs to improve the quality of the release area,

including improved vegetation cover through planting, installation of artificial shelters and supplementary feeding. Fischer and Lindenmayer (2000) found that mammal translocations with supportive measures implemented had lower failure rates (12%) compared to those without (42%).

Post-translocation dispersal, such as homing, premature migration, or dispersal away from the release area, can be a significant cause of translocation failure (Swaisgood 2010, Le Gouar et al. 2012). First, mortality is often highest immediately following a release. This is because animals are not only vulnerable to predation shortly after release due to disorientation and unfamiliarity with their new surroundings, but also might migrate away from the release site into less suitable habitat (Swaisgood 2010). Second, individuals that disperse are no longer contributing demographically or to the population gene pool (Le Gouar et al. 2012). Post-release dispersal was found to be one of the main reasons for the failure of a large number of herpetofauna translocations conducted between 1991 and 2006 (Germano and Bishop 2009), and is also an issue for various other vertebrate groups including mammals and seabirds (Parker et al. 2012). Dispersal from the release area can also compromise effective population monitoring and management (Swaisgood 2010), resulting in uncertainty of success.

1.2.5   Anchoring strategies and reducing post-release dispersal

Methods that aim to encourage an animal to remain at a release site by discouraging post-release dispersal are termed anchoring strategies. Various types of anchoring techniques have been tested on a wide range of bird and mammal species. Some commonly utilised methods involve improving habitat quality at release sites through the provision of food (Bright and Morris 1994, Finlayson and Moseby 2004, Reynolds and Klavitter 2006, Le Gouar et al. 2012), nest sites or burrows (Parker et al. 2012), or other essential resources (King and Gurnell 2005, Swaisgood 2010). Although artificial retreats have often been used to monitor translocated populations, I could find no examples of

studies where the release of animals into artificial retreats was specifically tested as an anchoring technique. Other techniques involve the manipulation of group dynamics in the release site, such as group size (Støen et al. 2009), ages or life stages of individuals (Germano and Bishop 2009), familiarity of individuals (Armstrong 1995, Armstrong and Craig 1995, Parker et al. 2012), or bonded, paired, or family groupings (Reynolds and Klavitter 2006, van Heezik et al. 2009, Swaisgood 2010). Releases are also often coincided with the time of year where individuals show the lowest levels of natural dispersal (Le Gouar et al. 2012). Housing animals in enclosures at release sites for some time before their release is termed a delayed or soft-release, and is often used as an alternative to an immediate, or hard-release. Soft releases are used to allow animals time to acclimatise to their new environment before being released (Le Gouar et al. 2012). However, there are varying levels of success with different species (Bright and Morris 1994, Fritts et al. 2001, King and Gurnell 2005, Reynolds and Klavitter 2006). Sound anchoring or playback calls are used to encourage animals to either remain within or return to a release site (Molles et al. 2008, Miskelly et al. 2009, Bradley et al. 2011, Parker et al. 2012). Different anchoring techniques have all had varying levels of success, as different species or populations will react differently to the same strategies due to behavioural and ecological differences.

Very few anchoring techniques have been tested on translocated populations of herpetofauna. Food supplementation has been used to successfully reduce post-translocation dispersal on some American and tropical herpetofauna species (Boutin 1990) as well as one Australian lizard, the pygmy bluetongue lizard (*Tiliqua adelaidensis*) (Ebrahimi and Bull 2012). Soft-releases have been successfully used on Caribbean rock iguanas (*Cyclura* species) (Alberts 2007) and gopher tortoises (*Gopherus polyphemus*) (Tuberville et al. 2005). Soft-releases were also trialled in a recent study on jewelled geckos (*Naultinus gemmeus*) (Knox and Monks 2014). The study found that post-release dispersal was successfully reduced after penning geckos at release sites for 10 months prior to

release (Knox and Monks 2014). The anchoring techniques of food and shelter supplementation were also used during a translocation of Tuatara (Nelson et al. 2002). To the best of my knowledge, there have been no other reported cases of the use of anchoring techniques for translocations of New Zealand native lizards.

1.3 Reptile Conservation in New Zealand

New Zealand is currently home to 99 native resident species of reptiles (Hitchmough et al. 2013). Among these species there is a high level of diversity, and NZ's native lizards show similar levels of diversity to terrestrial bird species (Daugherty et al. 1993). Thirty-two percent of NZ's reptile species are classified as threatened, 50% as at risk, 4% as data deficient, and only 13% as non-threatened (Hitchmough et al. 2013). Tuatara (*Sphenodon punctatus*) were the first species to be granted protection in 1895, and by 1981 all but four of our common lizard species were protected under the Wildlife Act (Daugherty et al. 1994). Currently all of our native herpetofauna are protected by law (Morris and Jewell 2008).

Population declines of NZ's reptile species are mostly the result of introduced predators and habitat loss. All of NZ's native species evolved in the absence of mammalian predators. Therefore, the introduction and establishment of eleven mammalian predatory species has contributed to drastic range reductions for many reptiles (Daugherty et al. 1994). Many reptile species are nocturnal, making them highly vulnerable to predation by introduced nocturnal mammal species such as cats, rats and mustelids (Daugherty et al. 1994). Other species are long-lived with low reproductive rates, resulting in delayed recovery after the removal of threats. Many of NZ's species are highly cryptic, making them much more difficult to monitor (DOC 2012). The development of effective long-term

post-release monitoring methods for highly cryptic reptile species is consequently a large part of reptile conservation in New Zealand.

Offshore islands play an important role in the conservation of New Zealand reptiles. For many lizards, offshore predator-free islands are the only places where they are able to thrive away from nocturnal mammalian predators (Daugherty et al. 1994). Tuatara and 37% of NZ's lizard species are now restricted to offshore islands (Towns et al. 2001). Because of their restricted distribution and inability for range expansion without assistance, translocations are increasingly important for reptile conservation in New Zealand (Sherley et al. 2010). Since the first translocation of tuatara in 1988, translocations of reptiles in New Zealand have become increasingly more common, with at least 85 separate events occurring in the following 22 years (Sherley et al. 2010).

1.3.1   Translocation history of *Hoplodactylus duvaucelii*

Translocations of *H. duvaucelii* to offshore islands have been conducted multiple times over the past 17 years. The first documented translocation events included two separate transfers of 21 and 19 geckos in February and November 1998 respectively, all of which were moved from North Brother Island in the Cook Strait to Mana Island near Wellington. Post-release monitoring was conducted following both events using pitfall trapping, spotlight searching, artificial shelters and radiotracking (Jones 2000). However, these extensive efforts resulted in only 18% (7/40) recapture success (the recapture of individuals following their release) during a year of monitoring (Jones 2000). Between 2009 and 2012 more monitoring was conducted, which indicated that the population was breeding and had increased in size (Bell 2012).

A further translocation occurred in December 2006, where 69 wild caught geckos from Korapuki Island were translocated to Tiritiri Matangi Island (19), Motuora Island (20) and Massey University Albany campus in Auckland (30) (Baling et al. 2007, van Winkel 2008). Those moved to Massey

University were used to establish a captive breeding programme of *H. duvaucelii* used for scientific research and public education (Baling et al. 2007). Translocations to Tiritiri Matangi and Motuora Islands were conducted to aid in both species and ecological restoration through the establishment of founding populations (Baling et al. 2007). Populations have been monitored regularly following release, providing evidence that both island populations have survived, remained within the release areas, and are breeding successfully (SOTM 2013, Manuela Barry, pers. comm.). This success lead to the release of more individuals in a supplementary translocation in early 2013 (see Barry 2014).

Another translocation occurred in March 2011, where 61 adults (28 males, 33 females) were moved from Brothers Island in the Cook Strait to Long Island in the Queen Charlotte Sounds (Marlborough Sounds) (Cash 2011). Geckos were released in small groups of 3-4, and placed into seabird burrows located in shrub-grassland habitat (Cash 2011). Immediate post-release monitoring was not planned, with first survey set to be conducted 5 years following the release date (Cash 2011).

The next translocation occurred in late February to early March 2013, where 180 adult and sub-adult geckos (90 males, 90 females) and 6 neonates, were translocated to Motuora and Tiritiri Matangi Islands in the Hauraki Gulf. Geckos were evenly sourced from Korapuki Island, Stanley Island (both in the Mercury Islands, Coromandel), and the Massey University Reptile facility (Barry 2014). This translocation provided the framework for research conducted throughout this thesis, and more details of the event are given in Chapter 2.

The most recent translocation was conducted in January 2014, when 85 individuals (50 females and 35 males) were translocated from Stanley Island in the Mercury Islands to Motuihe Island in the Hauraki Gulf (Ussher and Baber 2013).

1.4   Reptile Monitoring Techniques

The monitoring of reptiles in New Zealand is essential for ensuring the success of translocated

populations as well as to understand post-translocation behaviours and improve techniques for

maximising translocation success. Because of the large variation in life-history traits of New

Zealand's reptiles, a variety of methods are currently used for monitoring different species. Careful

consideration is always required when choosing which techniques are appropriate, and it is often

recommended that a combination of methods are used to maximise information gained (Goldingay

et al. 1996, DOC 2012)

1.4.1   Identification techniques

Marking of animals with non-toxic pens is a common method of identification for use in short-term

studies (Beausoleil et al. 2004, van Winkel 2008). However, markings are usually lost as they are

rubbed off or lost as an animal sheds its skin (Lettink et al. 2011). Information on physical location,

morphometric measurements, age, condition and gender can also be used to assist with short-term

identification of reptiles within a population.

Toe-clipping is the partial and permanent removal of toes in individual-specific combinations used

as a form of individual identification (Lettink et al. 2011). Toe-clipping is still used on occasion both

overseas (Perry et al. 2011) and in New Zealand (Barwick 1982, Newman 1994, Cash 2011) despite

ethical concerns and the uncertainty of effects on the behaviour of the modified individuals

(Beausoleil et al. 2004).

PIT tagging refers to the subcutaneous implantation of a passive integrated transponder (PIT), each

with a unique alphabetical sequence allowing identification using a PIT tag reader (Elbin and Burger

1994). PIT tags can remain within the animal for years or even a lifetime, making them very useful

for long-term identification (Beausoleil et al. 2004). However, they can migrate from their point of insertion, leading to health problems (Beausoleil et al. 2004). They have been used successfully for studies on a variety of herpetofauna including frogs and toads (Brown 1997), salamanders (Ott and Scott 1999), snakes (Jemison et al. 1995, Roark and Dorcas 2000), and lizards (van Winkel 2008).

Reptiles can also be monitored using radioisotopes. Animals are applied with radioactive material and located using radiation detecting equipment (Beausoleil et al. 2004). However, this material is both dangerous to the animal and the researcher, with exposure causing tissue damage as well as behavioural modifications (Beausoleil et al. 2004). Because of these dangers, radioisotopes are no longer commonly used for monitoring (Beausoleil et al. 2004).

Tattooing is used to permanently mark animals on smooth light coloured surfaces using tattoo devices. It is not used extensively due to the time consuming methods required and the need to often tattoo animals on their lighter ventral surface, therefore requiring recapture for identification (Beausoleil et al. 2004). Hot branding and freeze branding are two other methods that are used to apply permanent markings by changing the appearance of the skin using hot or cold branding tools. Neither of these methods is widely used in lizard monitoring in New Zealand (Beausoleil et al. 2004, Hitchmough et al. 2012).

Identification of individuals through photographs of natural markings is a widely used method (Hoare et al. 2013). Individuals are identified based on differences in coloration and/or patterning that remains stable over an animal's lifetime. These techniques have been used successfully for both exotic herpetofauna (Gamble et al. 2008), and New Zealand native lizards, such as jewelled geckos (Knox et al. 2013), southern forest geckos (*Mokopirirakau sp.* 'Southern forest gecko') (Hoare et al. 2013) and *H. duvaucelii* (Bell, 2009 and this study, see Figure 1.1).
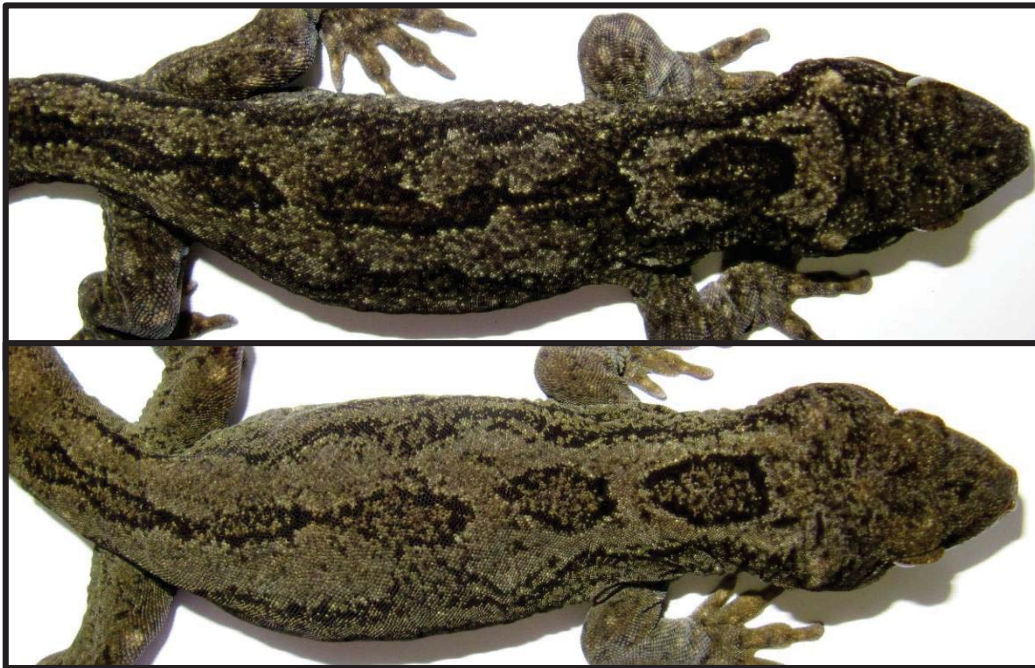
Figure 1.1. Dorsal photographs of two adult female Duvaucel's geckos, showing the differences in patterning allowing individual identification. Photos by author.

1.4.2   Tracking techniques

Footprint tracking is another useful method for lizard monitoring (Russell et al. 2010, Hare 2012b, Jarvie and Monks 2014). It involves the placement of tracking tunnels (long rectangular tubes) along sampling transects or within monitoring grids. Each tracking tunnel is set with a tracking card with an ink pad in the centre. Cards are then baited in the centre with a species appropriate attractant. Detection is often possible in low density populations and for highly cryptic species, making their use very popular. It also requires little time and effort, and does not require a large amount of training or special skills. Lizard prints are generally easy to identify. However species identification may require more knowledge and higher experience levels (Agnew 2009). Individual identification is not possible, so information gained from this method is limited. It is sometimes possible for experienced researchers to classify age groups for larger lizard species based on footprints, but the usefulness of this method is generally limited to presence absence detection. The efficacy of tracking

tunnels for determining abundance is yet to be tested for herpetofauna, although it has been confirmed to be of use for rodents (Hare 2012b).

Radiotracking is another widely utilised method for monitoring behaviour and movements of reptiles (Sabo 2003, Kerr and Bull 2004, Hoare et al. 2013, Romijn et al. 2014). It involves the attachment of a radio transmitter to an animal, followed by the use of telemetry equipment to pinpoint locations based on directional strength of radio signals. The main limitations are that equipment can be very costly and require a high level of training for proper use. Also, attaching transmitters is difficult and invasive, often resulting in injuries or mortalities (Gerner 2008, van Winkel 2008). It is recommended that attachments should not weigh more than 7.5% of the animals body weight, which often restricts their attachment to large adults (Knapp and Abarca 2009).

Fluorescent powder tracking is not commonly used for monitoring herpetofauna (Fellers and Drost 1989, Kearney 2002), and was originally designed to track small mammals (Lemen and Freeman 1985). It works by either laying out fluorescent powder at baiting stations, or releasing animals already covered in powder (Kearney 2002). The coloured UV detectable powder is then dispersed as the animal moves around, leaving a traceable path of its movements (Stark and Fox 2000). With this method it is possible to gather detailed information on the exact pathway an animal has taken. For example, Furman et al. (2011) tracked the exact movements of snakes (*Thamnophis* species) for more than 200m. Different colours can be used at different stations, and powders are cheap and are known to have been continually deposited by some animals for at least five days (Fellers and Drost 1989). It is also a good method to use for nocturnal, cryptic species whose detection probabilities are otherwise very low. It is non-invasive, requires very little training to implement, and allows the collection of information from small animals that cannot be monitored closely using other techniques (e.g. radio telemetry) (Furman et al. 2011). The disadvantages when using

powdered stations are that, as with tracking tunnels, individuals are not able to be identified unless the paths lead to the animal's current location. Determining the directionality of movements is also not always possible (Fellers and Drost 1989). This method has been successfully used to study the movements of frogs (Graeter and Rothermel 2007), salamanders (Roe and Grayson 2008), turtles (Blankenship et al. 1990), snakes (Furman et al. 2011), and lizards (Dodd 1992, Stark and Fox 2000).

1.4.3   Live-capture techniques

Live-trapping is a commonly used technique for monitoring lizards that allows data collection on habitat use, behaviour, biology, and many other population and individual level informative data. One of the main limitations is that capture probability can vary significantly with factors such as species (Greenberg et al. 1994), trap placement (Hare 2012a), weather (Fitch 1951), habitat (Jamieson and Neilson 2007, Barr 2009, Gebauer 2009), individual related factors (Pollock et al. 1990, Neilson et al. 2006), age, or gender (Hare 2012a). Another disadvantage is that there is often by-catch of non-target species, including small birds, mammals, and insects (Hare 2012a). Traps can also make the target species vulnerable to predation, and so it is also recommended that trapping should not take place in areas with introduced predatory mammals (Hare 2012a).

Pitfall traps are a common method used for sampling lizards (Towns 1994, Pearce et al. 2005, Lettink 2007, Monks et al. 2014) . They consist of containers of various materials and sizes placed into a hole made in the ground, with the top edge of the container being placed level with the ground (Hare 2012c). Animals crawling along the forest floor fall into the container and cannot get out (Hare 2012c). Pitfall trapping is generally not suitable for geckos as they can easily climb out (Jones 2000, Hare 2012c).

Funnel traps are a widely used tool for monitoring herpetofauna overseas (Greenberg et al. 1994) and are becoming increasingly common in New Zealand (Bell 2009, Gebauer 2009, Hare 2012a).

They consist of a cylinder shaped mesh container with an inverted funnel at either one or both ends, where the animal enters through but cannot exit (Hare 2012a). Traps are usually baited with food items that are attractive to the target species.

Systematic searches are a common method of reptile sampling both overseas (Buden 2011, Ganesh et al. 2013) and in New Zealand (Hoare et al. 2013, Romijn et al. 2014). It involves two types of techniques, visual searching and hand searching (Hare 2012d). Visual searching involves actively scanning a site for animals or signs of animals within a given search area. This includes spotlight searching, where nocturnal species are located through the use of spotlights to detect the eye-shine of active animals (Jones 2000, Lardner et al. 2009). Hand searching involves more active searching, where animals are located by lifting objects and searching through potential retreat sites.

Artificial retreats (ARs), also known as artificial refuges, artificial cover objects (ACOs), and cover boards, are now widely used for reptile monitoring both overseas (Webb and Shine 2000, Beck and Jennings 2003, Croak et al. 2010) and in New Zealand (Towns 1994, van Winkel 2008, Thierry et al. 2009, Lettink et al. 2011, O'Donnell and Hoare 2012). They consist of objects placed within a species habitat that provide shelter, protection, food sources or assisted thermoregulation. Shelters can also assist in both pre- and post-translocation programs, as well as general population monitoring. AR's are usually set up some months before monitoring begins to allow an acclimatisation period. Monitoring reptile populations using ARs requires low monetary and time commitments, requires very little maintenance, is easily standardised across space and time, and observer bias, habitat disturbance, and risk to animals is reduced (Bell 2009).

Bell (2009) introduced a new design of AR for lizard monitoring in New Zealand called closed-cell foam covers (CFRs). These shelters consisted of a piece of closed-cell foam attached to tree trunks using nails, leaving a large enough gap between the trunk and the material to allow a gecko to crawl

under. Monitoring of high density populations resulted in high capture rates. In low-density populations, monitoring was still able to detect presence but did not result in high captures. The design of closed-cell foam covers means they are able to be attached to many tree structures, are effectively insulated against environmental elements, are low cost, light-weight, easy to set-up, and long-lasting.

The use of ARs by animals is known to vary with site, weather, season, habitat type, shelter density, frequency of monitoring, age, design, predator abundance, and variation in individual behaviour over space and time (Anderson 2001, Hyde and Simons 2001, Kjoss and Litvaitis 2001, Anderson 2003, Francke 2005, Lettink and Seddon 2007, Wilson et al. 2007, O'Donnell and Hoare 2012). However, these types of variation are also encountered with other monitoring methods explored previously.

1.5 Retreat-Site Selection in Reptiles

Many factors related to the thermoregulatory benefits of a shelter are known to influence retreat site choice in reptiles (Kearney and Predavec 2000, Kearney 2002). In particular, temperature (Sabo 2003, Webb et al. 2004, Aguilar and Cruz 2010, Andersson et al. 2010), humidity (Schlesinger and Shine 1994, Cohen and Alford 1996), orientation (Shah et al. 2004), shelter material (Goldsbrough et al. 2006, Lettink and Cree 2007, Thierry et al. 2009, Andersson et al. 2010), layering (Lettink and Cree 2007), crevice structure (Webb and Shine 2000, Webb et al. 2004, Croak et al. 2008, 2010), and placement in relation to other natural structures (Quirt et al. 2006, Wilson et al. 2007) are all known to effect shelter usage. For many species, shelter usage patterns are also affected by season (Kearney and Predavec 2000, Lettink 2007, Monks et al. 2014), reproductive status (Rock et al. 2002, Sabo 2003, Thierry et al. 2009), vulnerability to predators (Amo et al. 2004, Shah et al. 2004, Quirt

et al. 2006) and presence of conspecifics (Schlesinger and Shine 1994, Shah et al. 2003). Barry (2010) investigated the shelter preference traits for *H. duvaucelii* in a lab environment and found there was no preference for different crevice widths (thought to represent vulnerability to predators), nor to humidity level or shelter overlay material. However, there was a noticeable preference for warmer shelters.

1.6 Knowledge Gaps

Many of the currently utilised reptile monitoring techniques can be time consuming, expensive, require high levels of training, or are difficult to repeat over space and time. Others are only useful to a subset of species, and many result in low capture rates. This is especially true for many of the techniques available for monitoring arboreal or semi-arboreal, highly cryptic lizard species. Commonly used monitoring methods such as trapping, hand searching and radiotracking are all difficult to conduct, expensive, or result in low return per unit of effort for these types of species. Bell (2009) tested the usefulness of cell foam retreats (CFRs) for monitoring various cryptic, arboreal lizards, and found that they were useful at detecting species within both high and low-density resident populations. However, this type of monitoring technique is yet to be tested for the monitoring of low-density, translocated populations. Therefore, I aimed to investigate the effectiveness of a similar design of double-layered CFR for the PTM two populations of *H. duvaucelii*.

As well as the lack of effective PTM techniques, post-release dispersal away from release sites is another major problem for conservation management of lizards, often leading to the failure or uncertainty of success of translocation programmes. Anchoring techniques have been successfully used to reduce dispersal for many species of mammals and birds, and a few overseas studies have successfully trialled their use on reptile populations. However, until recently anchoring techniques

had yet to be used for any highly cryptic, arboreal lizard species, which are often the species which are the most difficult to monitor following a translocation event. Knox and Monks (2014) recently tested the use of a soft-release strategy (penning) for reducing post-release dispersal in diurnal jewelled geckos and found that dispersal distances were reduced with a ten month pre-release penning treatment. Therefore, I aimed to test the effectiveness of two alternative anchoring techniques, temporary food provisioning and release into artificial retreats, at reducing post-release dispersal and improving the monitoring ability of *H. duvaucelii* following a translocation.

1.7 Research Goals

In this study I investigate how anchoring techniques and CFRs can help to improve the monitoring of highly cryptic, low-density populations of arboreal lizards. I tested two main hypotheses relating to the improvement of PTM for *H. duvaucelii*:

1) Anchoring techniques result in a reduction in post-release dispersal, and improved monitoring success of *H. duvaucelii* through an increase in CFR use following a translocation (Chapter 3)

2) CFRs are useful tools for the PTM of populations of *H. duvaucelii*, as they a) are revisited by *H. duvaucelii* following release, b) are continuously used throughout the monitoring period, and c) are used by all cohorts (Chapter 4).

1.8 Thesis Outline

In Chapter One I provide an introduction to the topic through a literature review, and describe the knowledge gaps that exist which are hoped to be filled with the research conducted in this thesis.

In Chapter Two I describe the study site and species, and provide a description of the general methods used to explore multiple hypotheses investigated throughout the thesis.

In Chapter Three, I tested the hypothesis that the two anchoring techniques, the temporary provision of food and the release of geckos into CFRs, result in a reduction in post-release dispersal distances following a translocation. This involved the use of radiotracking, funnel trapping, and CFR check data to compare the distances geckos travelled at different points in time following their release. I also tested the hypothesis that the two anchoring techniques would result in an improvement in monitoring through an increase in CFR use. I used data from regular CFR checks to compare the patterns of CFR use by geckos.

In Chapter Four, I tested the hypothesis that CFRs are a useful tool for monitoring *H. duvaucelii* following a translocation. I investigated the usefulness of CFRs through regular, monthly checks over a ten month time period, and also incorporated data from the scheduled population monitoring conducted twelve months following the release. I investigated several aspect relating to their usefulness, including the utilisation of different areas within the CFRs, use of CFRs by different cohorts, and the spatial and temporal variation in CFR use. CFRs were also set-up at existing monitoring grids to investigate their usefulness for monitoring established populations of the species. I used tracking tunnels to compare the use of CFRs to that of the surrounding area, and measured a suite of environmental variables including CFR climate and surrounding microhabitat, to investigate their contribution to the spatial variation in CFR and tracking tunnel use that was observed. Using these data I tested the hypotheses that 1) various environmental factors affect the use of CFRs and tracking tunnels, and 2) factors that significantly affect CFR use by geckos are different to those which affect tracking tunnel use. This chapter therefore not only discusses the usefulness of CFRs for monitoring both existing and translocated populations of *H. duvaucelii*, but

also provides information on habitat selection, and the features of CFRs that are selected for in the species.

Following this is a final data chapter, where I report findings on the usefulness of the same CFRs for monitoring other species. In this chapter, Chapter Five, I provide observations on the usage of CFRs by other lizard and invertebrate species. I report on the usefulness of the CFR design for the detection and monitoring of both lizards and invertebrates, and report the spatial and temporal variation of CFR use by these groups. Further, I test the hypothesis that CFR microhabitat variables affect invertebrate density and richness over space and time.

A summary of results and recommendations, including future research directions, are presented in a final chapter (Chapter 6). References from each chapter are presented in a single section at the end of this thesis. All appendices are also presented at the end of the thesis in a single section.

Chapter 2   General Methods

2.1 Study Species

2.1.1 Natural history

Duvaucel's geckos (*Hoplodactylus duvaucelii* Duméril, 1836) are New Zealand's largest species of extant native gecko, and one of the largest in the world (Robb 1980). Adults from northern populations (Poor Knights Islands) reach up to 160 mm snout-vent-length (SVL) (or 320 mm total) and weigh up to 118 g (Whitaker 1968), whereas southern distributions are much smaller (Barwick 1982). The gender of mature adults can be determined by the presence of a hemipenal sac and large cloacal spurs in the males, and femoral pores in the females. *H. duvaucelii* show delayed maturity, with both sexes reaching reproductive capacity after four to seven years, corresponding to approximately 95 mm SVL for Cook Strait populations (Barwick 1982) and 110 mm SVL for Coromandel populations (Barry et al. 2014). They also show extreme longevity, with some wild individuals thought to have reached at least 50 years of age (Thompson et al. 1992, Wilson 2010). As with all but one species of New Zealand's native lizards, *H. duvaucelii* are viviparous. Females generally give birth in late summer to one to two young, after a gestation period of about five to eight months (Barwick 1982).

2.1.2 Behaviour

H. duvaucelii are highly cryptic and nocturnal in nature, and are most active a few hours after dusk until a few hours before dawn (Barwick 1982, van Winkel 2008). They are known to occasionally sun

bask (Whitaker 1968) but generally take refuge in retreats during the day (Barry et al. 2014). They

are habitat generalists, and forage both within foliage and on the ground (Whitaker 1968). They are

also known to regularly move between habitat types such as coastal and forest (Hoare et al. 2007).

They are known to form diurnal shelter aggregations and exhibit scent communication, indicating

the existence of complex social behaviours (Bell 2009, Barry 2010). Individuals show strong site

fidelity. One individual on North Brother Island was found within five metres of its first location 29

years later (Thompson et al. 1992, Jones 2000). Natural populations exhibit overall low levels of

dispersal, with the largest previously recorded movement by a resident *H. duvaucelii* being 73 m

over three nights (Whitaker 1987). Populations translocated to both Tiritiri Matangi and Motuora

Islands in 2006 showed higher levels of dispersal following release, with average daily movements

of 8.2 m and 11.5 m recorded for geckos on each island respectively, and a maximum daily

movement of over 50 m having been recorded (van Winkel 2008). Previous maximum post-release

dispersal distances (the maximum distances geckos were reencountered at from their release sites)

of geckos moved to offshore islands have been 64.5 m and 220 m (Jones 2000, van Winkel 2008).

2.1.3 Diet

H. duvaucelii have a diverse diet including fruits, seeds, nectar, insects, honeydew, and occasionally

smaller native lizards (Barwick 1982, Whitaker 1987, Towns 2002). They appear to prefer large prey

items, as a study on one population found that one third of their chosen prey were larger than

10mm in length (Christmas 1995). Commonly foraged plant species include pohutukawa

(*Metrosideros excelsa*), ngaio (*Myoporum laetum*), flax (*Phormium tenax*), karaka (*Corynocarpus*

laevigatus), various *Coprosma* species, black nightshade (*Solanum nodiflorum*), kawakawa

(*Marcopiper excelsum*), and karo (*Pittosporum crassifolium*) (Whitaker 1987). They are often found

congregated on trees infested with endemic honeydew producing scale insects (*Coelostomidia zealandica* (Hemiptera: Margarodidae)) (Towns 2002).

2.1.4   Distribution and conservation status

Numerous *H. duvaucelii* fossils have been found throughout both the North and South Islands of New Zealand, indicating that they were once widely distributed throughout the mainland (Worthy and Holdaway 1995, Worthy 2001). Natural wild populations are now restricted to predator-free offshore islands off the northeast coast of the North Island and the Cook Strait (Towns and Daughtery 1994). They are currently classified as 'lower-risk/least concern' by the IUCN, and because of their restricted distribution classified as 'at risk' and 'relict' by the New Zealand Department of Conservation (DOC) (Hitchmough et al. 2013). Apart from this, little is known about the species behaviour in the wild, as their nocturnal and cryptic nature makes them difficult to monitor in the field.

2.2   Study Sites

2.2.1   Motuora Island

Motuora Island (36"30'S, 174'47'E) (**Error! Reference source not found.**) is situated in the Hauraki Gulf, 3 km east of Mahurangi Heads (Figure 2.2) (Gardner-Gee et al. 2007). It measures 80 ha, is long, narrow, and relatively flat topped, surrounded by coastal cliffs and sandy beaches, and reaches a maximum elevation of 75 m above sea level (Gardner-Gee et al. 2007). The current dominant vegetation types include coastal forest, grassland and regenerating forest. Motuora Island was farmed extensively from the 1850's (Hawley and Buckton 1997) until 1990 when ecological restoration began (Gardner-Gee et al. 2007). Prior to and during the years of farming, most of the native bush was cleared by both Maori and Europeans and replaced with dominant exotic species,

leaving only 20 ha of remnant bush dominated by pohutukawa, mahoe (*Melicytus ramiflorus),* and

karo, situated along the inaccessible coastal cliffs (Gardner-Gee et al. 2007). By 2006, volunteers

had planted over 200,000 native trees and shrubs covering 35 ha, with 5 ha left as managed

grassland (Hawley and Buckton 1997, Gardner-Gee et al. 2007). Despite the islands extensive

farming history, it has never been successfully colonised by any introduced mammalian pest species

(Hawley and Buckton 1997). Ecological restoration on Motuora Island so far has focused on

regeneration and translocations of species that are 1) thought to have previously existed on the

island, 2) unable to recolonise by other means, 3) threatened, and 4) ecologically important

(Gardner-Gee et al. 2007). Consequently, the majority of reintroductions have been of native plants,

as well as some keystone fauna including seabirds, lizards (shore skink (*Oligosoma smithii*) and *H.*

duvaucelii) and invertebrates (wetapunga – *Deinacrida* species). Since 1999, the island has also been

used as a kiwi crèche for the Operation Nest Egg (ONE) programme (Gardner-Gee et al. 2007). The

island is classified as an open sanctuary, and is jointly managed by the Motuora Restoration Society

(MRS) and the New Zealand DOC (Gardner-Gee et al. 2007).

Figure 2.1. Satellite image of Motuora Island as at 11/12/2013 (Google Earth 2013b).
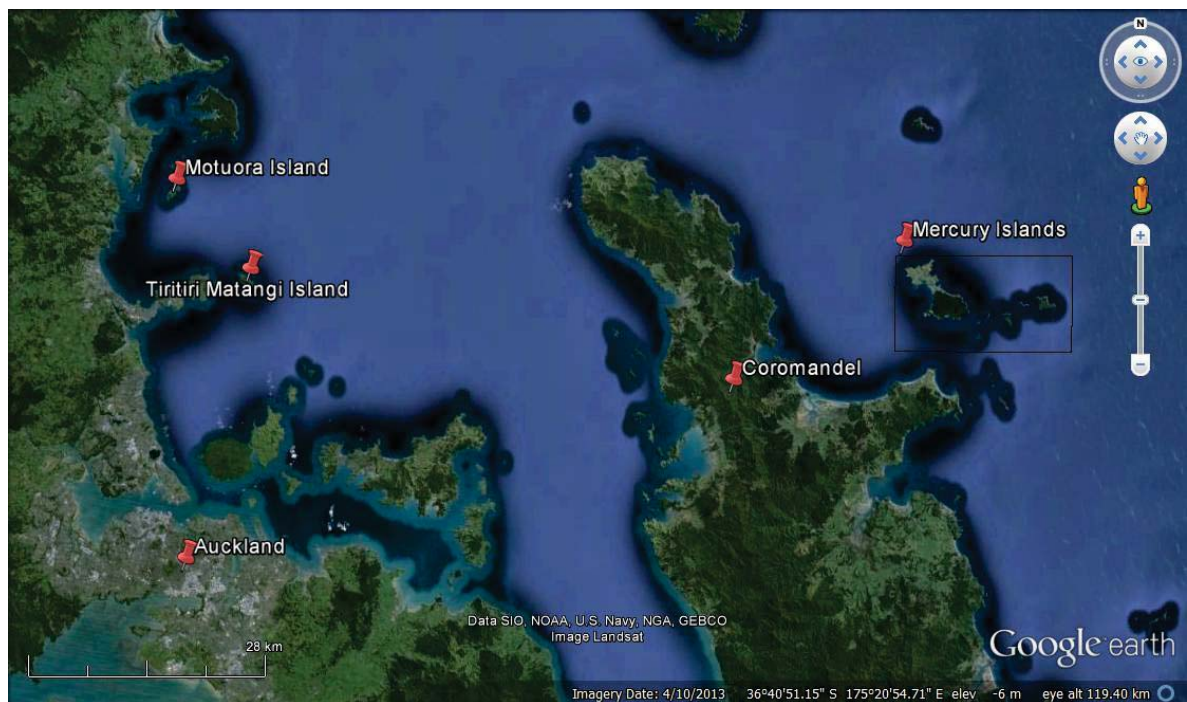
Figure 2.2. Satellite image of the Hauraki Gulf region showing the locations of Motuora Island, Tiritiri Matangi Island, and the Mercury Islands in relation to Auckland city and the Coromandel (Google Earth 2013a).

2.2.2   Tiritiri Matangi Island

Tiritiri Matangi Island (36"35'S, 174'53'E) (Figure 2.3) is situated in the Hauraki Gulf, 4 km east of Whangaparoa Peninsula (Figure 2.2). It measures 220 ha, is 2.7 km long, and relatively flat with gentle slopes reaching a maximum elevation of 91 m above sea level (Baber and Craig 2003a). The current vegetative cover consists of (excluding the coastline and beach) approximately 43% native grass and shrubs, 19% mature forest, 33% open native grasslands, 3% tracks and 2% farmland (Baber and Craig 2003a). The island was farmed extensively for 120 years until 1971, when it was retired for conservation purposes, and in 1987 was officially classified as a conservation island (Baber and Craig 2003a, b). By the time farming ceased, 94% of the native bush had been cleared (Dawson 1994). Efforts by volunteers during 1984 and 1994 resulted in the planting of up to 300,000 trees and the restoration of the island to its current vegetative state. The Pacific rat, which was the only

25

introduced mammalian predator to establish on the island, was successfully eradicated in 1993 (Galbraith and Cooper 2013). These initial restoration efforts were followed by the introduction of several threatened and endangered species, some of which are considered to have self-sustaining populations on the island (Baber and Craig 2003a). To date there have been fourteen successful translocations of native fauna, including primarily birds (e.g. hihi (*Notiomystis cincta*), brown teal (*Anas chlorotis*), North Island kokako (*Callaeas cinerea*), red-crowned parakeet (*Cyanoramphus novaezelandiae*), little spotted kiwi (*Apteryx owenii*), and South Island takahe (*Porphyrio hochstetteri*)), as well as a few reptiles (tuatara (*S. punctatus*), shore skink, *H. duvaucelii*) and invertebrates (wetapunga) (Galbraith and Cooper 2013). Restoration of the island is managed by DOC and the Supporters of Tiritiri Matangi (SOTM), a non-profit community group (Ortiz-Catedral and Brunton 2009, Galbraith and Cooper 2013). The island is currently classified as a scenic reserve (Galbraith and Cooper 2013).

Figure 2.3. Satellite image of Tiritiri Matangi Island as at 11/12/13 (Google Earth 2013c).

2.3   Research Framework

This study was conducted on two populations of *H. duvaucelii* translocated to Tiritiri Matangi and

Motuora Islands in late February to early March 2013 (see Barry 2014 for more information). In this

study, geckos were monitored from release until February/April 2014 using a variety of methods

including cell foam retreats (CFRs), radiotracking, funnel traps, and chance encounters. During this

time monitoring was conducted for both experimental purposes and as part of the overall PTM

programme. Data collected throughout the study was also collated with data collected by other

researchers in order to determine the success of the translocation, by gathering information on

survival, growth and reproduction.

2.3.1   Source of geckos

A total of 180 adult geckos were sourced from three separate locations, 60 wild captured from

Stanley Island, 60 wild captured from Korapuki Island, and another 60 captive individuals (Korapuki

Island origin) from the Massey University Reptile facility (Barry 2014). Adult and sub-adult geckos

were translocated (Snout to vent length (SVL) mean=117.4 mm, min=89 mm, max=136 mm, weight

mean=50.7 g, min=17.3 g, max=84.7 g) at a sex ratio of approximately 1:1. Gravid females were

chosen for translocation over non-gravid females to increase the size of the founding population. In

addition, two neonates were released on Tiritiri Matangi Island and four onto Motuora Island.

2.3.2   Release sites

Three release sites per island were chosen within regenerating coastal forest with sufficient food

availability and ground cover, and an average canopy height of at least 5.5 m. Sites were located

away from other ecologically sensitive areas (Barry 2013a, b), and grid perimeters were spaced at

least 50 m apart on Motuora Island, and 200 m apart on Tiritiri Matangi Island.

2.3.3   Monitoring grids

Monitoring grids were set up at all six 2013 release sites and the two 2006 release sites on Tiritiri Matangi and Motuora Islands. At the 2013 monitoring grids and the Tiritiri Matangi Island 2006 grid, 25 sampling points were positioned 15 m apart in a five by five grid layout (60 by 60 metre area) (Figure 2.4). Due to the location of the 2006 Motuora Island grid in a small confined area between two cliffs, only a 45 x 60 metre area could be utilised safely. Therefore only twenty sampling points were set out in a four by five grid layout. Locations of all sampling points within each grid were assigned unique identification codes and recorded using two Garmin handheld GPS devices (model types GPSMAP® 64 and 64s), with data stored in the Garmin Ltd. computer application 'BaseCamp'. At each sampling point, a double layered CFR (Figure 2.5) and tracking tunnel (Figure 2.6) were set up. Placement of CFRs followed a standardised set-up, with attachment to trees with a minimum trunk circumference of 20 cm at approximately chest height (140 cm). As suitable trees were not always within the vicinity of a sampling point, CFRs were occasionally placed on trees with multiple smaller trunks or those with a suitable trunk circumference at a lower height. CFRs were set-up facing the direction which allowed ease of access, and the lowest possible level of habitat disturbance. CRF's were installed at least two months before the first translocation date to allow the materials to weather and be inhabited by species already present in the surrounding area.

CFRs were made from pieces of black cell foam material (see Bell, 2009), each measuring 50 cm by 100 cm. Material was folded in half and attached to a tree at the fold using a piece of biodegradable rope. Two branchlets (diameter 2-3 cm) were placed between the CFR and the tree trunk to provide sufficient space for a large gecko to pass through. Once tied to the tree, a slit was cut down the middle of each layer to improve accessibility to both geckos and researchers. A piece of bungee cord with only enough tension to hold the skirts down was then wrapped around each structure. Tracking

tunnels were installed during May at the base of all trees with CFRs. Each tunnel was set with an

inked tracking card and fresh banana placed in a milk-bottle cap for containment.
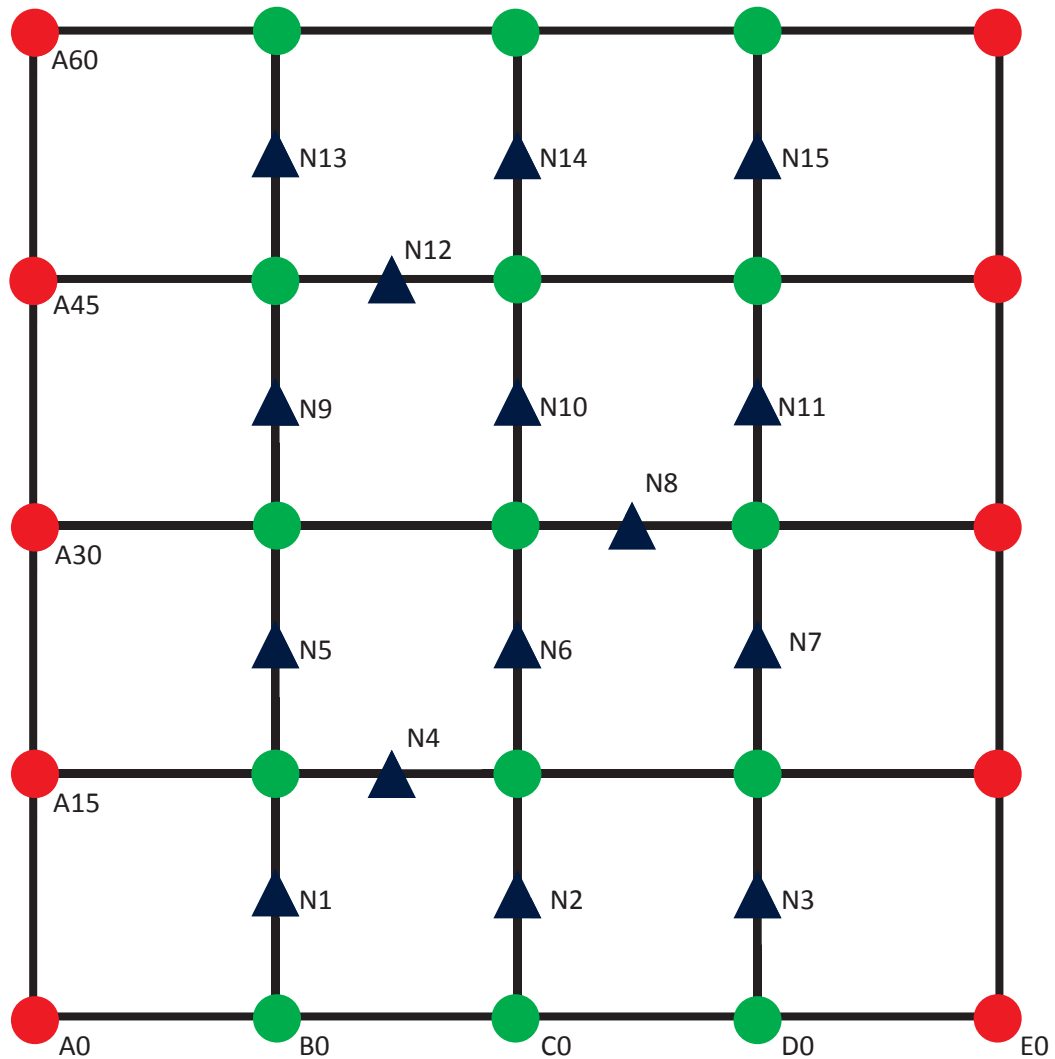
Figure 2.4. Layout of the Duvaucel's gecko monitoring grids including approximate locations of the 25 CFRs (15 release CFRs (green circles) and 10 non-release CFRs (red circles)) and 15 natural release sites (triangles). Note that the 2006 Motuora Island monitoring grid did not include the five sampling points positioned on the 60 metre transect. Note also that release positions do not apply to 2006 monitoring grids which were set up after the release of geckos onto those sites.

Slit cut in the middle of both layers for ease of access for geckos, and to make shelter checking faster (and therefore less disruptive) for monitoring

ACO closing mechanism made with plastic hooks (A) or knotted bungee (B), and held using cable ties (A and B)

Branchlets placed on either side of the central slit to create a gap large enough for a gecko to fit through. For ease of access by geckos, and to give the CFR a more 'natural' feeling.

Cell-foam material used for the CFR. Folded in half and tied to the tree with rope

Upper and inner skirts. Two layers provide a dry inner area for geckos to retreat into

Figure 2.5. Design and set-up of the double-layered CFRs used throughout this study. Each feature is described in a corresponding text box.

Figure 2.6. Setup of the tracking tunnels at each sampling point. Photos show a tracking tunnel at the base of a tree with a CFR attached, and a tracking card removed from a tunnel, with an empty bait cup and Duvaucel's gecko prints on the card.

2.3.4   Gecko release 2013

A total of 180 adult and sub-adult (and six neonate (juvenile)) geckos were released onto Tiritiri Matangi and Motuora Islands, 30 onto each of the six monitoring grids. Half of the geckos were released into CFRs and the other half in their plastic travel tubes placed within natural sites, such as flax or other dense vegetation (see Appendix A for more information on release anchoring treatments). Neonates were released along with their mothers. Due to a delay in the capture of geckos from Stanley Island, their release occurred approximately one week later than that of the captive and wild geckos of Korapuki origin. Release dates on Tiritiri Matangi Island were the 18th of February for Korapuki island geckos, and the 27th of February for Stanley Island geckos, and on Motuora Island were the 22nd of February for Korapuki Island geckos and the 1st of March for Stanley Island geckos. A mixture of captive and wild Korapuki Island geckos were released onto two out of three grids on each island, and wild Stanley Island geckos were released

31

onto the third grid on each island. Different cohorts (males, females, gravid females, and juveniles born pre-release) were spread as evenly as possible across the islands and grids, and size was also accounted for to ensure an even distribution of individuals of different ages.

Radio-transmitters were attached to 36 adult geckos two days before release. Transmitters were attached using a harness (backpack) design (Van Winkel and Ji 2014) (see Barry (2014) for a detailed description). The backpacks were attached only to males and non-gravid females weighing more than 46 g, as the combined weight of the harness and transmitter could not exceed 5% of the animal's body weight (Barry 2014). Prior to release, morphometric measurements and dorsal photographs were taken from each gecko and catalogued for future identification purposes. Each gecko was assigned a unique identification number, and this was marked on their ventral side using a black, non-toxic marker pen. Numbers were reapplied the day before release to allow quick identification upon recapture in the field. Detailed information on each of the released geckos, including their release location ID and release anchoring treatments are given in Appendix B.

2.4 *Hoplodactylus duvaucelii* Monitoring

2.4.1 CFR checks

Monitoring of CFRs began immediately following release (February/March) at the 2013 release sites and in April at the 2006 release sites. All grids were then monitored through to November 2013. Additional CFR checks were also conducted in February/April 2014 as part of the ongoing routine monitoring programme, and these data are also discussed throughout the thesis. Release locations were checked the day after release to assess the wellbeing of geckos, and to gather descriptive information on dispersal immediately following release. Geckos were not removed from CFRs or individually identified during this time. Due to time constraints, one grid (M4) was not checked on the first but the second day following release. CFRs on 2013 grids were

also checked at one and two weeks following release. However, due to the one week delay in release of Stanley Island geckos, only data from the first week was obtainable. By April, all eight grids were monitored, and were checked twice each over two consecutive days. From May until November 2013, CFRs were checked monthly using a 'three checks over five days' method (checked on days one, three and five of each monitoring week). The same method was utilised for the routine monitoring conducted in early 2014. Exact CFR check dates for each island and monitoring grid are given in Appendix C. CFRs were checked during daylight between the hours of 8:30am and 6:30pm, and at least all CFRs within the same grids were checked within the same day. Additional CFR checks were conducted outside of the scheduled monthly events due to the need to capture more geckos for radio-tracking purposes (for a parallel study). However, these data are not included in any analyses throughout this thesis.

2.4.2   Tracking tunnel checks

Tracking tunnels were checked from May until November 2013, and again in early 2014 as part of the ongoing routine population monitoring. Tunnels were set at the beginning of every monitoring week, and checked over the next five consecutive days. Tunnel checks were always conducted over the same five consecutive days that CFR checks were conducted to allow comparison of visitation rates. Banana bait was replaced when it had dried out, been taken, or alternatively after two days. Tracking cards were replaced when lizard prints were found (Figure 2.7), or where invertebrate prints or water damage made the cards unusable. Cards were always noted with the location (grid and sampling point ID), date of setting, and date of removal. Tunnels were left set at the end of every week to provide additional descriptive information of activity between monthly checks.

Figure 2.7. Two tracking cards showing Duvaucel's gecko footprints. (a) The original placement of the bait cap on the tracking card, with the food missing, and (b) a bait cap which has moved and the food was not taken.

2.4.3 Processing geckos

Whenever a gecko was encountered, it was immediately captured and checked for any temporary identification number, which were marked on the ventral side of the animal using xylene-free black or silver marker pens. When encountered in a CFR, the geckos horizontal (left, middle or right third) and depth (against the tree or between the skirts) position, as well as the CFR ID, were recorded. When located using radio-telemetry, chance encounters, or funnel trapping, capture location was recorded using a GPS. The gecko's age (adult or juvenile) and gender (adults only) were recorded. Multiple photographs of dorsal skin patterns were also taken for future identification purposes. Geckos were assigned temporary identification numbers (if not already present) and released back to their original locations. When multiple geckos were at the same location they were captured and held separately in cloth-bags under shaded vegetation while waiting to be processed. Handling times were recorded to ensure stress was kept to a minimal level.

Chapter 3 Testing two anchoring techniques to improve post-translocation monitoring of Duvaucel's geckos (*Hoplodactylus duvaucelii*)

3.1 Introduction

Effective post translocation monitoring (PTM) is essential for studying species ecology and behaviour, monitoring the progress of a translocated population, and consequently determining the reasons for translocation success or failure (Sherley et al. 2010, Nichols and Armstrong 2012, Seddon et al. 2012). However, translocation programmes often report difficulties in monitoring attributed to the movement of animals away from the release site, and consequent inability to re-capture or detect animals (Swaisgood 2010, Le Gouar et al. 2012). These difficulties can lead to a lack of information that is essential for effective PTM (survival, condition, breeding, dispersal and behaviour), which in turn leads to a reduced ability to improve monitoring techniques through adaptive management.

A solution to the issue of post-release dispersal is the use of techniques that anchor animals to a release site. For many bird and mammal species, anchoring techniques have included temporary or long-term food supplementation, provision of other important and lacking resources (e.g. habitat/vegetation, retreat sites, nests and burrows), soft versus hard releases, sound anchoring, and manipulations of individuals included in release groups, such as their gender, age, or size of groups (Le Gouar et al. 2012, Parker et al. 2012). However, little is known about the effectiveness of various anchoring techniques on lizards. A few studies have successfully used soft-releases (Tuberville et al. 2005, Alberts 2007, Knox and Monks 2014) and

food supplementation (Boutin 1990, Ebrahimi and Bull 2012) for anchoring various reptile species. Many New Zealand lizard species are also particularly difficult to monitor due to their cryptic and nocturnal behaviour.

Despite these issues with post-release dispersal in some species, there has so far been only one reported case of anchoring techniques being tested on New Zealand lizard species. This study involved the successful use of penning, a type of soft release strategy, to reduce post-release dispersal behaviour in jewelled geckos (Knox and Monks 2014). *H. duvaucelii* may travel large distances to forage or to find mates, and are also known to show high levels of post-release dispersal (Whitaker 1987, Jones 2000, van Winkel 2008). However, some individuals show strong site fidelity (Thompson et al. 1992), suggesting that the provision of sufficient resources could influence dispersal distances and site fidelity. Dispersal away from translocation release sites has in the past proved to be an issue for monitoring *H. duvaucelii* (Jones 2000) and is always a risk following any translocation event. Post-release dispersal may occur because animals move to find a more familiar habitat, to find a higher quality of habitat (food and shelter sites), or in search of conspecifics.

This study therefore tests the usefulness of two types of anchoring techniques aimed at reducing post-release dispersal and improving the general monitoring of *H. duvaucelii* following a translocation. The first anchoring technique involves temporary food provisioning at release sites, and the second involves the release of geckos into cell foam retreats (CFRs). Techniques were trialled on two populations of *H. duvaucelii* translocated to Tiritiri Matangi and Motuora Islands. It is predicted that overall these two anchoring techniques will help to improve the PTM of populations through an increase in CFR use, and a reduction in post-release dispersal behaviour. The specific objectives and hypotheses I will conduct throughout this chapter are given below. I will also consider the temporal variation in the effects of each anchoring treatment throughout each part of the study.

Objective 1) Test whether temporary food supplementation and CFR release increase CFR visitation rates

> *Hypothesis 1) Food treatment grids show higher CFR visitation rates compared to control grids (no food treatment)*

> *Hypothesis 2) Within food treatment grids, food treatment CFRs show higher CFR visitation rates compared to control CFRs (no food treatment)*

> *Hypothesis 3) Release treatment CFRs (gecko released into) show higher CFR visitation rates compared to control CFRs (no gecko released)*

> *Hypothesis 4) Temporary food supplementation results in an increase in CFR visitation rates at both a large (grid treatment) and small (individual CFR treatment) spatial scale*

> *Hypothesis 5) Temporary food supplementation and CFR release treatments result in an increase in CFR visitation rates in both the short and long term*

Objective 2) Test whether temporary food supplementation and CFR release increase CFR use by geckos

> *Hypothesis 1) Geckos released on food treatment grids show higher CFR use compared to those released on control grids (no food treatment)*

> *Hypothesis 2) Within food treatment grids, geckos released into food treatment CFRs show higher CFR use compared to those released into control CFRs (no food treatment)*

> *Hypothesis 3) Geckos released into CFRs show higher CFR use than those released at natural sites*

> *Hypothesis 4) Temporary food supplementation results in an increase in CFR use by geckos at both a large (grid treatment) and small (individual CFR treatment) spatial scale*

> *Hypothesis 5) Temporary food supplementation and CFR release treatment result in an increase in CFR use by geckos in both the short and long term*

Objective 3) Test whether CFR release and temporary food supplementation reduce post-release dispersal behaviour of geckos

Hypothesis 1) Geckos released on food treatment grids show reduced dispersal distances compared to those released on control grids (no food treatment)

Hypothesis 2) Within food treatment grids, geckos released into food treatment CFRs show reduced dispersal distances compared to those released into control CFRs (no food treatment)

Hypothesis 3) Geckos released into CFRs show reduced dispersal distances compared to those released at natural sites

Hypothesis 4) CFR release and temporary food supplementation result in a reduction in dispersal behaviour by geckos in both the short and long term

3.2 Methods

3.2.1 Anchoring treatments

3.2.1.1 *Release treatment*

H. duvaucelii were released onto monitoring grids as described in Chapter 2 (see section 2.3.4, 'Gecko release 2013'). Geckos released inside CFRs (90 geckos) were the release treatment gecko group, whereas those released at natural sites (90 geckos) were the release control gecko group. CFRs in which geckos were released (90 CFRs) were the release treatment CFR group, whereas those in which no gecko was released were the release control CFR group (60 CFRs).

3.2.1.2 *Temporary food supplementation treatment*

An energy-rich food supplement (banana) was provided weekly at the three treatment sites for a two month period following release. The allocation of treatment and control sites followed a randomised balanced design. This ensured that there was at least one treatment and one control site per island (to account for island effects) and at least one treatment and control site per gecko origin type (to account for differences between Stanley Island and Korapuki Island geckos). On treatment grids, food was supplied at every second CFR (twelve or thirteen per grid) by hanging a milk bottle cap from a wire, which was placed in the middle of the CFR under the outer layer. Mashed banana was chosen as the temporary food source as *H. duvaucelii* are known to feed on food with a high sugar content such as fruit and honeydew (Barwick 1982) and individuals in captivity readily take banana. A small amount of honey was added to the mashed banana to inhibit mould growth. When restocking each week any remaining mixture was removed.

Individuals of different cohorts (male/female, size, origin) were assigned evenly to each release anchoring treatment, then randomly assigned to an exact release location. Ninety geckos were

released onto three food treatment grids and another 90 onto three control grids. See Appendix

A for more information on the number of geckos within each treatment group.

3.2.2 Monitoring techniques

Geckos were monitored throughout the year using a variety of methods. When encountered,

geckos were processed using methods described in Chapter 2 (see section 2.4.3, 'Processing

geckos').

3.2.2.1 *CFR use*

CFR use by geckos was monitored using the methods described in Chapter 2 (see section 2.4.1,

'CFR checks').

3.2.2.2 *Radiotracking*

Radiotracking was conducted during the first two months following release to assess whether

gecko dispersal distances were affected by their release anchoring treatment. Transmitters were

attached to geckos before release using the methods described in Chapter 2 (see section 2.3.4

'Gecko release 2013'). Geckos were tracked following release at least once per week for two

months. Triangulation methods were used initially to pinpoint a gecko's location to within a five

metre radius. However, after a large number of transmitters were lost, methods were adjusted

to pinpoint locations to within a one metre radius, and visual confirmation was obtained

whenever possible. Positions were recorded using two Garmin handheld GPS devices (model

types GPSMAP® 64 and 64s) and general descriptions of the gecko's habitat were noted. Lost

transmitters were reattached to the next gecko encountered of sufficient size. A total of 46

individual geckos were fitted with radio-transmitters during the first two months following

release (see Appendix D for more information on the availability of GPS location data for each

gecko).

3.2.2.3 *Other capture techniques*

Geckos were often encountered and captured by chance throughout the study. These data were lumped into a category termed chance encounters. The majority of these finds occurred while either searching for lost transmitters by hand, or detecting a gecko's sudden movement when startled while sun-basking.

Funnel traps (Figure 3.1) were set during two scheduled mark-recapture events to capture both 2013 and 2006 release geckos for overall population monitoring purposes. The first event occurred on both islands in spring 2013. Trapping on Tiritiri Matangi Island occurred from the 10th to the 13th of October and used 106 traps (71 set at 2013 grids, 35 at the 2006 grid). Trapping on Motuora Island occurred from the 14th to the 17th of October and used 100 traps (20 at 2013 grids, 80 at the 2006 grid). The second trapping session occurred from the 25th to the 28th of February 2014 on Motuora Island, and from the 1st to the 4th of April 2014 on Tiritiri Matangi Island. A total of 100 traps were set on Motuora Island (75 at 2013 release grids, 25 at the 2006 grid) and 96 on Tiritiri Matangi Island (70 at 2013 grids, 26 at the 2006 grid). Captures of 2006 released geckos and their offspring are not included in this study. Traps were set either within monitoring grids or in surrounding areas in optimal gecko habitat (generally in large flax patches). Traps were set late in the day, left overnight and checked for geckos in the early morning over the next three consecutive days. The GPS location of each trap was recorded when set, and flagging tape placed nearby to make relocation easier. Each trap was set with a piece of fresh banana on a leaf to reduce the chance of being taken from outside of the trap.

Figure 3.1. An adult Duvaucel's gecko caught inside a funnel trap, and a typical set-up of a funnel trap.

3.2.3 Data analysis

IBM SPSS statistics version 21 computer software was used to perform all descriptive and statistical analyses. P-values of less than 0.05 (5% level) were considered to represent statistical significance for all analyses conducted throughout the study. Throughout the chapter, 'CFR visitation rates' refers to the number of times any given CFR, or group of CFRs, were used by Duvaucel's geckos. In comparison, 'CFR use' refers to the number of times any given gecko, or group or geckos, used any CFRs.

3.2.3.1 *Defining treatment and control groups*

I investigated CFR usage patterns and the effects of the anchoring treatments on CFR use and dispersal distances. Specifically, I used a balanced, hierarchical design to test the effects of gecko release treatment (CFR vs natural release) and temporary food supplementation (banana vs no banana provided) on CFR visitation rates (number of visits to CFRs per unit time) and CFR use by geckos (number of CFR uses per unit time). Additionally, I compared CFR use between 2013 translocated geckos and resident geckos at the 2006 release sites.

3.2.3.2 *CFR use patterns*

CFR use by juveniles was not considered in analyses of anchoring techniques as release anchoring treatments were not applied to this group. CFR visit data obtained within two days of release were not used in analyses of anchoring techniques to allow geckos time to leave CFRs and consequently avoid the use of biased data.

CFR use data were split into four sampling seasons. Season one included data from the first two months (end of February to April), season two from three to five months (June to August), season three from six to nine months (September to November), and season four from ten to fourteen months (December 2013 to March 2014) following release. Data were split in this way based on noticeable differences in gecko activity levels, and because the months were approximately corresponding to seasons. For some statistical analyses I pooled data from seasons two to four due to low CFR visitation rates.

The effects of the anchoring treatments on CFR usage by released adults was considered from two different angles. These were 1) the effects on CFR visitation rates, and 2) the effects on CFR use by geckos. To investigate the effects on CFR visitation rates, two response factors were considered. These were whether or not a CFR was used at least once during a sampling season (CFR used Yes/No), and the total number of times the CFR was used (CFR total visits). Instances where the CFR was used by multiple geckos on the same day, as well as where it was used by the same gecko on multiple days, were all included in the total visits calculations. CFR use by unidentified geckos was included in all of these analyses. To investigate the effects on CFR use by geckos, two response factors were also considered. These were whether or not a gecko used any CFR at least once during each sampling season (CFR used Yes/No), and the total number of times a gecko used a CFR (gecko total visits). Instances where the same CFR was used over multiple days was included in the total visits calculations. CFR use by unidentified geckos was excluded from these analyses.

3.2.3.2.1   Proportional comparisons

Presence/absence data (CFR visited at least once) were used to compare the proportion of visited CFRs between treatment and control groups. Presence/absence data were also used to compare the proportion of geckos from treatment and control groups that used CFRs at least once. I analysed data separately for each of the four sampling seasons. In addition, I also analysed a pooled data set covering the fourteen month sampling period. Proportions were compared using Mann-Whitney U tests, as data followed a non-normal distribution. The effects of grid food treatment, individual CFR food treatment, and release treatment were explored using these data.

3.2.3.2.2   Frequency comparisons

Due to the small sample size of the anchoring treatment group "CFR food treatment", effects on total visits were not explored in these comparative analyses. Only "grid food treatment" and "release treatment" were considered.

The short term effects (within two months following release) of anchoring treatments on CFR visitation rates and CFR use by geckos, were analysed using generalised linear models (GLMs). During the treatment period there was a large enough sample size to allow for these more sophisticated statistical analyses. However following the treatment period there was a lack of data, so post-treatment data was lumped together and only general trends could be explored using less sophisticated analyses. The long-term effects (from three to fourteen months following release) of anchoring treatments on CFR visitation rates, and CFR use by geckos were analysed using Mann-Whitney U-tests, as sample sizes were too small to justify the use of GLMs.

I used GLMs to analyse the short-term effects of release treatment and temporary food supplementation on CFR visitation rate (number of visits per CFR, per time unit) and CFR use by geckos (number of CFR visits per gecko, per time unit). This statistical test allowed the use of

nested models and data with a negative binomial distribution in the analysis (Quinn and Keough 2002). I used a likelihood ratio test with a profile likelihood confidence interval to account for the small sample sizes (Agresti 1996, Hosmer et al. 1997), and specified a negative binomial probability distribution with a log link function for all modelling. The overall suitability of the models was confirmed firstly by investigating the significance value of the likelihood ratio chi-square. I further explored the goodness of fit by producing residual plots, and ensuring the standardised deviance of residuals were sufficiently small (at least 95% of values fall within ±2, and almost all within ±3) (Field 2005). When a significant effect of both anchoring treatments was revealed using these analyses, I conducted Mann-Whitney U tests to investigate the effects of release treatment alone.

For the analysis of the effect of the anchoring treatments on CFR visitation rate, I used the two variables "grid food treatment (Yes/No)" and "release treatment (Yes/No)" as predictor variables in the GLM model. Given the hierarchical experimental design, "release treatment (Yes/No)" was nested within "grid food treatment (Yes/No)" for this analysis. For the analysis of the effects of the anchoring treatments on CFR use by geckos, I used the variables "release grid food treatment (treatment/control)" and "release treatment (CFR/control)" as predictor variables in the GLM model. "Release treatment (CFR/control)" was nested within "release grid food treatment (treatment/control)" for this analysis.

3.2.3.3 *Post release dispersal*

I investigated the effects of two anchoring techniques on post-release dispersal using GPS location data from three seasons. I focused my analysis on short-term dispersal (within the first two months following release, during summer/autumn) using the collected GPS telemetry data. I also considered long-term dispersal distances (at both eight months (spring) and twelve months (summer) following release) using GPS location data from CFR checks, funnel trapping

and chance encounters. Telemetry data from the first two months following release were divided into four 'time periods'. These were (A1) during week one, (A2) during week two, (A3) during weeks three and four, and (A4) during weeks five to eight. I recorded the greatest distance (maximum distance) a gecko had moved from its point of release during each of these four time periods. Maximum distances may have been exposed to bias due to the transmitters falling off geckos. However, it was assumed that any bias caused by this would be acting upon each treatment group equally, so this potential bias was not considered in any analyses. I analysed the maximum distance travelled during the first two months in relation to anchoring treatments (CFR versus natural release, food treatment CFR versus non-food treatment CFR release, and grid food treatment versus control grid release). I used the first location/capture point of a gecko in the analysis for months eight and twelve following release. The Garmin Ltd. computer application 'BaseCamp' was used to explore the GPS location data. I summarised dispersal distances firstly by calculating the 'point distances' travelled by each gecko, which I defined as the maximum straight line distance from the geckos exact translocation release point to the later recapture point. I also summarised the same data by categorising it into groups representing distance from the edge of the release grid (termed 'category distances'). These categories were (0) within the 60x60 m release grid, (1) within 20 m of the grid, (2) between 20 m and 60 m, and (3) more than 60 m.

I analysed both point distance and category distance data against release treatment, grid food treatment, and individual CFR food treatment. Due to few recaptures of geckos within the release grids throughout the study period, I combined distance category zero with category one for statistical analysis. Mean values (and their associated standard errors) were reported for point distances, and medians reported for category distances. Because the same individuals were repeatedly sampled over time, post-release dispersal distances (both point and category distances) during the first two months following release were analysed using generalised estimation equations (GEEs) (Liang and Zeger 1986). This allowed within-individual correlations

to be accounted for. The model for analysing point distance data used a gamma probability distribution and a log link function, with 'gecko ID' as a subject effect. The model for analysing category distance data used a multinomial probability distribution and a cumulative logit link function with 'gecko ID' as a subject effect. Post-release dispersal distances were analysed for both eight and twelve months following release using non-parametric (two-tailed) Mann-Whitney U-tests using both point and category distance data.

3.3 Results

A total of 26% (51/195) of CFRs were used by a total of 59 *H. duvaucelii* (40 adults and 17 juveniles released in 2013, and two resident geckos from 2006 grids) at least once during the entire fourteen month monitoring period. Geckos were encountered inside CFRs a total of 127 times. CFR use was highest immediately following release, and declined throughout the monitoring period. Seventeen 2013 born juveniles were encountered inside CFRs throughout the monitoring period. However, these geckos are excluded from analysis. Two geckos were encountered inside two different CFRs at the 2006 release sites, however these are also excluded from analysis. For more information on CFR use by *H. duvaucelii* see Chapter 4.

3.3.1 Effects of anchoring treatments on CFR use

3.3.1.1 *Effects of anchoring treatments on CFR visitation rates*

A higher number of CFRs within food treatment grids compared to those within control (no food) grids were used both at least once and more than once over the entire fourteen month sampling period (Appendix E). A much higher number of food treatment CFRs were used at least once during the first two months, and similar numbers were used from three to five months, six to nine months, and ten to fourteen months (Figure 3.2a).A higher percentage of food treatment CFRs compared to control (no food) CFRs (within food treatment grids only) were used at least once, but an equivalent percentage were used more than once over the entire fourteen month sampling period (Appendix E). A higher percentage of food treatment CFRs were used during the first two months, three to five months, and six to nine months, and a higher percentage of control CFRs were used from ten to fourteen months following release (Figure 3.2b). A higher percentage of CFRs where geckos were released into (treatment) compared to those where no gecko was released (control) were used both at least once and more than once over the entire fourteen month sampling period (Appendix E). A higher percentage of release treatment CFRs were used across all four seasons (Figure 3.2c).
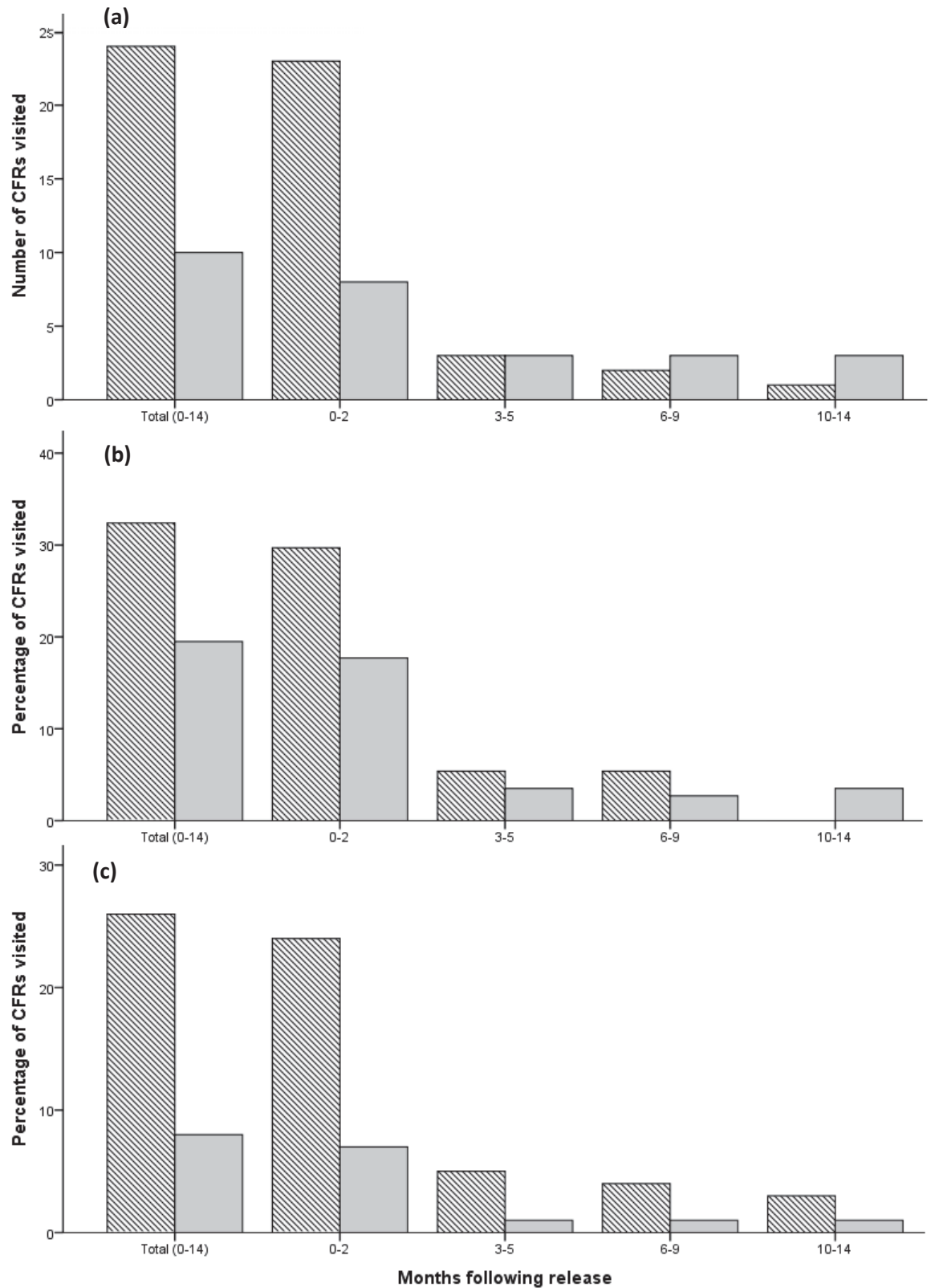
Figure 3.2. The number or percentage of treatment and control CFRs that were used at least once over the fourteen month sampling period, and during each of the four separate 'seasons' following release. (a) Number of CFRs visited on food treatment grids (dashed bars) and control grids (solid bars), (b) percentage of food treatment CFRs (dashed bars) and control CFRs (solid bars) visited, and (c) percentage of release treatment (dashed bars) and control (solid bars) CFRs visited.

Short-term effects of anchoring treatments on CFR visitation rates

There was no difference in the mean number of visits to grid food treatment CFRs compared to control CFRs during the first two months following release (Appendix F). There was also no difference in the mean number of visits to CFRs that geckos were released into compared to those that geckos were not released into during the first two months following release (Appendix F).

The goodness of fit chi-square test confirmed that the model containing both the 'grid food' and 'gecko release' treatment factors was a good fit to the data (p=1.227). The overall model was a significant predictor for the total number of CFR visits (X^2=15.127, df=3, p=0.002). Grid food treatment alone was a significant predictor of total CFR visits (X^2=10.905, df=1, p=0.001) as was release treatment nested within grid food release (X^2=6.636, df=2, p=0.036) (Appendix G). The calculated odds ratios show that CFR use was 10.0 times more likely on food treatment grids than control grids (Appendix H). Within food treatment grids, CFR use was 1.6 times more likely in the release treatment group than control group, and within food control grids CFR use was 7.3 times more likely in the treatment group than control group (Appendix H).

A separate Mann-Whitney U-test revealed a significant effect of release treatment alone on the number of CFR visits during the first two months following release. Release treatment CFRs had a higher number of visits than control CFRs during the first two months following release (the mean ranks of control and treatment CFRs were 68.79 and 79.97 respectively, U=2297.5, z=-2.189, p=0.031).

Long-term effects of anchoring treatments on CFR visitation rates

There was no difference in the mean number of visits to CFRs on food treatment grids compared to those on control grids within three to fourteen months following release (Appendix F). A Mann-Whitney U test, revealed that there was no significant effect of food grid treatment on

the number of CFR visits during this time (the mean ranks of control and treatment CFRs were 75.58 and 75.42 respectively, U=2806.5, z=-0.052, p=0.798). There was also no difference in the mean number of visits to CFRs that geckos were released into compared to those that geckos were not released into within three to fourteen months following release (Appendix F). However, a Mann-Whitney U test revealed that there was no significant effect of release of a gecko into a CFR on the number of CFR visits during this time (the mean ranks of control and treatment CFRs were 74.13 and 76.42 respectively, U=2617.5, z=-0.732, p=0.348).

3.3.1.2 *Effects of anchoring treatments on CFR use by geckos*

A higher number of geckos released on food treatment grids (treatment) compared to those released on non-food treatment grids (control) used CFRs both at least once and more than once over the entire fourteen month sampling period (Appendix I). There was a larger number of treatment geckos that used CFRs during the first two months following release, equal numbers from three to five and six to nine months, and more control geckos from ten to fourteen months (Figure 3.3a). A higher percentage of geckos released in food treatment CFRs (treatment) compared to those released in non-food treatment CFRs (control) used CFRs both at least once and more than once over the entire fourteen month sampling period (Appendix I). There was a higher percentage of treatment geckos that used CFRs within two months following release, slightly higher percentages from three to five and six to nine months, and slightly lower from ten to fourteen months (Figure 3.3b). A higher number of geckos released into CFRs (treatment) compared to those released at natural sites (control) used CFRs both at least once and more than once over the entire fourteen month sampling period (Appendix I). There was a higher number of treatment geckos that used CFRs within two months following release, slightly more from three to five months, and the same numbers from six to nine and ten to fourteen months (Figure 3.3c).
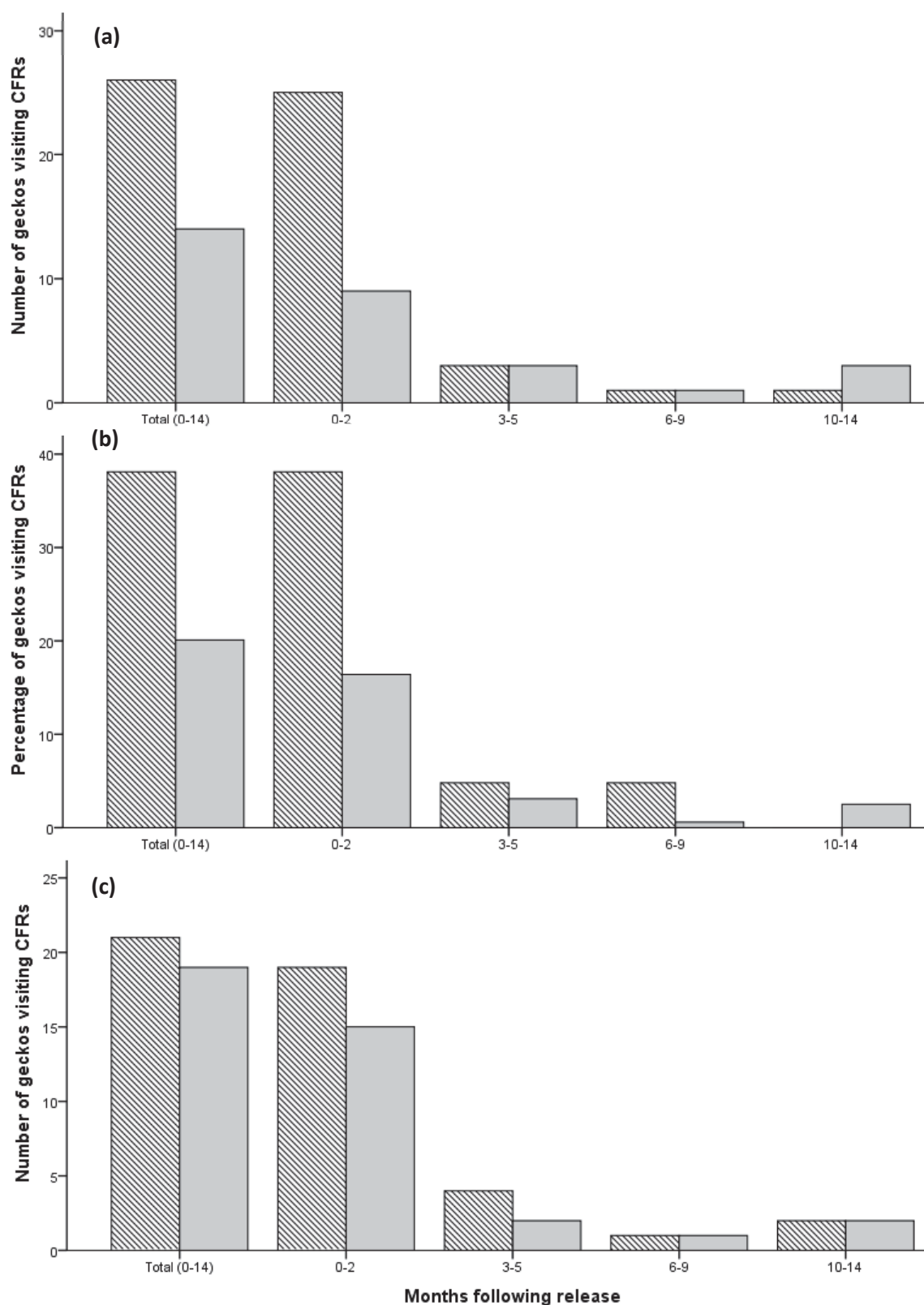
Figure 3.3. The number or percentage of treatment and control geckos that used CFRs at least once over the fourteen month sampling period, and during each of the four separate 'seasons' following release. (a) Number of geckos released on food treatment grids (dashed bars) and control grids (solid bars) visiting CFRs, (b) percentage of geckos released in food treatment CFRs (dashed bars) and control CFRs (solid bars) (on treatment grids only) visiting CFRs, and (c) number of geckos released inside CFRs (dashed bars) and released at natural sites (solid bars) visiting CFRs.

Short-term effects of anchoring treatments on CFR use by geckos

There was no difference in the mean number of visits to CFRs by geckos released on grid food treatment grids, compared to those released on control grids, during the first two months following release (Appendix J). There was also no difference in the mean number of visits to CFRs by geckos released inside CFRs, compared to those released naturally, during the first two months following release. (Appendix J). The goodness of fit chi-square test revealed that the overall model containing both the grid food treatment and release treatment factors was a good fit to the data (p=0.001). The overall model was a significant predictor for the total number of CFR visits by a released gecko (X^2=8.801, df=3, p=0.032). Release grid food treatment alone was a significant predictor of total CFR visits by a gecko (X^2=7.869, df=1, p=0.005) (Appendix G). However, release treatment nested within grid food treatment was not significant (X^2=0.684, df=2, p=0.710) (Appendix G). The calculated odds ratios show that there was 2.2 times more CFR use by geckos released on food treatment grids than control grids (Appendix H).

Long-term effects of anchoring treatments on CFR use by geckos

There was no difference in the mean number of CFR visits by geckos released on grid food treatment grids, compared to those released on control grids, from three to fourteen months following release (Appendix J). A Mann-Whitney U test revealed no significant effect of release grid food treatment on the number of CFR visits by a gecko during this time (the mean ranks of control and treatment group geckos were 91.00 and 90.00 respectively, U=4005.0, z=-0.310, p=0.789). There was also no difference in the mean number of visits to CFRs by geckos released inside CFRs, compared to those released naturally, from three to fourteen months following release (Appendix J). A Mann-Whitney U test revealed no significant effect of CFR release on the total number of CFR visits by a gecko (the mean ranks of control and treatment CFRs were 89.94 and 91.06 respectively, U=4000.0, z=-0.345, p=0.662).

3.3.2   Effects of anchoring treatments on dispersal distances

Maximum point distances travelled differed markedly between seasons (Table 3.1). Mean distances travelled increased overall throughout the first two months following release (Table 3.1). However, 95% confidence intervals for the mean show that only the first week following release had lower dispersal distances than all other time periods and seasons (Table 3.1).

Table 3.1.Maximum point distance (m) travelled by geckos during each season.

Time Following Release	N	Mean (SE)	95% CI Mean		Min	Max	Range
			Lower	Upper			
Week 1	36	32.8 (4.2)	24.2	41.5	0	91	91
Week 2	25	73.1 (11.0)	50.3	95.8	7	223	216
Weeks 3-4	20	74.3 (13.3)	46.5	102.0	0	210	210
Weeks 5-8	14	101.4 (22.8)	52.0	150.7	24	256	232
8 months	19	85.7 (22.7)	38.0	133.4	10	316	306
12 months	36	67.8 (9.7)	48.1	87.4	7	294	287

Effects of anchoring treatments on short-term dispersal

A larger number of geckos released within food treatment grids (treatment) in comparison to those released within non-food treatment grids (control), were located during all four time periods within the two months following release (Appendix K). During week one following release, median category distances were approximately equal for geckos from treatment (0 m) and control (0.5 m) grids, during week two and weeks five to eight, distances were higher for control geckos (week 2 T=1 m, C=2.5 m, weeks 5-8 T=1 m, C=2 m), and during weeks three to four distances were higher for treatment geckos (T=2.0, C=1.5). Mean dispersal distances were no different for treatment and control geckos during any of the four time periods following

release (Appendix L). The GEE revealed no significant effect of grid food treatment on dispersal distances during any of the four time periods within two months following release for either point distances (Wald X^2= 0.001, df=1, p= 0.970) or category distances (Wald X^2= 0.828, df=1, p= 0.363) (Appendix M).

Median category distances were equal during week one (T=1.0, C=1.0), and lower during all three time periods from weeks two to eight (week 2 T=1.0, C= 2.0, weeks 3-4 T=1.5, C=2.0, weeks 5-8 T=1.0, C=2.0), for the geckos released inside food treatment CFRs (treatment), compared to geckos released inside non-food treatments CFRs (control). Mean dispersal distances were no different for treatment and control geckos during any of the four time periods following release (Appendix N). The GEE revealed no significant effect of CFR food treatment on dispersal distances during any of the four time periods within two months following release for either point distances (Wald X^2= 1.869, df=1, p= 0.172) or category distances (Wald X^2= 0.491, df=1, p= 0.483) (Appendix M).

Median category distances were equal for geckos released inside CFRs (treatment) and geckos released at natural sites (control) during week one (T=1.0, C=1.0), lower for treatment geckos during the two time periods from weeks two to four (week 2 T=1.0, C=2.0, weeks 3-4 T=1.5, C=2.0), and higher for treatment geckos during week's five to eight (T=2.0, C=1.0). Mean dispersal distances were no different for treatment and control geckos during any of the four time periods following release (Appendix O). The GEE revealed no significant effect of release treatment on dispersal distances during any of the four time periods within two months following release for either point distances (Wald X^2= 0.568, df=1, p= 0.451) or category distances (Wald X^2= 0.116, df=1, p=0.734) (Appendix M).

Effects of anchoring treatments on long-term dispersal

Less geckos released on food treatment grids (treatment) compared to those released on non-food treatment grids (control) were located at both eight and twelve months following release (Appendix K). The percentage of geckos within each of the four distance categories was similar for the control and treatment groups (Appendix K). The median category distance for eight and twelve months following release was equal for treatment and control geckos (eight months T=1.0, C=1.0, twelve months T= 2.0, C=2.0). Mean dispersal distances were no different for treatment and control geckos at either eight or twelve months following release (Appendix L). The Mann-Whitney U-tests revealed no significant effect of grid treatment at eight months following release on either point distance (mean ranks of control and treatment geckos were 10.18 and 9.75 respectively, U=42, z=-0.166, p=0.888) or category distance (mean ranks of control and treatment geckos were 9.91 and 10.13 respectively, U=43, z=-0.091 p=1.000), nor at twelve months following release for either point distance (mean ranks of control and treatment geckos were 18.30 and 18.75 respectively, U=156, z=-0.127, p=0.906) or category distance (mean ranks of control and treatment geckos were 18.20 and 18.88 respectively, U=154, z=-0.205, p=0.881) (Appendix Q).

Median category distances were lower for geckos released inside food treatment CFRs (treatment) compared to those released in non-food treatment CFRs (control) at eight months (median T=1.0, C=2.0), and did not differ at twelve months following release (median T=2.0, C=2.0). Mean dispersal distances were no different for treatment and control geckos at either eight or twelve months following release (Appendix N). However, the Mann-Whitney U-tests revealed no significant effect of CFR food treatment at eight months on either point distance (mean ranks of control and treatment geckos were 10.50 and 5.75 respectively, U=8.5, z=-1.132, p=0.298) or category distance (mean ranks of control and treatment geckos were 10.53 and 5.50 respectively, U=8, z=-1.313 p=0.439), nor at twelve months for either point distance (mean ranks

of control and treatment geckos were 17.92 and 23.13 respectively, U=45.5, z=-0.932, p=0.373) or category distance (mean ranks of control and treatment geckos were 18.13 and 21.50 respectively, U=52.0, z=-0.650, p=0.688) (Appendix Q).

Median category distances were higher for geckos released inside CFRs (treatment) compared to geckos released at natural sites (control) at both eight (T=1.5, C=1.0) and twelve months (T=2.0, C=1.0) following release. Mean dispersal distances were no different for treatment and control geckos at either eight or twelve months following release (Appendix O). However, the Mann-Whitney U-tests revealed no significant effect of release treatment at eight months on either point distance (mean ranks of control and treatment geckos were 10.17 and 9.85 respectively, U=43.5, z=-0.123, p=0.920) or category distance (mean ranks of control and treatment geckos were 9.61 and 10.35 respectively, U=41.5, z=-0.314 p=0.880), nor at twelve months for either point distance (mean ranks of control and treatment geckos were 20.74 and 15.37 respectively, U=110.5, z=-1.509, p=0.135) or category distance (mean ranks of control and treatment geckos were 15.43 and 20.69 respectively, U=111.5, z=-1.587, p=0.123) (Appendix Q).

3.4 Discussion

3.4.1 Effectiveness of anchoring techniques for increasing CFR use

Overall, 59 *H. duvaucelii* used CFRs, and 51 out of 195 CFRs were used throughout the fourteen months of monitoring. A total of 57 out of 218 2013 released *H. duvaucelii* (40 adults and 17 juveniles) used a total of 49 CFRs from 2013 release grids, as well as two resident adult geckos which used two CFRs on the 2006 monitoring grids.

Effects of temporary food supplementation on CFR visitation rates and CFR use by geckos

Temporary food supplementation encouraged geckos to use CFRs within treatment grids more during the first two months following release. Geckos released onto grids where food was provided may have been more inclined to remain within the area due to the benefits of the high quality food resource, and the attraction to the scent of the banana. However, as geckos released onto treatment grids did not use CFRs any more than those released onto control grids, it is also likely that geckos released onto control grids were also attracted to the treatment grids. Providing food at individual CFRs appeared to have an effect on the visitation rates to treatment CFRs, as well as the use of CFRs by treatment geckos. However, as sample sizes were too small to analyse the trends statistically, further research is required to confirm the effects of temporary food treatment at the individual CFR level on CFR use.

Food supplementation can influence reptile populations in a variety of ways, including reducing home range size, and increasing home range overlap, adult and juvenile body weight, growth rate, adult and juvenile survival, immigration to the site, and productivity (Boutin 1990). Ebrahimi and Bull (2012) found that when food was provided at their release burrows, pygmy bluetongue lizards were more likely to remain within them, spent less time exposed outside, and were less likely to move out of the general release area. This evidence provides support for

my finding that temporary food provisioning resulted in an increase in CFR use by *H. duvaucelii* in the first two months following release.

The effects of temporary food supplementation were not lasting, as no effect was found after two months following release. This is likely due to the limited timeframe the treatment was applied for. As food was only provided during the first two months following release, the attraction of geckos to those CFRs and entire monitoring grids was likely to have reduced, consequently leading to CFRs not being visited as often by geckos. Once the food was no longer provided, geckos may have also moved away from monitoring grids in search of other high quality food sources. Ebrahimi and Bull (2012) also found the benefits of food supplementation to only exist whilst the treatment was applied. They found that when treatment was applied, activity and dispersal levels were reduced, and when removed the opposite trends occurred. Very little other work exists on the use of food supplementation for translocated reptile populations, and more research is required to support the results of this study.

It is also possible that the densities of prey items inside CFRs affected the use of supplementary food by geckos. Average invertebrate densities inside CFRs were at their lowest immediately following the gecko's release, and increased rapidly from May onwards (see Chapter 5). Therefore it is possible that following the two month food treatment period (late February to late April) geckos were no longer attracted to CFRs that used to contain the food, as there were sufficient prey densities in other locations.

Most other studies that have manipulated food supply to populations have done so due to a perceived lack of resources at study sites (Boutin 1990). In this study this may not have been the case, as pre-release surveys found that there were sufficient food sources at release sites (Barry 2014), and densities of invertebrates encountered inside CFRs throughout this study were also generally high (see Chapter 5). Therefore it is possible that the temporary food provisioning treatment did not have a long-lasting effect due to the availability of alternative food sources at

release sites. Geckos may not have been sufficiently encouraged to remain within the release sites, and therefore dispersed away in search of other important resources such as natural retreat sites or conspecifics.

Effects of release treatment on CFR visitation rates and CFR use by geckos

Release treatment resulted in an increase in CFR visitation during the first two months following release. Also, 2013 release sites where geckos were released into many of the CFRs, in comparison to 2006 sites where no geckos were released into CFRs, had much higher levels of CFR visitation, and visitation continued throughout the monitoring period (see Chapter 4). One reason for this may be the attraction of geckos to CFRs containing the scent of previous inhabitants. Reptiles are known to rely heavily on chemical senses (Martín and López 2011), and experiments have found that chemical cues are important for territoriality, mate choice, reproductive decisions, and intrasexual aggression between males (Martín and López 2011). Scent communication is known to occur in *H. duvaucelii*, and evidence suggests that they also exhibit marking behaviour (Barry 2010). Some reptile species, including *H. duvaucelii*, also use scent to differentiate between genders (Barry 2010), ages (Martín and López 2013), familiar and unfamiliar individuals (Kondo et al. 2007, Carazo et al. 2008), or even related individuals (Léna et al. 2000, Galliard et al. 2003). Therefore scent attraction could be the main reason why geckos used release CFRs more than non-release, and why geckos from 2013 grids used CFRs more than those on 2006 grids. Scent attraction experiments should be conducted in the field to gain a better understanding of this behaviour in wild populations of *H. duvaucelii*.

Another reason that release CFRs may have been used more is because of their location. All of the release CFRs were concentrated between the three central transects, which is also where all of the geckos (including those not released into CFRs) were released within each grid. Visitation rates to release CFRs may have been higher, because higher densities of geckos were initially present within their proximity, and therefore had a higher probability of being used. However,

as radiotracking data show that many geckos dispersed significant distances away from their release sites immediately following their release, I believe that this is probably not the main reason why release CFRs were used more. The overall translocation project used as the base for this study required that geckos be released far enough apart as to not encourage dispersal away from conspecifics, but close enough together as to provide opportunity for geckos to encounter each other in the future. Therefore it was not possible to ensure that release and non-release CFRs were randomly distributed in this study. To account for this potentially influential factor in future studies, release and non-release CFRs should be separated into different 'treatment' (all geckos released inside all CFRs) and 'control' (no geckos released inside CFRs) grids. Because several aspects were being tested (food supplementation, CFR release, use of CFRs as monitoring tools), as well as the limitations of release sites and animals, it was not possible to use this experimental layout in this study.

CFR release only had an effect on CFR visitation rates within the first two months following release. Visitation rates in general declined after two months following release, as geckos most likely had settled and found suitable natural shelters. The lack of an effect of release treatment may also be due to the scent contained within the CFRs beginning to fade or being washed away over time, leading to a reduction in the attractiveness of those CFRs and therefore lower levels of visitation. It may also be due to the smaller sample sizes encountered following the initial two month period, therefore leading to significant effects being missed. However, as CFR use generally decreased with increasing time since release (see Chapter 4) large sample sizes were not obtainable in this study. In order to confirm that release treatment has no significant effect on CFR use after two months following release, future studies should aim to include larger sample sizes in analyses.

There was no noticeable effect of release treatment on the use of CFRs by treatment geckos at any stage following release. Geckos were released early in the day to allow as much time as

possible for them to naturally acclimatise to the CFRs before becoming active at night. However, as their release treatment appears to have had no effect on their likelihood of using CFRs again, a longer period of time may be required to allow geckos to become accustomed to the CFRs and to use them again in the future. Despite the lack of difference in CFR use by treatment (those released inside CFRs) and control (those released naturally) geckos, there is some evidence that release treatment had an effect of the CFR use. For example, the fact that non-release CFRs were used by geckos at all, and that geckos that were released naturally also used CFRs regularly, suggests that geckos may have learned to recognise, and therefore use CFRs. However, due to the nature of the experimental design (i.e. no separate control and treatment CFR release grids), the effect is not measurable in this study. Geckos from 2013 release sites (where half the geckos were released into CFRs) used CFRs much more, and continued to use them throughout the monitoring period, whereas geckos from 2006 sites (where no geckos were released into CFRs) very rarely used them at all (see Chapter 4). This also provides evidence that release treatment does have some effect on CFR use. Further research is therefore required to investigate the effects of release treatment on CFR use by translocated *H. duvaucelii*. Future research should separate release treatments into separate grids to better isolate the effects of release treatment on geckos.

Relationships between grid food treatment and release treatment on CFR visitation rates and use of CFRs by geckos

The model including the effects of both grid food treatment and release treatment on visitation to individual CFRs during the first two months following release showed firstly that CFRs on food treatment grids had 10.0 times higher visitation rates than those on control grids. The model also showed that within food treatment grids, release CFRs had 1.6 times higher visitation than non-release, and within non-food treatment grids, release CFRs had 7.3 times higher visitation. These results suggest that food treatment had a much larger effect on CFR visitation rates than

release treatment, and also that the effects of release treatment are more evident when food treatment is not applied. The results also show that both anchoring treatments together increase the level of visitation to CFRs, as well as each anchoring treatment separately. These results have important implications for future translocation events, as they show that either of the treatments are able to increase the use of CFRs within the first two months and therefore also our monitoring ability of *H. duvaucelii* during this time. They also show that a combination of the two treatments is the most beneficial for increasing CFR use.

The model including the effects of both grid food treatment and release treatment on CFR use by individual geckos during the first two months following release showed firstly that geckos released onto grid food treatment grids showed 2.2 times more CFR visitation than those released on control grids. However, release treatment was not found to significantly affect CFR visitation rates by geckos (discussed earlier). This suggests that temporary food supplementation has a stronger effect that release treatment on CFR use by geckos.

3.4.2   Effectiveness of anchoring techniques for reducing post-release dispersal

Mean dispersal distances by *H. duvaucelii* increased gradually throughout the first two months following release, which is comparable to results from other studies on this species (Jones 2000, van Winkel 2008)*.* Distances were then stable at both eight months and twelve months following release, as geckos are expected to have become established and were therefore no longer dispersing large distances during these times. None of the anchoring treatments were found to effect dispersal distances in either the short-term (during the first two months following release) or long-term (at eight and twelve months following release). Anchoring treatments also had no effect during any of the four fine scale time periods during the first two months following release. Only a subset of geckos could be monitored due to the limitations of radiotransmitter attachment and the cryptic nature of the species. Future studies should therefore aim to

monitor a larger number of geckos to better determine the effects of anchoring treatments on dispersal behaviour.

Providing food at release sites has been found to affect dispersal patterns in other reptile populations (Boutin 1990, Ebrahimi and Bull 2012). However, it was not found to have any effect during this study. This may be because the food that was provided was not enough of an attractant to encourage geckos to remain within the release area. Artificial retreats have been provided to other translocated populations of reptiles, and varying effects on dispersal and population establishment have also been found. For example, Grand Cayman iguanas (*Cyclura lewisi*) provided with artificial retreats were successfully encouraged to settle in the chosen areas (Alberts 2007). However, the provision of artificial nest sites had varying levels of success with other iguana species (Cayot et al. 1994, Hayes et al. 2004). This supports our finding that release inside artificial retreats has no effect on post-release dispersal behaviour.

3.5 Conclusions

Forty adult and seventeen juvenile 2013 geckos used CFRs, as well as two adult 2006 released, resident geckos. Both of the anchoring treatments had an effect on CFR visitation during the first two months following release, but had very little or no lasting effects. The lack of any lasting effects is likely due to the settlement of geckos at natural shelter sites, the gradual loss of the scent provided by geckos at their release locations, and the discontinuation of the food treatment following the two month period. Although release treatment did not result in an increase in CFR use by geckos released inside CFRs, evidence suggests that release treatment does have an effect. However, further research is required to confirm this. Grid food treatment had a stronger impact on CFR visitation rates than the release treatment, and the effect of the release treatment was stronger when the grid food treatment was not applied. All of these results show that the two anchoring treatments were able to increase CFR use by geckos following a translocation. However, they also show that this increase is not continued in the long-term. Each of the anchoring treatments did not have any effect on reducing the post-release dispersal distances of *H. duvaucelii* in either the short or long-term. In conclusion, temporary food supplementation and CFR release are useful techniques for improving our PTM ability of *H. duvaucelii* through an increase in CFR visitation rates, but do not appear to result in a reduction in post-release dispersal.

Chapter 4   Effectiveness of double-layered cell foam retreats as post-translocation monitoring tools for Duvaucel's geckos *(Hoplodactylus duvaucelii)*

4.1 Introduction

Post translocation monitoring (PTM) is an essential part of any translocation effort, and is required to gain information on the success of an event. Effective PTM techniques require the collection of information on survival, condition, breeding, dispersal and behaviour of both the founding individuals and their progeny (Seddon et al. 2012). Determining success can also require long-term monitoring for some long-lived and slowly reproducing species (Towns and Ferreira 2001). Therefore, effective monitoring techniques need to show longevity, and be easily repeatable over time.

Various methods currently exist for monitoring reptile species in New Zealand (DOC 2012). Many widely used techniques are not always suitable for effective monitoring of arboreal forest geckos, many of which are highly cryptic, nocturnal and are found in low densities. *H. duvaucelii* are a species of large, nocturnal, highly cryptic, long-lived and slowly reproducing lizard endemic to New Zealand (Barwick 1982). The combination of these factors makes them highly difficult to detect and monitor. *H. duvaucelii* currently have a restricted distribution, and are being conserved primarily through the monitoring of existing populations and through translocations to predator-free offshore islands. Conservation of the species therefore requires a technique able to both detect and monitor the species at low densities, and that is suitable for long-term

monitoring studies. Techniques currently utilised for monitoring *H. duvaucelii* include radiotracking, live trapping, footprint tracking, and systematic searching. However, many of these methods produce a low detection rate, limited information, and/or require high cost and time commitments.

Artificial retreats have been used in the past to monitor *H. duvaucelii* and have had varying results with different designs and populations monitored (van Winkel 2008, Bell 2009). Various designs of small, tree mounted artificial retreats were trialled for PTM of two populations of *H. duvaucelii* (van Winkel 2008). However, they showed very low levels of detection (van Winkel 2008). Simple, single layered cell foam retreats (CFRs) were designed and trialled on one existing population of *H. duvaucelii,* and were highly effective at monitoring the high density population (Bell 2009). The same CFRs were also able to successfully detect low-density populations of two other species of arboreal forest gecko (Bell 2009). Similar types of artificial retreats have yet to be trialled for use in monitoring any low-density populations of *H. duvaucelii,* or for the PTM of the species.

In this study, CFRs are trialled for monitoring two populations of geckos translocated to Tiritiri Matangi and Motuora Islands in early 2013. The main objective of this study is to trial the usefulness of a more complex, double-layered CFR for the PTM of *H. duvaucelii*. A double-layered design was chosen over the simple single layered design used by Bell (2009) for three main reasons. Firstly, the attachment method of the double-layered design is less invasive (tying around the trunk versus nails). Secondly, the additional layer provides geckos with a larger area. Finally, the two skirts likely provide more variation in microhabitat, in particular a drier space between the two skirts. I will also investigate the spatial and temporal variation in CFR use, and attempt to identify which environmental factors contribute to this variation. My specific research questions, and consequent investigations or comparative tests I will conduct, are outlined below.

Objective 1) Are CFRs generally useful for the long-term, PTM of *H. duvaucelii*?

- *Report the ease of capture of geckos encountered inside CFRs*

- *Report the use of CFRs by different cohorts*

- *Compare the level of CFR use between males and females, gravid and non-gravid females, and adults and juveniles*

- *Report the length of time geckos continue to use CFRs for following release*

Objective 2) Are CFRs useful for monitoring low-density, resident populations of *H. duvaucelii*?

- *Report the use of CFRs by geckos found on 2006 release grids*

Objective 3) Is the double-layered design of the CFR beneficial for the monitoring of *H. duvaucelii*?

- *Report and compare the proportional use of the different CFR layers by H. duvaucelii*

Objective 4) Does CFR use vary with season or time since release?

- *Compare CFR visitation rates of all geckos, adults only, and juveniles only, within 2 months, 3-5 months, 6-9 months, and 10-14 months following release*

Objective 5) Does CFR visitation show spatial variation?

- *Compare visitation rates to CFRs across islands, grids, and individual CFRs*

Objective 6) Can the spatial variation in CFR use be explained by any microhabitat or environmental factors?

Objective 7) Is the spatial variation in CFR use explained by the same factors that explain the variation in tracking tunnel visitation?

- *Compare individual CFR visitation rates to the CFR microhabitat, surrounding vegetation and proximity to flax*

- *Compare tracking tunnel visitation rates to the CFR microhabitat, surrounding vegetation and proximity to flax*

> • *Compare the factors that affect CFR visitation rates to those that affect tracking tunnel*
>
>   *visitation*

Objective 8) Do the two CFR layers differ in their microclimate?

> • *Compare the temperature and humidity of the two CFR layers*

Objective 9) Do CFRs show a high level of functional integrity throughout the long-term

monitoring of *H. duvaucelii*?

> • *Investigate the length of time CFRs remain functional for*

4.2 Methods

All data used in this chapter, including observations, were obtained from the CFR check sessions conducted from February 2013 to April 2014 as part of the overall study (see section 2.4.1 'CFR checks'). All descriptions of CFR use patterns use the following data unless stated otherwise; 1) data from both adult and juvenile geckos, 2) data from both 2006 and 2013 release grids, and 3) data from the entire fourteen month sampling period following translocation.

Seasonal effects were investigated in two ways, first by separating data monthly, and also separating it into four broader 'seasons'. Season one included data from March and April 2013, season two from May to August 2013, season three from September to November 2013, and season four from February to April 2014. These broader 'seasons' were classified based on noticeable differences in activity patterns relating to the time of year, time since release, as well as the differences in experimental anchoring treatments applied during each time period (see Chapter 3). Positions of geckos in CFRs were noted as part of the CFR check sessions and methods are described in Chapter 2 (section 2.4.1 'CFR checks'). The proportional use of different shelter areas were compared using Pearson's chi-square tests.

4.2.1 Differences in CFR use by cohorts

The maximum number of neonates, or newborn animals, released was calculated based on the assumptions that each gravid female released in 2013 had survived long enough post-release to give birth, and that each female produced two offspring (19 gravid females x 2 neonates = 38 neonates). Post-release deaths were not considered in cohort comparisons as it is assumed that any deaths have occurred evenly across all cohorts. Differences in proportions of geckos from each cohort that used CFRs were compared using Pearson's chi-squared tests, and multiple testing adjusted for using Bonferroni corrections.

4.2.2 Predicting CFR and tracking tunnel visitation using environmental factors

CFR and tracking tunnel visitation rates were explored in relation to three different sets of environmental factors all thought to potentially affect the use of CFRs by geckos (see section 1.5 'Retreat-Site Selection in Reptiles'). These were 1) factors directly related to the CFR microhabitat, 2) factors related to the surrounding vegetation, and 3) factors related to the surrounding flax.

4.2.2.1 *CFR microhabitat factors*

Microhabitat factors considered to affect CFR and tracking tunnel visitation rates included temperature, humidity, CFR tree species, CFR tree total basal area (TBA), CFR tree height, aspect, and canopy cover over 9 m^2 surrounding the CFR. Before the model selection process, all pairs of factors were checked for correlations, and sufficiently low levels (below 0.3) meant that all seven factors could be included in the model selection process. Aspect of CFR was not considered as a factor in the analysis on tracking tunnel visitation rates due to its irrelevance.

Temperature (°C) and humidity (% relative humidity (RH)) measurements were obtained using handheld 'Precision Hygro-Thermometers' (Model CEM DT-3321), with an accuracy of+/- 0.5°C and +/- 4% RH. Because of the multi-layered design of the CFR's, measurements were taken in 3 areas, 1) outside the CFR (air), 2) between the skirts (skirts), and 3) between the CFR and the tree (tree). I attempted to collect data on the first day of each monthly check session, and additional data were collected whenever time permitted and equipment was available. Data were collected before CFRs were disturbed to obtain the most accurate readings. Both grids and individual CFRs were sampled in different orders each time to account for variation caused by time of day. The time when readings were taken were noted and later used to ensure that sampling order was randomised.

Only data where 1) all CFRs from the same island were sampled on the same day, and 2) both islands were checked during the same week, were used for analysis. Following these criteria, six sets of measurements from all 195 CFRs were used (three sets from August, two from October, and one from November). Temperature and humidity measurements from the three CFR areas were used to describe differences in microhabitat within the CFRs. The differences in temperature and humidity between the tree, skirts and air were all calculated, and each two-way comparison graphed using frequency plots to explore if there were any consistent differences. Measurements from the 'tree' area alone were averaged over the 6 sample days obtained for each CFR, and these were used as the factors "average temperature" and "average humidity" included in statistical analyses.

Tree species was identified for each CFR tree. Due to a large number of species and highly skewed frequencies, tree species were categorised into two groups for analysis, those providing natural shelter to geckos, and those that did not (called shelter providing tree species). Because all but one CFR tree was a species that provided some source of food for *H. duvaucelii*, (either in the form of fruit, seeds or nectar), and it could not be determined which species would provide more benefit to the species, this was not considered any further in tree species comparisons. CFR tree height was estimated using a 2 m long bamboo pole. TBA was calculated by measuring the circumference of all branches larger than 4 cm in diameter at 140 cm above the ground, and converting those measurements into basal area using the equation $A = c^2/4\pi$ (where c=circumference and A=area) (Mitchell 2010). Area was calculated in centimetres squared.

Aspect for each CFR was determined by first measuring the direction which the centre of the CFR was facing using a compass (measured as degrees true north). Measurements were then converted into four equal categories. Values from 316-360 and 0-45 were classified as north, from 46-135 as east, from 136-225 as south, and 226-315 as west (Jenness 2007).

4.2.2.2 *Surrounding vegetation cover*

Ground and canopy cover was sampled in 25 individual 1x1 m squares, making up 25 m^2 of sampled area surrounding each CFR (Figure 4.1c). Within each square, canopy cover was classified as either full (2), partial (1) or none (0). Ground cover was divided into the following categories; 1) bare ground, 2) leaf litter, 3) herbs and grass, 4) fern, 5) flax, 6) *Muehlenbeckia*, 7) other shrubs, and 8) tree trunks, roots and logs. The percentage of cover was estimated and assigned a category from 0-4 (0= 0% cover, 1=1-25%, 2=26-50%, 3=51-75%, and 4=76-100%).

Cover of each vegetation type was averaged for the 25 squares, and these values were used for analysis. Canopy cover was also averaged over the central nine squares for use in the analysis of CFR microhabitat factors. Vegetation cover categories were checked for correlations (using a 2-tailed Pearson's correlation test) before analysis. Bare ground and leaf litter were highly correlated and so bare ground was removed as a factor. All other relationships had sufficiently low correlation coefficients ($r \leq 0.3$) so were included in the model selection process (Quinn and Keough 2002). The eight factors that were included in the initial model of effects of surrounding vegetation cover were canopy cover, leaf litter, herbs and grass, fern, flax, *Muehlenbeckia*, other shrubs, and tree trunks, roots and logs.
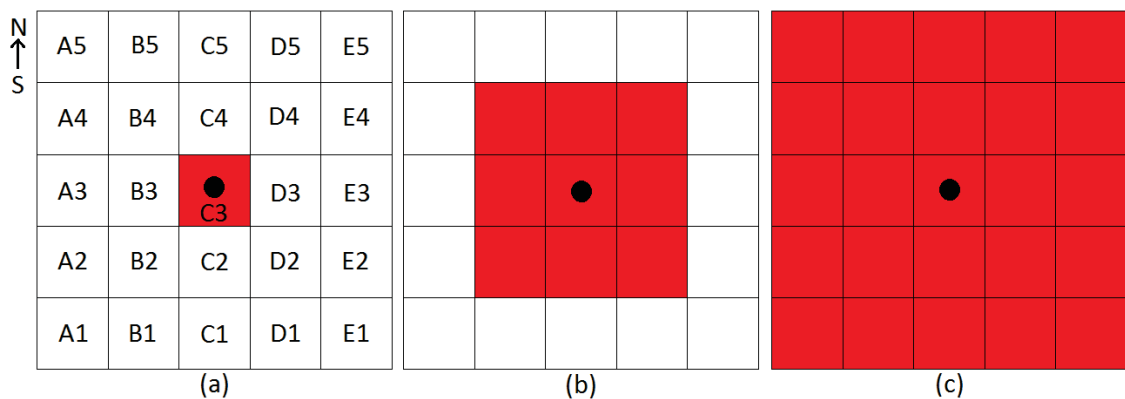
Figure 4.1. Diagram of the grids used to sample surrounding vegetation cover (a) 1 m^2, (b) 9 m^2, and (c) 25 m^2 surrounding each CFR (black dot).

4.2.2.3 *Surrounding flax*

A patch of flax was defined as any flax that measured more than 0.5 m by 0.5 m across. Sections of flax were considered to be within the same "patch" when their edges were less than 0.5 m apart. All patches of flax fell within 5 m of a CFR were measured for area, height and distance from CFR.

Patch TBA was measured by first placing a pole into what was estimated to be the central area of the patch. The outer edge of the patch was defined as where there was some solid structure of live or dead flax vegetative material at a height of approximately 30 cm above ground. The length from the central point to the outer edge was measured in eight different directions spaced 45° apart (N, NE, E, SE, S, SW, W, and NW). Lengths were measured using a 2 m long stick marked at every 5 cm. Patch TBA was calculated by translating the eight pairs of length measurements into eight separate triangle areas, which were then summed to give an approximate measurement of TBA. Where no flax patch existed within a 5 m radius a value of zero was assigned. Only the TBA of the largest patch was used for analysis, and this was represented by the factor "largest patch TBA".

Height was measured 20 cm in from the northern and southern edges and at the tallest point of the patch. The measurement was taken from the highest point where any part of the flax made contact with the measuring pole, when pointing straight up at approximately a 90 degree angle to the ground. These three measurements were then averaged to obtain the factor "average height" for analysis. Only the average height of the largest patch was used for analysis, and this was represented by the factor "largest patch average height".

The distance from the CFR to the edge of each patch was measured using a 50 m measuring tape. When no flax patch fell within a 5 m radius, the distance to the closest patch within a 10 m radius was measured. From this data only the closest distance was used for analysis, which

were categorised into 1) 0-2 m, 2) 2-5 m, 3) 5-10 m and 4) >10 m. This was represented by the factor "closest patch distance"

Largest patch TBA, largest patch average height and closest patch distance were the three factors considered in analyses. The interaction between largest patch basal area and average height was also incorporated into the analysis.

4.2.2.4 *Do environmental factors effect CFR and tracking tunnel visitation rates?*

Effects of CFR microhabitat features, surrounding vegetation cover and surrounding flax on total CFR visitation and tracking tunnel visits were analysed using generalised linear models. A backwards step-wise elimination process was used to identify the best and most parsimonious models for predicting CFR and tracking tunnel visitation rates based on the three groups of habitat factors. This involved including all factors in the model, then removing factors one by one based on the highest p-values. When a factor was removed the model was run again, and if the AICC value declined then the factor was left out of the model, and the factor with the next highest p-value was removed. Factors were continued to be removed until all remaining factors were significant or the AICC value was as low as possible. Release year was included as a factor in all models investigating the effects of microhabitat factors on tracking tunnel visits, due to large noticeable differences in tracking tunnel visitation rates between 2006 and 2013 release grids.

4.3 Results

4.3.1 Longevity

Over the entire fourteen month sampling period only 2% (4/195) of CFRs had structural failures. One CFR was destroyed during a storm, another fell down when the biodegradable rope broke in October, and two more gradually fell down because the CFR was not attached above a branching point. There were also a few CFR trees that died during the sampling period (mainly cabbage trees that were presumed to be suffering from the widely occurring bacterial disease *Candidatus Phytoplasma australiense* (Andersen et al. 2001)) but had not yet fallen over and so the CFRs remained attached. Bungee cords holding CFRs down were closed by placing hooks through loops which were 'sealed' using either knots or cable ties. Knotted loops never required any re-tying, whereas cable ties on occasion became loose and required replacement. Loose cable ties did not affect CFR functionality between check sessions, as the loops did not open until the bungee was disturbed during the CFR checks.

4.3.2 Capture success

Over the entire fourteen month study period, geckos were encountered in CFRs 127 times, including adult males and females as well as juveniles. Out of these, only one instance resulted in the inability to capture the gecko. All other geckos were able to be captured easily and processed, including times where up to three geckos were encountered in the same CFR.

4.3.3 Use of various CFR areas

There were 104 cases where the location of geckos in the CFR was recorded (Table 4.1). The most common vertical position was the upper third (81% of encounters), then the middle third (13%), with the lower third being used the least (6%) (Table 4.1). Geckos used the two depth positions equally (58% were against the tree, 42% between the skirts) (Table 4.1). A chi-squared test revealed that there were significant differences between the percentage of geckos

encountered in each of the six combined depth and vertical positions (X^2=8.209, df=2, p=0.017).

When the depth and vertical position categories were analysed separately, chi-squared tests

showed that there was a significant difference between the percentage of geckos encountered

at each of the three vertical positions (X^2=106.231, df=2, p < 0.001) but no significant difference

between the percentage of geckos encountered at each of the two depth positions (X^2=2.462,

df=2, p=0.141).

Table 4.1. Vertical and depth position of each gecko encountered in a CFR during each check session over the entire fourteen month study period. (Skirts = between the two skirts, tree = between the back flap and the tree).

Depth Position	VERTICAL POSITION			TOTAL
	Upper	Middle	Lower	
Skirts	40 (38%)	1 (1%)	3 (3%)	44 (42%)
Tree	44 (42%)	13 (12%)	3 (3%)	60 (58%)
TOTAL	84 (81%)	14 (13%)	6 (6%)	104 (100%)

4.3.4 Differences in temperature and humidity within CFRs

Mean temperature and humidity readings differed between the three CFR areas (Figure 4.2).

Mean temperature was higher in the air compared to both the skirts and tree areas, but there

was no large difference between the mean temperature of the skirts and the tree (Figure 4.2).

Humidity was lower in the air compared to both the skirts and the tree areas, but there was no

difference between the skirts and the tree (Figure 4.2).

4.3.5 Visitation differences across islands and grids

Overall, 26% (51/195) of CFRs were used at least once throughout the entire fourteen month sampling period by either adult or juvenile geckos (Table 4.2). This included one CFR from each of the islands 2006 release sites (M1 and T4), both of which occurred in May (season two) (Table 4.2). Of the 2013 CFRs, 33% (49/150) were used. One CFR was used a total of fourteen times, and another eleven times. There was a high level of variation in CFR use across all of the monitoring grids (Table 4.2). Grids where Stanley Island geckos were released (grids T1 and M3) had much lower CFR visitation, with only two CFRs used in season one on Motuora, and no CFRs used at any other time (Table 4.2).
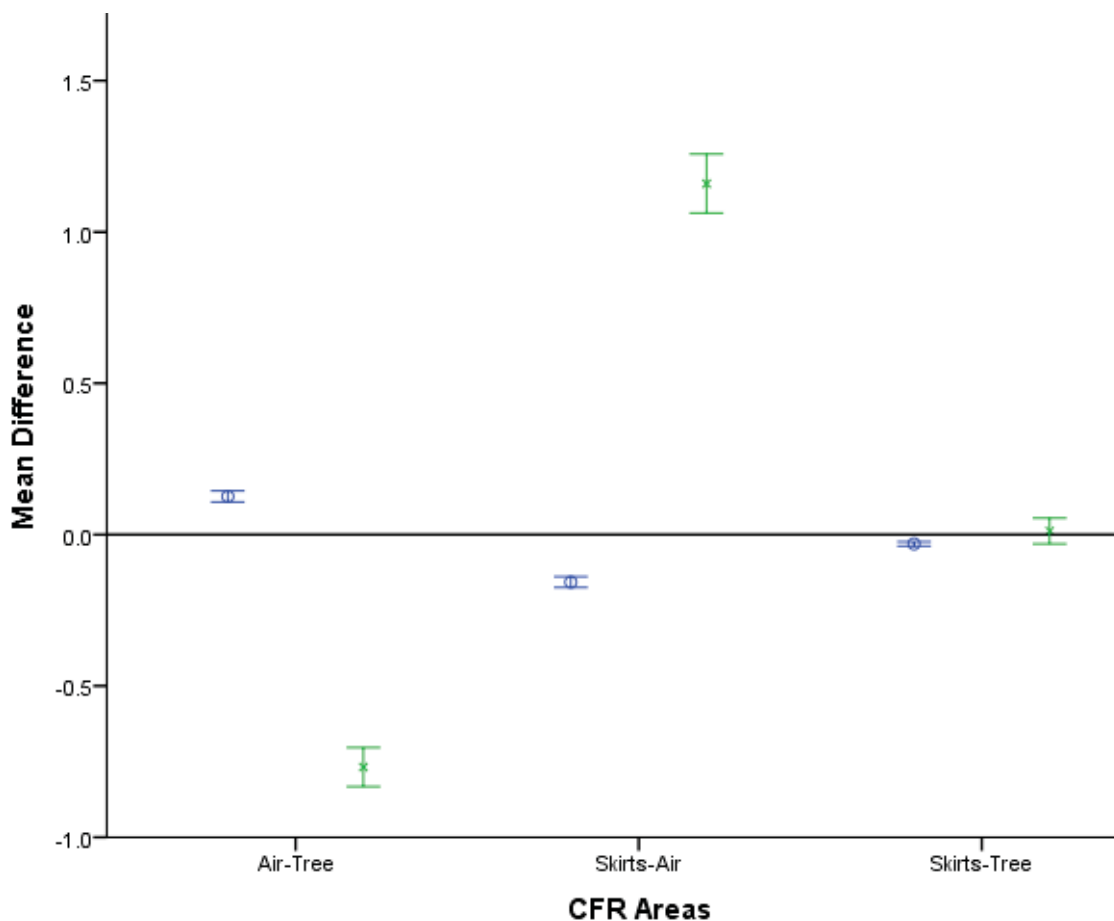
Figure 4.2. The mean difference in temperature and humidity between each pairing of the three measured CFR areas. Treatment= blue circles, humidity= green crosses. Error bars show ±1 standard error (SE). Differences in temperature are measured in degrees Celsius, differences in humidity are measured in percent relative humidity. Differences between the two areas were calculated by the first named category minus the second (i.e. Air-Tree means the air minus the tree measurement).

Table 4.2. Number of CFRs used at least once at each of the 2013 and 2006 release grids during each of the four study seasons, and over the entire fourteen month study period.

2013 RELEASE GRIDS

	T1	T2	T3	TIRI TOTAL	M2	M3	M4	MOTUORA TOTAL	TOTAL
S1	0	15	8	**23**	8	2	1	**11**	*34*
S2	0	3	4	**7**	6	0	6	**12**	*19*
S3	0	1	3	**4**	8	0	2	**10**	*14*
S4	0	1	3	**4**	0	0	0	**0**	*4*
Total	0	16	11	**27**	14	2	6	**22**	*49*

2006 RELEASE GRIDS

	M1	T4	TOTAL
S1	0	0	**0**
S2	1	1	**2**
S3	0	0	**0**
S4	0	0	**0**
Total	1	1	**2**

4.3.6   Duration of CFR Use

The longest period of time the same adult gecko used the same CFR was three days (two consecutive check days). The longest period of time a juvenile gecko used the same CFR was over two months (six consecutive checks over a two month period) (Appendix P).

4.3.7   Seasonality of CFR use

The average number of CFRs used per check session, per monitoring grid, was highest during the start of the year, declined throughout the first few months, then remained at a stable low level throughout the remainder of the year and through to 2014 (Figure 4.3). The number of geckos using CFRs throughout the year followed a very similar trend, as generally there was only one gecko encountered in each CFR (Figure 4.4). There does not appear to be any consistent differences between the two islands throughout the entire sampling period, but there were differences for some individual months (Figure 4.4).

Different trends appeared when the total number of geckos using CFRs was split into adults and juveniles. On Motuora Island, adults only used CFRs during the end of February until April, and from May onwards there were no adult geckos ever encountered in CFRs (Figure 4.5). On Tiritiri Matangi Island there was still a decline in CFR use; however this was more gradual and did not reach zero until July (Figure 4.5). Adult geckos were encountered in CFRs again later in the year (September 2013 and April 2014) on Tiritiri Matangi Island but were not encountered again on Motuora (Figure 4.5). There was greater variation in CFR use by juveniles throughout the year, as well as across the two islands (Figure 4.6). During February, there were no juveniles encountered in CFRs, with numbers then fluctuating on both islands from March to June (Figure 4.6). After this point, CFR use on Tiritiri Matangi Island was generally zero. On Motuora Island, numbers remained stable at a high level from July to September, and then declined through October/November (Figure 4.6).
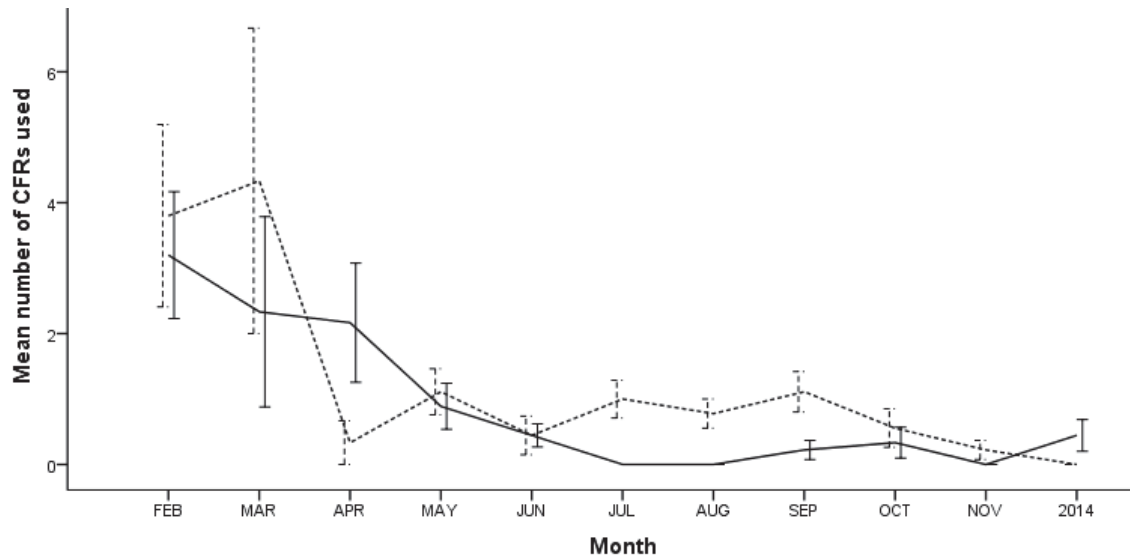
Figure 4.3. Average number of CFRs used per 2013 monitoring grid per check day for each separate sampling month. Tiritiri Matangi Island = solid line, Motuora Island = dotted line. Error bars indicate ±1 standard error (SE).Does not include data from 2006 grids.
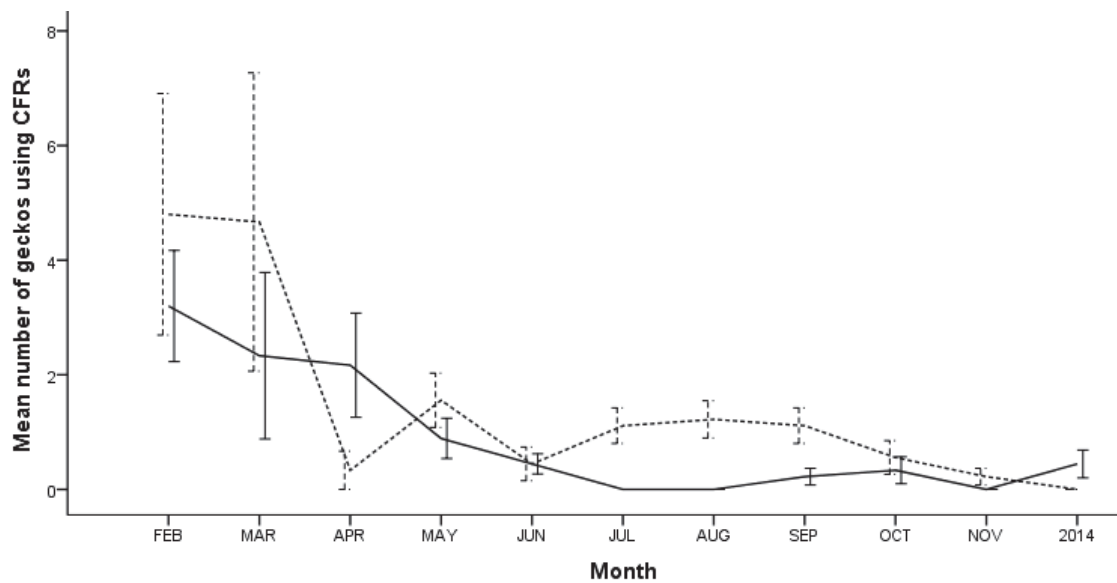
Figure 4.4. Average number of total geckos found in CFRs per monitoring grid per check day for each separate sampling month. Tiritiri Matangi Island = solid line, Motuora Island = dotted line. Error bars indicate ±1 standard error (SE). Does not include data from 2006 grids.
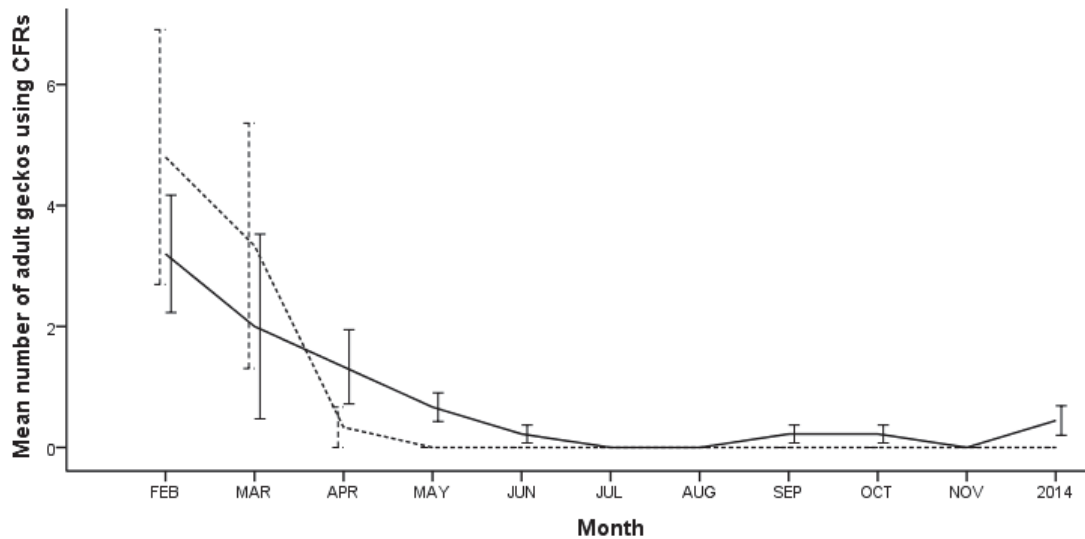
Figure 4.5. Average number of adult geckos found in CFRs per monitoring grid per check day for each separate sampling month. Tiritiri Matangi Island = solid line, Motuora Island = dotted line. Error bars indicate ±1 standard error (SE). Does not include data from 2006 grids.
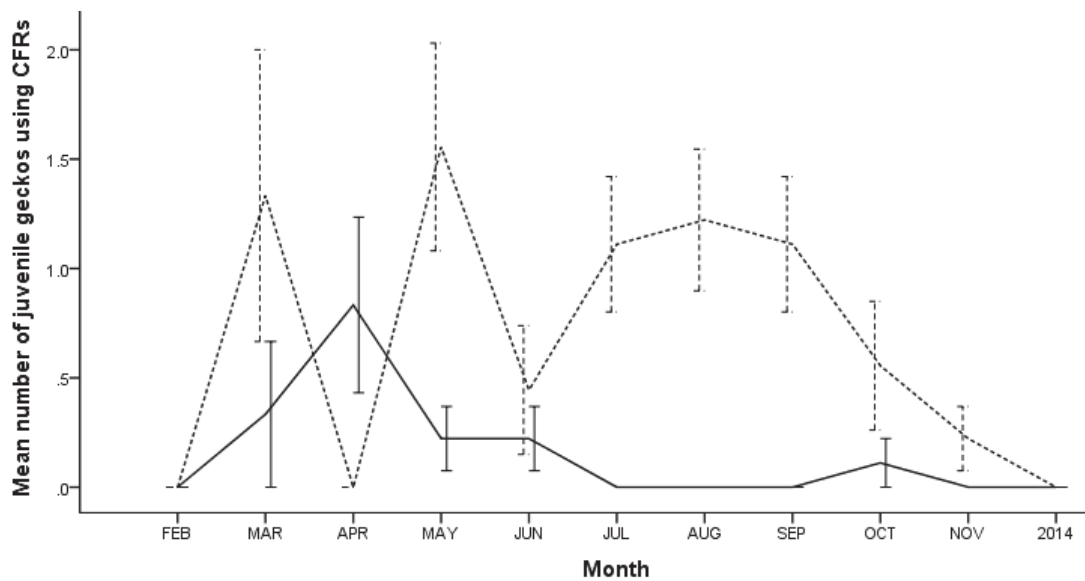
Figure 4.6. Average number of juvenile geckos found in CFRs per monitoring grid per check day for each separate sampling month. Tiritiri Matangi Island = solid line, Motuora Island = dotted line. Error bars indicate ±1 standard error (SE). Does not include data from 2006 grids.

4.3.8   CFR use by different cohorts

A total of 57 geckos (26% of those released) used CFRs at least once throughout the monitoring period (Table 4.3). Use by different cohorts was approximately equal across the two islands (Table 4.3).

4.3.8.1   *CFR use by males versus females*

Over the fourteen month monitoring period, sixteen males and 24 females used CFRs at least once (Table 4.3). A chi-square test showed that this difference was not significant (X^2=2.057, df=1, p=0.209) (Table 4.4). During season one alone, fourteen males and twenty females used CFRs, and during the combined season's two to four, five males and six females used CFRs (Table 4.4). Chi-square tests revealed that these differences were also not significant (season one X^2=1.305, df=1, p=0.341, seasons two to four X^2=0.097, df=1, p=1.000) (Table 4.4).

4.3.8.2   *CFR use by gravid versus non-gravid females*

Throughout the fourteen month monitoring period, 68% (13/19) of gravid and 15% (11/71) of non-gravid females (at release) used CFRs, which was similar across the two islands when analysed separately (Table 4.3). A chi-square test showed that over the fourteen month monitoring period, there was a significant difference in the percentage of gravid and non-gravid females that used CFRs at least once (X^2=21.472, df=1, p <0.001) (Table 4.4). During season one alone, 58% (11/19) of gravid and 13% (9/71) of non-gravid females used CFRs at least once (Table 4.4). A chi-square test showed that this was a significant difference (X^2=17.732, df=1, p <0.001) (Table 4.4). During the combined season's two to four, 21% (4/19) of gravid and 3% (2/71) of non-gravid females used CFRs (Table 4.4). A chi-square test showed that over seasons two to four there was an overall significant difference (X^2= 8.011, df=1, p=0.017) (Table 4.4).

4.3.8.3 *CFR use by adults versus juveniles*

At least 45% (17/38) of juveniles born from 2013 released gravid females were encountered at least once throughout the fourteen month study period, compared to 22% (40/180) of adults (Table 4.4). A chi-square test showed that this difference was significant (X^2=8.236, df=1, p=0.005) (Table 4.4).

During seasons one, two, and three, a higher percentage of juveniles used CFRs than adults, and during season four a higher percentage of adults used CFRs (Table 4.4). Multiple chi-square tests showed that the differences were significant for seasons two (X^2=28.630, df=1, p<0.001) and three (X^2=19.123, df=1, p<0.001) but not seasons one (X^2=0.456, df=1, p=0.505) or four (X^2=0.860, df=1, p=0.603) (Table 4.4). There was an overall significant difference in usage rates by juveniles and adults during seasons two to four combined (X^2=21.564, df=1, p<0.001) (Table 4.4).

Table 4.3. Number of geckos in each cohort on each island that used CFRs at least once over the entire fourteen month sampling period. T=Tiritiri Matangi Island, M=Motuora. Percentages are of those released.

	Released			Used CFRs		
	T	M	TOTAL	T	M	**TOTAL**
Males	45	45	90	10 (22%)	6 (13%)	**16 (18%)**
Females	45	45	90	11 (24%)	13 (29%)	**24 (27%)**
Gravid F	*9*	*10*	*19*	*6 (67%)*	*7 (70%)*	***13 (68%)***
Non-Gravid F	*36*	*35*	*71*	*5 (14%)*	*6 (17%)*	***11 (15%)***
TOTAL ADULTS	90	90	180	21 (23%)	19 (21%)	**40 (22%)**
Juveniles	18	20	38	7 (39%)	10 (50%)	**17 (45%)**
TOTAL GECKOS	**108**	**110**	**218**	**28 (26%)**	**29 (26%)**	**57 (26%)**

4.3.9   Observations of juvenile CFR use patterns

Ten (59%) of the seventeen juveniles that used CFRs at least once during the fourteen month monitoring period, used them more than once. Two juvenile geckos, J2 and J3 (both from grid M2) used CFRs throughout all three 2013 seasons, and were encountered in CFRs seventeen and sixteen times respectively (Appendix P). Two other juveniles, J8 and J9 (from grid M4) were found throughout both seasons two and three, and were encountered twelve and six times respectively (Appendix P). Juvenile geckos were regularly encountered in the same CFRs on consecutive occasions, and were also encountered in different CFRs on consecutive occasions.

Table 4.4. Number and percentage of geckos released in different cohorts that used CFRs again at least once during each of the four separate study seasons, during seasons two to four combined and over the entire fourteen month study season, and the results of chi-square tests run for each cohort comparison.

Cohort Comparison	Released	SEASON					
		S1	S2	S3	S4	S2-4	Total
Male vs Female							
Male	90	14 (16%)	5 (6%)	0 (0%)	1 (1%)	5 (6%)	16 (18%)
Female	90	20 (22%)	1 (1%)	2 (2%)	3 (3%)	6 (7%)	24 (27%)
Total Adults	180	34 (19%)	6 (7%)	2 (1%)	4 (2%)	11 (6%)	40 (22%)
Pearson X^2		1.305	-	-	-	0.097	2.057
df		1	-	-	-	1	1
sig		0.341	-	-	-	1.000	0.209
Gravid vs Non-gravid Females							
Non-Gravid	71	9 (13%)	0 (0%)	0 (0%)	2 (3%)	**2 (3%)**	11 (15%)
Gravid	19	11 (58%)	1 (5%)	2 (11%)	1 (5%)	**4 (21%)**	13 (68%)
Total Females	90	20 (22%)	1 (1%)	2 (2%)	3 (3%)	**6 (7%)**	21 (23%)
Pearson X^2		17.732	-	-	-	8.011	21.472
df		1	-	-	-	1	1
sig		**<0.001**	-	-	-	**0.017**	**<0.001**
Adults vs Juveniles							
Adult	180	34 (19%)	6 (3%)	2 (1%)	4 (2%)	11 (6%)	40 (22%)
Juvenile	38	9 (24%)	11 (29%)	6 (16%)	0 (0%)	12 (32%)	17 (45%)
Total Geckos	218	43 (20%)	17 (8%)	8 (4%)	4 (2%)	23 (11%)	57 (26%)
Pearson X^2		0.456	28.630	19.123	0.860	21.564	8.236
df		1	1	1	1	1	1
sig		0.505	**<0.001**	**<0.001**	0.603	**<0.001**	**0.005**

4.3.10 Effects of environmental factors on CFR and tracking tunnel

visitation

Several factors were revealed to be significant predictors of both CFR and tracking tunnel visitation rates (Table 4.5). The significance of each factor in each model is displayed in Table 4.5 along with the directionality of the effect. Release year was accounted for in all three models run on the effects of environmental factors on tracking tunnel visitation rates. The effects of all significant factors revealed during each model selection process are further described below.

4.3.10.1 *Effects of CFR microhabitat on CFR visits*

The best overall model (X^2=50.127, df=7, p<0.001, AICC=256.033) for predicting CFR visitation based on CFR microhabitat features included temperature, canopy cover (within 9 square metres), CFR tree height, CFR tree TBA and aspect (Appendix R). CFR temperature, canopy cover and CFR tree TBA all had a negative effect, with an increase in each factor leading to a decrease in CFR visitation (Appendix R). CFR tree height had a positive effect, with an increase in height leading to an increase in CFR visitation (Appendix R). North facing CFRs had significantly less CFR visitation than both south and east facing CFRs (Appendix R).

4.3.10.2 *Effects of CFR microhabitat on tracking tunnel visits*

The best overall model (X^2=58.782, df=4, p<0.001, AICC=567.877) for predicting tracking tunnel visitation based on CFR microhabitat features included grid release year, canopy cover (within 9 square metres), average humidity, and CFR tree height (Appendix S). Canopy cover humidity, and CFR tree height all had a negative effect, with an increase in each factor leading to less tracking tunnel visitation (Appendix S).

4.3.10.3 *Effects of surrounding vegetation cover on CFR visits*

The final best overall model (X^2=29.895, df=6, p<0.001, AICC=274.859) for predicting CFR visitation based on the surrounding vegetation cover within 25 square metres included *Muehlenbeckia*, canopy cover, fern, other shrubs, flax, and tree trunks, roots and logs (Appendix T). *Muehlenbeckia*, canopy cover, and other shrubs all had a negative effect, where an increase in each factor lead to a decrease in CFR visitation (Appendix T). Fern, flax and tree trunks, roots and logs all had a positive effect, where an increase in each factor lead to increased CFR visitation (Appendix T).

4.3.10.4 *Effects of surrounding vegetation cover on tracking tunnel visits*

The final best overall model (X^2=102.599, df=6, p<0.001, AICC=535.082) for predicting tracking tunnel visitation based on the surrounding vegetation cover within 25 square metres included grid release year, herbs and grass, fern, other shrubs, flax and tree trunks, roots and logs (Appendix U). Herbs and grass, fern, other shrubs, flax, and tree trunks, roots and logs all had a positive effect, with an increase in each factor leading to an increase in tracking tunnel visitation (Appendix U).

4.3.10.5 *Effects of surrounding flax on CFR visits*

The final best overall model (X^2=17.677, df=4, p=0.001, AICC=278.494) for predicting CFR visitation based on the surrounding flax included largest flax TBA and nearest flax distance category (Appendix V). Both largest flax TBA and nearest flax distance category had a positive effect, with an increase in both factors leading to an increase in CFR visitation (Appendix V).

4.3.10.6 *Effects of surrounding flax on tracking tunnel visits*

The final best overall model (X^2=90.472, df=5, p<0.001, AICC=506.224) for predicting tracking

tunnel visitation based on the surrounding flax included grid release year, largest flax basal area

and nearest flax distance category (Appendix W). Largest flax basal area had a positive effect,

with an increase leading to an increase in tracking tunnel visitation (Appendix W). Nearest flax

distance had a negative effect, with an increase leading to a decrease in tracking tunnel visitation

(Appendix W).

Table 4.5. All factors considered in the model selection process for determining which habitat factors effected CFR visitation and tracking tunnel visitation rates. Ticks indicate a significant factor, crosses a non-significant factor. Direction of the effect on each significant factor is indicated by positive (+) and negative (-) signs. 13' =2013, 06'= 2006. The effect of categorical variables (release year and aspect) are given in more detail. N/A indicates factors that were not considered in the model selection process.

Factor	CFR Visits		Tracking Tunnel Visits	
CFR Microhabitat				
Release Year	N/A		✓	13'<06'
Temperature	✓	-	✗	
Humidity	✗		✓	-
CFR tree height	✓	+	✗	
CFR tree TBA	✓	-	✗	
Shelter providing CFR tree species	✗		✗	
CFR Aspect	✓	S&E>N	N/A	
Canopy cover (9 m^2)	✓	-	✓	-
Surrounding Vegetation Cover (25 m^2)				
Release Year	N/A		✓	13'<06'
Leaf litter	✗		✗	
Herbs and grass	✗		✓	+
Fern	✓	+	✓	+
Flax	✓	+	✓	+
Muehlenbeckia	✓	-	✗	
Other Shrubs	✓	-	✓	+
Tree trunks, roots and logs	✓	+	✓	+
Canopy Cover (25 m^2)	✓	-	✗	
Surrounding Flax				
Release Year	N/A		✓	13'<06'
Largest patch TBA	✓	+	✓	+
Largest patch average height	✗		✗	
Interaction TBA x average height	✗		✗	
Closest patch distance category	✓	+	✓	-

4.4 Discussion

Design, functionality, and general usefulness

The design of the CFRs showed a high level of functional integrity throughout the fourteen month monitoring period, the same level as was observed using the initial single layered design (Bell, 2009). Only a small number of CFRs fell down during the study, the reasons for which can all be avoided with some minor alterations to the placement and materials of CFRs (see Chapter 6). The bungee cord used to close the CFRs worked well as there were no deaths or injuries inflicted on geckos by the cord, skirts were successfully held closed throughout the study, and CFRs were able to be opened quickly and quietly with little disturbance to any inhabitants.

CFRs provided useful tools for monitoring *H. duvaucelii* for several reasons. First, 57 adult and juvenile geckos were encountered a total of 127 times inside CFRs throughout the study period. Considering the small population of (up to) 218 geckos released onto the two islands, this recapture rate is relatively high, and similar to the study conducted by Bell (2009), which monitored high density resident populations using a similar single-layered design. However, the two techniques should not be directly compared due to potential differences in habitat, lizard densities and sampling effort. Other studies have also found artificial refuges to be useful tools for monitoring herpetofauna (Webb and Shine 2000, Wakelin et al. 2003, Lettink and Cree 2007, Croak et al. 2010), although their level of success is often affected by the density of the population being monitored (van Winkel 2008, Bell 2009). This may also be the case for the CFRs trialled in this study.

Second, a large number of separate CFRs on 2013 release grids were used by geckos during the year, many of which were used multiple times. The highest occupancy rate of CFRs occurred immediately following release in February, where an average of 18% of CFRs were used on each monitoring grid. Occupancy declined throughout the remainder of the monitoring period. A

resident, high density population of *H. duvaucelii* was monitored by Bell (2009) during March-April 2008 using similar single-layered CFRs, and resulted in an occupancy rate of 25% (20 out of 80 possible structures occupied). In comparison, our method showed similar occupancy rates immediately following release, although this did not continue throughout the year. As mentioned earlier, differences in factors such as lizard densities and habitat are likely to affect occupancy rates, therefore studies must be compared with caution.

Furthermore, the capture rate of geckos encountered in CFRs was over 99%. In comparison, another study using artificial retreats for monitoring high density terrestrial lizard populations reported nearly 5% miscapture (Lettink and Cree 2007). However, the three species encountered in that study are often found in large groups and are much quicker than *H. duvaucelii*, making them more difficult to capture (Lettink and Cree 2007). CFRs were also used by more than one gecko on multiple occasions. As *H. duvaucelii* are thought to show some level of complex social behaviour (Barry 2010), the presence of multiple geckos inside CFRs provides opportunity to study these potential behaviours in the field.

Another reason CFRs were useful monitoring tools is that, despite the seasonality of CFR use (discussed later), at least some CFRs were used during each of the fourteen months of monitoring. In comparison, other monitoring methods often result in no captures or even detection during some seasons. For example, Bell (2009) found that spotlighting, pitfall traps, g-minnow (funnel) traps, lizard houses and Onduline artificial retreats, were all unable to detect two species of arboreal gecko during sampling sessions in March-April, whereas CFRs resulted in some detection.

CFRs were also used by all cohorts at some point throughout the study, including males and females, juveniles and adults, and both gravid and non-gravid females. Other methods of monitoring often do not detect all cohorts. Other types of artificial shelters are often limited in their ability to locate or even detect juveniles (van Winkel 2008, Bell 2009), and radio-tracking

is generally not possible for gravid females or juveniles. The ability to detect and monitor all cohorts using CFRs makes them more useful compared to other monitoring techniques. Finally, the fact that a small number of the CFRs at 2006 sites were used by geckos suggests that they could also be useful for monitoring pre-established populations of *H. duvaucelii*.

Other benefits of this method for monitoring *H. duvaucelii* include the requirements of a low level of effort, low cost, low maintenance, and limited knowledge and training. The method is also easily repeatable over space and time, long-lasting, and has the potential to be used for obtaining various kinds of information, including species presence, indicators of abundance, and observations of species behaviour.

Use of different CFR areas

Geckos utilised the tree depth layer slightly more than the 'between the skirts' layer, although this difference was not statistically significant. The fact that both layers were used by geckos indicates that the double layered design is beneficial for monitoring *H. duvaucelii*. Temperature and humidity measurements were not consistently different between the two depth layers, suggesting that there was no higher thermoregulatory benefit of either layer, which may be why the two layers were used generally equally. The slight difference in use of the two CFR layers may therefore be due to other subtle factors such as the structural features of the layers, or differences in invertebrate (prey) densities. Size, shape and other structural features are common influences of retreat site selection in lizard species, and choices are thought to represent underlying predator avoidance behaviour (Diaz and Carrascal 1991, Downes and Shine 1998, Cooper et al. 1999, Amo et al. 2004). Potential prey abundance has also been found to influence site selection in lizards and snakes (Diaz and Carrascal 1991, Webb and Shine 2000). Although there was no consistent difference in humidity found between the two CFR layers, it was commonly observed that following any rain, the skirts layer provided a much drier area within the CFR, whereas the tree trunk was generally very wet. This may not have been picked

up in the humidity data, as measurements may not have been taken immediately following any rain event. Therefore CFRs may in fact show variation in climate in certain conditions. Temperature and humidity should be measured in a range of conditions in future studies to gain a better understanding of the benefits of the different CFR layers.

H. duvaucelii used the three horizontal positions to different degrees (upper > middle > lower), indicating a preference for upper positions within CFRs. It is possible that as I approached the CFRs or began to open them, geckos moved higher into the crevices. However, as geckos could generally be heard moving inside CFRs, and tended to freeze when they were exposed after opening CFRs, I believe this is not the main reason the upper regions were used more than the lower. The upper portion usually had more tension provided by both the bungee cord and rope tying the CFR to the tree, which may have created a more compact area, reduced the degree to which the skirts moved in the wind, and may have also effected the microhabitat. However, temperature and humidity differences were not measured for each of the horizontal positions. Therefore, differences in microhabitat between these areas cannot be confirmed. The fold in the material between the skirts provided a highly enclosed area in the upper third, which many adult and juvenile geckos seemed to prefer. The reason behind this apparent preference may be related to predator avoidance behaviour, as more enclosed areas with fewer entry points would likely provide a safer retreat from potential predators. Various other lizard species are known to preferentially select retreats based on characteristics that lead to improved predator avoidance (Amo et al. 2004, Shah et al. 2004, Quirt et al. 2006). However, Barry (2010) observed that in a lab environment, *H. duvaucelii* had no preference for different crevice widths, which were thought to represent vulnerability to predators. Geckos may select for other factors that affect vulnerability to predators, however these remain to be tested.

Geckos may have also used the upper and middle thirds more as they preferred the natural feel of the sticks placed against the tree. When both adult and juvenile geckos were encountered

against the tree in the upper or middle areas, they were usually located right next to the sticks. Often these structures did not extend down the full length of the CFR, which could explain why the upper and middle portions of the 'against the tree' depth layer were used substantially more than the lower. Extending the length of the sticks to protrude down the full length of the CFR may increase the use of this area by geckos located against the tree.

Spatial variation in CFR use

The variation in CFR visitation rates across islands and grids is likely due to various habitat factors such as microhabitat, surrounding vegetation, and proximity to other suitable habitat and retreat sites. These were all measured during this study and various factors were indeed revealed to affect CFR visitation rates. Differences may also be related to the origin of the geckos released within monitoring grids, as Stanley Island gecko release sites on both islands had very few CFR visits throughout the entire year. This may be due to behavioural differences between wild Korapuki and Stanley Island populations. Behavioural differences between populations of the same species commonly exist in various species of fish (Magurran 1986, Dingemanse et al. 2007), birds (Petrie and Kempenaers 1998), mammals (Rasmuson et al. 1977), and reptiles (Baird et al. 1997). Differences in behaviour between two populations may therefore also exist for *H. duvaucelii*.

The release year of geckos present at each monitoring grid is also a likely contributing factor to the different level of CFR use at each monitoring grid. Only one gecko on each of the two 2006 grids was ever encountered inside a CFR, compared to 57 geckos that were released across six release grids in 2013. Approximately 30 geckos were released at each 2013 release grid, and approximately 20 geckos were released at each of the 2006 release sites, which are known to have reproduced. Consequently, it is expected that more geckos are in fact present at the 2006 release sites. Differences in population sizes of geckos at each monitoring grid are therefore probably not the main reason for the different level of CFR use at the 2006 versus 2013 release

grids. Another explanation is that the geckos released in 2006 have had longer to disperse away from the release site and so lower densities remain within the monitoring grid. However, footprint tracking was conducted at all eight monitoring grids throughout the year, and in fact both of the 2006 release sites were shown to have the highest number of footprints. This indicates that high densities of geckos are still present on the 2006 release grids. It is also possible that different release techniques have resulted in the differential CFR use, as half of geckos in 2013 were released inside CFRs, and the other half released inside travel tubes at natural sites, whereas all geckos in 2006 were released in travel tubes. The effect of release treatment was investigated in Chapter 3 of this thesis, and various effects on CFR use were noticeable. Another likely explanation for the difference is that many 2006 release geckos may have found and become established at higher quality, natural retreat sites, whereas geckos released in 2013 have not yet done this and were therefore utilising artificial retreat sites. This is supported by evidence that translocated *H. duvaucelii* have been found to show strong site fidelity, and that translocated geckos show higher levels of dispersal than resident populations (Whitaker 1968, Jones 2000, van Winkel 2008). The low level of CFR use is also consistent with the 2013 CFR use patterns, where CFR use declined rapidly with time since release.

Seasonality of CFR Use

CFR use was highest immediately following release and generally declined throughout the remainder of the monitoring period. The same seasonal trends in occupancy of artificial retreats were found during the study following the original translocation of the species to the two study islands, where occupancy rates were the highest during the first few months following release and declined thereafter (van Winkel 2008). In the previous study, initial trends were attributed to both the theoretically highest density of geckos existing within monitoring grids during the earlier months (due to post-release dispersal), and the unfamiliarity of geckos with their new habitat (van Winkel 2008). Later trends were accredited to a reduction in numbers due to

increased dispersal over time and the occupancy of alternative natural retreat sites (van Winkel 2008). Trends in occupancy during this study are likely to have been caused by the same factors of post-release dispersal, unfamiliarity with the new environment, and a high availability of alternative natural retreat sites. Increasing dispersal distances recorded following release (see Chapter 3) provide evidence for decreasing densities of geckos on monitoring grids over time. Dispersal away from release sites is a common behaviour in other translocation events (Swaisgood 2010, Le Gouar et al. 2012). The low density of geckos at each grid also means that it is likely that there were sufficient numbers of natural refuges available, reducing the need for geckos to use CFRs (van Winkel 2008). The slight increase in CFR use at the end of the year may be explained by the increased activity levels of geckos in summer due to increased dispersal to find mates. Throughout the study, many more individuals were observed sun-basking during the later warmer months, and many groups of individuals were caught in the same traps, usually consisting of one male and one to two females. Radiotracking data conducted for a concurrent study showed that activity levels increased later in the year, and that many individuals remained within the same flax bushes for a number of months, suggesting that mating behaviour was occurring (V. Glenday, *unpublished data*). These trends indicate that CFRs may be most beneficial to populations immediately following a translocation, as they may provide protection from predators when animals are most vulnerable in their new, unfamiliar surroundings (Sullivan et al. 2004).

CFR use by different cohorts

There was no difference in CFR use by males and females throughout the study. This finding is supported by two other studies on the use of artificial retreats by *H. duvaucelii* that found both genders utilised shelters equally (van Winkel 2008, Barry 2010).

Gravid females used CFRs proportionally more than any other cohort (males, non-gravid females and juveniles). Although data from this study suggests that there are no thermal benefits of

CFR's, this finding alone suggest that CFRs may provide some thermal benefit to gravid females, and should therefore be explored further in the future. Alternatively, CFRs may be seen by gravid females as a safe place for avoiding predators while giving birth. On one occasion, a juvenile gecko was found inside the same CFR as a previously gravid female, suggesting that at least some females may have given birth inside CFRs. As geckos were released around the time of year they are known to give birth, females would have had little time to disperse away from monitoring grids before giving birth. It is known that for some lizard species, juveniles and mothers share some level of social interaction after birth, which in the common lizard (*Lacerta vivipara*) has also been shown to affect dispersal behaviour (Galliard et al. 2003). Both mothers and offspring of some species are also able to differentiate between the scents of related and unrelated individuals (Léna et al. 2000). *H. duvaucelii* are also thought to exhibit complex social interactions, and are known to be able to discriminate between siblings and non-siblings (Barry 2010). However, little else is known about this aspect of their behaviour, and further research is required. The high level of CFR use by both gravid females and juveniles provides excellent opportunities to study social behaviour in these geckos.

A much higher proportion of juveniles used CFRs than adult geckos, and they used CFRs continuously throughout the year in comparison to adults who rarely used them after April-May. This may be due to differences in dispersal behaviour between adults and juveniles. It has been suggested that juvenile dispersal may be limited in this species and juveniles may remain close to their birthplace (Barry 2010), whereas adults are known to show high levels of dispersal following a translocation (Jones 2000, van Winkel 2008). Another reason could be that juvenile geckos may be more vulnerable to predators, and show limited dispersal as a predator avoidance mechanism. Recent research investigating 57 reptile species has shown that survival rates of juveniles may not be as low as previously thought, but were underestimated due to difficulty in finding juveniles (Pike et al. 2008). Regardless, survival rates of juvenile reptiles are on average 13% lower than that of conspecific adults (Pike et al. 2008) and in juvenile velvet

geckos (*Oedura lesueurii*) are lower in hatchlings than yearlings (Webb 2006). Another explanation could be that juvenile geckos do not have the same need or desire to disperse as adults do, such as to establish territories or to find mates. Animals often prefer familiar habitats, and will disperse away from unfamiliar release sites in search of these habitats (Stamps and Swaisgood 2007). As juveniles do not have any previous experience with different habitat types, they may be less likely to exhibit this behaviour.

Other differences in behaviour also appear to have affected CFR use patterns in juveniles. Some juvenile geckos were actively seeking out CFRs for shelter, which was evident in that four juveniles were encountered in many different CFRs over consecutive check days. For example, gecko J3 during September moved from C15 on sampling day one, to C45 on day two, and then B45 on day three (Appendix P). This happened many times throughout the year for many of the juvenile geckos. This suggests that juveniles are not only encountered more in CFRs due to remaining within release areas, but may also have a preference for CFRs over other natural retreat sites. Juvenile geckos also appeared to be returning to certain CFRs regularly, suggesting firstly that there was a preference for particular CFRs over others, and furthermore, that they were able to identify and successfully navigate their way back to those CFRs. For example, both geckos J8 and J9 would occasionally move to other CFRs or alternative natural retreat sites, but would then return to CFR B45 regularly, often for many consecutive days (Appendix P). Juvenile reptiles are often very difficult to detect and monitor, leading to a lack of knowledge on these life stages (Pike et al. 2008). The ability to detect juveniles at all using this method is therefore a large benefit on its own, and even more so with our ability to continuously monitor those juveniles over time.

There does not appear to be any long-term use of CFRs by adult geckos, as the longest period of time the same gecko was using the same CFR for was three days (two consecutive check days). CFR use by adult geckos may therefore be haphazard rather than a learnt behaviour or territorial

use. Adults may also be developing 'trap shy' behaviour after being captured every time they are encountered in the CFRs, and so actively avoid the same CFR in the future. However, as the same individuals were encountered in different CFRs, this behaviour may not be long-lasting. Data from the regular PTM conducted in February and November 2014 suggests that one CFR (T3 D45) may be regularly used by an adult gecko, as a shed skin was found inside the CFR during each monitoring trip, as well as adult geckos caught in funnel traps within the general proximity. This CFR was also used by an adult gecko late in the monitoring season of this study. Therefore it is possible that there may be some long-term use of CFRs by adult geckos, and that this pattern was just not detected in the monthly monitoring sessions conducted throughout this study.

Pairs of juvenile geckos were encountered in the same CFRs on many occasions, and would occasionally move from one CFR to another together. This suggests that juvenile geckos may be involved in some complex social interactions. For example, J8 and J9 were both in CFR B30 on the first check day in May, and by the second check day they had both moved to CFR B45, then remained in this CFR together until the third check day (Appendix P). This is supported by previous findings that aggregations of *H. duvaucelii* often included juveniles of the same size, suggesting that pairs of siblings may remain together (Barry 2010). This could also be the case for the juveniles encountered together in this study. Barry (2010) also found that juvenile only aggregations were rare, as they were usually found along with other adults. The finding of many pairs of juveniles alone in CFRs is therefore even more important, as it suggests that juveniles may not remain with their parents as was previously thought. However, as this study was conducted on a translocated population, and the previous study on a resident wild population, it is possible that geckos behave differently in each situation.

Effects of microhabitat factors on CFR and tracking tunnel visitation

Several microhabitat factors correlated with CFR usage, including average CFR temperature, canopy cover, and the direction the CFR was facing (aspect). Temperature was negatively

correlated with CFR use, suggesting that geckos preferred to use cooler CFRs. However, the negative relationship with canopy cover at both the nine and twenty-five square metre level suggests that geckos are in fact using CFRs in areas with less canopy cover, and therefore more access to direct sunlight. The fact that *H. duvaucelii* are known to occasionally sun-bask, a behaviour by which an animal lays in the direct sun in order to thermoregulate, supports this finding (Whitaker 1968). Aspect had a significant relationship with CFR visitation, where rates were higher in south and east facing CFRs compared to north facing CFRs. This contrasts with what would be expected if geckos were using CFRs for warmth, as north facing CFRs would be exposed to more hours of sun. When considering the relationships of CFR visitation rates with temperature, canopy cover and aspect together, it appears that geckos are using trees that receive more sunlight due to less surrounding canopy cover, but the CFRs themselves are cooler and are facing a direction that receives less direct sunlight. This may suggest that geckos are actively thermoregulating by emerging from CFRs to sun bask during the day, and return to them later to be in a cooler and potentially more stable environment. CFRs in open areas may also get too hot for the geckos. These findings are contradictory to many other studies showing that other lizard species prefer warmer temperatures in artificial shelters (Schlesinger and Shine 1994, Downes and Shine 1998, Kearney 2002, Andersson et al. 2010). Other research on *H. duvaucelii* showed that shelters used by geckos in the wild were generally cooler than their body temperatures, supporting the theory that *H. duvaucelii* use artificial shelters to maintain a constant body temperature rather than to increase it (Barry 2010). Also, New Zealand lizards are adapted to the cooler climate, and many species are more active at night when temperatures are much lower (Hare et al. 2010).

Visitation rates of tracking tunnels located at the base of CFR trees were correlated with similar microhabitat factors to those which were correlated with CFR visitation rates. These included release year of the monitoring grid, average CFR humidity, and canopy cover. Release year correlated with visitation rates, where 2006 grids had much higher levels than 2013 grids. This

is probably due to these grids having higher densities of geckos during sampling, which is likely given the reproduction that is known to have occurred in the years since the population's release (SOTM 2013). The negative correlation of visitation rates with both humidity and canopy cover together suggests that geckos are using areas more with more available sunlight, which may provide opportunity for thermoregulatory behaviours.

CFR tree height was also revealed to be positively correlated with CFR visitation rates. This was expected as taller trees provide a better habitat for geckos for many reasons. Taller trees provide more variation in microhabitat for thermoregulation, and height may be correlated with an increase in number of branches and therefore perching sites available for basking (Harmon et al. 2007, Buckland et al. 2014). Taller trees also allow geckos to be further away from ground-dwelling predators. This preference has also been found in other lizard species. For example, both adults and juveniles of *Phelsuma guimbeaui* were found to prefer taller trees (Buckland et al. 2014). Unexpectedly, CFR tree TBA was revealed to negatively correlate with CFR use. Geckos were using CFRs on trees with a smaller basal area, whereas it was expected that geckos would prefer to use larger trees due to the consequent increase in height and size, and variation in microhabitat (Buckland et al. 2014). The negative correlation with size may be related to other important factors such as tree species, which was not tested due to the spatial variation and large number of tree species that existed. Larger sample sizes should therefore be obtained to test whether tree species has an effect on CFR visitation rates by *H. duvaucelii*. One possible explanation for the negative effect of CFR tree TBA on CFR use could be that trees with larger TBAs are generally located at sites with larger, more mature vegetation, and therefore also higher availability of alternative natural shelter sites. Under this situation geckos might not utilise CFRs as much, as the natural shelter sites are preferred.

CFR tree height was revealed to have the opposite, negative effect on tracking tunnel visitation rates. This was not expected, as prior research has indicated that arboreal lizards prefer larger,

therefore also taller trees, due to the increase in the variation in microhabitat (Buckland et al. 2014). The reason tracking tunnel visitation rates were higher in areas with smaller trees may be due to related factors that were not able to be considered in analysis, such as tree species. CFR tree TBA was not correlated with tracking tunnel visitation rates, which was expected, as this factor was only predicted to effect the use of those particular trees, and not the use of the general surrounding area.

Effects of surrounding vegetation types on CFR and tracking tunnel visitation

The vegetation types surrounding each CFR were revealed to affect CFR visitation rates by *H. duvaucelii*. Fern, flax, and tree trunks, roots and logs all showed positive correlations. This was expected, as these types of vegetation are known to be utilised by the species for both retreat sites and foraging habitat (van Winkel 2008). *Muehlenbeckia* and other shrubs showed negative correlations, which was unexpected as these types of vegetation were also thought to be utilised by the species (van Winkel 2008). A possible explanation for this could be that in areas where these vegetation types exist at a higher density, other more preferred types such as flax are in lower densities. Although each category was checked for correlations before the analysis was run, there may be more complex relationships that were not detected.

Surrounding vegetation also showed correlations with visitation rates to tracking tunnels. The same positive correlations with fern, flax, and tree trunks, roots and logs were revealed, as was expected based on the known preference of these vegetation types. The two vegetation types, herbs and grasses and other shrubs, both showed positive correlations with tracking tunnel visitation rates, which were not found to effect CFR visitation rates. These differences may suggest that areas with these vegetation types may be used more for foraging purposes but not as diurnal retreat sites. These findings are supported by another study which found that *H. duvaucelii* used different habitat types to varying degrees for the two different purposes of foraging and as diurnal retreat sites (van Winkel 2008). The utilisation of different habitat types

by these populations of *H. duvaucelii* was also investigated by another concurrent study (V. Glenday, *unpublished data)* which may assist in confirming why these differences occurred.

Effects of surrounding flax on CFR and tracking tunnel visitation

Both the size and distance of flax patches from sampling points showed a significant relationship with CFR visitation rates by geckos. CFRs surrounded by larger flax patches (at close proximity) had higher visitation rates than those surrounded by smaller patches. This was expected as larger flax patches likely attract more geckos, therefore increasing the likelihood of a gecko encountering and using a CFR. CFRs that were located further away from flax patches showed higher visitation rates than those located closer to flax patches. This was not expected as it contradicts the previous prediction that more flax would lead to a higher chance of encounter. Largest patch TBA showed the same correlations with tracking tunnel visitation rates, where larger patches resulted in higher visitation. Nearest flax patch distance had the opposite relationship, where those with closer patches showed more visitation. These findings suggest that more geckos are found in areas with more flax, and flax within a closer proximity to CFRs, but where flax is found closer to CFRs, geckos prefer to use flax as retreat sites rather than CFRs. Geckos may only be using CFRs when more optimal natural retreat sites, such as flax, are not available within the general area.

Radiotracking and chance encounters indicate that geckos were regularly found in flax patches, and would often move from CFRs into these habitats. Other populations of *H. duvaucelii* often use flax, and the level of this use may be explained by the density of flax within the area (Hoare et al. 2007, van Winkel 2008). The dense, thick nature of flax may provide safe refuges and beneficial microclimate such as increased humidity levels and insulation (van Winkel 2008). Habitat utilisation and dispersal behaviour of the two translocated populations was investigated more thoroughly in a concurrent study (V. Glenday, *unpublished data*), and results may provide further evidence of the preference for flax over other habitat types.

4.5 Conclusions

Double layered cell-foam retreats (CFRs) are useful tools for the PTM of *H. duvaucelii*. They showed a high level of functional integrity throughout the monitoring period, allowed for the successful capture of over 99% of geckos encountered, were used by all cohorts, and were continued to be visited by geckos throughout the entire study. A great proportion of geckos used a large percentage of CFRs at least once throughout the monitoring period. Furthermore, the CFRs were used by individuals as well as small groups. Juveniles and gravid females appeared to use CFRs more often than other cohorts, and juveniles appeared to actively seek out and continually utilise CFRs throughout the year. Both layers of the CFR were utilised equally by geckos. However, there was a preference for the upper areas of the CFR over the lower area. CFR use by adults was highest immediately following release and declined thereafter, which is likely due to the increasing level of dispersal away from monitoring grids, and the settlement of geckos at alternative, more optimal natural retreat sites. There was also a high level of spatial variation in CFR use. Differences in CFR and tracking tunnel use were able to be explained by differences in microhabitat, surrounding vegetation, and proximity to flax, the results of which demonstrate under which conditions CFRs are utilised by *H. duvaucelii*, therefore providing invaluable information for future studies. Geckos from 2006 grids rarely utilised CFRs, indicating that they may have limited benefit for monitoring low density, resident populations of *H. duvaucelii.* However, CFR use may be encouraged by releasing geckos into CFRs (see Chapter 3). Overall, this study provides important information for conservation practitioners to decide on the best monitoring programmes for highly cryptic, semi-arboreal lizard species.

Chapter 5   Cell foam retreat usage patterns of

invertebrates and other lizard species

5.1 Introduction

Invertebrates constitute the majority of biodiversity in terrestrial ecosystems, and insects alone account for more species and genetic variation (at the species level) than any other groups including plants (Hutcheson et al. 1999). Invertebrates play a key role in terrestrial ecosystem functioning through processes such as pollination, soil formation and fertility, organic decomposition, regulation of other populations through predation and parasitism, and providing food-sources for vertebrate species including lizards (Hutcheson et al. 1999, Ward and Larivière 2004). For example, invertebrates are both a key food source and competition for *H. duvaucelii*, and their monitoring can therefore contribute to determining the suitability of habitats for translocations of the species. Various invertebrates have also been used as indicator species for monitoring general ecosystem trends (Hutcheson et al. 1999). Because of all of these factors, the monitoring of terrestrial ecosystems cannot be accomplished without any monitoring of terrestrial invertebrates (Hutcheson et al. 1999).

Despite their level of importance there is currently a general lack of knowledge on invertebrates, with monitoring and management efforts in the past having been focused mainly on vertebrates and flowering plants (Ward and Larivière 2004). Such a lack of knowledge can be attributed in part to both the lack of value placed on invertebrates by the general public, as well as the fact that monitoring of such species is often considered too difficult (Ward and Larivière 2004). Currently popular methods for monitoring terrestrial invertebrates can result in high mortality

rates and by-catch (Pearce et al. 2005), and be time consuming and destructive to the environment. Other methods are designed to target particular species (e.g. Trewick & Morgan-Richards, 2000), often making them unsuitable for gathering information on terrestrial ecosystems as a whole.

Lizards also play an important role in ecosystem functioning, contributing to processes such as pollination, seed dispersal, and various roles within the food web (Whitaker 1987, Wotton 2002). A variety of methods for monitoring these species are available, but usually result in only a small subset of lizards being detected (e.g. diurnal species, ground-dwelling species, or either geckos and skinks but not both) and low-density populations are often missed (DOC 2012).

Long-term monitoring methods capable of detecting a range of important species and functional groups such as invertebrates and lizards would be highly beneficial for the monitoring and conservation of terrestrial ecosystems. Other favourable characteristics of monitoring techniques include being easily repeatable and therefore comparable over space and time, non-destructive and non-lethal, easily implemented, and low-cost. The ability to monitor both invertebrates and lizards using one method would also provide the opportunity to study the relationships that exist between the groups, such as predator-prey interactions or competition. The aim of this study was therefore to report the usefulness of one relatively new method for monitoring lizards and invertebrates within terrestrial ecosystems. Double-layered cell foam retreats (CFRs) were trialled for use in both the detection and monitoring of various invertebrate and lizard groups on two offshore predator-free islands.

My specific research objectives, and consequent investigations I will conduct, are as follows:

Objective 1) Report the usefulness of CFRs for monitoring lizard species

- *Report the density and species (other than H. duvaucelii) of lizards that used CFRs throughout the year*

- *Report the use of different CFR areas by lizards, and compare this use to the CFR microclimate*

Objective 2) Report the usefulness of CFRs for monitoring invertebrates

- *Report the use of CFRs by different invertebrate groups, especially Isoptera, Blattodea, weta (Orthoptera), spiders (Araneae), and giant centipedes (Chilopoda)*

- *Report the use of different CFR layers by invertebrate groups*

- *Report the seasonal and spatial variation in CFR use by invertebrates*

Objective 3) Investigate whether the seasonal and spatial variation in invertebrate densities encountered inside CFRs can be explained by environmental variables, or the ecology of the commonly occurring invertebrate groups

- *Investigate the effects of CFR tree species on total invertebrate densities, and on the densities of the most commonly occurring invertebrate groups*

- *Investigate the effects of CFR temperature and humidity on total invertebrate densities, and on densities of the most commonly occurring invertebrate groups*

- *Discuss the potential effects of ecology on the density of the most commonly occurring invertebrate groups*

5.2 Methods

Data were collected on Tiritiri Matangi and Motuora Islands, two predator-free offshore islands situated within the Hauraki Gulf (see section 2.2, 'Study Sites'). Five species of native lizard were present on both islands at the time of the study, the moko skink (*Oligosoma moco*), copper skink (*Oligosoma aeneum),* shore skink, common gecko (*Woodworthia maculatus*), and Duvaucel's gecko (*H. duvaucelii)* (Gardner-Gee et al. 2007, Ji et al. 2007, SOTM 2013). Tuatara were also present on Tiritiri Matangi Island (SOTM 2013). Shore skinks and common geckos primarily occupy rocky and sandy habitats in coastal areas, whereas moko skinks, copper skinks, and *H. duvaucelii* all inhabit forest and scrub habitat (Morris and Jewell 2008).

All lizard and invertebrate observational data were obtained through the monthly monitoring check sessions of CFRs conducted as part of a PTM programme for *H. duvaucelii* (see section 2.3, 'Research Framework'). *H. duvaucelii* were consequently also encountered inside CFRs. However, these findings are discussed in detail in a separate chapter (see Chapter 4). Monitoring grids containing CFRs were only set up within forest habitat, therefore only the three forest dwelling lizard species (moko skinks, copper skinks and *H. duvaucelii*) were expected to be encountered during monitoring. Information on temperature, humidity, and CFR tree species were obtained as part of the study investigating CFR use by *H. duvaucelii*, and detailed methods are covered in Chapter 4 (see section 4.2.2.1, 'CFR microhabitat factors').

5.2.1 Lizard sampling

When lizards (other than *H. duvaucelii*) were encountered within CFRs, information on their horizontal (upper, middle or lower third) and depth (between the skirts or against the tree) position within the CFR was noted. Date and time of capture was recorded, species identified, and multiple photographs were taken for later species confirmation. Individuals were only removed from CFRs to take photographs, and no morphometric measurements were taken.

5.2.2   Invertebrate sampling

Invertebrate data were collected during the first day of each monthly CFR check. Data were collected once per month from March to November (nine months) for all 195 CFRs on all eight monitoring grids (six 2013 gecko release sites, and two 2006 release sites). Invertebrates encountered between the skirts and against the tree were counted and recorded separately. They were classified into the narrowest groupings possible, either by order, class, or subclass. A total of twenty groups were classified (see Appendix X). Orders Orthoptera (weta) and Araneae (spiders) were divided into size classes due to their large variation in size, and importance as prey or potential competition to other invertebrates or lizards. Giant centipedes (*Cormocephalus rubriceps*) were recorded separately to other Chilopoda due to their ecological importance and rarity, and the known fact that species in the genus are known predators of small lizards (Kearney and Downes 1998, Morris and Jewell 2008). Spiders were divided into small (<1cm), medium (1-2cm), large (2-3cm) and extra-large (>3cm). From March to June Orthoptera were only divided into small (<1cm) and unknown (>1cm) size classes, and from July onwards divided further into small (<1cm), medium (1-3cm), large (3-5cm) and extra-large (>5cm). Size was based on body length only and was estimated by eye. Invertebrates were estimated to the exact number when there were less than twenty, to the closest ten when less than 200, and to the closest hundred when more.

5.2.3   Data analysis

All data analysis was conducted using the computer software program IMB SPSS statistics version 21. For all statistical tests p-values less than 0.05 (95% level) were considered to represent statistical significance. CFRs for which invertebrates could not be sampled every month were excluded from analysis (one was torn down in a storm).

Seasonal variation was investigated by calculating the average densities of the five most numerous invertebrate groups (Isoptera, Blattodea, Orthoptera, Araneae, and Coleoptera), as

well as the average total density, and richness (number of invertebrate groups) for each separate sampling month. Averages were calculated on a per-CFR and per check session basis. Spatial variation was investigated by calculating the average total density and richness for each of the 195 CFRs separately, which were also calculated on a per-check session basis. For each individual CFR, average densities of the five most numerous invertebrate groups, average total density, and average richness were all compared to the average CFR temperature and humidity levels using multiple Pearson's correlations. For all significant two-way relationships ($p<0.05$), positive r-values were considered to represent a positive relationship, and negative values a negative relationship. Average temperature and humidity levels for each CFR were calculated using methods described in Chapter 4 (see section 4.2.2.1, 'CFR microhabitat factors'). The relationship between tree species and average invertebrate densities was explored firstly by running a Kruskal Wallis test. When a significant overall effect of tree species was revealed, differences in invertebrate densities for each tree species were assessed by inspecting the 95% confidence intervals of the means, and the mean ±1 SE (standard error). Species with non-overlapping 95% confidence intervals were considered to have significantly different invertebrate densities, and those with overlapping means ±1 SE were considered to not have significantly different densities.

5.4 Results

5.4.1 CFR use by lizards

Two species of native skink were encountered in CFRs on Motuora Island on six different occasions, in three different CFRs (Table 5.1). No skinks were ever reported in CFRs on Tiritiri Matangi Island. During this study both copper skinks (Figure 5.1) and moko skinks (Figure 5.2) were encountered in some of the CFRs on multiple occasions, and they used a variety of positions within the CFRs (Table 5.1). The CFRs used multiple times in the same monthly check may have been used by the same individual each time. However, this could not be determined as they were not individually identifiable. All three of the CFRs used were located on the border of the forest and open areas of grass or flax. *H. duvaucelii* were also encountered inside CFRs (see Chapter 4).

5.4.1.1 *Position in CFRs and corresponding microhabitat*

On each of the four occasions where ad hoc humidity readings were taken, lizards were encountered in the depth position with the highest humidity level of the two options (Table 5.1). The chosen position also always had either equal or higher humidity levels than the surrounding air (Table 5.1). On each of the five occasions where ad hoc temperature readings were available, lizards were encountered in the depth position with either equal or lower temperatures of the two areas (Table 5.1). There were no consistent differences in temperature between the chosen position in the CFR and the surrounding air (Table 5.1)

Figure 5.1. A copper skink (*Oligosoma aeneum*) found in a CFR. Found in CFR M2 E0 on 20/9/13 at 5pm.
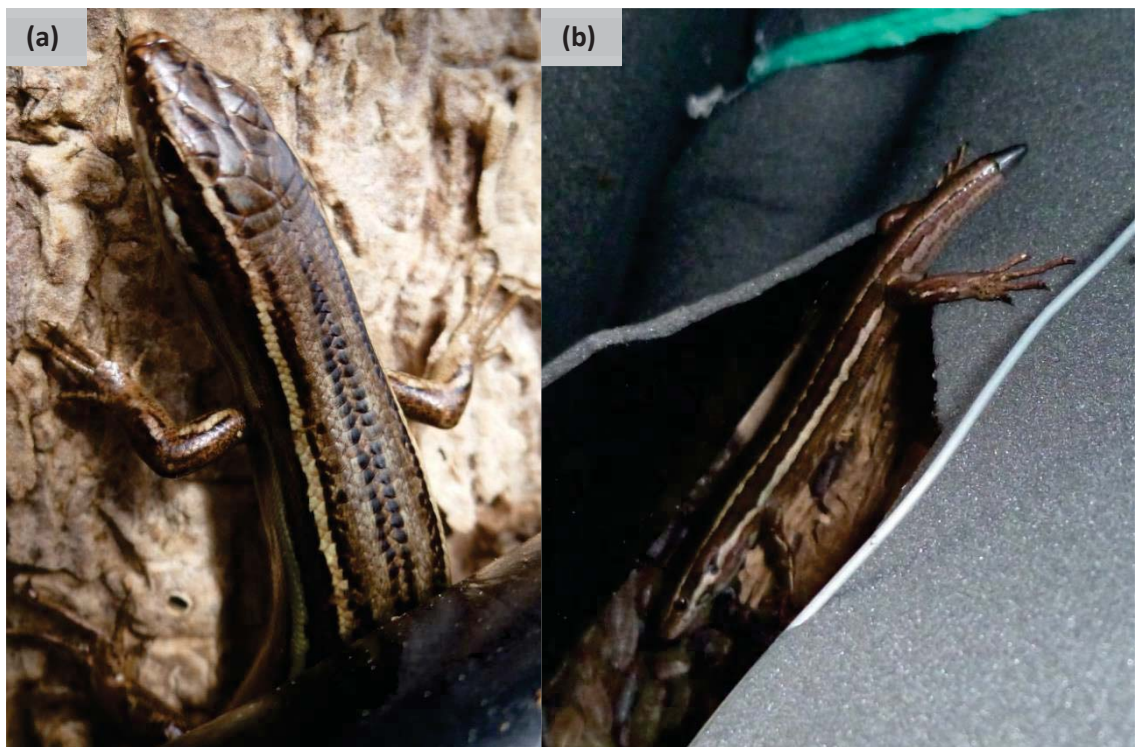
Figure 5.2. Two moko skinks (*Oligosoma moco*) found in CFRs. (a) Found 19/8/13 at 1pm in shelter M2 C60, (b) found 8/6/13 at 4:30pm.

Table 5.1. Use of three CFRs by two native skink species, including their positions within the CFRs and the corresponding temperature and humidity readings of the CFR at the time the CFR was checked. Underlined temperature and humidity readings represent the area the individual was encountered in, and gaps in data represent days where readings were not measured. T= tree, S= skirts.

Date	Shelter	Species		Vertical Position	Depth Position	Time	Temperature			Humidity		
							Skirts	Tree	Air	Skirts	Tree	Air
19/08/13	M2 C60	moko skink	*Oligosoma moco*	upper	T	13:00	18.9	_18.3_	18.0	72	_86.5_	76
21/08/13	M2 C60	moko skink	*Oligosoma moco*	upper	S	09:43	_12.8_	12.8	13.2	_94.1_	94	94.1
23/08/13	M2 C60	moko skink	*Oligosoma moco*	upper	T	14:28	18.9	_18.7_	16.6	68	_84_	73.4
20/09/13	M2 E0	copper skink	*Oligosoma aeneum*	lower	S	15:59	_18.2_	18.2	18.0			
24/09/13	M2 E0	copper skink	*Oligosoma aeneum*	middle	T							
14/10/13	M4 E15	moko skink	*Oligosoma moco*	middle	T	13:52	19.2	_19.2_	19.3	68.1	_68.3_	68.2
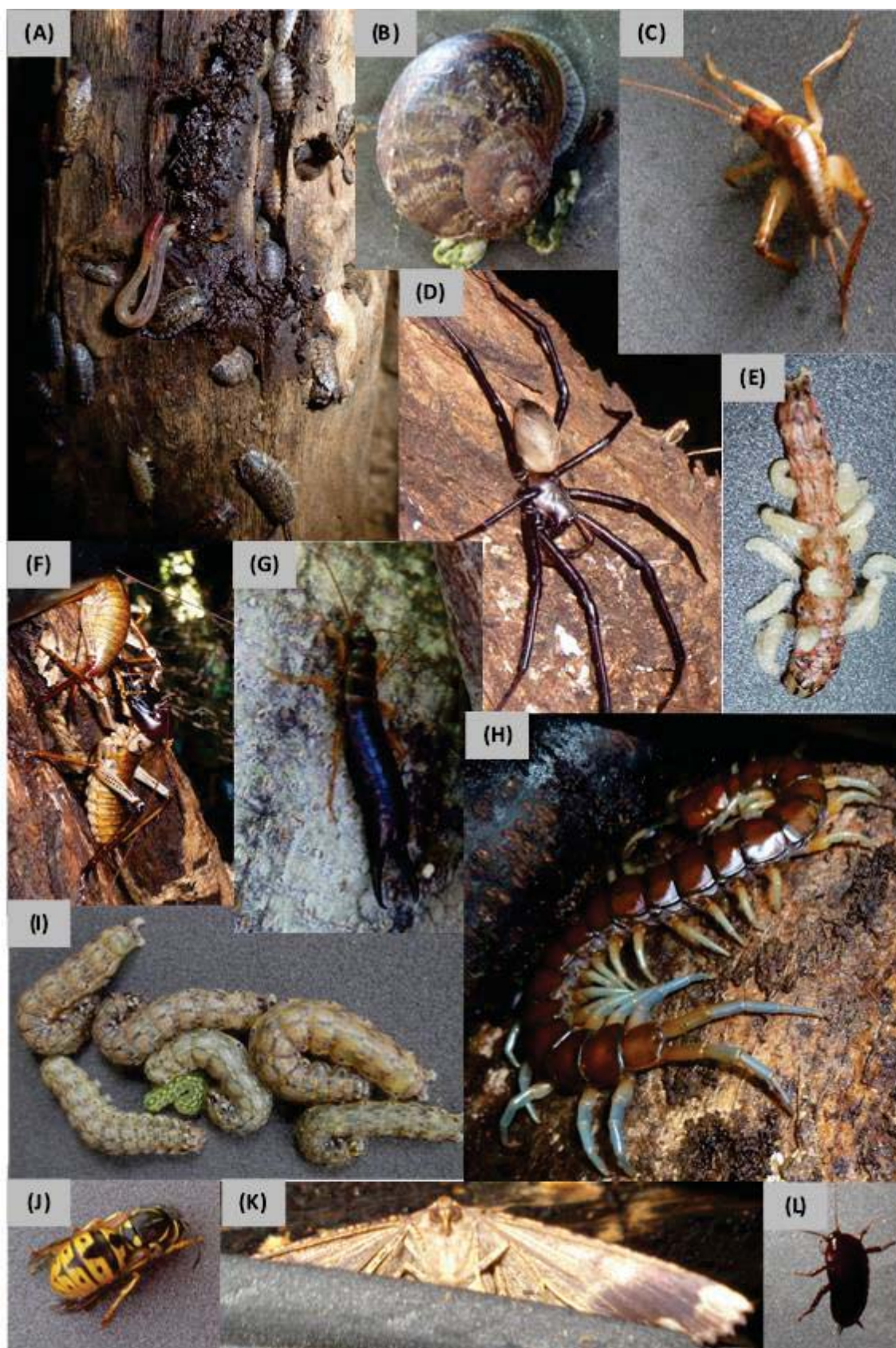
Figure 5.3. Photos of various invertebrates found inside CFRs. (A) Isoptera and Oligochaeta, (B) Gastropoda, (C) small Orthoptera, (D) Araneae, (E) unidentified larvae, (F) large Orthoptera, (G) Dermaptera, (H) giant Chilopoda, (I) more unidentified larvae, (J) Hymenoptera, (K) Lepidoptera, and (L) Blattodea. Photos by author and Vivienne Glenday.

5.4.2 CFR use by invertebrates

Over the entire nine months of invertebrate sampling (March to November 2013) a large variety of invertebrates were encountered inside the CFRs (Figure 5.3). Overall there were twenty different groups of invertebrates encountered (Appendix X). An average of 75 invertebrates were encountered per CFR per check session (131,194 invertebrates inside 195 CFRs over nine monthly checks). The groups Isopoda and Blattodea accounted for 79.8% and 15.7% of the total invertebrate density respectively, together making up 95.5% (Appendix X). The groups Coleoptera (1.6%), Orthoptera (1.4%) and Araneae (0.8%) were the next most numerous, together making up 3.8% of the remaining 4.5% of total invertebrate density (Appendix X). The other fifteen invertebrate groups together accounted for only 0.7% of the total density (Appendix X).

Overall, 75% of the total invertebrate density was encountered between the inner skirt and the tree, with only 25% encountered between the two skirts (Appendix X). However, for each invertebrate group the spread of individuals between the two depth positions differed considerably (Appendix X). The majority of individuals were encountered between the inner skirt and the tree for the groups Isopoda (77%), Blattodea (65%), Coleoptera (91%) and Orthoptera (87%), whereas the majority of individuals were encountered between the two skirts for the groups Lepidoptera (70%), Diptera (100%) and unknown larvae (79%) (Appendix X). Other groups such as Araneae had a relatively equal spread of individuals between the two depth regions (Appendix X).

Cockroaches were most commonly encountered between the inner skirt and the tree (65% of total density) (Appendix X). Weta were encountered mostly between the inner skirt and the tree (87% of total density) (Appendix X). The >3 cm size class of spiders were encountered against the tree 91% of the time, compared to 61% of the 2-3 cm and 1-2 cm spiders, and 20% of the <1 cm spiders (Appendix X).

Observations of invertebrate species inhabiting CFRs

Cockroaches inhabiting CFRs throughout the year included native bush cockroaches (*Celoblatta* species), and black cockroaches (*Platyzosteria novaeseelandiae*) (Figure 5.6). Weta commonly inhabiting CFRs throughout the monitoring period included tree weta and cave weta (Figure 5.5a and b). Weta were regularly observed huddled together in groups, sometimes numbering over twenty (Figure 5.5c). The same sized groups often occupied the same CFRs on consecutive check occasions, suggesting that groups may use CFRs for semi-permanent residence. Spiders inhabiting CFRs throughout the year included slater spiders (*Dysdera crocata*), nursery-web spiders (*Dolomedes* species) and most commonly sheet-web spiders (*Cambridgea* species) (Figure 5.4). Both nursery-web and sheet-web spiders often took up permanent residence within CFRs and laid egg sacks throughout the year.

Multiple giant centipedes *(*Figure 5.3H*)* were encountered inside CFRs on both Tiritiri Matangi and Motuora Islands between May and November. One individual was encountered on Motuora Island on 14/10/13. Three individuals were encountered on Tiritiri Matangi Island, two individuals in the same CFR on the 16/5/13 and 10/11/13, and one in another CFR on 12/8/13. All four individuals were encountered against the tree in the CFRs (Appendix X). All individuals were thought to be adults and were estimated to measure more than 15 cm in length.

Figure 5.6. Photos of cockroaches found inside CFRs.
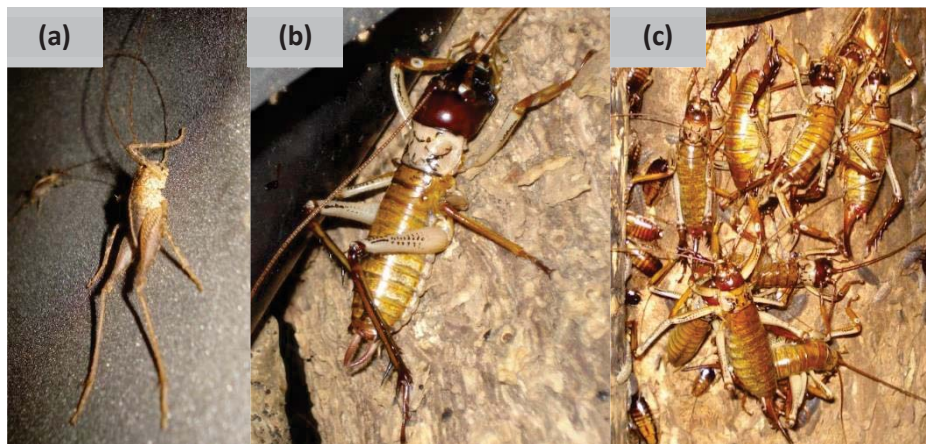
Figure 5.5. Photos of weta found inside CFRs. (a) Two small cave weta, (b) a large individual male tree weta, and (c) a large group of tree weta.
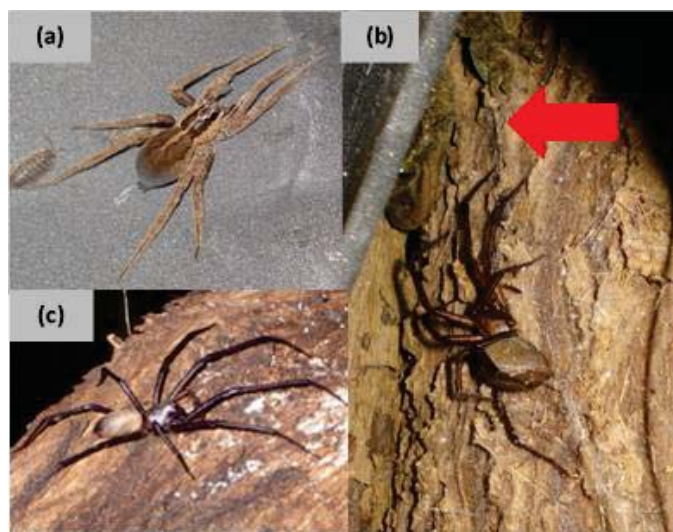
Figure 5.4. Photos of spiders found inside CFRs. (a) A nursery-web spider and (b and c) two sheet-web spiders. Image (b) also shows the coexistence of a Duvaucel's gecko (indicated by arrow) and large sheet-web spider inside a CFR.

5.4.2.1 *Relationship between tree species and invertebrate density*

Across the two islands there were fourteen tree species (plus one unidentifiable dead tree) that CFRs were placed on (Appendix Y). The most common species were the cabbage tree (59/195), and the pohutukawa tree (52/195) (Appendix Y). Tree species composition varied across monitoring grids and between both islands (see Appendix Z). A Kruskal Wallis test showed that average invertebrate density varied significantly between CFR tree species (X^2= 79.596, df=14, p<0.001). A comparison of 95% confidence intervals of the mean invertebrate densities showed that cabbage trees had higher invertebrate densities than all other CFR tree species (Appendix Y). Various other species were also found to differ in invertebrate densities (non-overlapping 95% CI's), and others found to be no different (overlapping ±1 SE of means) (Appendix Y).

5.4.2.2 *Invertebrate Group Correlations*

All two-way relationships between the five main groups of invertebrates (Isopoda, Blattodea, Orthoptera, Coleoptera and Araneae) showed positive correlations, excluding that between Coleoptera and Araneae which showed no significant relationship (Table 5.2).

5.4.2.3 *Temperature and Humidity Correlations*

Neither average invertebrate richness nor density were correlated with average temperature (Table 5.2). Orthoptera were the only of the five main groups that showed a significant correlation with average temperature, which was weak and negative (r=-0.189, p=0.008) (Table 5.2). Both richness (r=0.528, p<0.001) and density (r=0.251, p<0.001) were positively correlated with average humidity (Table 5.2). Isoptera (r=0.207, p=0.004), Blattodea (r=0.446, <0.001), Orthoptera (r=0.384, p<0.001) and Araneae (r=0.332, p<0.001) were all positively correlated with average humidity, whereas Coleoptera were not significantly correlated with average humidity (r=0.136, p=0.059) (Table 5.2).

5.4.2.4   *Spatial Variation (Islands, Grids and Individual CFRs)*

There was a high level of variation in invertebrate density and richness between islands, release grids, and individual CFRs (see Appendix AA for more information on individual CFR differences). On Tiritiri Matangi Island invertebrate densities were generally much lower than those on Motuora Island (Figure 5.7). However, there was no noticeable difference in invertebrate richness (Figure 5.8). On Motuora Island average densities were highest at grid M2 and decreased throughout grids M3, M4 and M1 respectively (Appendix BB). On Tiritiri Matangi Island densities were highest at grid T1 and decreased throughout grids T2, T3 and T4 respectively (Appendix BB). The same trends were seen in average invertebrate richness for grids on both islands, but differences were less extreme (Appendix BB).

Table 5.2. Results of multiple Pearson's correlations run between the densities of the five main invertebrate groups, total density and richness, and average temperature and humidity. Significant correlations are highlighted in bold, and negative correlations indicated in brackets .

		Isoptera	Blattodea	Orthoptera	Coleoptera	Araneae	Density	Richness	Temperature
Blattodea	r	0.440							
	p	**<0.001**							
Orthoptera	r	0.429	0.669						
	p	**<0.001**	**<0.001**						
Coleoptera	r	0.297	0.427	0.334					
	p	**<0.001**	**<0.001**	**<0.001**					
Araneae	r	0.172	0.219	0.160	0.024				
	p	**0.016**	**0.002**	**0.026**	0.743				
Temperature	r	(-0.113)	(-0.095)	(-0.189)	0.098	(-0.136)	(-0.117)	(-0.133)	
	p	0.116	0.188	**0.008**	0.173	0.059	0.105	0.065	
Humidity	r	0.207	0.446	0.384	0.136	0.332	0.251	0.528	-0.297
	p	**0.004**	**<0.001**	**<0.001**	0.059	**<0.001**	**<0.001**	**<0.001**	**<0.001**
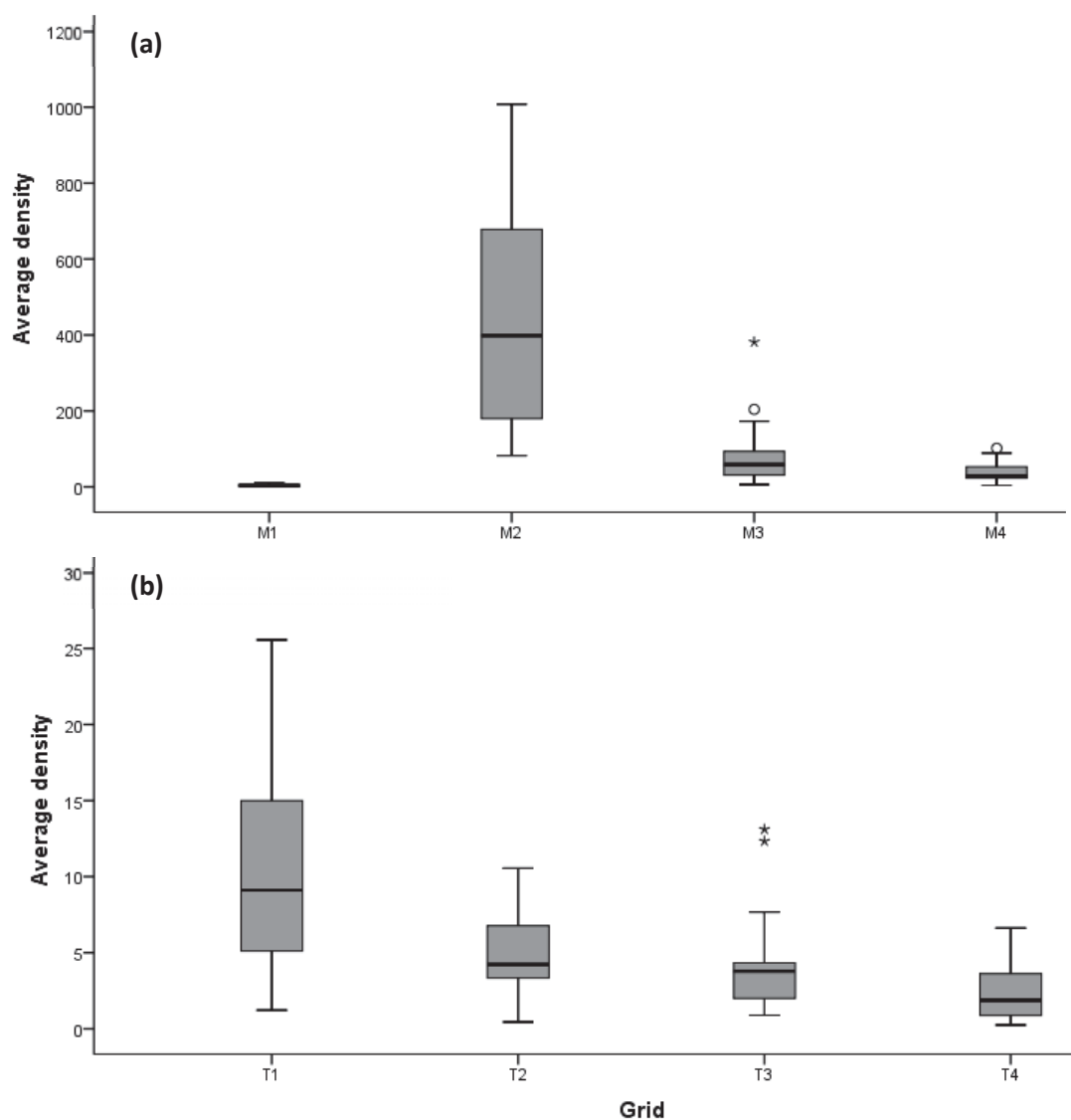
Figure 5.7. Boxplot of average invertebrate densities per CFR per check session for each monitoring grid. (a) Motuora Island, (b) Tiritiri Matangi Island. Asterisks indicate outliers, circles suspected outliers, whiskers the minimum and maximum values, boxes the upper and lower quartile, and the central lines the median.
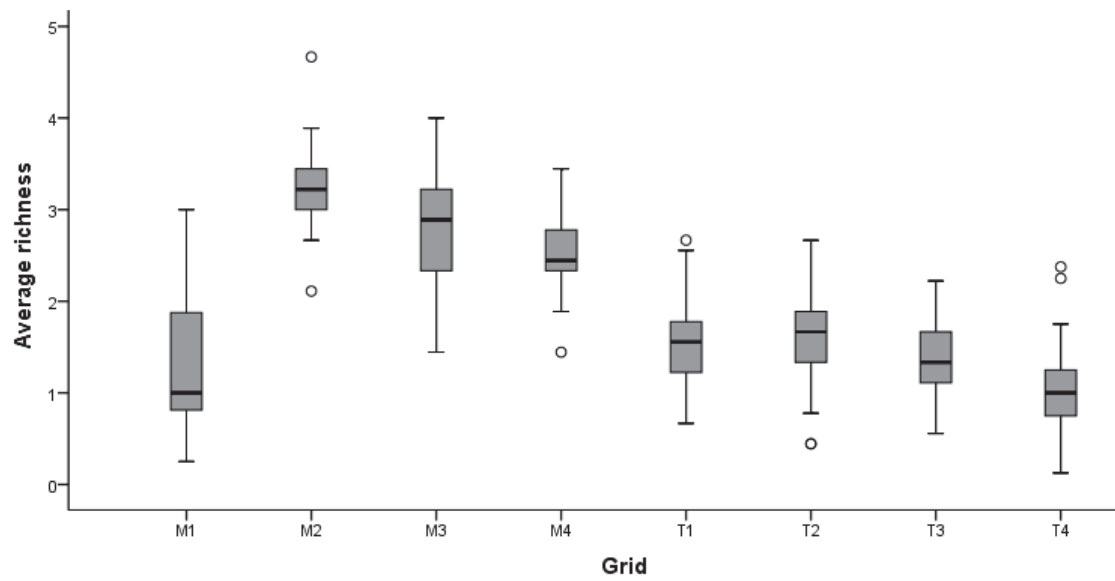
Figure 5.8. Boxplots of average invertebrate richness per CFR per check session for each monitoring grid on Motuora and Tiritiri Matangi Islands. Circles indicate suspected outliers, whiskers the minimum and maximum values, boxes the upper and lower quartile, and the central lines the median.

5.4.2.5 *Seasonal Variation*

The average density of invertebrates per CFR showed large seasonal variation (Figure 5.9). Densities were very low over the autumn months of March and April, and increased slightly in late autumn (May) (Figure 5.9). Numbers then dipped again in June, then peaked in mid-winter (July), followed by a gradual decrease again throughout spring (September, October and November) (Figure 5.9). Species richness showed a general increase throughout the year, reached a maximum around August, and remaining stable throughout the remaining three months (Figure 5.10).

Densities of Isoptera and Blattodea followed approximately the same trends throughout the sampling year (Figure 5.11 and Figure 5.12). During March and April densities were very low, then fluctuated but generally increased until July, then declined gradually until the end of sampling in November (Figure 5.11 and Figure 5.12). Coleoptera appeared in CFRs for the first time in June, thereafter their density increased slightly until October, then declined marginally in November (Figure 5.13).

Densities of Orthoptera of different size classes differed during each month (Figure 5.14). Densities for small weta were highest during March and May, then declined and remained at a stable level throughout the remainder of the year (Figure 5.14). There was also a significant dip in density during April. Larger weta densities were stable throughout the year (Figure 5.14).

Densities of Araneae of different size classes generally remained stable throughout the year (Figure 5.15). Small spider densities were stable from March to June, increased from July to October, and dropped back down in November (Figure 5.15). There was a slight increase in medium sized spiders in July, then densities dropped back down again in the following months (Figure 5.15).
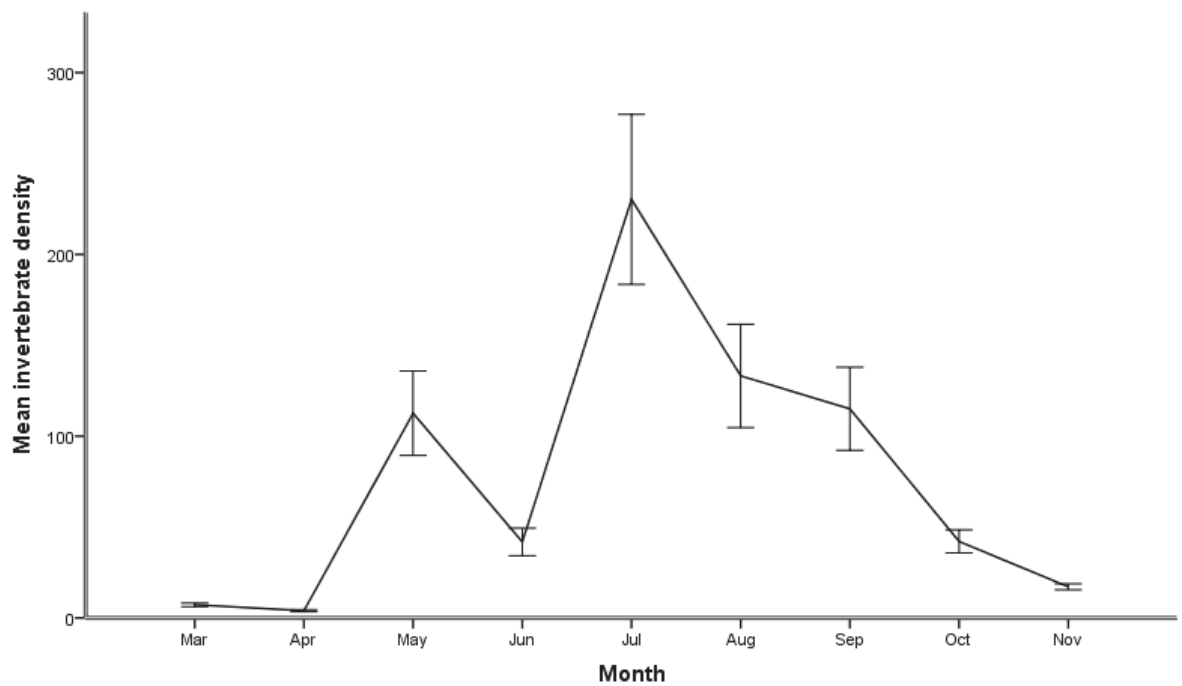
Figure 5.9. Mean invertebrate density per CFR per check session for each monitoring month. Error bars indicate the mean ±1 SE.
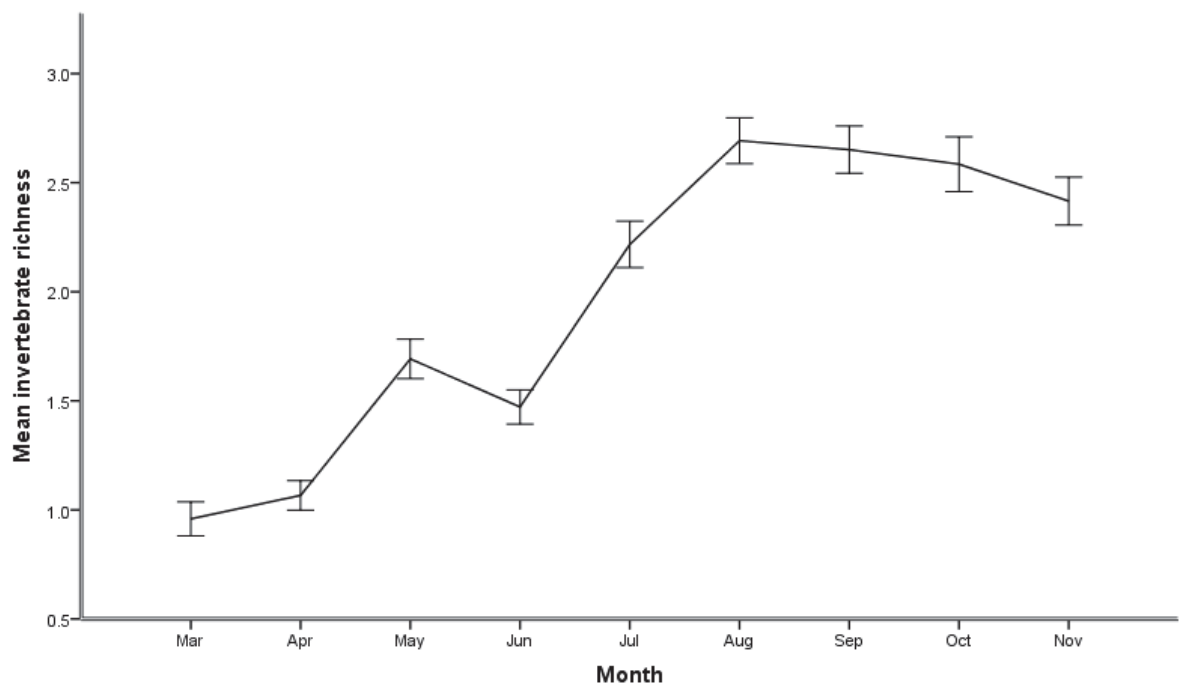
Figure 5.10. Mean invertebrate richness per CFR per check session for each monitoring month. Error bars indicate the mean ±1 SE.

125
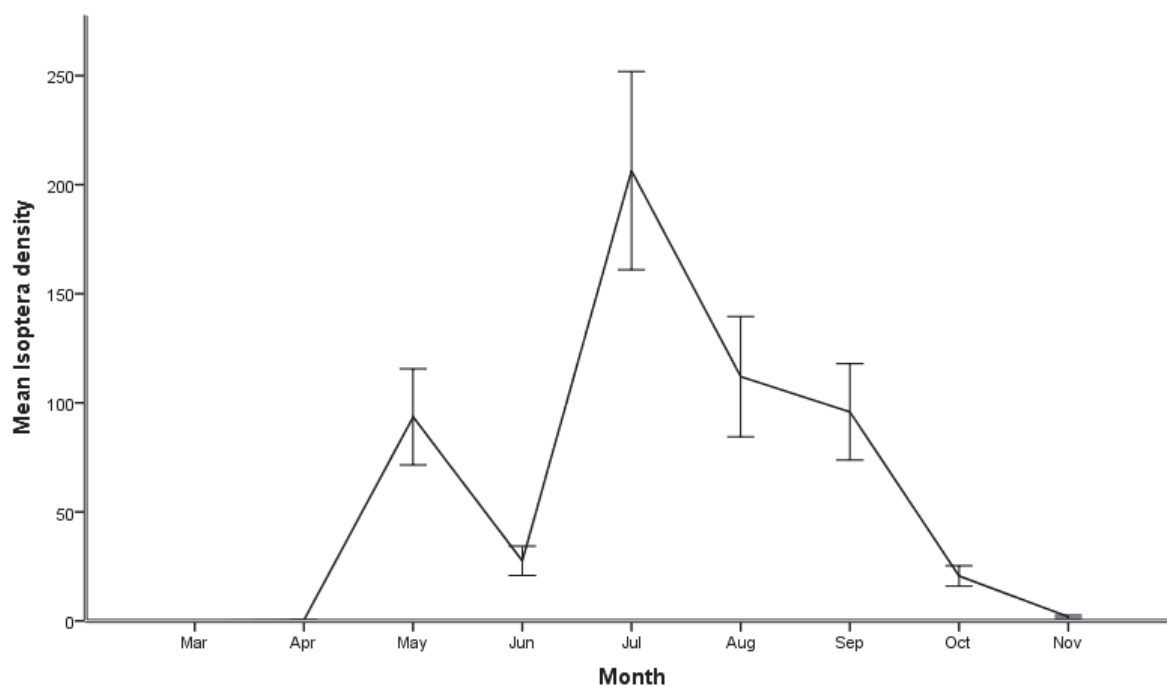
Figure 5.11. Mean Isoptera density per CFR per check session for each monitoring month. Error bars indicate the mean ±1 SE.
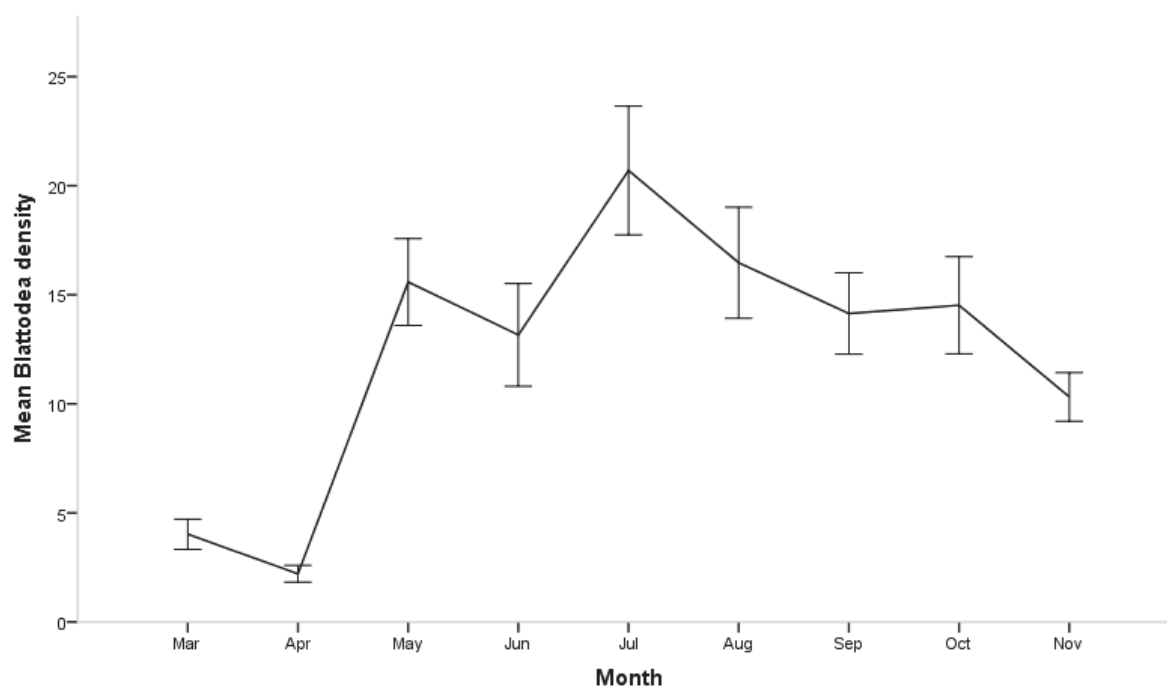
Figure 5.12. Mean Blattodea density per CFR per check session for each monitoring month. Error bars indicate the mean ±1 SE.
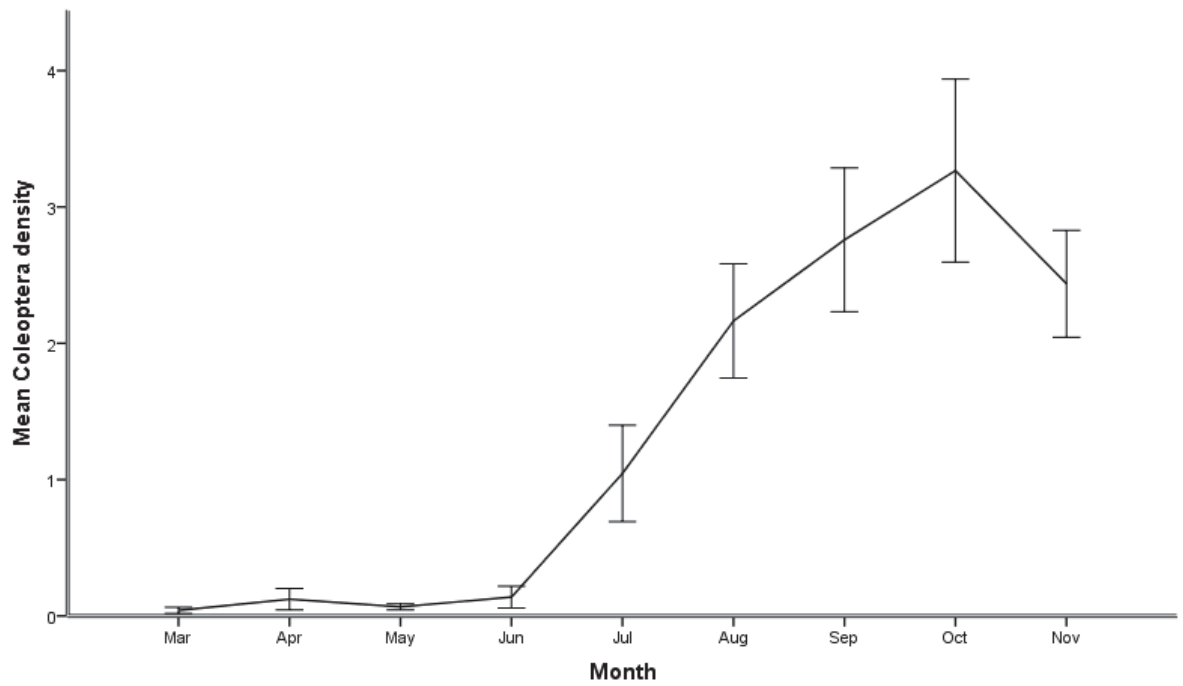
Figure 5.13. Mean Coleoptera density per CFR per check session for each monitoring month. Error bars indicate the mean ±1 SE.
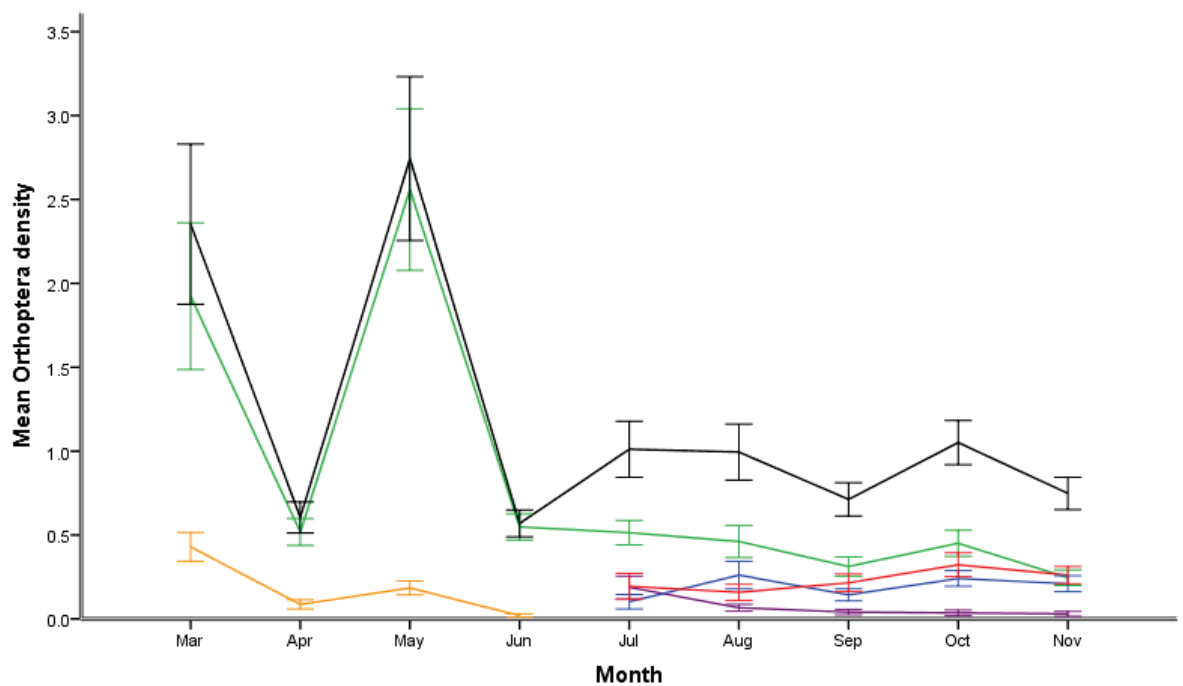
Figure 5.14. Mean total number of Orthoptera per CFR per check session for each monitoring month, in total and for each size class separately. Total=black, small=green, medium=purple, large=blue, extra-large=red, unknown=orange. (Note: after June the unknown larger size class was further divided into medium, large and extra-large).
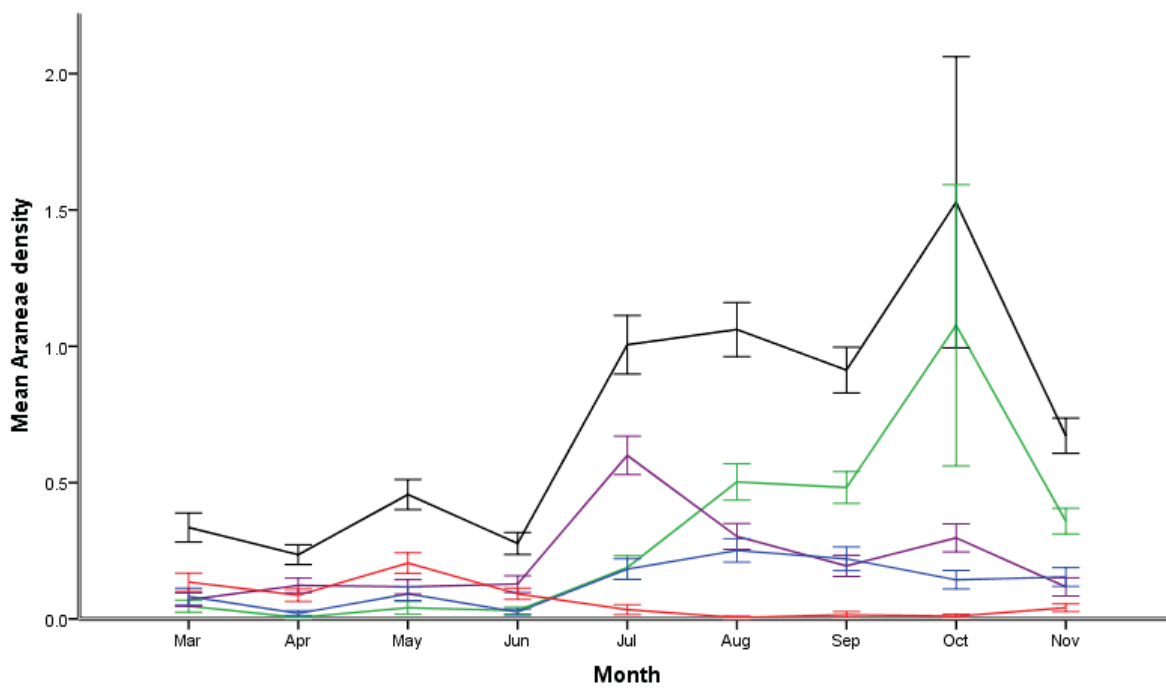
Figure 5.15. Mean total number of Araneae per CFR per check session for each monitoring month, in total and for each size class separately. Total=black, small=green, medium=purple, large=blue, extra-large=red.

5.5 Discussion

5.5.1   Use of CFRs by other lizard species

Moko skinks and copper skinks were encountered inside CFRs on multiple occasions on Motuora Island. Unidentified but presumably the same species of skinks were found inside other types of artificial retreats in the past on both Tiritiri Matangi and Motuora Island (van Winkel 2008). However, use was mainly restricted to those placed at ground level (van Winkel 2008). Maximum occupancy rates by skinks were higher in artificial retreats used in the past (4.5%) compared to those used in this study (1%). This difference is likely due to the placement of retreats in more suitable habitat, rather than a higher attractiveness of previous designs. As copper and moko skinks are primarily ground dwelling species, it is expected that they utilise artificial retreats located closer to the ground more than those located higher off the ground. It is also possible that previously used artificial retreats were placed in closer proximity to more suitable vegetation such as flax and low-lying scrub, as these habitat types were prominent within the monitoring grids used in the previous study.

The utilisation of CFRs by moko skinks and copper skinks as well as *H. duvaucelii* (see Chapter 4) suggests that they may be suitable for monitoring a variety of lizard species. Because both species of skink are diurnal and primarily ground-dwelling in nature (Morris and Jewell 2008), and *H. duvaucelii* are arboreal and nocturnal, this finding is particularly important as it suggests that species of various habits may be detectable using this method. Bell (2009) also suggested the potential usefulness of CFRs for monitoring a variety of lizards, after finding that three different species of arboreal, nocturnal, forest dwelling gecko (*H. duvaucelii,* Pacific gecko (*Dactylocnemis pacificus),* and Forest gecko (*Mokopirirakau granulatus)*) utilised single layered CFRs. The ability to detect and monitor a variety of lizard species using CFRs may also provide the opportunity to study important

relationships between the species. For example, *H. duvaucelii* have been known to prey on smaller

lizards (Barwick 1982).

Utilisation of the different CFR layers may be related to the thermoregulation benefits of each layer.

All six skinks encountered inside CFRs sheltered in the layer that had both the highest humidity and

lowest temperature of the two layers, and also had higher humidity levels when compared to the

surrounding air. This suggests that skinks are using CFRs to cool down and avoid dehydration,

therefore indicating thermoregulatory behaviour. Retreat site selection in various reptile species is

commonly effected by thermoregulatory benefits, as species generally select for warmer rather

than cooler temperatures (Schlesinger and Shine 1994, Kearney 2002, Goldsbrough et al. 2006,

Andersson et al. 2010), as was the case in this study. However, other studies show that lizards do

occasionally select for cooler shelter areas when they are within their preferred thermal range

(Thierry et al. 2009). *H. duvaucelii* in this study also preferred to use cooler CFRs (see Chapter 4).

However, as skinks were only encountered inside CFRs on six occasions throughout the entire nine

months of monitoring, and temperature was not recorded in all six cases, further research is

required to confirm the significance of the apparent trends.

Skinks were encountered in CFRs at various times throughout the day, ranging from morning to late

afternoon. As both species are diurnal they are not generally expected to use retreats during the

day. This suggests that they may be using CFRs for a variety of day activities. For example, the

potential use of CFRs for thermoregulatory purposes was discussed earlier. Various other lizard

species are known to use artificial retreats for a variety of reasons including aggregation (Shah et al.

2003), social interactions (Schlesinger and Shine 1994), thermoregulation, and predator avoidance

(Downes and Shine 1998, Cooper et al. 1999, Amo et al. 2004). Skinks may have also visited CFRs to

feed on invertebrates. The occurrence of skinks in CFRs in the late afternoon may suggest that CFRs

are also being used as nocturnal retreat sites. However, as no CFR checks were conducted at night, further research is required to investigate the possibility. Results also indicate that the same individuals may use the same CFRs over consecutive days, suggesting a preference for certain CFRs. However, skinks were not individually identifiable and sample sizes not large enough to run statistical analyses, so further research is required to test this hypothesis.

No skinks were encountered inside CFRs at any stage on Tiritiri Matangi Island. This could firstly be caused by the differential placement of CFRs in relation to suitable habitat, with those placed closer to suitable habitat being more likely to detect existing populations. Both copper skinks and moko skinks are known to favour habitats in open areas, with large amounts of leaf litter and low-lying, dense vegetation (Morris and Jewell 2008, Lindsey and Morris 2011). The CFRs in which skinks were encountered on Motuora Island were all located on the fringe of the forest habitat surrounded by either grassland or flax, suggesting that this may have had some effect on the use of CFRs by skinks. Detectability of the two skink species in the future therefore may be improved by installing CFRs within close proximity to suitable skink habitat. However, as the proximity of CFRs to certain habitat types was not measured during this study, further research is required to confirm whether this factor effects CFR visitation by skinks. Differences in detection of skinks across the two islands could also be due to differences in species densities between the two study islands caused by various factors such as predator, competitor, or prey abundance, or differences in habitat suitability. For example, Tiritiri Matangi Island has a much higher diversity and density of insectivorous birds including morepork (*Ninox novaeseelandiae*), and is also home to tuatara (*S. punctatus*), both of which may have reduced lizard densities through direct predation or competition for resources (van Winkel 2008). The low level of CFR use by these species may also be due to the resident populations taking a longer period of time to discover and consequently use the CFRs. CFRs should therefore be

monitored over several years to determine their suitability for the long-term monitoring of populations of lizards.

5.5.2   Use of CFRs by invertebrates

A variety of invertebrates utilised CFRs throughout the monitoring period. This suggests that CFRs are a suitable tool to monitor invertebrates, as similar groups are encountered in other types of artificial shelters. For example, CFRs used in this study were able to detect and monitor weta throughout the nine month monitoring period, and appeared to be equally as successful as wooden tree mounts and artificial roost designed specifically for monitoring the species (Trewick and Morgan-Richards 2000, Bowie et al. 2006). Other types of artificial retreats designed to monitor reptiles have also been used by a variety of invertebrates (Webb and Shine 2000, van Winkel 2008, Bell 2009, Croak et al. 2010).

The invertebrate assemblage encountered in CFRs was comprised of primarily terrestrial groups such as slaters, cockroaches, weta, spiders, beetles, centipedes, millipedes, worms, slugs, and snails. A small number of flying invertebrates including moths, flies, wasps, and bees were also encountered. These findings indicate that CFRs could be a valuable tool for invertebrate monitoring. However, the ability to monitor changes in population densities may only be possible for some terrestrial groups, whereas monitoring of flying groups may be restricted to species detection. A trial study by Bell (2009) using single layered cell foam covers also found a variety of invertebrate species inhabiting the structures. However, all invertebrate groups were primarily ground-dwelling, with no flying invertebrate groups encountered (not including ground beetles). This may be related to differences in microclimate between each study, or the single layer design of the CFRs, which reduces the amount of space and potentially variety of microhabitat available. As most groups of invertebrates in this study were encountered under both layers of the CFRs throughout the year,

this also supports the idea that the double layered design of the CFRs is an effective and worthwhile modification that benefits the monitoring ability of a variety of invertebrate groups.

Many lizard species such as *H. duvaucelii* are known frequently prey on a range of the invertebrates encountered inside CFRs throughout the monitoring period (Barwick 1982). Because these invertebrates as well as *H. duvaucelii* CFRs (see Chapter 4) were able to be monitored, CFRs provide valuable opportunity to study the relationships between *H. duvaucelii* and their invertebrate prey.

The ability to continuously monitor invertebrate numbers throughout the year is highly beneficial, as it permits the detection of seasonal trends in density and diversity. One of the reasons for this is that live sampling was used, which is regarded as a highly important feature of successful long-term monitoring techniques for invertebrates (Bowie et al. 2006). There also appeared to be a preference for CFRs by some invertebrates, as many individuals were observed to quickly return to their original positions after falling or moving out of CFRs during checks, and the same invertebrates also appeared to occupy CFRs over many consecutive months. The ability to collect continuous seasonal information could prove to be highly beneficial for studying various aspects of invertebrate populations such as behaviour and ecology.

The greatest densities of invertebrates were encountered between the inner skirt of the CFR and the tree. This is due to the bulk of the overall invertebrate density falling into the groups Isoptera and Blattodea, both of which were primarily encountered between the second skirt and the tree. This finding was expected for three reasons. Firstly, both groups of invertebrates feed on decaying material found in damp forest environments (Forster and Forster 1970, Parkinson and Horne 2007), and the tree surface of many CFRs often remained damp for some time following rainfall. Secondly, loose bark is optimal habitat for both Blattodea and Isoptera (Forster and Forster 1970, Early and Horne 2009), and the space between the CFR and the tree trunk is assumed to provide a very similar

microhabitat. Finally, the tree area of the CFR is theoretically more accessible to these crawling groups which gain access by climbing up or down the trunk of the tree.

Other invertebrate groups such as Lepidoptera, Diptera and (unknown) larvae were primarily encountered between the skirts of the CFRs. This could also be due to the different microhabitat traits or ease of accessibility of the CFR layers. Species within all three groups are likely to prefer the drier environment provided by the skirts area. As all three groups consist mainly of flying species (larvae cannot be confirmed but are thought to be mostly from Lepidoptera or Diptera species), access to CFRs would likely have been from flight rather than crawling up the tree trunk. The area between the skirts often had larger openings compared to the tree area therefore providing easier access. These differences in habitat preferences and method of access both provide an explanation for the different proportional use of the two CFR areas by flying and terrestrial invertebrate groups. This indicates that the double layered aspect of the design is highly beneficial for allowing the detection of flying invertebrate groups.

5.5.2.1 *CFR use by weta (Orthoptera)*

Weta are an important species to monitor in forest ecosystems as they can be used as indicators of ecosystem health (Spurr and Drew 1999, Trewick and Morgan-Richards 2000). They are however considered to be a difficult group to monitor in the wild due to their nocturnal and arboreal habits (Trewick and Morgan-Richards 2000, Watts et al. 2011). They were often found in social aggregations, but also individually inside CFRs. Weta seemed to remain in CFRs over multiple days or even months, and were even observed to immediately return to their positions after being disturbed. Some weta species have been observed to be 'faithful' to other types of artificial shelters, having been seen in the same places over sequential checks (Trewick and Morgan-Richards 2000). The combination of faithfulness and sociality of weta in CFRs provides excellent opportunity to study

various aspects of the social behaviour of the species utilising the CFRs. Other techniques used to monitor weta include a novel method of footprint tracking tunnels, a lethal method of pitfall trapping, spotlight searching, and the use of in situ monitoring using artificial roost sites (Trewick and Morgan-Richards 2000, Bowie et al. 2006, Watts et al. 2011). When considering the benefits of each method in terms of effort required, amount and types of information returned, and lethality of sampling, use of CFRs appears at least equally or even more beneficial than alternative methods for both the detection and monitoring of various weta species.

The majority of total weta density was encountered against the tree, which was unexpected as weta are thought to prefer dry environments (Lindsey and Morris 2011). This could suggest that other factors such as the physical aspects of the tree area (tighter spaces and narrower openings) are more important than microhabitat features such as temperature and humidity. Tree and cave weta are often found in tight crevices with narrow openings such as hollow logs and holes in trunks or branches (Gibbs and Morris 1998, Parkinson and Horne 2007), habitat which is very similar to that provided by the tree area of the CFR. However, as physical dimensions of CFRs were not measured in this study, further research into the structural preferences of weta are required to investigate these possibilities. Weta encountered against the tree were usually in large social groupings, whereas those found between the skirts were single individuals. The proportional use of the two different CFR areas also differed between size classes. Both of these findings could be evidence of complex social behaviours occurring within CFRs, which may provide further explanation for the use of the tree layer by higher densities of weta. Many species of weta are known to form large social groupings called harems, which consist of one large dominant male and multiple females (Moller 1985, Gibbs and Morris 1998, Gwynne and Jamieson 1998). Within the CFRs it appeared that harems dominated the area against the tree, whereas smaller individuals (often smaller males) were displaced and therefore used the area between the skirts.

5.5.2.2 *CFR use by spiders (Araneae)*

Many different species of spiders were encountered within CFRs throughout the sampling year, and were observed on several occasions to remain in CFRs over multiple days or even months. They were also frequently observed to immediately return to their positions after being disturbed, indicating site fidelity. The most common type observed to behave this way were sheet-web spiders, which are known to set up and maintain webs used for hunting (Crowe 2007). CFRs therefore provide opportunity to study various long-term behaviours in these solitary spider species. Artificial refuges have been used successfully in the past to detect and monitor spider populations, including both wooden pitfall trap covers and Onduline retreats, which were used successfully to detect all life stages of the NZ native red katipo spider (*Latrodectus katipo*) (Lettink and Patrick 2006). These methods are all placed at ground level and therefore target ground dwelling species, whereas CFRs can be placed at different heights on trees and are consequently more suitable for monitoring arboreal species. Different size-classes of spiders showed different proportional use of the two different CFR layers, which may be indicative of some complex social behaviours occurring. Behaviours such as territoriality and aggression are known to occur in various species of spider (Jackson and Cooper 1991, Moya-Laraño et al. 2002), and the double layered design of the CFRs could provide valuable opportunities to study these potential behaviours.

One interesting observation was the occurrence of nursery-web spiders inside CFRs on multiple occasions. This was particularly important as CFRs were set-up inside patches of regenerating forest, and these spiders are generally believed not to occur in forest habitats (Early and Horne 2009). Their occurrence inside CFRs could be explained by the close proximity of the structures to more open areas of grassland. However, CFRs used by nursery-webs were often located further than 20 m from this habitat type. These observations require further research to determine whether these few

findings were rare occurrences, or if these species can in fact be regularly found inside forests, and that their detection in these habitats in the past was not possible using other sampling methods.

5.5.2.3 *CFR use by giant centipedes (Chilopoda)*

Giant centipedes were encountered in CFRs on both Tiritiri Matangi and Motuora Islands. Direct observations of this species are rare, and the single finding on Motuora Island appears to be the first reported sighting of an adult on the island, whereas adults have been reported only a few times previously on Tiritiri Matangi Island (Gardner-Gee et al. 2007, SOTM 2013). Giant centipedes were only ever encountered against the tree inside the CFRs, suggesting that the double-layered design may not provide any added benefits over a single-layered design for detecting this species. This is supported by the fact that giant centipedes were also encountered under single layered CFRs designed by Bell (2009). Published information on the species biology is lacking, and the species use of CFRs could provide excellent opportunity to fill this knowledge gap. The use of CFRs by giant centipedes could also have important implications for lizard conservation, as the New Zealand species of giant centipede, as well as other closely related exotic species, are known to prey on small lizards (Kearney and Downes 1998, Morris and Jewell 2008). CFRs could therefore also be useful for determining suitability of sites for future lizard (and invertebrate) releases based on the presence or absence of such predators.

5.5.2.4 *Relationship between CFR tree species and invertebrate densities*

Cabbage trees had the highest level of invertebrate density overall which, as mentioned earlier, is primarily due to the prevalence of slaters and cockroaches. Cabbage trees provide optimal habitat to both invertebrate groups as their surfaces remain damp due to their soft and spongy bark, therefore providing an ideal food source and overall habitat. Pohutukawa trees on the other hand

had low levels of invertebrate density. This may also be related to the moisture levels of the bark, as pohutukawa trees tended to have relatively dry, tough surfaces making them sub-optimal habitats for both slaters and cockroaches. The same low densities were also seen with smooth, hard barked tree species such as mahoe, karo, kohekohe and puriri. Differences in densities on other tree species may also be related to subtle differences in surface microhabitat. However, due to the small sample sizes obtained for many tree species in this study, further research is required to investigate this.

5.5.2.5 *Relationship between invertebrate densities and microhabitat factors*

Apart from beetles and spiders, positive two-way relationships existed between the average densities of all pairs of invertebrates found inside CFRs. This could be due to high quality habitats having overall higher densities of invertebrates, consequently leading to CFRs within these habitats housing higher densities of invertebrates. It could also be explained by individual CFRs themselves providing different levels of habitat quality, with high quality CFRs leading to overall higher densities. This is supported by the fact that the humidity levels of CFRs were revealed to positively correlate with overall richness and density, as well as the densities of slaters, cockroaches, weta and spiders. This indicates that each group is attracted to more humid CFRs. The two main groups of invertebrates, slaters and cockroaches, are known to have a preference for damp environments, as do many of the various other invertebrate groups encountered (Forster and Forster 1970, Parkinson and Horne 2007). However, weta are thought to prefer dry roost sites, and therefore may be attracted to more humid CFRs for other reasons, such as the availability of food sources or prey items, or other related microhabitat variables. Weta densities were also negatively correlated with temperature, with higher densities encountered in cooler CFRs. The fact that average temperature and humidity were negatively correlated provides evidence that weta may have selected cooler

CFRs, with higher humidity levels being a consequence of this selectivity. Coleoptera densities were not correlated with average humidity, which may also be explained by microhabitat preferences in the species encountered. Many beetle species are often found in damp environments such as rotting debris, and beetle eggs are often laid in trees which hatch to consume the wood (Parkinson and Horne 2007). These traits suggest that beetle densities would have a positive relationship with humidity. However, as this was not the case there must be more complex relationships occurring which are not identifiable using the few factors measured in this study. Relationships with temperature and humidity may be species specific, therefore requiring identification to this level in order to investigate the relationship with microhabitat features more closely.

5.5.2.6 *Spatial variation in CFR use by invertebrates*

Invertebrate densities were generally higher on Motuora Island than on Tiritiri Matangi Island. These findings are similar to those of another study conducted on the same islands in 2006 (van Winkel 2008). The spatial variation in invertebrate densities across the two different islands could be explained by factors such as predator abundance, habitat type, or age of vegetation. Tiritiri Matangi Island is home to a large density of birdlife, much of which consists of insectivorous species. This may provide some explanation for the lower overall density of invertebrates encountered on Tiritiri Matangi Island. Habitat also differs across the two islands, with each island containing different floral and faunal species compositions, as well as ages of regenerating forest patches. For example, differences in invertebrate densities may be partially caused by the differences in the type and amount of ground cover (both leaf litter and vegetation) which exists both across and within islands, as many invertebrate groups are known to prefer this type of habitat. The variation across different grids and individual CFRs is likely also due to the differences in tree species and humidity. Other factors such as local predator, competitor or prey abundances, or surrounding habitat type are also

likely influences. However, as these factors were not considered in this study, further research is required to confirm whether they have any effect on the spatial variation in invertebrate density and richness.

5.5.2.7 *Seasonal variation in CFR use by invertebrates*

Overall invertebrate densities were highest during the winter months of June to August. This was likely due to a higher level of moisture under CFRs due to larger levels of rainfall during winter. This change in moisture would have likely resulted in larger amounts of soft vegetative matter on the tree trunks under CFRs, therefore attracting higher numbers of detritivores (in particular slaters and cockroaches), which accounted for over 95% of the overall invertebrate density. Changes in densities may also be related to the lifecycle of the invertebrate groups. However, both cockroaches and slaters are active year-round, and slaters are known to reproduce in the warm winter months (Bell et al. 2007, Minor 2014). This suggests that the peak in overall density was probably not primarily explained by the lifecycles of these two most common groups, but due to seasonal changes in microhabitat factors and consequent change in attractiveness of CFRs. In the study conducted on the same islands in 2006, invertebrate occupancy of artificial retreats followed completely different trends (van Winkel 2008). It is important to note that the previous study used differences in occupancy rates to explore seasonal changes, whereas this study used changes in average densities as an indicator. Therefore slightly different trends are expected to emerge. On Tiritiri Matangi Island occupancy increased from March to September, and on Motuora Island peaked in February and April, with a trough in July (van Winkel 2008). These large differences may be explained by the different designs and/or placement of artificial retreats making them more attractive to invertebrates at different times of the year. For example, many of the artificial retreats used in 2006 were placed at ground level, which may have resulted in their flooding during the wetter winter

months leading to lower occupancy rates. Differences may also be attributed to the different types of invertebrates attracted to each type of artificial retreat, at the main types encountered in CFRs may not have been attracted to previously used designs.

Average richness followed a different trend to density throughout the year, showing a general increase up until August where it appeared to reach a maximum, then declined slowly through the remainder if the monitoring period. The initial increase is likely due to the timing since the CFRs were set-up. As they were only installed in late 2012, some invertebrate groups may have required more time to inhabit the CFRs before invertebrate monitoring began in March 2013. Other studies on different types of artificial shelters used for monitoring invertebrates have shown delayed occupancy rates from several months to several years (Trewick and Morgan-Richards 2000, Bowie et al. 2006). From August onwards the decline in richness could then be attributed to seasonal trends in richness caused by invertebrate lifecycles. For example, groups that are more prevalent during the cool, wet winter months may become more conspicuous or change habitats, therefore becoming less detectable inside CFRs. Other studies using artificial shelter have also found these seasonal fluctuations in invertebrates (Trewick and Morgan-Richards 2000). Any further investigation into the reasoning behind the seasonal changes in particular invertebrate groups may require knowledge of ecology at the species level, as changes in one species within a group will not always coincide with changes in other similar species. Identification of invertebrates to the species or at least genus level is suggested to investigate these changes more closely. Monitoring should be continued for several years to confirm whether trends are caused by time since CFR installation or by natural seasonal fluctuations.

Orthoptera densities inside CFRs were less effected by season, as numbers remained relatively consistent throughout the year. Weta are able to reproduce at any time during the year, but prefer

to lay eggs during April and May when the soil begins to soften (Gibbs and Morris 1998, Parkinson and Horne 2007). Apart from these events there are no other known changes in weta lifecycle that could influence densities. This provides an explanation as to why densities remained relatively consistent throughout the year. The small changes in densities observed may be caused by parallel changes in microhabitat factors, evidence of which is provided by the finding that weta densities were correlated with humidity levels of CFRs. Spider densities inside CFRs were also relatively consistent throughout the year. However, there was a general increase towards the later, warmer months of August to November. This could be explained by the fact that the more common spider species in New Zealand are more active during the warmer months, and are generally inactive during the winter (Crowe 2007). Changes in densities are also probably related to seasonal changes in weather, evidence of which is provided by the correlation of density with CFR humidity levels. Coleoptera appear to be a group that is slow to occupy CFRs, as numbers were very low up until July, after which densities increased throughout the remainder of the sampling period. It is possible that changes in numbers could be related to the species lifecycle. However, many of the individuals were ground beetles, which are known to be active year-round (Crowe 2002). Further classification to the species level may be required to confirm why changes in densities have occurred.

5.6 Conclusions

CFRs were useful for the detection and/or monitoring of lizards with a variety of habits, including diurnal, nocturnal, ground-dwelling, and arboreal species. Microhabitat factors may affect CFR use by skinks, though further research is required in this area. Use of CFRs may be maximised by placing them in areas with more suitable habitat, or by allowing more time for the resident populations to discover them. There was a large variety of invertebrates encountered in CFRs throughout the entire nine months of monitoring, suggesting that CFRs could be a highly useful tool for monitoring

multiple invertebrate species. They have the potential to be used for sampling both terrestrial and flying invertebrates, although usefulness for flying groups may be limited to species detection. The fact that invertebrates were encountered under both layers of the CFRs suggests that the double layered design is important in the overall design when used for monitoring invertebrates, but may not be required for the detection of certain invertebrate species (e.g. giant centipede). The CFRs also allow for the monitoring of invertebrate populations across seasons, and provide opportunities to investigate the general ecology and distribution of species, including potentially complex social behaviours. Seasonal changes in densities occurred for different invertebrate groups, which may be attributed to changes in weather, lifecycle of different species, or time since CFRs were set-up. Densities also varied with tree species suggesting that this may be an important factor to consider for the future use and placement of CFRs for invertebrate monitoring. Overall double layered CFRs provide a cost-effective, simple, and reliable long-term alternative to the currently utilised methods for monitoring various lizard and invertebrate populations.

Because CFRs can be used successfully to monitor both invertebrates and lizards, they also provide a great opportunity to investigate the various relationships between the invertebrate and lizard groups. These include the interactions between lizards and their invertebrate prey, invertebrates (giant centipedes) and their lizard prey, and the predatory or competitive relationships between lizard species. Overall, CFRs provide valuable information to conservation practitioners for designing and implementing PTM programmes for both lizards and invertebrates.

Chapter 6   Conclusions, Recommendations and Future Directions

6.1 Anchoring Techniques

Both anchoring techniques (temporary food supplementation and cell foam retreat (CFR) release) had an effect on increasing the monitoring ability of *H. duvaucelii* immediately following release, through an increase in CFR use. However, these effects were not long lasting. Also, dispersal distances were not reduced through the use of anchoring treatments. Anchoring techniques may need be modified, or alternative strategies used, in order to improve the PTM of the species in the future. Future studies should test the effectiveness of the following modifications for improving the PTM of *H. duvaucelii* and similar species.

Increase the length of the food treatment period, the number of food provision locations, or the frequency of food replacement

Providing food once a week for two months following release had a positive short term effect on CFR usage, but did not result in any long-term benefits in terms of increased CFR use or reduced dispersal distances. One way to improve the effectiveness of the temporary food supplementation anchoring technique could be to increase the length of time the food is made available for. Researchers studying the gopher tortoise suggested that supplementary food should be maintained

for up to two years in order to result in the successful establishment of translocated populations at their release sites (Tuberville et al. 2005, Field et al. 2007).

Temporary food provisioning appeared to have only a small effect on dispersal distances even within the two month treatment period, and CFR use was also found to decline throughout the treatment period. There are many changes that could be made to the technique to increase the level of effectiveness during the treatment period. During the treatment the banana mash was often observed to have dried out within a few days of being put out, likely also losing its scent and therefore becoming undetectable to geckos. Ensuring the detectability of the food may prevent geckos from dispersing away from release sites in search of other food sources, leading to the desired increase in CFR use and a reduction in dispersal distances. One strategy to improve the effectiveness of the anchoring treatment could therefore be to increase the frequency with which food supply is replaced. This would increase the total number of days that the food was fresh for, consequently increasing the amount of time the food remained attractive to geckos.

Increasing the number of locations, or the density at which food is provided at within a monitoring grid, may also result in an increase in effect. A small amount of food was provided at only twelve or thirteen CFRs per treatment grid, whereas at least 30 geckos were released on each grid. Many lizard species are known to show territorial behaviour, and both inter and intra-sexual aggression has been observed in *H. duvaucelii* (Barry 2010). Therefore, it is possible these behaviours may result in many of the geckos not having access to the provided food sources, and consequently dispersing away in search of alternatives. The low density of the provided food sources, in particular the spacing of the sites at least 15m apart, may have also meant that some geckos were unaware of their presence, as they may have not been able to detect the scent from a distance and may have never come within a detectable range. Increasing the density would therefore also increase their detectability and

chance of encounter by geckos. Although increasing the density of food sources would slightly increase the time and money commitment required, the potentially added benefits of the prolonged food supplementation is likely to outweigh these costs. The density at which supplementary food is provided has been found to effect behaviour in birds (Boutin 1990). However, examples of studies involving reptiles could not be found in the literature. To the best of my knowledge, there is nothing known about the distances at which reptiles can detect scent from. Further study is therefore required to determine what densities of food sources may be suitable for maximising their likelihood of detection by reptile species.

Pre-release exposure to CFRs (training)

One potentially useful alteration to the CFR release anchoring treatment could be to familiarise animals with the CFRs in a pre-release training period. Animals are known to prefer areas that are familiar to their natal habitat, a phenomenon known as natal habitat preference induction (NHPI) (Stamps and Swaisgood 2007). The pre-release exposure of animals to structures that exist at release sites is likely to reduce the probability of animals dispersing in order to find more familiar habitats (Stamps and Swaisgood 2007). It is also believed that allowing animals to become familiar with artificial retreats before release may increase the probability that they will be accepted by animals, and successfully impact the probability of population settlement (Stamps and Swaisgood 2007). Therefore, not only will the pre-release training of geckos to CFRs increase the likelihood of those structures being used, but it will also be likely to reduce levels of post-release dispersal away from monitoring sites. Pre-release training could be conducted either during the holding and quarantine phase, or during a soft-release phase at the release sites, and would require CFRs to be placed within small enclosures along with the geckos.

Pre-release training has also been suggested to potentially benefit other translocated reptile populations. Hawksbill turtles were observed to not utilise natural shelter items following a release, consequently becoming more exposed to harsh environmental conditions (Okuyama et al. 2010). Researchers suggested pre-release training to familiarise turtles with the structures before release, with the aim that they would learn to associate them with beneficial shelter sites and consequently use them more in the wild (Okuyama et al. 2010). Important activities for Caribbean rock iguanas such as anti-predator behaviour and optimal foraging have also been suggested to benefit from pre-release training (Alberts 2007).

Add conspecific scent to CFRs to increase their attractiveness to geckos

Releasing geckos into CFRs did not have an effect on the released gecko's future CFR use behaviour, but did result in the increased use of CFRs that geckos were released into. In order to increase the use of CFRs by geckos in the future, conspecific scent could be applied to all CFRs in future translocation events to increase their attractiveness. During a study on scent communication in *H. duvaucelii*, scent samples were collected from geckos by placing absorbent filter paper inside the containers of captive geckos (Barry 2010). Those scents were then successfully detected by conspecifics at a later time (Barry 2010). Therefore it is possible that scent could also be collected from captive geckos and samples placed inside CFRs to serve as attractants to conspecifics. The use of scent is comparable to the use of audio attractants, which are currently used for anchoring or encouraging the return of bird species to release sites (Molles et al. 2008, Miskelly et al. 2009, Bradley et al. 2011, Parker et al. 2012). Some materials may be able to hold a gecko's scent for longer that the cell foam material used for CFRs, and this should be investigated to help determine the potential for using scent samples as attractants to geckos in the field.

Soft-release strategy

Another possible anchoring technique which was not trialled in this study is the delayed release of geckos at release sites, or a soft-release strategy. Other studies have successfully used soft-releases to reduced dispersal in lizards and turtles (Tuberville et al. 2005, Alberts 2007, Knox and Monks 2014), and may therefore also be able to effect dispersal behaviour in *H. duvaucelii*. This release technique would allow geckos to become acclimatised to their new surroundings, which could include the familiarisation of geckos with CFRs (discussed earlier). Some researchers believe that long-distance movements away from release sites occur because animals prefer familiar habitats, and when release sites lack familiar cues they reject the release area and consequently disperse away in search of familiarity (Stamps and Swaisgood 2007). Soft-releases allow animals to become acclimatised to new environmental cues such as shelter sites, food sources, climate, vegetation, and presence of other species, therefore reducing the likelihood of dispersal (Alberts 2007, Swaisgood 2010).Translocations events can also be highly stressful for animals, especially for those involving long-distance movements (Knapp and Hudson 2004). Two species of iguana were found to show elevated corticosterone levels for up-to a month following release as a result of their translocations (Alberts 2007). Soft-releases are thought to allow time for these stress levels to reduce before alternative stressors associated with the new, unfamiliar environment are introduced (Alberts 2007, Dickens et al. 2010). Therefore using a soft-release strategy for the translocation of *H. duvaucelii* could not only reduce post-release dispersal, but also benefit the population through a decline in stress levels, which is often thought to contribute to mortality and overall translocation failure (Dickens et al. 2010). As well as reducing dispersal and stress levels, soft-releases have also been found to influence whether or not supplementary food is utilised in some translocation events (Bright and Morris 1994). Therefore, a soft-release strategy may also improve the effectiveness of the food provisioning anchoring technique.

6.2 CFRs as Monitoring Tools for *Hoplodactylus duvaucelii*

Overall, CFRs were useful as monitoring tools for *H. duvaucelii*. They were used by at least some geckos throughout the monitoring period, and were used by all cohorts. CFRs were also used frequently by juvenile geckos, a group usually considered to be difficult to monitor or even detect due to their small size and cryptic nature. Use of CFRs was highest immediately following release, with a decline in use thought to be due to the dispersal of geckos away from the release sites, and their settlement at alternative natural retreat sites. CFRs may therefore be more useful in habitats with less available natural retreat sites. This would be likely to include habitats with higher densities of geckos, as this would also result in a reduction in the availability of natural retreat sites. CFRs may also be more useful in areas with less suitable vegetation, as surrounding vegetation and flax were both revealed to influence CFR use in this study. The decline in CFR use over time suggests that CFRs may only be useful as short-term monitoring tools, however their usefulness for long-term monitoring is yet to be determined. I recommend that CFRs should be used as PTM tools for *H. duvaucelii*, especially in the few months immediately following a release, and that their use should continue to be documented in order to determine their suitability as long-term monitoring tools. They should also be trialled for use in lower quality habitats, and for higher density populations, where it is expected that in both situations CFR visitation rates would be much higher than in this study.

CFRs may also be useful for studying several aspects of lizard behaviour. These include social interactions (as multiple individuals were encountered inside the same CFRs, including pairs of juveniles and groups of adults), thermoregulation, and dispersal. For example, CFR usage data from this study indicated that juveniles and adults may show differences in dispersal patterns, as juvenile geckos appear to show more solitary behaviour. This should be investigated further, as it could mean

that juveniles may be more suited to translocations because they show lower levels of dispersal away from release sites.

CFRs showed high levels of functional integrity throughout the fourteen months of monitoring, although a few did fall down throughout this time. There are some minor modifications that could be made to CFRs to increase their durability for monitoring *H. duvaucelii* and similar species. First, biodegradable rope should not be used in the future to attach CFRs to trees in damp habitats such as forests, as in these conditions the rope degrades too rapidly. Second, it should be ensured that CFRs are attached to a tree above a branching point whenever possible, as this will prevent the structure from gradually sliding down the tree trunk as the rope loses tension. Another recommendation is to avoid the use of cable ties to create loops in the bungee cord, as although they allowed the use of a shorter length of bungee cord, they often came loose when opening CFRs and had to be replaced. The alternative method of tying knots showed greater longevity.

The length of the CFR may be able to be reduced in the future as geckos were rarely encountered in the lower third of the CFR, and only encountered slightly more often in the middle third. This would reduce the costs of the CFRs as less material would be required for each individual CFR. It is possible that reducing the size of the CFR may increase their use by geckos, as it is commonly found that lizards prefer shelters with smaller areas and smaller crevices, both believed to be related to predator avoidance behaviour and/or thermal properties (Schlesinger and Shine 1994, Webb and Shine 2000, Quirt et al. 2006, Thierry et al. 2009). However, as it is possible that microhabitat factors may have affected the proportional use of the areas, it is important to consider that these factors may be altered by the reduction in total length. Further research to confirm exactly which factors lead to the preferential use of the upper areas is therefore required to confirm whether or not the current size can be reduced without effecting CFR use by *H. duvaucelii*. It is also important to

consider that in high-density populations multiple geckos may use the CFRs at the same time and therefore require a larger area for shelter. Under these situations it may not be a good idea to reduce the size of the CFR.

6.3 CFRs as Monitoring Tools for Lizards and Invertebrates

CFRs are useful tools for detecting and monitoring a range of lizards and invertebrates. The double layered design appears to be beneficial, as many groups of invertebrates and lizards were encountered under both layers of the CFR. The usage patterns of CFRs by skinks requires further investigation to clarify the suitability of the tools for monitoring these species. In particular, skinks should be individually identified in the future to establish whether there is any repeated use of CFRs. In addition, CFRs should be set up within a closer proximity to suitable skink habitat, and this habitat be measured, to determine whether habitat factors effect CFR use by skinks. CFRs should also be monitored over a number of years to determine whether CFR use increases as more skinks encounter the structures over time.

CFRs have the potential to be used to monitor overall terrestrial ecosystem health, and as monitoring tools for various groups of invertebrates and lizards. They also provide the opportunity to study several aspects of ecology and behaviour in some species, and to study the various relationships between lizards and invertebrates. For example, it is possible to study the relationship between *H. duvaucelii* and their lizard or invertebrate prey, and also or their invertebrate predators (giant centipedes).

References

Agnew, W. 2009. What made these tracks? A guide to assist in interpreting the tracks of small mammals, lizards and insects. 3 edition. Chappell Printing Ltd, Warkworth.

Agresti, A. 1996. An Introduction to Categorical Data Analysis. Wiley, New York.

Aguilar, R. and F. B. Cruz. 2010. Refuge Use in a Patagonian Nocturnal Lizard, Homonota darwini : The Role of Temperature. Journal of Herpetology **44**:236-241.

Alberts, A. C. 2007. Behavioral considerations of headstarting as a conservation strategy for endangered Caribbean rock iguanas. Applied Animal Behaviour Science **102**:380-391.

Amo, L., P. López, and J. Martín. 2004. Trade-offs in the choice of refuges by common wall lizards: do thermal costs affect preferences for predator-free refuges? Canadian Journal of Zoology **82**:897-901.

Andersen, M. T., R. E. Beever, P. W. Sutherland, and R. L. S. Forster. 2001. Association of "Candidatus Phytoplasma australiense" with Sudden Decline of Cabbage Tree in New Zealand. Plant Disease **85**:462-469.

Anderson, D. R. 2001. The Need to Get the Basics Right in Wildlife Field Studies. Wildlife Society Bulletin **29**:1294-1297.

Anderson, D. R. 2003. Response to Engeman: Index Values Rarely Constitute Reliable Information. Wildlife Society Bulletin **31**:288-291.

Andersson, M., A. Krockenberger, and L. I. N. Schwarzkopf. 2010. Experimental manipulation reveals the importance of refuge habitat temperature selected by lizards. Austral Ecology **35**:294-299.

Armstrong, D. P. 1995. Effects of familiarity on the outcome of translocations, II. A test using New Zealand Robins. Biological Conservation **71**:281-288.

Armstrong, D. P. and J. L. Craig. 1995. Effects of familiarity on the outcome of translocations, I. A test using saddlebacks Philesturnus carunculatus rufusater. Biological Conservation **71**:133-141.

Atkinson, I. A. E. and E. K. Cameron. 1993. Human influence on the terrestrial biota and biotic communities of New Zealand. Trends in Ecology & Evolution **8**:447-451.

Baber, M. J. and J. L. Craig. 2003a. Home range size and carrying capacity of the South Island takahe (Porphyrio hochstetteri) on Tiritiri Matangi Island. Notornis **50**:67-74.

Baber, M. J. and J. L. Craig. 2003b. The relationship between foraging behaviour and habitat use by South Island takahe (Porphyrio hochstetteri) on Tiritiri Matangi Island. Notornis **50**:59-66.

Baird, T. A., S. F. Fox, and J. K. McCoy. 1997. Population differences in the roles of size and coloration in intra-and intersexual selection in the collared lizard, Crotaphytus collaris: influence of habitat and social organization. Behavioral Ecology **8**:506-517.

Baling, M., W. Ji, and D. H. Brunton. 2007. Reptile Translocation Report - Translocation of Duvaucel's gecko from Korapuki Island, and shore skink from Tawharanui Regional Park, to Tiritiri Matangi Island, Motuora Island, and into captivity, 2006. Unpublished report to the Department of Conservation.

Barr, B. C. 2009. Spatial ecology, habitat use, and the impacts of rats on chevron skinks (Oligosoma homalonotum) on Great Barrier Island.Massey University, Auckland. 181 p. . Massey University, Auckland.

Barry, M. 2010. Shelter aggregations, social behaviour, and seasonal plasma corticosterone levels in captive and wild Duvaucel's geckos, *Hoplodactylus duvaucelii*. Massey University, Albany, New Zealand.

Barry, M. 2013a. Summary report of the Duvaucel's gecko translocation to Motuora 2013. Unpublished report to the Motuora Restoration Society.

Barry, M. 2013b. Summary report of the Duvaucel's gecko translocation to Tiritiri Matangi 2013. Unpublished report to the Supporters of Tiritiri Matangi Inc.

Barry, M. 2014. Duvaucel's gecko translocation and population monitoring -Unpublished report to the Department of Conservation.

Barry, M., U. Shanas, and D. H. Brunton. 2014. Year-Round Mixed-Age Shelter Aggregations in Duvaucel's Geckos (Hoplodactylus duvaucelii). Herpetologica **70**:395-406.

Barwick, R. E. 1982. The growth and ecology of the gecko Hoplodactylus duvaucelii at The Brothers islands. Pages 377-391 *in* D. G. Newman, editor. New Zealand herpetology: proceedings of a symposium held at Victoria University of Wellington 29-31 January 1980. New Zealand Wildlife Service occasional publication No. 2, Wellington, N.Z.

Beausoleil, N. J., D. J. Mellor, and K. J. Stafford. 2004. Methods for marking New Zealand wildlife: amphibians, reptiles and marine mammals. Department of Conservation, Wellington, New Zealand.

Beck, D. D. and R. D. Jennings. 2003. Habitat Use by Gila Monsters: The Importance of Shelters. Herpetological Monographs **17**:111-129.

Bell, T. P. 2009. A novel technique for monitoring highly cryptic lizard species in forests. Herpetological Conservation and Biology **4**:415-425.

Bell, T. P. 2012. Following up Duvaucel's gecko (Hoplodactylus duvaucelii) on Mana Island.*in* Sanctuaries of New Zealand.

Bell, W. J., L. M. Roth, and C. A. Nalepa. 2007. Cockroaches: Ecology, Behavior, and Natural History. The John Hopkins University Press, Baltimore, Maryland.

Bellingham, P. J., D. R. Towns, E. K. Cameron, J. J. Davis, D. A. Wardle, J. M. Wilmshurst, and C. P. H. Mulder. 2010. New Zealand island restoration: seabirds, predators, and the importance of history. New Zealand Journal of Ecology **34**:115-136.

Blankenship, E. L., T. W. Bryan, and S. P. Jacobsen. 1990. A method for tracking tortoises using fluorescent powder. Herpetological Review **21**:88-89.

Boutin, S. 1990. Food supplementation experiments with terrestrial vertebrates: patterns, problems, and the future. Canadian Journal of Zoology **68**:203-220.

Bowie, M., S. Hodge, J. Banks, and C. Vink. 2006. An appraisal of simple tree-mounted shelters for non-lethal monitoring of weta (Orthoptera: Anostostomatidae and Rhaphidophoridae) in New Zealand nature reserves. Journal of Insect Conservation **10**:261-268.

Bradley, D. W., C. E. Ninnes, S. V. Valderrama, and J. R. Waas. 2011. Does 'acoustic anchoring' reduce post-translocation dispersal of North Island robins? Wildlife Research **38**:69-76.

Bright, P. W. and P. A. Morris. 1994. Animal Translocation for Conservation: Performance of Dormice in Relation to Release Methods, Origin and Season. Journal of Applied Ecology **31**:699-708.

Brown, L. J. 1997. An Evaluation of Some Marking and Trapping Techniques Currently Used in the Study of Anuran Population Dynamics. Journal of Herpetology **31**:410-419.

Buckland, S., N. C. Cole, B. Godsall, J. Rodríguez-Pérez, L. E. Gallagher, S. M. Henshaw, and S. Harris. 2014. Habitat selection of the Mauritian lowland forest day gecko at multiple spatial scales: A baseline for translocation. Global Ecology and Conservation **1**:71-79.

Buden, D. W. 2011. Reptiles of Fais Island, Yap State, Federated States of Micronesia. Pacific Science **65**:277-283.

Carazo, P., E. Font, and E. Desfilis. 2008. Beyond 'nasty neighbours' and 'dear enemies'? Individual recognition by scent marks in a lizard (Podarcis hispanica). Animal Behaviour **76**:1953-1963.

Cash, W. F. 2011. Duvaucel's Gecko - From Brothers Island to Long Island. DOCDM-865117.

Cayot, L. J., H. L. Snell, W. Llerena, and H. M. Snell. 1994. Conservation biology of Galapagos reptiles: twenty-five years of successful research and management. Pages 297–305 *in* J. B. Murphy, Adler, K., Collins, J.T., editor. Captive Management and Conservation of Amphibians and Reptiles. Society for the Study of Amphibians and Reptiles, Ithaca, NY.

Christmas, E. 1995. Interactions between Duvaucel's gecko (*Hoplodactylus duvaucelii*) and kiore (*Rattus exulans*). University of Otago, Dunedin, New Zealand.

Cohen, M. P. and R. A. Alford. 1996. Factors Affecting Diurnal Shelter Use by the Cane Toad, Bufo marinus. Herpetologica **52**:172-181.

Cooper, W. E., J. H. Van Wyk, P. Le F, and N. Mouton. 1999. Incompletely Protective Refuges: Selection and Associated Defences by a Lizard, Cordylus cordylus (Squamata: Cordylidae). Ethology **105**:687-700.

Craig, J., S. Anderson, M. Clout, B. Creese, N. Mitchell, J. Ogden, M. Roberts, and G. Ussher. 2000. Conservation Issues in New Zealand. Annual Review of Ecology and Systematics **31**:61-78.

Croak, B. M., D. A. Pike, J. K. Webb, and R. Shine. 2008. Three-dimensional crevice structure affects retreat site selection by reptiles. Animal Behaviour **76**:1875-1884.

Croak, B. M., D. A. Pike, J. K. Webb, and R. Shine. 2010. Using Artificial Rocks to Restore Nonrenewable Shelter Sites in Human-Degraded Systems: Colonization by Fauna. Restoration Ecology **18**:428-438.

Crowe, A. 2002. Which New Zealand Insect? Penguin Books Ltd., Rosedale, New Zealand.

Crowe, A. 2007. Which New Zealand Spider? Penguin Books Ltd., Rosedale, New Zealand.

Daugherty, C. H., G. W. Gibbs, and R. A. Hitchmough. 1993. Mega-island or micro-continent? New Zealand and its fauna. Trends in Ecology and Evolution **8**.

Daugherty, C. H., G. B. Patterson, and R. A. Hitchmough. 1994. Taxonomic and conservation review of the New Zealand herpetofauna. New Zealand Journal of Zoology **21**:317-323.

Dawson, N. 1994. The behavioural ecology and management of the takahe. Page 85pp. University of Auckland, New Zealand.

Diaz, J. A. and L. M. Carrascal. 1991. Regional Distribution of a Mediterranean Lizard: Influence of Habitat Cues and Prey Abundance. Journal of Biogeography **18**:291-297.

Dickens, M. J., D. J. Delehanty, and L. M. Romero. 2010. Stress: An inevitable component of animal translocation. Biological Conservation **143**:1329-1341.

Dingemanse, N. J., J. Wright, A. J. N. Kazem, D. K. Thomas, R. Hickling, and N. Dawnay. 2007. Behavioural syndromes differ predictably between 12 populations of three-spined stickleback. Journal of Animal Ecology **76**:1128-1138.

DOC. 2012. Inventory and monitoring toolbox: herpetofauna - Introduction to herpetofauna monitoring. Department of Conservation.

Dodd, C. K. 1992. Fluorescent powder is only partially successful in tracking movements of the Six-lined Racerunner (Cnemidophorus sexlineatus). Florida Field Naturalist **20**:8-14.

Dodd, C. K. and R. A. Seigel. 1991. Relocation, repatriation, and translocation of amphibians and reptiles: are they conservation strategies that work? Herpetologica **47**:336-350.

Downes, S. and R. Shine. 1998. Heat, safety or solitude? Using habitat selection experiments to identify a lizard's priorities. Animal Behaviour **55**:1387-1396.

Duméril, A. and G. Bibron. 1836. Enpétologie générale ou historie naturelle complétedes reptiles. Roret, Paris.

Early, J. and D. Horne. 2009. Know Your New Zealand Insects & Spiders. New Holland Publishers (NZ) Ltd., Auckland, New Zealand.

Ebrahimi, M. and C. M. Bull. 2012. Food supplementation reduces post-release dispersal during simulated translocation of the Endangered pygmy bluetongue lizard Tiliqua adelaidensisÂ Endangered Species Research **18**:169-178.

Elbin, S. B. and J. Burger. 1994. In My Experience: Implantable Microchips for Individual Identification in Wild and Captive Populations. Wildlife Society Bulletin **22**:677-683.

Fellers, G. M. and C. A. Drost. 1989. Fluorescent powder - A method for tracking reptiles. Herpetological Review **20**:91-92.

Field, A. 2005. Discovering Statistics Using SPSS. Second edition. SAGE publications Ltd, London.

Field, K. J., C. R. Tracy, P. A. Medica, R. W. Marlow, and P. S. Corn. 2007. Return to the wild: Translocation as a tool in conservation of the Desert Tortoise (Gopherus agassizii). Biological Conservation **136**:232-245.

Finlayson, G. R. and K. E. Moseby. 2004. Managing confined populations: the influence of density on the home range and habitat use of reintroduced burrowing bettongs (<i>Bettongia lesueur)</i>. Wildlife Research **31**:457-463.

Fischer, J. and D. B. Lindenmayer. 2000. An assessment of the published results of animal relocations. Biological Conservation **96**:1-11.

Fitch, H. S. 1951. A simplified type of funnel trap for reptiles. Herpetologica **7**:77-80.

Forster, R. R. and L. M. Forster. 1970. Small Land Animals of New Zealand. John McIndoe Limited, Dunedin, New Zealand.

Francke, J. V. A. 2005. Ecological Implications of Habitat Fragmentation and Restoration for the Gecko Hoplodactylus Maculatus: This Thesis is Submitted for the Fulfilment of the Requirement of Obtaining a Masters of Science in Ecology. Victoria University of Wellington.

Fritts, S. H., C. M. Mack, D. W. Smith, K. M. Murphy, M. K. Phillips, M. D. Jimenez, E. E. Bangs, J. A. Fontaine, W. G. Brewster, and T. J. Kaminsk. 2001. Outcomes of hard and soft releases of reintroduced wolves to central Idaho and the greater Yellowstone area. Pages 125-147 *in* R. F. N. D. S. Maehr, and J. L. Larkin, editor. Large mammal restoration: ecological and sociological challenges in the 21st century. Island Press, Washington, D.C., USA.

Furman, B. L. S., B. R. Scheffers, and C. A. Paszkowski. 2011. The use of fluorescent powdered pigments as a tracking technique for snake. Herpetological Conservation and Biology **6**:473-478.

Galbraith, M. and H. Cooper. 2013. Tiritiri Matangi–an overview of 25 years of ecological restoration. New Zealand Journal of Ecology **37**:258-260.

Galliard, J.-F. L., R. Ferrière, and J. Clobert. 2003. Mother-Offspring Interactions Affect Natal Dispersal in a Lizard. Proceedings: Biological Sciences **270**:1163-1169.

Gamble, L., S. Ravela, and K. McGarigal. 2008. Multi-scale features for identifying individuals in large biological databases: an application of pattern recognition technology to the marbled salamander *Ambystoma opacum*. Journal of Applied Ecology **45**:170-180.

Ganesh, S. R., S. R. Chadramouli, R. Sreekar, and P. G. Shankar. 2013. Reptiles of the Central Western Ghats, India — A Reappraisal and Revised Checklist, with Emphasis on the Agumbe Plateau. Russian Journal of Herpetology **20**:134-142.

Gardner-Gee, R., S. Graham, R. Griffiths, M. Habgood, S. H. Dunlop, and H. Lindsay. 2007. Motuora Native Species Restoration Plan.*in* D. o. Conservation, editor., Auckland, New Zealand.

Gebauer, K. 2009. Trapping and identification techniques for small-scaled skinks (*Oligosoma microlepis*).*in* D. o. Conservation, editor., Wellington.

Germano, J. M. and P. J. Bishop. 2009. Suitability of Amphibians and Reptiles for Translocation. Conservation Biology **23**:7-15.

Gerner, T. 2008. Home range, habitat use and social behaviour of the endangered Mauritian gecko *Phelsuma guntheri*. University of Zurich, Zurich.

Gibbs, G. and R. Morris. 1998. New Zealand Weta. Reed Publishing (NZ) Ltd., Birkenhead, Auckland.

Goldingay, R., G. Daly, and F. Lemckert. 1996. Assessing the impacts of logging on reptiles and frogs in the montane forests of southern New South Wales. Wildlife Research **23**:495-510.

Goldsbrough, C. L., R. Shine, and D. F. Hochuli. 2006. Factors affecting retreat-site selection by coppertail skinks (*Ctenotus taeniolatus*) from sandstone outcrops in eastern Australia. Austral Ecology **31**:326-336.

GoogleEarth. 2013a. 7.1.2.2041. Hauraki Gulf, New Zealand. 36°40'51.15"S, 175°20'54.71"E, elevation -6 m, eye alt 119.40 km. SIO, NOAA, U.S. Navy, NGA, GEBCO. Landsat.

GoogleEarth. 2013b. 7.1.2.2041. Motuora Island, New Zealand. 36°30'29.03"S, 174°47'21.21"E, elevation 38 m, eye alt 915 m. SIO, NOAA, U.S. Navy, GEBCO. CNES/Astrium 2014.

GoogleEarth. 2013c. 7.1.2.2041. Tiritiri Matangi Island, New Zealand. 36°36'17.96"S, 174°53'33.59"E, elevation 55 m, eye alt 1.05 km. SIO, NOAA, U.S. Navy, GEBCO. TerraMetrics 2014, CNES/Astrium 2014.

Graeter, G. J. and B. B. Rothermel. 2007. The effectiveness of fluorescent powdered pigments as a tracking technique for amphibians. Herpetological Review **38**:162–166.

Greenberg, C. H., D. G. Neary, and L. D. Harris. 1994. A comparison of hereptofaunal sampling effectiveness of pitfall, single-ended, and double-ended funnel traps used with drift fences. Journal of Herpetology:319-324.

Gwynne, D. T. and I. Jamieson. 1998. Sexual selection and sexual dimorphism in a harem-polygynous insect, the alpine weta (Hemideina maori, Orthoptera Stenopelmatidae). Ethology Ecology & Evolution **10**:393-402.

Hare, K. M. 2012a. Funnel trapping.*in* T. Greene and K. McNutt, editors. Biodiversity Inventory and Monitoring Toolbox. Department of Conservation, Wellington, New Zealand.

Hare, K. M. 2012b. Indices of abundance.*in* T. Greene and K. McNutt, editors. Biodiversity Inventory and Monitoring Toolbox. Department of Conservation, Wellington, New Zealand.

Hare, K. M. 2012c. Pitfall trapping.*in* T. Greene and K. McNutt, editors. Biodiversity Inventory and Monitoring Toolbox. Department of Conservation, Wellington, New Zealand.

Hare, K. M. 2012d. Systematic searches.*in* T. Greene and K. McNutt, editors. Biodiversity Inventory and Monitoring Toolbox. Department of Conservation, Wellington, New Zealand.

Hare, K. M., S. Pledger, M. B. Thompson, J. H. Miller, and C. H. Daugherty. 2010. Nocturnal lizards from a cool-temperate environment have high metabolic rates at low temperatures. Journal of Comparative Physiology B-Biochemical Systemic and Environmental Physiology **180**:1173-1181.

Harmon, L. J., L. L. Harmon, and C. G. Jones. 2007. Competition and community structure in diurnal arboreal geckos (genus Phelsuma) in the Indian Ocean. Oikos **116**:1863-1878.

Hawley, J. and L. Buckton. 1997. Motuora restoration working plan.*in* D. o. Conservation., editor. Department of Conservation. , Auckland.

Hayes, W. K., R. L. Carter, S. Cyril, and B. Thornton. 2004. Conservation of an endangered Bahamian rock iguana I: population assessments, habitat restoration, and behavioral ecology. Pages 232-257 *in* A. C. Alberts, R. L. Carter, W. K. Hayes, and E. P. Martins, editors. Iguanas: Biology and Conservation. . University of California Press, Berkeley.

Hitchmough, R., K. Neilson, K. Goddard, M. Goold, B. Gartrell, S. Cockburn, and N. Ling. 2012. Assessment of microbranding as an alternative marking technique for long-term identification of New Zealand lizards. New Zealand Journal of Ecology **36**:151-156.

Hitchmough, R. A., P. J. Anderson, B. Barr, J. M. Monks, M. Lettink, J. Reardon, M. D. Tocher, and T. Whitaker. 2013. Conservation status of New Zealand reptiles, 2012. Page 16 p. *in* D. o. Conservation, editor.

Hoare, J. M., P. Melgren, and E. E. Chavel. 2013. Habitat use by southern forest geckos (Mokopirirakau 'Southern Forest') in the Catlins, Southland. New Zealand Journal of Zoology **40**:129-136.

Hoare, J. M., S. Pledger, N. J. Nelson, and C. H. Daugherty. 2007. Avoiding aliens: Behavioural plasticity in habitat use enables large, nocturnal geckos to survive Pacific rat invasions. Biological Conservation **136**:510-519.

Hosmer, D. W., T. Hosmer, S. Le Cessie, and S. Lemeshow. 1997. A comparison of goodness-of-fit tests for the logistic regression model. Statistics in Medicine **16**:965-980.

Hutcheson, J., P. Walsh, and D. Given. 1999. Potential value of indicator species for conservation and management of New Zealand terrestrial communities. Pages 1173-2946. Department of Conservation, Wellington, New Zealand.

Hyde, E. J. and T. R. Simons. 2001. Sampling Plethodontid Salamanders: Sources of Variability. The Journal of Wildlife Management **65**:624-632.

IUCN. 1987. IUCN position statement on the translocation of living organisms: introductions, re-introductions, and re-stocking., Gland, Switzerland.

IUCN/SSC. 2013. Guidelines For Reintroductions And Other Conservation Translocations. IUCN Species Survival Commission, Gland, Switzerland.

Jackson, R. R. and K. J. Cooper. 1991. The influence of body size and prior residency on the outcome of male-male interactions of Marpissa marina, a New Zealand jumping spider (Araneae Salticidae). Ethology Ecology and Evolution **3**:79-82.

Jamieson, H. and K. Neilson. 2007. Detecting the undetectable—developing new ways to catch cryptic reptiles. New Zealand Journal of Zoology **34**:264.

Jarvie, S. and J. M. Monks. 2014. Step on it: can footprints from tracking tunnels be used to identify lizard species? New Zealand Journal of Zoology **41**:210-217.

Jemison, S. C., L. A. Bishop, P. G. May, and T. M. Farrell. 1995. The Impact of PIT-Tags on Growth and Movement of the Rattlesnake, Sistrurus miliarius. Journal of Herpetology **29**:129-132.

Jenness, J. S. 2007. Some Thoughts on Analyzing Topographic Habitat Characteristics.

Ji, W. H., M. Baling, M. Barry, D. Van Winkel, C. Wedding, B. Barr, and D. H. Brunton. 2007. Translocation of duvaucel's gecko and shore skinks to tiritiri matangi island, motuora island and massey university captive breeding facility. New Zealand Journal of Zoology **34**:264-265.

Jones, N. 2000. Establishment, dispersal and population viability of translocated Duvaucel's gecko (*Hoplodactylus duvaucelii*) on Mana Island. Victoria University, Wellington, New Zealand.

Kearney, M. 2002. Hot rocks and much-too-hot rocks: seasonal patterns of retreat-site selection by a nocturnal ectotherm. Journal of Thermal Biology **27**:205-218.

Kearney, M. and S. Downes. 1998. Underwoodisaurus milii (thick-tailed gecko): cross predation. Herpetological Review **29**:169.

Kearney, M. and M. Predavec. 2000. Do Nocturnal Ectotherms Thermoregulate? A Study of the Temperate Gecko Christinus marmoratus. Ecology **81**:2984-2996.

Kerr, G. D. and C. M. Bull. 2004. Microhabitat Use by the Scincid Lizard Tiliqua rugosa: Exploiting Natural Temperature Gradients beneath Plant Canopies. Journal of Herpetology **38**:536-545.

King, S. R. B. and J. Gurnell. 2005. Habitat use and spatial dynamics of takhi introduced to Hustai National Park, Mongolia. Biological Conservation **124**:277-290.

Kjoss, V. A. and J. A. Litvaitis. 2001. Comparison of 2 Methods to Sample Snake Communities in Early Successional Habitats. Wildlife Society Bulletin **29**:153-157.

Knapp, C. R. and J. G. Abarca. 2009. Effects of Radio Transmitter Burdening on Locomotor Ability and Survival of Iguana Hatchlings. Herpetologica **65**:363-372.

Knapp, C. R. and R. D. Hudson. 2004. Translocation strategies as a conservation tool for West Indian iguanas. Pages 199-209 *in* A. C. Alberts, R. L. Carter, W. K. Hayes, and E. P. Martins, editors. Iguanas: Biology and Conservation. University of California Press, Berkeley.

Knox, C. D., A. Cree, and P. J. Seddon. 2013. Accurate identification of individual geckos (Naultinus gemmeus) through dorsal pattern differentiation. New Zealand Journal of Ecology **37**:60-66.

Knox, C. D. and J. M. Monks. 2014. Penning prior to release decreases post-translocation dispersal of jewelled geckos. Animal Conservation **17**:18-26.

Kondo, J., S. J. Downes, and S. J. Keogh. 2007. Recent Physical Encounters Affect Chemically Mediated Retreat-Site Selection in a Gecko. Ethology **113**:68-75.

Lardner, B., J. A. Savidge, G. H. Rodda, R. N. Reed, and A. A. Yackel-Adams. 2009. The results of nocturnal visual surveys are influenced by lamp properties. Applied Herpetology **6**:391-396.

Le Gouar, P., J.-B. Mihoub, and F. Sarrazin. 2012. Dispersal and Habitat Selection: Behavioural and Spatial Constraints for Animal Translocations. Pages 138-164 *in* J. G. Ewen, D. P. Armstrong, K. A. Parker, and P. J. Seddon, editors. Reintroduction Biology: Integrating Science and Management. Blackwell Publishing Ltd., Oxford, UK.

Lemen, C. A. and P. W. Freeman. 1985. Tracking Mammals with Fluorescent Pigments: A New Technique. Journal of Mammalogy **66**:134-136.

Léna, J. P., M. De Fraipont, and J. Clobert. 2000. Affinity towards maternal odour and offspring dispersal in the common lizard. Ecology Letters **3**:300-308.

Lettink, M. 2007. Detectability, movements and apparent lack of homing in Hoplodactylus maculatus (Reptilia : Diplodactylidae) following translocation. New Zealand Journal of Ecology **31**:111-116.

Lettink, M. and A. Cree. 2007. Relative use of three types of artificial retreats by terrestrial lizards in grazed coastal shrubland, New Zealand. Applied Herpetology **4**:227-243.

Lettink, M., C. F. J. Donnell, and J. M. Hoare. 2011. Accuracy and precision of skink counts from artificial retreats. New Zealand Journal of Ecology **35**:236-246.

Lettink, M. and B. H. Patrick. 2006. Use of artificial cover objects for detecting red katipo, Latrodectus katipo Powell (Araneae: Theridiidae). New Zealand Entomologist **29**:99-102.

Lettink, M. and P. J. Seddon. 2007. Influence of Microhabitat Factors on Capture Rates of Lizards in a Coastal New Zealand Environment. Journal of Herpetology **41**:187-196.

Liang, K.-Y. and S. L. Zeger. 1986. Longitudinal Data Analysis Using Generalized Linear Models. Biometrika **73**:13-22.

Lindsey, T. and R. Morris. 2011. Collins Field Guide to New Zealand Wildlife. HarperCollinsPublishers, Auckland, New Zealand.

Magurran, A. E. 1986. Predator Inspection Behaviour in Minnow Shoals: Differences between Populations and Individuals. Behavioral Ecology and Sociobiology **19**:267-273.

Martín, J. and P. López. 2011. Chapter 6 - Pheromones and Reproduction in Reptiles. Pages 141-167 *in* D. O. N. H. Lopez, editor. Hormones and Reproduction of Vertebrates. Academic Press, London.

Martín, J. and P. López. 2013. Responses of female rock lizards to multiple scent marks of males: Effects of male age, male density and scent over-marking. Behavioural Processes **94**:109-114.

Minor, M. 2014. Guide to New Zealand Soil Invertebrates - Isopoda.

Miskelly, C. M. and R. G. Powlesland. 2013. Conservation translocations of New Zealand birds, 1863-2012. Notornis **60**.

Miskelly, C. M., G. A. Taylor, H. Gummer, and R. Williams. 2009. Translocations of eight species of burrow-nesting seabirds (genera Pterodroma, Pelecanoides, Pachyptila and Puffinus: Family Procellariidae). Biological Conservation **142**:1965-1980.

Mitchell, K. 2010. Quantitative Analysis by the Point-Centered Quarter Method. arXiv e-print 1010.3303.

Moller, H. 1985. Tree wetas (Hemideina crassicruris) (Orthoptera: Stenopelmatidae) of Stephens Island, Cook Strait. New Zealand Journal of Zoology **12**:55-69.

Molles, L. E., A. Calcott, D. Peters, G. Delamare, J. Hudson, J. Innes, I. Flux, and J. Waas. 2008. "Acoustic anchoring" and the successful translocation of North Island kokako (Callaeas cinerea wilsoni) to a New Zealand mainland management site within continuous forest. Notornis **55**.

Monks, J. M., A. Monks, and D. R. Towns. 2014. Correlated recovery of five lizard populations following eradication of invasive mammals. Biological Invasions **16**:167-175.

Morris, R. and T. Jewell. 2008. A Photographic Guide to Reptiles and Amphibians of New Zealand. New Holland Publishers (NZ) Ltd., Auckland, New Zealand.

Moya-Laraño, J., J. M. Orta-Ocaña, J. A. Barrientos, C. Bach, and D. H. Wise. 2002. Territoriality in a Cannibalistic Burrowing Wolf Spider. Ecology **83**:356-361.

Neilson, K., J. M. Curran, D. R. Towns, and H. Jamieson. 2006. Habitat use by chevron skinks (*Oligosoma homalonotum*) (Sauria: Scincidae) on Great Barrier Island, New Zealand. New Zealand Journal of Ecology **30**:435-356.

Nelson, N. J., S. N. Keall, D. Brown, and C. H. Daugherty. 2002. Establishing a New Wild Population of Tuatara (Sphenodon guntheri)

Establecimiento de una Nueva Población Silvestre de Tuatara (Sphenodon guntheri). Conservation Biology **16**:887-894.

Newman, D. G. 1994. Effects of a mouse, Mus musculus, eradication programme and habitat change on lizard populations of Mana Island, New Zealand, with special reference to McGregor's skink, Cyclodina macgregori. New Zealand Journal of Zoology **21**:443-456.

Nichols, J. D. and D. P. Armstrong. 2012. Monitoring for Reintroductions. Pages 223-255 *in* J. G. Ewen, D. P. Armstrong, K. A. Parker, and P. J. Seddon, editors. Reintroduction Biology: Integrating Science and Management. Blackwell Publishing Ltd., Oxford,UK.

NZBS. 2000. The New Zealand Biodiversity Strategy.*in* D. o. Conservation, editor. Department of Conservation, Wellington, New Zealand.

O'Donnell, C. F. J. and J. M. Hoare. 2012. Monitoring trends in skink sightings from artificial retreats: Influences of retreat design, placement period, and predator abundance. Herpetological Conservation and Biology **7**:58-66.

Okuyama, J., T. Shimizu, O. Abe, K. Yoseda, and N. Arai. 2010. Wild versus head-started hawksbill turtles Eretmochelys imbricata: post-release behavior and feeding adaptions. Endangered Species Research **10**:181-190.

Ortiz-Catedral, L. and D. H. Brunton. 2009. Nesting sites and nesting success of reintroduced red-crowned parakeets (Cyanoramphus novaezelandiae) on Tiritiri Matangi Island, New Zealand. New Zealand Journal of Zoology **36**:1-10.

Ott, J. A. and D. E. Scott. 1999. Effects of Toe-Clipping and PIT-Tagging on Growth and Survival in Metamorphic Ambystoma opacum. Journal of Herpetology **33**:344-348.

Parker, K. A., M. J. Dickens, R. H. Clarke, and T. G. Lovegrove. 2012. The Theory and Practice of Catching, Holding, Moving and Releasing Animals. Pages 105-137 *in* J. G. Ewen, D. P. Armstrong, K. A. Parker, and P. J. Seddon, editors. Reintroduction Biology: Integrating Science and Management. Blackwell Publishing Ltd., Oxford, UK.

Parkinson, B. and D. Horne. 2007. A Photographic Guide to Insects of New Zealand. New Holland Publishers (NZ) Ltd., Auckland, New Zealand.

Pearce, J. L., D. Schuurman, K. N. Barber, M. Larrivée, L. A. Venier, J. McKee, and D. McKenney. 2005. Pitfall trap designs to maximize invertebrate captures and minimize captures of nontarget vertebrates. The Canadian Entomologist **137**:233-250.

Perry, G., M. C. Wallace, D. Perry, H. Curzer, and P. Muhlberger. 2011. Toe Clipping of Amphibians and Reptiles: Science, Ethics, and the Law1. Journal of Herpetology **45**:547-555.

Petrie, M. and B. Kempenaers. 1998. Extra-pair paternity in birds: explaining variation between species and populations. Trends in Ecology & Evolution **13**:52-58.

Pike, D. A., L. Pizzatto, B. A. Pike, and R. Shine. 2008. Estimating Survival Rates of Uncatchable Animals: The Myth of High Juvenile Mortality in Reptiles. Ecology **89**:607-611.

Pollock, K. H., J. D. Nichols, C. Brownie, and J. E. Hines. 1990. Statistical inference for capture-recapture experiments. Wildlife Monographs **107**:1-97.

Quinn, G. P. and M. J. Keough. 2002. Experimental Design and Data Analysis for Biologists. Cambridge University Press, New York.

Quirt, K. C., G. Blouin-Demers, B. J. Howes, and S. C. Lougheed. 2006. Microhabitat Selection of Five-Lined Skinks in Northern Peripheral Populations. Journal of Herpetology **40**:335-342.

Rasmuson, B., M. Rasmuson, and J. A. N. Nygren. 1977. Genetically controlled differences in behaviour between cycling and non-cycling populations of field vole (Microtus agrestis). Hereditas **87**:33-41.

Reynolds, M. and J. Klavitter. 2006. Translocation of wild Laysan duck Anas laysanensis to establish a population at Midway Atoll National Wildlife Refuge, United States and US Pacific Possession. Conservation Evidence **3**:6-8.

Roark, A. W. and M. E. Dorcas. 2000. Regional Body Temperature Variation in Corn Snakes Measured Using Temperature-Sensitive Passive Integrated Transponders. Journal of Herpetology **34**:481-485.

Robb, J. 1980. New Zealand amphibians and reptiles in colour. Collins, Auckland.

Rock, J., A. Cree, and R. M. Andrews. 2002. The effect of reproductive condition on thermoregulation in a viviparous gecko from a cool climate. Journal of Thermal Biology **27**:17-27.

Roe, A. W. and K. L. Grayson. 2008. Terrestrial movements and habitat use of juvenile and emigrating adult Eastern Red-Spotted Newts, *Notophthalmus viridescens*. Journal of Herpetology **42**:22-30.

Romijn, R. L., N. J. Nelson, and J. M. Monks. 2014. Forest geckos (Mokopirirakau 'Southern North Island') display diurno-nocturnal activity and are not reliant on retreats. New Zealand Journal of Zoology **41**:103-113.

Russell, J. C., R. Klette, and C.-Y. Chen. 2010. Tracking small artists. Arts and Technology **30**:165-172.

Sabo, J. L. 2003. Hot Rocks or No Hot Rocks: Overnight Retreat Availability and Selection by a Diurnal Lizard. Oecologia **136**:329-335.

Saunders, A. and D. A. Norton. 2001. Ecological restoration at Mainland Islands in New Zealand. Biological Conservation **99**:109-119.

Saunders, A. J. 1998. Vertebrate pest control at mainland islands. Pages 61-68 *in* 11th Australasian Vertebrate Pest Conference, Bunbury, W.A.

Schlesinger, C. A. and R. Shine. 1994. Selection of Diurnal Retreat Sites by the Nocturnal Gekkonid Lizard Oedura Lesueurii. Herpetologica **50**:156-163.

Seddon, P. J. 1999. Persistence without intervention: assessing success in wildlife re-introductions. Trends in Ecology and Evolution **14**:503.

Seddon, P. J., W. M. Strauss, and J. Innes. 2012. Animal Translocations: What Are They and Why Do We Do them? Pages 1-32 *in* J. G. Ewen, D. P. Armstrong, K. A. Parker, and P. J. Seddon, editors. Reintroduction Biology: Integrating Science and Management. Blackwell Publishing Ltd., Oxford, UK.

Shah, B., R. Shine, S. Hudson, and M. Kearney. 2003. Sociality in Lizards: Why Do Thick-Tailed Geckos (Nephrurus milii) Aggregate? Behaviour **140**:1039-1052.

Shah, B., R. Shine, S. Hudson, and M. Kearney. 2004. Experimental analysis of retreat-site selection by thick-tailed geckos *Nephrurus milii*. Austral Ecology **29**:547-552.

Sherley, G. H., I. Stringer, and G. R. Parrish. 2010. Summary of native bat, reptile, amphibian and terrestrial invertebrate translocations in New Zealand.*in* D. o. Conservation, editor., Wellington.

SOTM. 2013. Tiritiri Matangi Island Biodiversity Plan 2013.

Spurr, E. B. and K. W. Drew. 1999. Invertebrates feeding on baits used for vertebrate pest control in New Zealand. New Zealand Journal of Ecology **23**:167-173.

Stamps, J. A. and R. R. Swaisgood. 2007. Someplace like home: Experience, habitat selection and conservation biology. Applied Animal Behaviour Science **102**:392-409.

Stark, R. C. and S. F. Fox. 2000. Use of fluorescent powder to track horned lizards. Herpetological Review **31**:230-231.

Støen, O.-G., M. L. Pitlagano, and S. R. Moe. 2009. Same-site multiple releases of translocated white rhinoceroses Ceratotherium simum may increase the risk of unwanted dispersal. Oryx **43**:580-585.

Sullivan, B. K., M. A. Kwiatkowski, and G. W. Schuett. 2004. Translocation of urban Gila Monsters: a problematic conservation tool. Biological Conservation **117**:235-242.

Swaisgood, R. R. 2010. The conservation-welfare nexus in reintroduction programmes: a role for sensory ecology. Animal Welfare **19**:125-137.

Thierry, A., M. Lettink, A. A. Besson, and A. Cree. 2009. Thermal properties of artificial refuges and their implications for retreat-site selection in lizards. Applied Herpetology **6**:307-326.

Thompson, M. B., C. H. Daugherty, A. Cree, D. C. French, J. C. Gillingham, and R. E. Barwick. 1992. Status and longevity of the tuatara, *Sphenodon guntheri,* and Duvaucel's gecko, *Hoplodactylus duvaucelii,* on North Brother Island, New Zealand. Journal of the Royal Society of New Zealand **22**:123-130.

Towns, D. R. 1994. The role of ecological restoration in the conservation of Whitaker's skink (Cyclodina whitakeri), a rare New Zealand lizard (Lacertilia: Scincidae). New Zealand Journal of Zoology **21**:457-471.

Towns, D. R. 2002. Interactions between geckos, honeydew scale insects and host plants revealed on islands in northern New Zealand, following eradication of introduced rats and rabbits. Pages 329–335 *in* C. R. Veitch and M. N. Clout, editors. Turning the tide: the eradication of invasive species. IUCN SSC Invasive Species Specialist Group, Gland, Switzerland.

Towns, D. R. and I. A. E. Atkinson. 2004. Restoration plan for Korapuki Island (Mercury Islands), New Zealand 2004-2024.*in* D. o. Conservation, editor., Wellington.

Towns, D. R. and W. J. Ballantine. 1993. Conservation and restoration of New Zealand Island ecosystems. Trends in Ecology & Evolution **8**:452-457.

Towns, D. R., C. H. Daugherty, and A. Cree. 2001. Raising the prospects for a forgotten fauna: a review of 10 years of conservation effort for New Zealand reptiles. Biological Conservation **99**:3-16.

Towns, D. R. and C. H. Daughtery. 1994. Patterns of range contractions and extinctions in the New Zealand herpetofauna following human colonisation. New Zealand Journal of Zoology **21**:325-339.

Towns, D. R. and S. M. Ferreira. 2001. Conservation of New Zealand lizards (Lacerttilia: Scincidae) by translocation of small populations. Biological Conservation **98**:211-222.

Towns, D. R., D. Simberloff, and I. A. E. Atkinson. 1997. Restoration of New Zealand Islands:redressing the effects of introduced species. Pacific Conservation Biology **3**:99-124.

Trewick, S. A. and M. Morgan-Richards. 2000. Artificial weta roosts: A technique for ecological study and population monitoring of Tree Weta (Hemideina) and other invertebrates. New Zealand Journal of Ecology **24**:201-208.

Tuberville, T. D., E. E. Clark, K. A. Buhlmann, and J. W. Gibbons. 2005. Translocation as a conservation tool: site fidelity and movement of repatriated gopher tortoises (Gopherus polyphemus). Animal Conservation **8**:349-358.

Ussher, G. and M. J. Baber. 2013. Motuihe Duvaucel's Gecko Translocation Application 11 Nov 2013. Tonkin & Taylor.

van Heezik, Y., R. F. Maloney, and P. J. Seddon. 2009. Movements of translocated captive-bred and released Critically Endangered kaki (black stilts) Himantopus novaezelandiae and the value of long-term post-release monitoring. Oryx **43**:639-647.

van Winkel, D. 2008. Efficiency of techniques for post-translocation monitoring of the Duvaucel's gecko (*Hoplodactylus duvaucelii)* and evidence of native avian predation on lizards. Massey University, Auckland, New Zealand.

van Winkel, D., M. Baling, M. Barry, W. H. Ji, and D. H. Brunton. 2010. Translocation of Duvaucel's geckos to Tiritiri Matangi and Motuora Islands, Hauraki Gulf, as part of island ecological restoration initiatives.*in* P. S. Soorae, editor. Global Re-introduction Perspectives: 2010. Additional case-studies from around the globe. IUCN/SCC RSG.

Van Winkel, D. and W. H. Ji. 2014. Attaching Radio-Transmitters to Geckos: Trials and Tribulations. Herpetological Review **45**:13-17.

Wakelin, M., C. Smuts-Kennedy, T. Thurley, and N. Webster. 2003. Artificial cover objects for leiopelmatid frogs. DOC SCIENCE INTERNAL SERIES 120. Page 17 *in* D. o. Conservation, editor., Wellington, New Zealand.

Ward, D. F. and M. C. Larivière. 2004. Terrestrial invertebrate surveys and rapid biodiversity assessment in New Zealand: lessons from Australia. New Zealand Journal of Ecology **28**:151-159.

Watts, C. H., D. P. Armstrong, J. Innes, and D. Thornburrow. 2011. Dramatic increases in weta (Orthoptera) following mammal eradication on Maungatautari – evidence from pitfalls and tracking tunnels. New Zealand Journal of Ecology **35**:261-272.

Webb, J. K. 2006. Effects of tail autotomy on survival, growth and territory occupation in free-ranging juvenile geckos (Oedura lesueurii). Austral Ecology **31**:432-440.

Webb, J. K., R. M. Pringle, and R. Shine. 2004. How Do Nocturnal Snakes Select Diurnal Retreat Sites? Copeia **2004**:919-925.

Webb, J. K. and R. Shine. 2000. Paving the way for habitat restoration: can artificial rocks restore degraded habitats of endangered reptiles? Biological Conservation **92**:93-99.

Whitaker, A. H. 1968. The lizards of the Poor Knights Island, New Zealand. New Zealand Journal of Science **11**:623-651.

Whitaker, A. H. 1987. The roles of lizards in New Zealand plant reproductive strategies. New Zealand Journal of Botany **25**:315-328.

Wilmshurst, J. M., A. J. Anderson, T. F. G. Higham, and T. H. Worthy. 2008. Dating the late prehistoric dispersal of Polynesians to New Zealand using the commensal Pacific rat. Proceedings of the National Academy of Sciences **105**:7676-7680.

Wilson, D. J., R. L. Mulvey, and R. D. Clark. 2007. Sampling skinks and geckos in artificial cover objects in a dry mixed grassland-shrubland with mammalian predator control. New Zealand Journal of Ecology **31**:169-185.

Wilson, J. 2010. Population viability and resource competition on North Brother island: Conservation implications for tuatara (Sphenodon punctatus) and Duvaucel's gecko (*Hoplodactylus duvaucelii*). Victoria University, Wellington, New Zealand.

Worthy, T. H. 2001. A fossil vertebrate fauna accumulated by laughing owls (*Sceloglaux albifacies*) on the Gouland Downs, northwest Nelson, South Island. Notornis **48**:225-233.

Worthy, T. H. and R. N. Holdaway. 1995. Quaternary fossil faunas from caves on Mt Cookson, North Canterbury, South Island, New Zealand. Journal of the Royal Society of New Zealand **25**:333-370.

Wotton, D. M. 2002. Effectiveness of the common gecko (*Hoplodactylus maculatus*) as a seed disperser on Mana Island, New Zealand. New Zealand Journal of Botany **40**:639-647.

Appendices

Appendix A. Number of CFRs and geckos of each treatment type, at each of the six 2013 release grids. T= Tiritiri Matangi Island, M= Motuora Island, S=Stanley Island origin, K=Korapuki Island origin, C=control, T=treatment.

Grid	Gecko Origin	Release Type	Grid Food T/C	CFR Food T/C	# CFRs	# Geckos
T1	S	AR	C	/	/	15
T1	S	Natural	C	/	/	15
T2	K	AR	T	T	13	7
T2	K	AR	T	C	12	8
T2	K	Natural	T	/	/	15
T3	K	AR	C	/	/	15
T3	K	Natural	C	/	/	15
M2	K	AR	T	T	12	7
M2	K	AR	T	C	13	8
M2	K	Natural	T	/	/	15
M3	S	AR	T	T	12	7
M3	S	AR	T	C	13	8
M3	S	Natural	T	/	/	15
M4	K	AR	C	/	/	15
M4	K	Natural	C	/	/	15

Appendix B. Information on all 180 adult geckos released in 2013. C=captive born Korapuki island, K= wild born Korapuki Island, S= wild born Stanley Island. RT= release treatment, GFT= grid food treatment, CFT=CFR food treatment, Gravid=gravid at release, Tracker= radio-tracker attached at release. Crosses indicate no's or control groups, ticks indicate yes's or treatment groups, and N/A indicates individuals that do not apply to the group.

Gecko ID	Sex	Origin	Release Grid	Release Site	RT	GFT	CFT	Gravid	Tracker
C39F	F	C	M2	N2	✗	✓	✗	✗	✗
C29F	F	C	M2	B30	✓	✓	✗	✗	✗
C45F	F	C	M2	N7	✗	✓	✗	✗	✗
C50F	F	C	M2	N8	✗	✓	✗	✗	✗
C06F	F	C	M2	C15	✓	✓	✗	✓	✗
C16F	F	C	M2	N9	✗	✓	✗	✗	✓
C07F	F	C	M2	D15	✓	✓	✓	✓	✗
C27M	M	C	M2	D30	✓	✓	✗	N/A	✗
C37M	M	C	M2	B15	✓	✓	✓	N/A	✗
C57M	M	C	M2	N5	✗	✓	✗	N/A	✗
C59M	M	C	M2	C30	✓	✓	✓	N/A	✗
C66M	M	C	M2	N6	✗	✓	✗	N/A	✗
C63M	M	C	M2	D60	✓	✓	✗	N/A	✗
C15M	M	C	M2	N11	✗	✓	✗	N/A	✓
C24M	M	C	M2	B60	✓	✓	✗	N/A	✓
K63F	F	K	M2	N13	✗	✓	✗	✗	✗
K14F	F	K	M2	C45	✓	✓	✗	✗	✗
K23F	F	K	M2	N15	✗	✓	✗	✗	✗
K13F	F	K	M2	C0	✓	✓	✓	✗	✓
K07F	F	K	M2	N10	✗	✓	✗	✗	✓
K04F	F	K	M2	B0	✓	✓	✗	✗	✓
K62F	F	K	M2	D45	✓	✓	✓	✓	✗
K35F	F	K	M2	N12	✗	✓	✗	✓	✗
K61M	M	K	M2	N14	✗	✓	✗	N/A	✗
K52M	M	K	M2	D0	✓	✓	✗	N/A	✗
K36M	M	K	M2	B45	✓	✓	✓	N/A	✗
K02M	M	K	M2	N4	✗	✓	✗	N/A	✗
K22M	M	K	M2	N1	✗	✓	✗	N/A	✗
K09M	M	K	M2	N3	✗	✓	✗	N/A	✓
K54M	M	K	M2	C60	✓	✓	✓	N/A	✓
S58F	F	S	M3	N11	✗	✓	✗	✗	✗
S25F	F	S	M3	B30	✓	✓	✗	✗	✗
S32F	F	S	M3	C15	✓	✓	✗	✗	✗
S56F	F	S	M3	N8	✗	✓	✗	✗	✓
S26F	F	S	M3	C45	✓	✓	✗	✗	✗

Appendix B continued…

Gecko ID	Sex	Origin	Release Grid	Release Site	RT	GFT	CFT	Gravid	Tracker
S59F	F	S	M3	N15	✗	✓	✗	✗	✓
S14F	F	S	M3	B15	✓	✓	✓	✗	✓
SX62F	F	S	M3	D60	✓	✓	✗	✗	✗
S36F	F	S	M3	N2	✗	✓	✗	✗	✗
S15F	F	S	M3	N5	✗	✓	✗	✗	✗
S04F	F	S	M3	D45	✓	✓	✓	✗	✗
S12F	F	S	M3	N1	✗	✓	✗	✗	✗
S27F	F	S	M3	N12	✗	✓	✗	✗	✗
S11F	F	S	M3	B0	✓	✓	✗	✗	✓
S42F	F	S	M3	D15	✓	✓	✓	✗	✓
S28F	F	S	M3	N10	✗	✓	✗	✗	✓
S02M	M	S	M3	N13	✗	✓	✗	N/A	✗
S31M	M	S	M3	N6	✗	✓	✗	N/A	✗
S16M	M	S	M3	N14	✗	✓	✗	N/A	✗
S37M	M	S	M3	C0	✓	✓	✓	N/A	✗
S55M	M	S	M3	D30	✓	✓	✗	N/A	✗
S24M	M	S	M3	C60	✓	✓	✓	N/A	✗
S20M	M	S	M3	B60	✓	✓	✗	N/A	✓
S18M	M	S	M3	B45	✓	✓	✓	N/A	✓
S52M	M	S	M3	N7	✗	✓	✗	N/A	✓
S34M	M	S	M3	N4	✗	✓	✗	N/A	✗
S39M	M	S	M3	D0	✓	✓	✗	N/A	✗
S09M	M	S	M3	N3	✗	✓	✗	N/A	✗
S17M	M	S	M3	N9	✗	✓	✗	N/A	✓
S03M	M	S	M3	C30	✓	✓	✓	N/A	✓
C41F	F	C	M4	N15	✗	✗	N/A	✗	✗
C54F	F	C	M4	N2	✗	✗	N/A	✗	✗
C40F	F	C	M4	N8	✗	✗	N/A	✗	✗
C52F	F	C	M4	D15	✓	✗	N/A	✗	✗
C17F	F	C	M4	B30	✓	✗	N/A	✗	✗
C61F	F	C	M4	N7	✗	✗	N/A	✓	✗
C13F	F	C	M4	C15	✓	✗	N/A	✓	✗
C23F	F	C	M4	N9	✗	✗	N/A	✗	✓
C30M	M	C	M4	N5	✗	✗	N/A	N/A	✗
C42M	M	C	M4	B15	✓	✗	N/A	N/A	✗
C53M	M	C	M4	D30	✓	✗	N/A	N/A	✗
C65M	M	C	M4	N6	✗	✗	N/A	N/A	✗
C05M	M	C	M4	C30	✓	✗	N/A	N/A	✗

Appendix B continued…

Gecko ID	Sex	Origin	Release Grid	Release Site	RT	GFT	CFT	Gravid	Tracker
C19M	M	C	M4	B60	✓	✗	N/A	N/A	✓
C58M	M	C	M4	N11	✗	✗	N/A	N/A	✓
K17F	F	K	M4	B45	✓	✗	N/A	✗	✗
K59F	F	K	M4	D45	✓	✗	N/A	✓	✗
K28F	F	K	M4	N4	✗	✗	N/A	✓	✗
K66F	F	K	M4	N13	✗	✗	N/A	✗	✗
K11F	F	K	M4	C45	✓	✗	N/A	✓	✗
K44F	F	K	M4	D0	✓	✗	N/A	✓	✗
K05M	M	K	M4	N1	✗	✗	N/A	N/A	✗
K45A	M	K	M4	N12	✗	✗	N/A	N/A	✗
K31M	M	K	M4	N14	✗	✗	N/A	N/A	✗
K33M	M	K	M4	N3	✗	✗	N/A	N/A	✓
K58M	M	K	M4	N10	✗	✗	N/A	N/A	✓
K47M	M	K	M4	C0	✓	✗	N/A	N/A	✓
K16M	M	K	M4	C60	✓	✗	N/A	N/A	✓
K55M	M	K	M4	B0	✓	✗	N/A	N/A	✓
K38M	M	K	M4	D60	✓	✗	N/A	N/A	✓
S13F	F	S	T1	N5	✗	✗	N/A	✗	✗
SX142F	F	S	T1	D30	✓	✗	N/A	✗	✗
S08F	F	S	T1	N7	✗	✗	N/A	✗	✗
S47F	F	S	T1	C30	✓	✗	N/A	✗	✗
S54F	F	S	T1	D0	✓	✗	N/A	✗	✓
SX64F	F	S	T1	D60	✓	✗	N/A	✗	✗
S57F	F	S	T1	N3	✗	✗	N/A	✗	✗
S06F	F	S	T1	D15	✓	✗	N/A	✗	✓
S30F	F	S	T1	N13	✗	✗	N/A	✗	✓
S43F	F	S	T1	C45	✓	✗	N/A	✗	✓
S01F	F	S	T1	B0	✓	✗	N/A	✗	✗
S33F	F	S	T1	B60	✓	✗	N/A	✗	✗
S29F	F	S	T1	B45	✓	✗	N/A	✗	✗
S19F	F	S	T1	B15	✓	✗	N/A	✗	✗
SX50F	F	S	T1	D45	✓	✗	N/A	✗	✓
SX59F	F	S	T1	N15	✗	✗	N/A	✗	✓
SX49M	M	S	T1	N11	✗	✗	N/A	N/A	✗
S22M	M	S	T1	N9	✗	✗	N/A	N/A	✗
S38M	M	S	T1	C60	✓	✗	N/A	N/A	✗
S49M	M	S	T1	C15	✓	✗	N/A	N/A	✗
S51M	M	S	T1	N2	✗	✗	N/A	N/A	✓

Appendix B continued…

Gecko ID	Sex	Origin	Release Grid	Release Site	RT	GFT	CFT	Gravid	Tracker
S41M	M	S	T1	N12	✗	✗	N/A	N/A	✗
S50M	M	S	T1	N4	✗	✗	N/A	N/A	✗
S10M	M	S	T1	N1	✗	✗	N/A	N/A	✓
SX43M	M	S	T1	N8	✗	✗	N/A	N/A	✓
S48M	M	S	T1	N6	✗	✗	N/A	N/A	✗
S23M	M	S	T1	B30	✓	✗	N/A	N/A	✓
S53M	M	S	T1	C0	✓	✗	N/A	N/A	✗
S40M	M	S	T1	N14	✗	✗	N/A	N/A	✗
S46M	M	S	T1	N10	✗	✗	N/A	N/A	✓
C33F	F	C	T2	N2	✗	✓	✗	✗	✗
C56F	F	C	T2	N7	✗	✓	✗	✗	✗
C36F	F	C	T2	N11	✗	✓	✗	✗	✗
C47F	F	C	T2	N4	✗	✓	✗	✗	✗
C09F	F	C	T2	B30	✓	✓	✗	✗	✗
C08F	F	C	T2	C15	✓	✓	✗	✗	✓
C10F	F	C	T2	D15	✓	✓	✓	✓	✗
C38M	M	C	T2	C30	✓	✓	✓	N/A	✗
C43M	M	C	T2	N1	✗	✓	✗	N/A	✗
C49M	M	C	T2	N6	✗	✓	✗	N/A	✗
C18M	M	C	T2	N5	✗	✓	✗	N/A	✗
C12M	M	C	T2	B60	✓	✓	✗	N/A	✗
C25M	M	C	T2	D60	✓	✓	✗	N/A	✓
C67M	M	C	T2	D30	✓	✓	✗	N/A	✓
C2M	M	C	T2	B15	✓	✓	✓	N/A	✓
K10F	F	K	T2	C45	✓	✓	✗	✗	✗
K20F	F	K	T2	B0	✓	✓	✗	✗	✗
K60F	F	K	T2	N15	✗	✓	✗	✗	✗
K29F	F	K	T2	D45	✓	✓	✓	✓	✗
K45F	F	K	T2	D0	✓	✓	✗	✓	✗
K06F	F	K	T2	N13	✗	✓	✗	✓	✗
K65F	F	K	T2	N10	✗	✓	✗	✗	✓
K24F	F	K	T2	N12	✗	✓	✗	✓	✗
K01M	M	K	T2	N14	✗	✓	✗	N/A	✗
K32M	M	K	T2	C60	✓	✓	✓	N/A	✗
K53M	M	K	T2	B45	✓	✓	✓	N/A	✗
K18M	M	K	T2	C0	✓	✓	✓	N/A	✓
K34M	M	K	T2	N8	✗	✓	✗	N/A	✓
K27M	M	K	T2	N3	✗	✓	✗	N/A	✓

Appendix B continued…

Gecko ID	Sex	Origin	Release Grid	Release Site	RT	GFT	CFT	Gravid	Tracker
K48M	M	K	T2	N9	✘	✓	✘	N/A	✓
C28F	F	C	T3	N8	✘	✘	N/A	✘	✘
C32F	F	C	T3	B30	✓	✘	N/A	✘	✘
C55F	F	C	T3	N9	✘	✘	N/A	✘	✘
C60F	F	C	T3	N2	✘	✘	N/A	✘	✘
C21F	F	C	T3	D15	✓	✘	N/A	✓	✘
C20F	F	C	T3	C15	✓	✘	N/A	✘	✓
C11F	F	C	T3	N7	✘	✘	N/A	✓	✘
C35M	M	C	T3	N6	✘	✘	N/A	N/A	✘
C44M	M	C	T3	N5	✘	✘	N/A	N/A	✘
C26M	M	C	T3	B15	✓	✘	N/A	N/A	✘
C62M	M	C	T3	D30	✓	✘	N/A	N/A	✘
C51M	M	C	T3	C30	✓	✘	N/A	N/A	✘
C14M	M	C	T3	D0	✓	✘	N/A	N/A	✘
C64M	M	C	T3	B60	✓	✘	N/A	N/A	✘
C03M	M	C	T3	N11	✘	✘	N/A	N/A	✓
K30BF	F	K	T3	D45	✓	✘	N/A	✘	✘
K46F	F	K	T3	N12	✘	✘	N/A	✘	✘
K12F	F	K	T3	N15	✘	✘	N/A	✘	✘
K41F	F	K	T3	N13	✘	✘	N/A	✓	✘
K42F	F	K	T3	C0	✓	✘	N/A	✘	✓
K51F	F	K	T3	N10	✘	✘	N/A	✘	✓
K64F	F	K	T3	C45	✓	✘	N/A	✓	✘
K56M	M	K	T3	N4	✘	✘	N/A	N/A	✘
K26M	M	K	T3	B45	✓	✘	N/A	N/A	✘
K19M	M	K	T3	N14	✘	✘	N/A	N/A	✘
K03M	M	K	T3	N1	✘	✘	N/A	N/A	✘
K50M	M	K	T3	N3	✘	✘	N/A	N/A	✓
K57M	M	K	T3	D60	✓	✘	N/A	N/A	✓
K37M	M	K	T3	B0	✓	✘	N/A	N/A	✓
K49M	M	K	T3	C60	✓	✘	N/A	N/A	✓

Appendix C. Dates of CFR checks, grid food treatment, and the origin of geckos released onto each monitoring grid C=control grid (no food), T=treatment grid (food), S= Stanley island, K=Korapuki Island. Note: from season 2 onwards, check dates apply to all four monitoring grids per island.

Grid		T1	T2	T3	T4	M1	M2	M3	M4
Grid Food Treatment		C	T	C	-	-	T	T	C
Gecko Origin		S	K	K	K	K	K	S	K
Release Date		27 Feb	18 Feb	18 Feb	2006	2006	22 Feb	1 Mar	22 Feb
CFR Check Dates									
Season 1									
	< 2 days	28 Feb	19 Feb	19 Feb	-	-	23 Feb	2-Mar	24 Feb
	1 week	5 Mar	24 Feb	25 Feb	-	-	1 Mar	9-Mar	1 Mar
	2 weeks	-	4 Mar	5 Mar	-	-	7 Mar	-	8 Mar
	April	3 & 4	2-3	1-2	3-4	7-8	6-7	6-7	6-7
Season 2									
	May		16, 18 & 20				10, 12 &14		
	June		10, 12 &14				8, 10 & 12		
	July		1, 3 & 5				15, 17 & 19		
	August		12, 14 & 16				19, 21 & 23		
Season 3									
	September		9, 11 & 13				20, 22 & 24		
	October		14, 16 & 18				14, 16 & 18		
	November		10, 12 & 14				3, 5 & 7		
Season 4									
	2014		31 Mar, 2 & 4 Apr				23, 25 & 27 Feb		

172

Appendix D. Availability of GPS location data for each radio-tracked gecko for each time period following release (A1= during week one, A2= during week two, A3= during weeks three and four, A4= during weeks five to eight, B= at 8 months, and C= at 12 months) for each of the 79 encountered geckos (ticks indicate at least one available GPS location point during that season therefore allowing inclusion in the analysis).

Gecko ID	A1	A2	A3	A4	B	C	Gecko ID	A1	A2	A3	A4	B	C
K16M	✓						C19M		✓			✓	
S42F	✓						K53M			✓		✓	
S46M	✓						K23F			✓	✓		
SX50F	✓						K04F			✓	✓		
C15M	✓						K29F				✓	✓	
K09M	✓			✓			C11F				✓	✓	✓
S28F	✓					✓	S34M					✓	
K07F	✓		✓				K26M					✓	
C23F	✓			✓		✓	K56M					✓	
K50M	✓		✓				K41F					✓	
K57M	✓		✓				SX142F					✓	
S30F	✓			✓			C27M						✓
S43F	✓			✓			C32F						✓
S54F	✓					✓	C40F						✓
SX59F	✓					✓	C51M						✓
C03M	✓	✓					C52F						✓
C08F	✓	✓					C55F						✓
C24M	✓	✓					C58M						✓
K18M	✓	✓					C59M						✓
S20M	✓	✓					C65M						✓
S11F	✓	✓					K45F						✓
S14F	✓	✓					S13F						✓
K37M	✓	✓		✓			S15F						✓
S17M	✓	✓		✓			S19F						✓
K51F	✓	✓	✓				K34M						✓
S52M	✓	✓	✓				K14F						✓
S03M	✓	✓	✓				C07F						✓
S18M	✓	✓	✓				K19M						✓
C25M	✓	✓	✓			✓	S26F						✓
K47M	✓	✓	✓			✓	S37M						✓
K48M	✓	✓	✓		✓	✓	C10F						✓
S56F	✓	✓	✓	✓			C13F						✓
S59F	✓	✓	✓	✓			K44F					✓	✓
K27M	✓	✓	✓	✓			C26M					✓	✓
K49M	✓	✓	✓	✓			C60F					✓	✓
K13F	✓	✓	✓	✓			K60F					✓	✓
K02M		✓					K20F					✓	✓
K24F			✓				K17F					✓	✓
K11F			✓				C09F					✓	✓
K22M			✓				TOTAL (79)	36	23	20	14	19	36

Appendix E. Number and percentage of treatment and control CFRs used multiple times for each anchoring treatment.

Number of Times Visited	Treatment # (%)	Control # (%)	All CFRs # (%)
Grid Food Treatment			
>0	24 (32%)	10 (13%)	34 (23%)
>1	10 (13%)	6 (8%)	16 (16%)
>2	6 (8%)	3 (4%)	9 (6%)
>3	1 (1%)	2 (3%)	3 (2%)
Total	75	75	150
CFR Food Treatment			
>0	12 (32%)	22 (19%)	-
>1	4 (11%)	12 (11%)	-
>2	3 (8%)	6 (5%)	-
>3	1 (3%)	2 (2%)	-
Total	37	113	150
Release Treatment			
>0	24 (27%)	10 (17%)	-
>1	10 (11%)	6 (10%)	-
>2	6 (7%)	3 (5%)	-
>3	1 (1%)	2 (3%)	-
Total	90	60	150

Appendix F. Descriptive statistics for the visitation rates to treatment and control CFRs within two months, and between three and fourteen months following release.

Grid Food Treatment	Release Treatment	N	min	max	mean	SE	mean -1 SE	mean +1 SE	Lower 95% CI	Upper 95% CI
2 months										
Control	Control	30	0	1	0.0333	0.03333	-0.00003	0.06663	-0.0348	0.1015
Control	Treatment	45	0	4	0.2444	0.10615	0.13825	0.35055	0.0305	0.4584
Treatment	Control	30	0	3	0.3667	0.15524	0.21146	0.52194	0.0492	0.6842
Treatment	Treatment	45	0	3	0.5333	0.12144	0.41186	0.65474	0.2886	0.7781
3-14 months										
Control	Control	30	0	1	0.0333	0.03333	-0.00003	0.06663	-0.0348	0.1015
Control	Treatment	45	0	3	0.2000	0.09847	0.10153	0.29847	0.0015	0.3985
Treatment	Control	30	0	1	0.0667	0.04632	0.02038	0.11302	-0.0281	0.1614
Treatment	Treatment	45	0	3	0.1111	0.07263	0.03847	0.18373	-0.0353	0.2575

Appendix G. Model effects for the two generalised linear models exploring the effects of grid food treatment and release treatment on CFR visitation rates and use of CFRs by geckos. Significant results are highlighted in bold.

	Likelihood Ratio X^2	df	sig
Effect on CFR visitation rates			
Intercept	70.545	1	**<0.001**
Grid Food Treatment	10.905	1	**0.001**
Release Treatment	6.636	2	**0.036**
Effect on CFR use by geckos			
Intercept	99.210	1	**<0.001**
Grid Food Treatment	7.869	1	**0.005**
Release Treatment	0.684	2	0.710

Appendix H. Parameter estimates for each of the significant factors calculated in the two generalised linear models on the effects of grid food treatment and release treatment on CFR visitation rates and CFR use by geckos. Significant results are highlighted in bold.

	B(SE)	95% CI for Odds Ratio			Hypothesis Test		
		Lower	Exp (B)	Upper	Wald	df	sig
Effect on CFR visitation rates							
Intercept	-3.401 (1.017)	0.002	0.033	0.155	11.195	1	**0.001**
Grid Food Treatment	2.303 (1.080)	1.752	10.000	189.283	4.544	1	**0.033**
Release Treatment (Grid Food Treatment)	0.470 (.444)	0.683	1.600	3.945	1.120	1	0.290
Release Treatment (Grid Food Control)	1.992 (1.071)	1.321	7.333	137.518	3.463	1	0.063
Effect on CFR use by geckos							
Intercept	-2.015 (.434)	0.051	0.133	0.289	21.493	1	**<0.001**
Grid Food Treatment	0.773 (.537)	0.783	2.167	6.631	2.076	1	0.150

Appendix I. Number and percentage of geckos in treatment and control groups that used CFRs at least once and more than once during the entire fourteen month monitoring period. Percentages are of total released geckos.

Number of Visits to CFRs	Treatment #(%)	Control #(%)	All Geckos #(%)
Grid Food Treatment			
>0	26 (29%)	14 (16%)	40 (22%)
>1	8 (9%)	3 (3%)	11 (6%)
Released	90	90	180
Individual CFR Food Treatment			
>0	8 (38%)	32 (20%)	-
>1	4 (19%)	7 (4%)	-
Released	21	159	180
Release Treatment			
>0	21 (23%)	19 (21%)	-
>1	8 (9%)	3 (3%)	-
Released	90	90	180

Appendix J. Descriptive statistics for the number of visits to CFRs by treatment and control geckos within two months, and between three and fourteen months following release.

Grid Food Treatment	Release Treatment	N	min	max	mean	SE	mean -1 SE	mean +1 SE	Lower 95% CI	Upper 95%CI
2 months										
Control	Control	45	0	2	0.1333	0.06030	0.073	0.19360	0.0118	0.2549
Control	Treatment	45	0	2	0.1111	0.05705	0.05405	0.16815	-0.0039	0.2261
Treatment	Control	45	0	3	0.2889	0.09332	0.19558	0.38222	0.1008	0.4770
Treatment	Treatment	45	0	2	0.4000	0.09211	0.30789	0.49211	0.2144	0.5856
3-14 months										
Control	Control	45	0	1	0.0889	0.04290	0.04600	0.13180	0.0024	0.1754
Control	Treatment	45	0	3	0.0889	0.06979	0.01911	0.15869	-0.0518	0.2295
Treatment	Control	45	0	1	0.0222	0.02222	-0.00002	0.04442	-0.0226	0.0670
Treatment	Treatment	45	0	2	0.1111	0.05705	0.05405	0.16815	-0.0039	0.2261

Appendix K. Cross-tabulation of the number of treatment and control geckos (of the grid food treatment) located at each category distance during each season and time period.

Distance Category	Grid Food Treatment		Total
	Control	Treatment	
Week 1			
On Grid	8 (53%)	11 (52%)	**19 (53%)**
<20m	2 (13%)	7 (33%)	**9 (25%)**
<60m	5 (33%)	2 (10%)	**7 (19%)**
>60m	0 (0%)	1 (5%)	**1 (3%)**
Total	15	21	**36**
Week 2			
On Grid	0 (0%)	5 (29%)	**5 (20%)**
<20m	3 (38%)	4 (24%)	**7 (28%)**
<60m	1 (13%)	7 (41%)	**8 (32%)**
>60m	4 (50%)	1 (6%)	**5 (20%)**
Total	8	17	**25**
Weeks 3-4			
On Grid	2 (33%)	4 (29%)	**6 (30%)**
<20m	1 (17%)	2 (14%)	**3 (15%)**
<60m	2 (33%)	3 (21%)	**5 (25%)**
>60m	1 (17%)	5 (36%)	**6 (30%)**
Total	6	14	**20**
Weeks 5-8			
On Grid	0 (0%)	3 (33%)	**3 (21%)**
<20m	1 (20%)	3 (33%)	**4 (29%)**
<60m	3 (60%)	0 (0%)	**3 (21%)**
>60m	1 (20%)	3 (33%)	**4 (29%)**
Total	5	9	**14**
8 months			
On Grid	4 (36%)	4 (50%)	**8 (42%)**
<20m	2 (18%)	0 (0%)	**2 (10%)**
<60m	2 (18%)	2 (25%)	**4 (21%)**
>60m	3 (27%)	2 (25%)	**5 (26%)**
Total	11	8	**19**
12 months			
On Grid	8 (40%)	7 (44%)	**15 (42%)**
<20m	1 (5%)	0 (0%)	**1 (3%)**
<60m	7 (35%)	5 (31%)	**12 (33%)**
>60m	4 (20%)	4 (25%)	**8 (22%)**
Total	20	16	**36**

Appendix L. Descriptive statistics for the effects of grid food treatment on the mean distance travelled by geckos during each of the time periods following release. T=treatment (released on a food treatment grid), C= control (released on a control grid).

Time Period	T/C	N	min	max	mean	SE	mean -1 SE	mean +1 SE	Lower 95% CI	Upper 95% CI
week 1	C	15	6	91	32.60	7.04	25.56	39.64	17.50	47.70
	T	21	0	87	33.00	5.42	27.58	38.42	21.69	44.32
week 2	C	8	19	223	102.38	27.64	74.74	130.01	37.02	167.73
	T	17	7	126	59.29	8.60	50.69	67.90	41.06	77.53
weeks 3-4	C	6	17	104	56.83	13.37	43.46	70.20	22.46	91.20
	T	14	0	210	81.71	17.98	63.74	99.69	42.88	120.55
weeks 5-8	C	5	48	219	100.20	30.90	69.30	131.10	96.50	84.00
	T	9	24	256	102.00	32.44	69.56	134.44	27.20	176.80
8 months	C	11	10	199	74.27	20.93	53.34	95.20	27.63	120.91
	T	8	15	316	101.50	47.16	54.34	148.66	-10.02	213.02
12 months	C	20	7	197	65.60	11.50	54.10	77.10	41.52	89.68
	T	16	14	294	70.44	16.78	53.66	87.21	34.68	106.19

Appendix M. Results of the generalised estimating equations run on data from within two months following release to determine the short term effects of grid food, CFR food and release anchoring treatments on category and point distances travelled by released geckos.

	Wald X^2	df	p-value	Sample Size	# Subjects
Grid Food Treatment					
Point Distance (m)					
Intercept	1313.188	1	<0.001		
Grid Food Treatment	0.001	1	0.970	93	46
Category Distance					
Grid Food Treatment	0.828	1	0.363	95	46
CFR Food Treatment					
Point Distance (m)					
Intercept	654.146	1	<0.001		
CFR Food Treatment	1.869	1	0.172	95	46
Category Distance					
CFR Food Treatment	0.491	1	0.483	95	46
Release Treatment					
Point Distance (m)					
Intercept	1295.661	1	<0.001		
Release Treatment	0.568	1	0.451	93	46
Category Distance					
Release Treatment	0.116	1	0.734	95	46

Appendix N. Descriptive statistics for the effects of CFR food treatment on the mean distance travelled by geckos during each of the time periods following release. T=treatment (released inside a food treatment CFR), C= control (released inside a non-food treatment CFR on a food treatment grid).

time slot	T/C	N	min	max	mean	SE	mean -1 SE	mean +1 SE	Lower 95% CI	Upper 95% CI
week 1	C	29	6	91	31.34	4.57	26.77	35.92	21.97	40.72
	T	7	0	87	39.00	11.39	27.61	50.39	11.12	66.88
week 2	C	20	7	223	78.10	12.76	65.34	90.86	51.39	104.81
	T	5	9	118	53.00	20.77	32.23	73.77	-4.66	110.66
weeks 3-4	C	16	0	210	80.06	14.89	65.18	94.95	48.34	111.79
	T	4	12	140	51.00	30.13	20.87	81.13	-44.88	146.88
weeks 5-8	C	12	26	256	113.00	25.13	87.87	138.13	57.69	168.31
	T	2	24	39	31.50	7.50	24.00	39.00	-63.80	126.80
8 months	C	17	10	316	92.82	24.84	67.98	117.66	40.16	145.48
	T	2	15	36	25.50	10.50	15.00	36.00	-107.92	158.92
12 months	C	32	7	294	67.63	10.86	56.76	78.49	45.47	89.78
	T	4	52	85	68.75	9.10	59.65	77.85	39.77	97.73

Appendix O. Descriptive statistics for the effects of release treatment on the mean distance travelled by geckos during each of the time periods following release. T=treatment (released inside a CFR), C= control (released at natural sites).

time slot	T/C	N	min	max	mean	SE	mean -1 SE	mean +1 SE	Lower 95% CI	Upper 95% CI
week 1	C	17	6	83	37.76	6.57	31.20	44.33	23.85	51.68
	T	19	0	91	28.42	5.48	22.94	33.90	16.91	39.93
week 2	C	10	7	223	88.50	18.33	70.17	106.83	47.03	129.97
	T	15	9	186	62.80	13.59	49.21	76.39	33.65	91.95
weeks 3-4	C	10	17	210	84.70	17.87	66.83	102.57	44.28	125.12
	T	10	0	195	63.80	19.96	43.84	83.76	18.65	108.95
weeks 5-8	C	8	26	256	93.00	31.99	61.01	124.99	17.35	168.65
	T	6	24	219	112.50	34.76	77.74	147.26	23.16	201.84
8 months	C	9	12	316	84.67	34.42	50.25	119.09	5.29	164.04
	T	10	10	316	86.70	31.77	54.93	118.47	14.82	158.58
12 months	C	15	7	294	65.60	20.31	45.29	85.91	22.04	109.16
	T	21	14	170	69.29	8.63	60.66	77.92	51.28	87.29

Appendix P. Location of four juvenile geckos (J2, J3, J8, and J9) at each CFR check session date. Dashes indicate that the gecko was not encountered in any CFR during the sampling session. J2 and J3 were from grid M2, J8 and J9 were from grid M4.

Date	Location of Gecko			
	J2	J3	J8	J9
23-Feb	C0	-	-	-
1-Mar	-	-	-	-
7-Mar	C0	E30	-	-
6-Apr	-	-	-	-
7-Apr	-	-	-	-
10-May	C15	-	B30	B30
12-May	C30	-	B45	B45
14-May	-	-	B45	B45
8-Jun	-	-	-	-
10-Jun	D15	B45	-	-
12-Jun	D15	C45	-	-
15-Jul	C45	C30	B45	B45
17-Jul	C45	B45	B45	-
19-Jul	C45	C30	B30	-
19-Aug	C15	C15	B45	B45
21-Aug	C15	C15	B45	A60
23-Aug	C15	C15	B45	-
20-Sep	B45	C15	B45	A60
22-Sep	A30	C45	B45	-
24-Sep	D30	B45	B45	-
14-Oct	C0	B45	-	-
16-Oct	C0	B45	-	-
18-Oct	C30	-	-	-
3-Nov	-	C60	-	-
5-Nov	-	C60	-	-
7-Nov	-	-	-	-

Appendix Q. Results of the Mann-Whitney U tests run on data from eight and twelve months following release to determine the long term effects of grid food, CFR food and CFR release anchoring treatments on category and point distances travelled by released geckos (T=Treatment group, C=Control group).

Time Since Release	Sample Size		Category Distance					Point Distance (m)				
			Mean Rank					Mean Rank				
	T	C	T	C	U	Z	p-value	T	C	U	Z	p-value
Grid Food Treatment												
8 months	8	11	10.13	9.91	43	-0.091	1.000	9.75	10.18	42	-0.166	0.888
12 months	16	20	18.88	18.20	154	-0.205	0.881	18.75	18.30	156	-0.127	0.906
CFR Food Treatment												
8 months	2	17	5.50	10.53	8.0	-1.313	0.439	5.75	10.50	8.5	-1.132	0.298
12 months	4	32	21.50	18.13	52.0	-0.650	0.688	23.13	17.92	45.5	-0.932	0.373
Release Treatment												
8 months	10	9	10.35	9.61	41.5	-0.314	0.880	9.85	10.17	43.5	-0.123	0.920
12 months	21	15	20.69	15.43	111.5	-1.587	0.123	20.74	15.37	110.5	-1.509	0.135

Appendix R. Results of the generalised linear model backward elimination model selection for CFR microhabitat effects on CFR visitation. Significant results are highlighted in bold.

Factor	Model Effects			Parameter Estimates					95% CI Odds Ratio		
	Likelihood Ratio X^2	df	sig	B (SE)	Hypothesis Test				Lower	Exp (B)	Upper
					Wald X^2	df	sig				
Intercept	0.969	1	0.325	2.036 (2.0591)	0.978	1	0.323		0.202	7.660	873.090
Temperature	5.061	1	**0.024**	-0.212 (0.1129)	3.532	1	0.060		0.615	0.809	0.976
Canopy Cover (9sqm)	10.267	1	**0.001**	-1.399 (0.4533)	9.524	1	**0.002**		0.098	0.247	0.587
CFR Tree Height	17.125	1	**<0.001**	0.486 (0.1256)	14.973	1	**<0.001**		1.282	1.626	2.103
CFR Tree TBA	4.358	1	**0.037**	-0.001 (0.0006)	4.038	1	**0.044**		0.998	0.999	1.000
Aspect	15.683	3	**0.001**								
= 1 S				0.516 (0.4267)	1.464	1	0.226		0.726	1.676	3.900
= 2 W				0.376 (0.4316)	0.759	1	0.384		0.624	1.457	3.411
= 3 N				-1.335 (0.5436)	6.034	1	**0.014**		0.084	0.263	0.727
= 4 E				/	/	/	/		/	/	/
= 4 E				-0.516 (0.4267)	1.464	1	0.226		0.256	0.597	1.377
= 3 N				-1.852 (0.5412)	11.703	1	**0.001**		0.050	0.157	0.430
= 2 W				-0.140 (0.4561)	0.094	1	0.759		0.353	0.869	2.124
= 1 S				/	/	/	/		/	/	/

Appendix S. Results of the generalised linear model backward elimination model selection for CFR microhabitat effects on tracking tunnel visitation. Significant results are highlighted in bold.

Factor	Model Effects			Parameter Estimates						
				Hypothesis Test				95% CI Odds Ratio		
	Likelihood Ratio X^2	df	sig	B (SE)	Wald X^2	df	sig	Lower	Exp (B)	Upper
Intercept	6.037	1	0.014	5.788 (2.6751)	4.682	1	0.030	1.797	326.516	65630.385
Canopy Cover (9sqm)	3.528	1	0.060	-0.533 (0.2851)	3.493	1	0.062	0.334	0.587	1.023
Humidity	3.356	1	0.067	-0.061 (0.0333)	3.308	1	0.069	0.881	0.941	1.004
CFR Tree Height	1.748	1	0.186	-0.087 (0.0663)	1.732	1	0.188	0.804	0.916	1.043
Release Year 2006	**42.451**	1	**<0.001**	1.366 (0.2180)	39.261	1	**<0.001**	2.572	3.919	6.053
2013	/		/	/	/	/	/	/	/	/

Appendix T. Results of the generalised linear model backward elimination model selection for surrounding vegetation effects on CFR visitation. Significant results are highlighted in bold.

Factor	Model Effects			Parameter Estimates						
				Hypothesis Test				95% CI Odds Ratio		
	Likelihood Ratio X^2	df	sig	B (SE)	Wald X^2	df	sig	Lower	Exp (B)	Upper
Intercept	4.864	1	0.027	-1.432 (0.6603)	4.703	1	0.030	0.064	0.239	0.854
Muehlenbeckia	2.236	1	0.135	-0.908 (0.6451)	1.981	1	0.159	0.097	0.403	1.306
Canopy Cover	2.620	1	0.106	-0.693 (0.4346)	2.541	1	0.111	0.208	0.500	1.155
Fern	2.850	1	0.091	0.460 (0.2654)	3.003	1	0.083	0.925	1.584	2.660
Other Shrubs	**4.113**	1	**0.043**	-0.997 (0.5007)	3.965	1	**0.046**	0.135	0.369	0.968
Flax	**3.854**	1	**0.050**	1.281 (0.6495)	3.887	1	**0.049**	1.002	3.599	13.445
Tree Trunks, Roots and Logs	**22.360**	1	**<0.001**	4.211 (0.9750)	18.653	1	**<0.001**	10.837	67.422	504.878

Appendix U. Results of the generalised linear model backward elimination model selection for surrounding vegetation effects on tracking tunnel visitation. Significant results are highlighted in bold.

Factor	Model Effects			Parameter Estimates						
	Likelihood Ratio X^2	df	sig	B (SE)	Hypothesis Test			95% CI Odds Ratio		
					Wald X^2	df	sig	Lower	Exp (B)	Upper
Intercept	10.238	1	0.001	-0.943 (0.5010)	3.542	1	0.060	0.144	0.389	1.031
Flax	48.071	1	**<0.001**	2.605 (0.4176)	38.924	1	**<0.001**	6.133	13.533	31.557
Tree Trunks, Roots and Logs	6.049	1	**0.014**	1.067 (0.4459)	5.725	1	**0.017**	1.237	2.907	7.158
Other Shrubs	2.527	1	0.112	0.551 (0.3483)	2.498	1	0.114	0.880	1.734	3.457
Herbs and Grass	2.685	1	0.101	0.310 (0.1914)	2.627	1	0.105	0.941	1.364	1.999
Fern	2.972	1	0.085	0.376 (0.2168)	3.001	1	0.083	0.949	1.456	2.236
Release Year 2013	6.080	1	**0.014**	-0.714 (0.2885)	6.127	1	**0.013**	0.278	0.490	0.863
2006				/	/	/	/	/	/	/

Appendix V. Results of the generalised linear model backward elimination model selection for surrounding flax (*Phormium tenax*) effects on CFR visitation. Significant results are highlighted in bold.

Factor		Model Effects			Parameter Estimates							
						Hypothesis Test			95% CI Odds Ratio			
		Likelihood Ratio X^2	df	sig	B (SE)	Wald X^2	df	sig	Lower	Exp (B)	Upper	
Intercept		33.516	1	<0.001	-2.516 (1.1398)	4.874	1	0.027	0.003	0.081	0.482	
Largest Flax Basal Area		5.894	1	**0.015**	0.011 (0.0053)	4.493	1	**0.034**	1.002	1.011	1.024	
Nearest Flax Distance		15.815	3	**0.001**								
= 4	>10m				2.165 (1.1515)	3.534	1	0.060	1.409	8.710	205.133	
= 3	5-10m				0.376 (1.3631)	0.076	1	0.782	0.113	1.457	42.172	
= 2	2-5m				1.196 (1.2019)	0.991	1	0.319	0.448	3.308	79.677	
= 1	0-2m				/	/	/	/	/	/	/	
= 1	0-2m				-2.165 (1.1515)	3.534	1	0.060	0.005	0.115	0.710	
= 2	2-5m				-0.968 (0.4586)	4.462	1	**0.035**	0.144	0.380	0.891	
= 3	5-10m				-1.788 (0.7651)	5.461	1	**0.019**	0.026	0.167	0.611	
= 4	>10m				/	/	/	/	/	/	/	

Appendix W. Results of the generalised linear model backward elimination model selection for surrounding flax (*Phormium tenax*) effects on tracking tunnel visitation. Significant results are highlighted in bold.

Factor	Model Effects			Parameter Estimates						
	Likelihood Ratio X^2	df	sig	B (SE)	Hypothesis Test			95% CI Odds Ratio		
					Wald X^2	df	sig	Lower	Exp (B)	Upper
Intercept	6.996	1	0.008	1.228 (0.2854)	18.525	1	<0.001	1.988	3.416	6.115
Largest Flax Basal Area	7.292	1	**0.007**	0.005 (0.0018)	6.349	1	**0.012**	1.001	1.005	1.008
Release Year	22.394	1	**<0.001**							
2013				-1.186 (0.2545)	21.718	1	**<0.001**	0.184	0.305	0.501
2006				/	/	/	/	/	/	/
Nearest Flax Distance	21.877	3	**<0.001**							
= 4 >10m				-0.810 (0.3190)	6.455	1	**0.011**	0.236	0.445	0.828
= 3 5-10m				-0.585 (0.4325)	1.832	1	0.176	0.238	0.557	1.305
= 2 2-5m				0.400 (0.3501)	1.302	1	0.254	0.752	1.491	2.979
= 1 0-2m				/	/	/	/	/	/	/
= 1 0-2m				0.810 (0.3190)	6.455	1	**0.011**	1.208	2.249	4.234
= 2 2-5m				1.210 (0.2784)	18.896	1	**<0.001**	1.958	3.354	5.843
= 3 5-10m				0.225 (0.3904)	0.333	1	0.564	0.575	1.253	2.681
= 4 >10m				/	/	/	/	/	/	/

Appendix X. Number of invertebrates encountered throughout the entire nine month sampling period. Numbers are separated into location (skirts, tree or total), size classification and group (O=Order, C=Class, SC=Sub-class). Underlined values indicate the five most commonly occurring invertebrate groups.

Group	Skirts		Tree		TOTAL	% Total Density
	#	%	#	%		
Insects						
O. Orthoptera (<1 cm)	*179*	*(14)*	*1113*	*(86)*	*1292*	*0.98*
O. Orthoptera (1-3 cm)	*17*	*(27)*	*47*	*(73)*	*64*	*0.05*
O. Orthoptera (3-5 cm)	*24*	*(14)*	*147*	*(86)*	*171*	*0.13*
O. Orthoptera (>5 cm)	*19*	*(9)*	*186*	*(91)*	*205*	*0.16*
O. Orthoptera (>1 cm)	*0*	*(0)*	*128*	*(100)*	*128*	*0.10*
O. Orthoptera Total	239	(13)	1621	(87)	1860	<u>1.42</u>
O. Blattodea	7186	(35)	13392	(65)	20578	<u>15.69</u>
O. Coleoptera	192	(9)	1951	(91)	2143	<u>1.63</u>
O. Lepidoptera	16	(70)	7	(30)	23	0.02
O. Diptera	7	(100)	0	(0)	7	0.01
O. Hymenoptera	116	(31)	262	(69)	378	0.29
O. Hemiptera	8	(80)	2	(20)	10	0.01
O. Dermaptera	1	(17)	5	(83)	6	0.00
O. Thysanura	10	(31)	22	(69)	32	0.02
Arachnids						
O. Araneae (<1 cm)	*370*	*(80)*	*92*	*(20)*	*462*	*0.35*
O. Araneae (1-2 cm)	*125*	*(39)*	*199*	*(61)*	*324*	*0.25*
O. Araneae (2-3 cm)	*80*	*(39)*	*127*	*(61)*	*207*	*0.16*
O. Araneae (>3 cm)	*10*	*(9)*	*96*	*(91)*	*106*	*0.08*
O. Araneae Total	585	(53)	514	(47)	1099	<u>0.84</u>
SC. Acari	0	(0)	30	(100)	30	0.02
O. Pseudoscorpionida	1	(100)	0	(0)	1	0.00
Crustaceans						
O. Isopoda	24,522	(23)	80,204	(77)	104,726	<u>79.83</u>
O. Amphipoda	0	(0)	1	(100)	1	0.00
Arthropods						
C. Chilopoda (Giant)	*0*	*(0)*	*4*	*(100)*	*4*	*0.00*
C. Chilopoda (Small)	*1*	*(11)*	*8*	*(89)*	*9*	*0.01*
C. Chilopoda Total	1	(8)	12	(92)	13	0.01
C. Diplopoda	0	(0)	21	(100)	21	0.02
Molluscs						
C. Gastropoda	21	(24)	67	(76)	88	0.07
Annelids						
O. Oligochaeta	1	(5)	21	(95)	22	0.02
Unidentified						
Wormlike	0	(0)	3	(75)	4	0.00
Larvae	120	(79)	32	(21)	152	0.12
TOTAL						
Density	33,026	(25)	98,167	(75)	131,194	100
Richness	16	(80)	18	(90)	20	

Appendix Y. Number of CFR housing trees of each species, and their corresponding average invertebrate densities. Descriptive statistics include sample size (N) minimum and maximum densities, mean, standard error (SE), the mean ±1 SE, and the upper and lower limits of the 95% confidence interval.

Tree Species		Number of CFRs	N	Min	Max	Mean	SE	Mean -1SE	Mean +1SE	95% CI Lower	95% CI Upper
Cordyline australis	Cabbage Tree	59	531	0	4003	206.51	21.37	185.14	227.87	164.54	248.48
Metrosideros excelsa	Pohutukawa	52	443	0	210	6.77	0.97	5.79	7.74	4.85	8.68
Pittosporum crassifolium	Karo	18	146	0	71	6.11	0.95	5.16	7.06	4.23	8.00
Aenetus virescens	Puriri	15	135	0	51	11.06	1.06	10.00	12.12	8.96	13.16
Melicytus ramiflorus	Mahoe	11	99	0	111	10.17	1.78	8.39	11.96	6.63	13.71
Leptospermum scoparium	Manuka	11	99	0	230	21.52	3.68	17.84	25.19	14.21	28.82
Kunzea ericioides	Kanuka	10	90	0	1123	78.21	17.32	60.89	95.53	43.80	112.62
Myoporum laetum	Ngaio	7	60	0	2051	88.30	35.18	53.12	123.48	17.91	158.69
Dysoxylum spectabile	Kohekohe	4	36	0	53	9.11	1.88	7.23	10.99	5.30	12.92
Sophora microphylla	Kowhai	3	27	0	118	16.19	5.58	10.60	21.77	4.71	27.66
Dodonaea viscosa	Akeake	1	9	3	211	57.00	24.11	32.89	81.11	1.41	112.59
Cyathea dealbata	Silver Fern	1	9	0	24	10.44	3.15	7.29	13.59	3.18	17.71
Acacia species	Wattle	1	9	0	7	1.67	0.80	0.87	2.47	-0.18	3.51
Knightia excelsa	Rewarewa	1	9	0	211	53.00	23.38	29.62	76.38	-0.91	106.91
UNKNOWN	DEAD	1	8	0	7	2.00	1.02	0.98	3.02	-0.41	4.41

Appendix Z. Number and percentage of trees of each species that CFRs were attached to. Data are divided into Motuora and Tiritiri Matangi Island, and into each of the 8 monitoring grids. Percentage of total CFR trees per island/grid are displayed in brackets. Dashes indicate values of zero.

CFR Tree Species		Motuora Island					Tiritiri Matangi Island				
		M1	M2	M3	M4	Total	T1	T2	T3	T4	Total
Cordyline australis	Cabbage Tree	-	24 (96)	6 (24)	10 (40)	40 (42)	8 (32)	3 (12)	8 (32)	-	19 (19)
Metrosideros excelsa	Pohutukawa	-	-	1 (4)	4 (16)	5 (5)	-	9 (36)	13 (52)	25 (100)	47 (47)
Pittosporum crassifolium	Karo	16 (80)	-	-	1 (4)	17 (18)	1 (4)	-	-	-	1 (1)
Aenetus virescens	Puriri	-	-	-	-	-	9 (36)	6 (24)	-	-	15 (15)
Melicytus ramiflorus	Mahoe	-	-	4 (16)	-	4 (4)	3 (12)	3 (12)	1 (4)	-	7 (7)
Leptospermum scoparium	Manuka	-	-	3 (12)	5 (20)	8 (8)	-	1 (4)	2 (8)	-	3 (3)
Kunzea ericioides	Kanuka	-	1 (4)	7 (28)	2 (8)	10 (11)	-	-	-	-	-
Myoporum laetum	Ngaio	3 (15)	-	4 (16)	-	7 (7)	-	-	-	-	-
Dysoxylum spectabile	Kohekohe	-	-	-	-	-	1 (4)	2 (8)	1 (4)	-	4 (4)
Sophora microphylla	Kowhai	-	-	-	1 (4)	1 (1)	1 (4)	1 (4)	-	-	2 (2)
Dodonaea viscosa	Akeake	-	-	-	1 (4)	1 (1)	-	-	-	-	-
Cyathea dealbata	Silver Fern	-	-	-	-	-	1 (4)	-	-	-	1 (1)
Acacia species	Wattle	-	-	-	-	-	1 (4)	-	-	-	1 (1)
Knightia excelsa	Rewarewa	-	-	-	1 (4)	1 (1)	-	-	-	-	-
UNKNOWN	DEAD	1 (5)	-	-	-	1 (1)	-	-	-	-	-
Total		20	25	25	25	95	25	25	25	25	100

194

Appendix AA. Mean invertebrate density and richness for each individual CFR, for each of the eight monitoring grids separately.
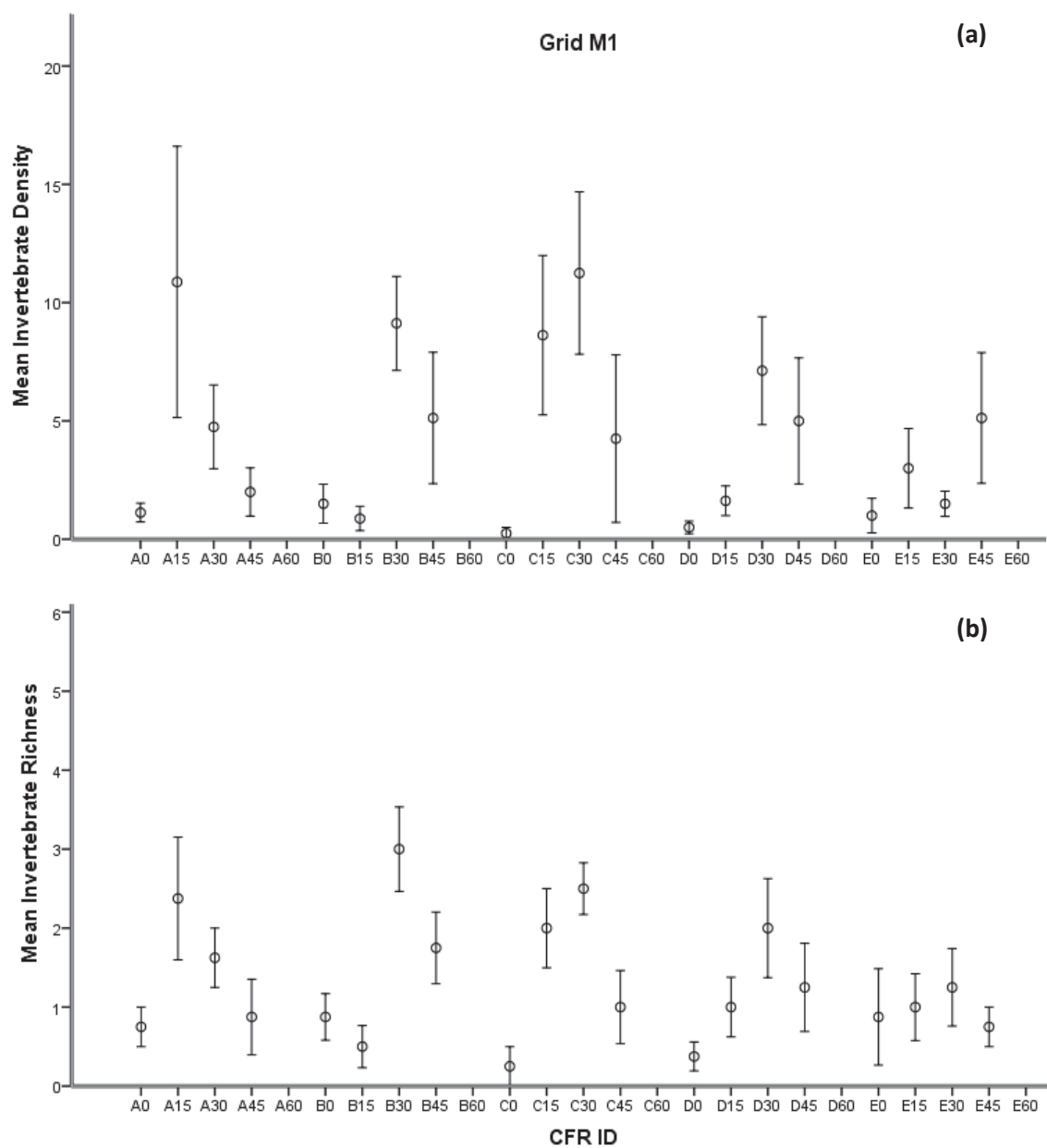

Figure U 1. Mean invertebrate density (a) and richness (b) for each individual CFR on grid M1. Error bars indicate the mean ±1 SE.
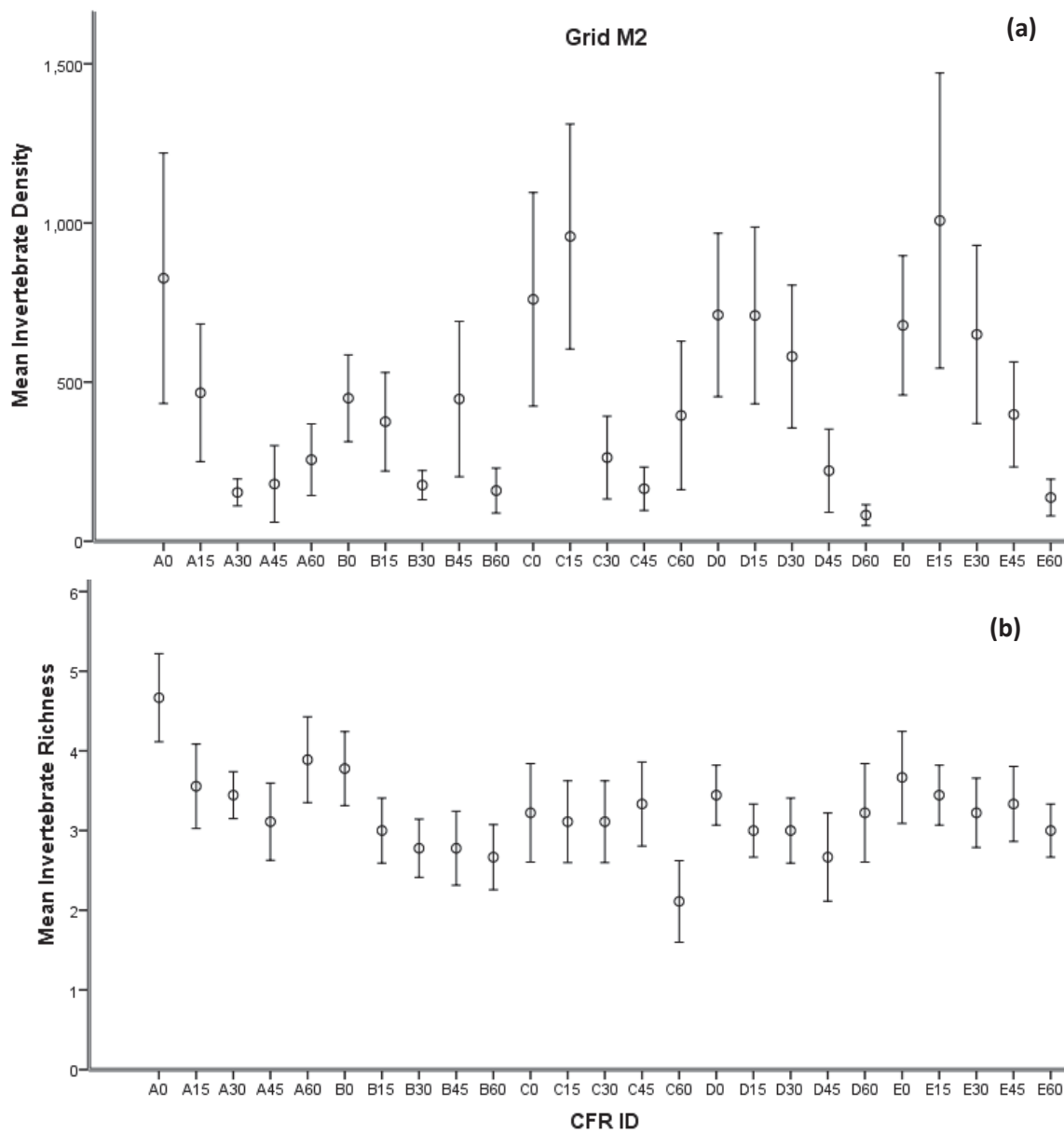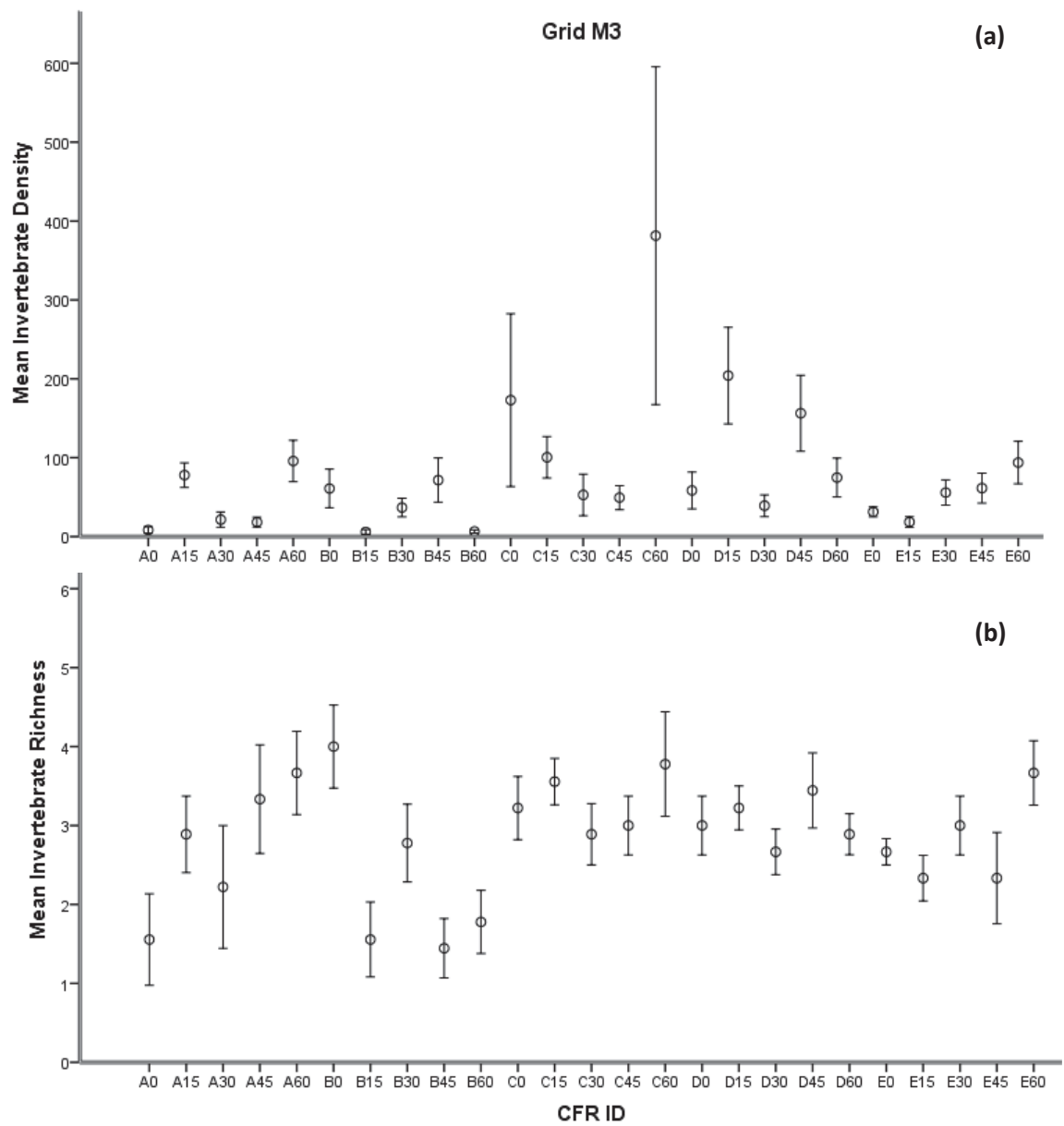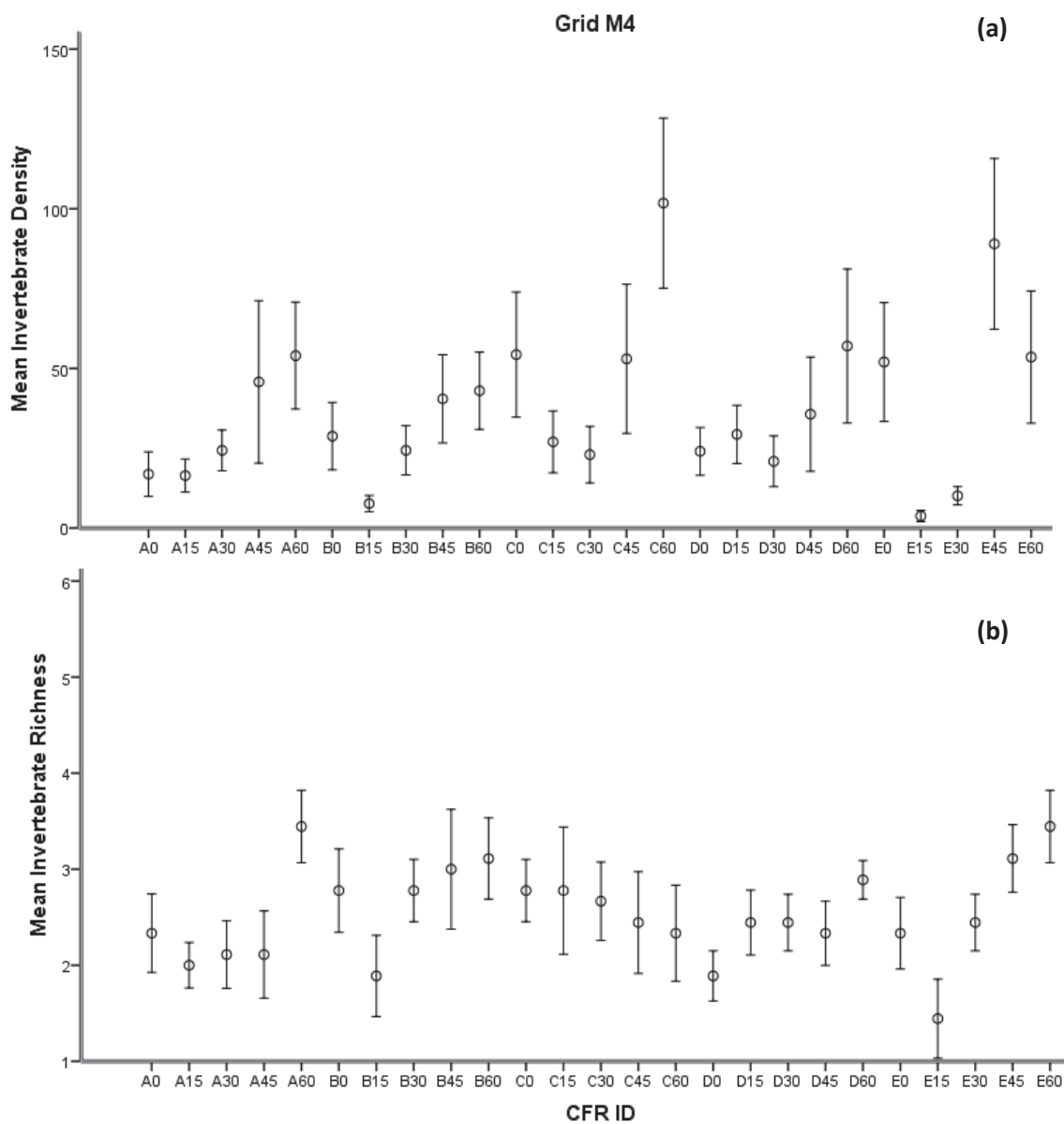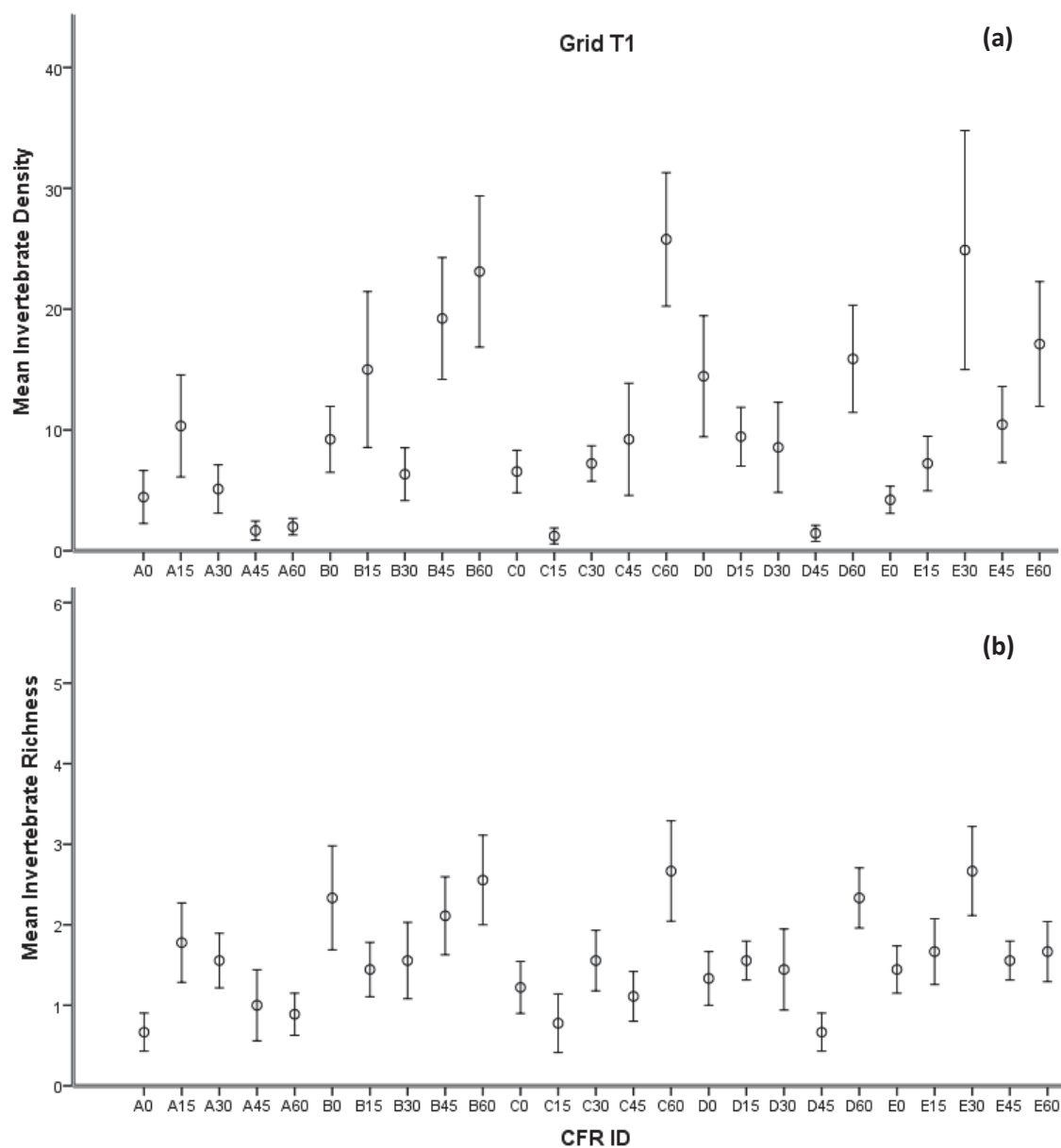
Appendix AA continued…

Figure U 2. Mean invertebrate density (a) and richness (b) for each individual CFR on grid M2. Error bars indicate the mean ±1 SE.

Appendix AA continued…
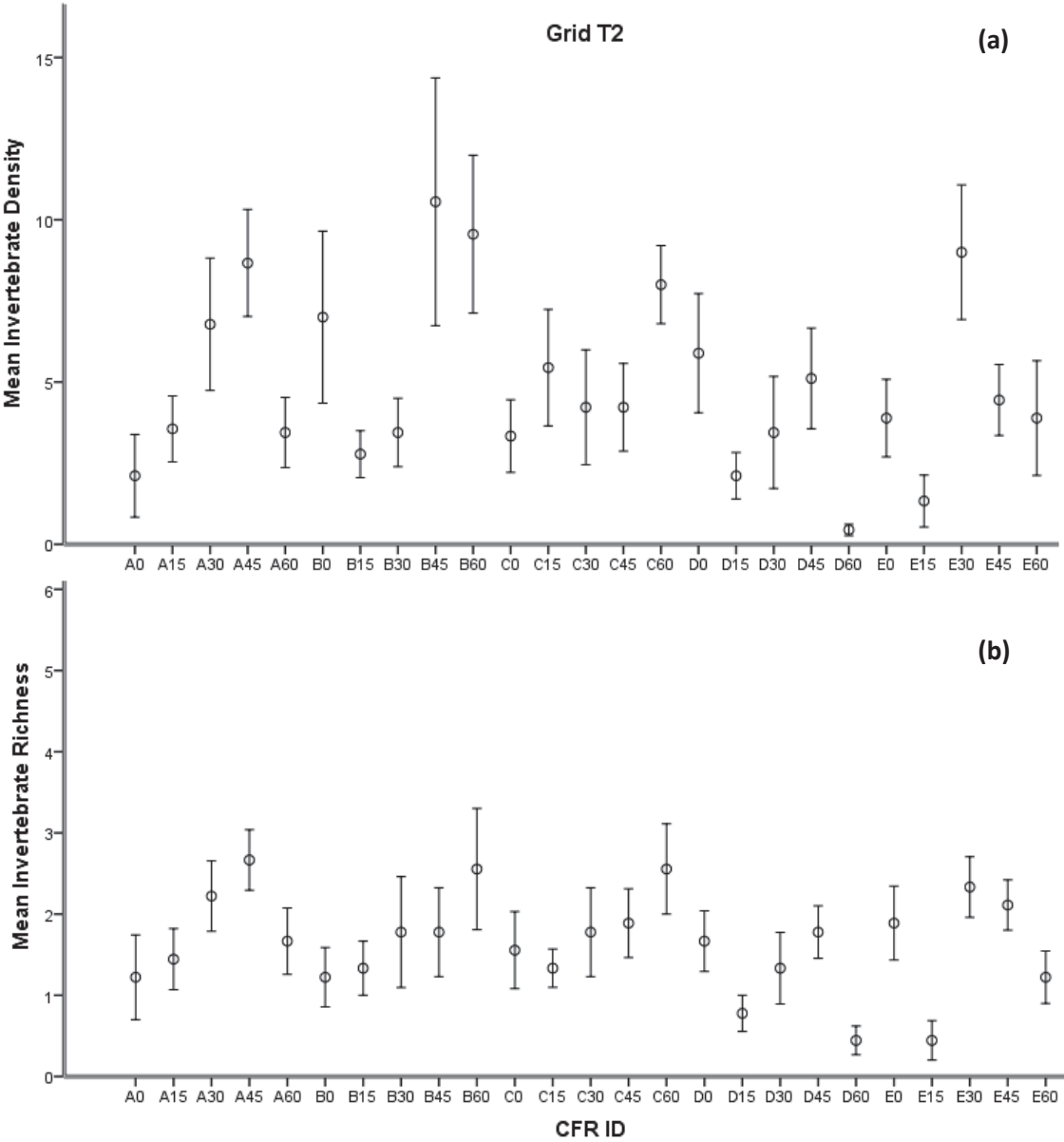

Figure U 3. Mean invertebrate density (a) and richness (b) for each individual CFR on grid M3. Error bars indicate the mean ±1 SE.

Appendix AA continued…

Figure U 4. Mean invertebrate density (a) and richness (b) for each individual CFR on grid M4. Error bars indicate the mean ±1 SE.

Appendix AA continued…

Figure U 5. Mean invertebrate density (a) and richness (b) for each individual CFR on grid T1. Error bars indicate the mean ±1 SE.

Appendix AA continued…

Figure U 6. Mean invertebrate density (a) and richness (b) for each individual CFR on grid T2. Error bars indicate the mean ±1 SE.
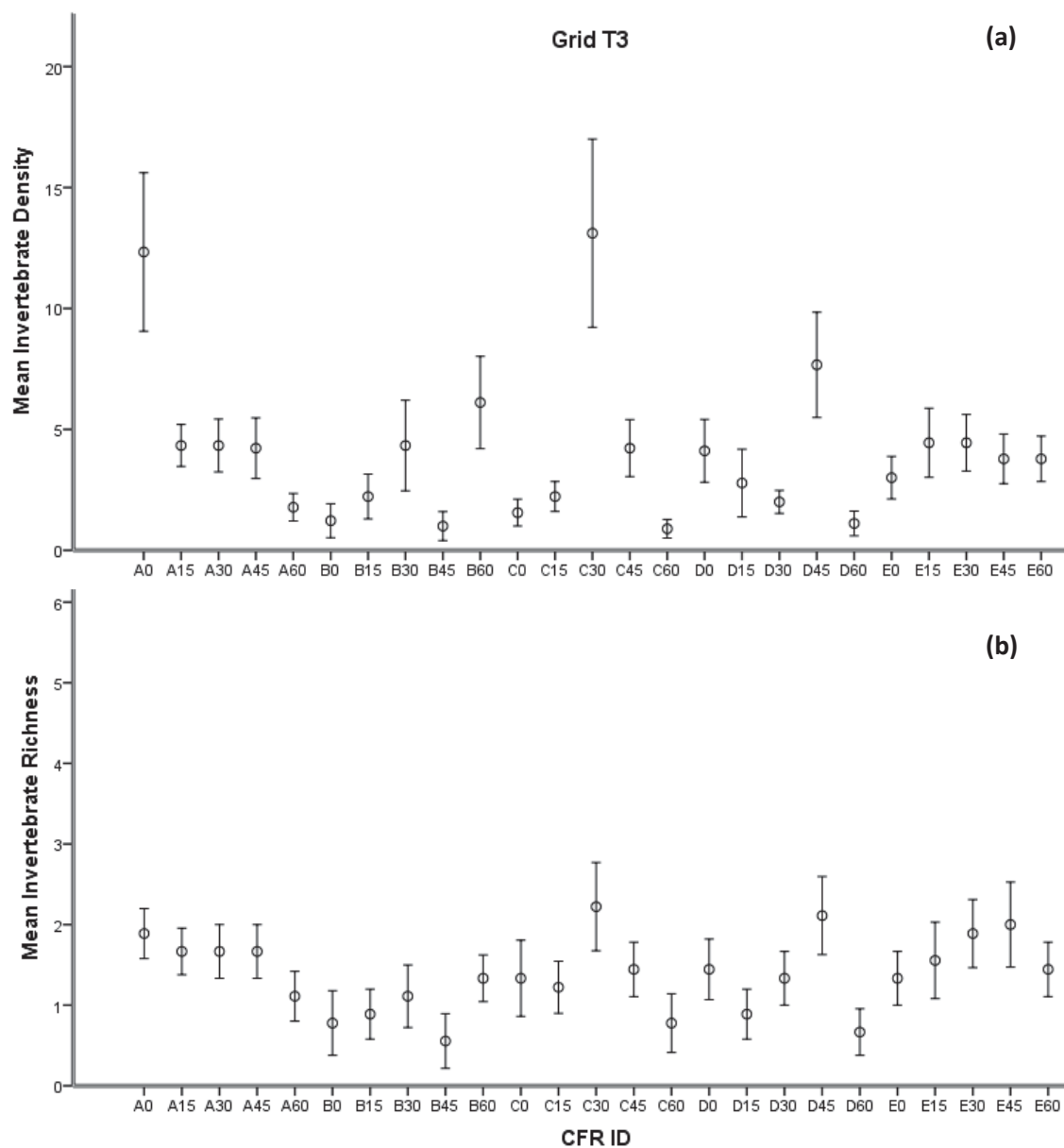
Appendix AA continued…

Figure U 7. Mean invertebrate density (a) and richness (b) for each individual CFR on grid T3. Error bars indicate the mean ±1 SE.
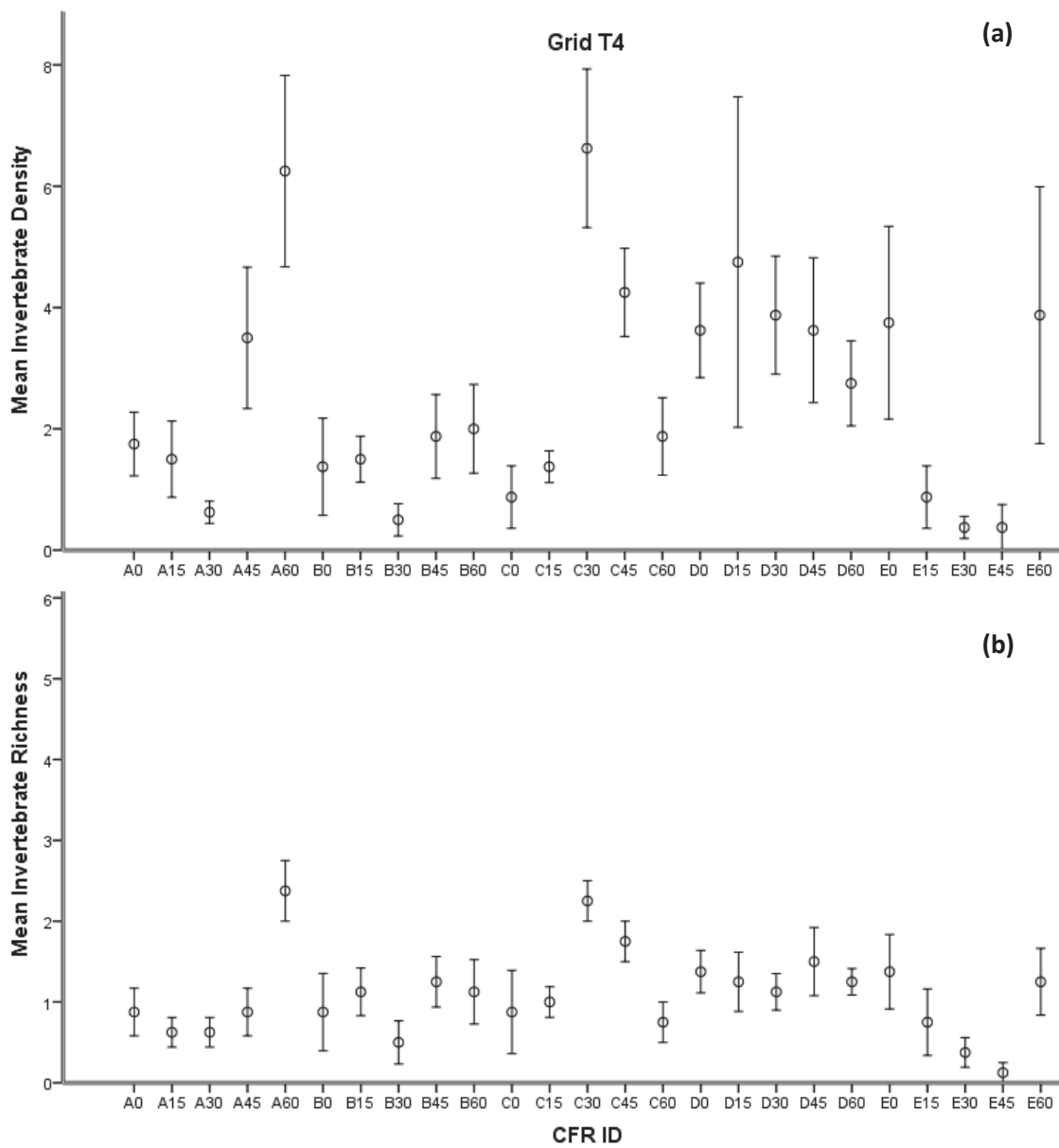
Appendix AA continued…

Figure U 8. Mean invertebrate density (a) and richness (b) for each individual CFR on grid T4. Error bars indicate the mean ±1 SE.

Appendix BB. Descriptive statistics (minimum, maximum, mean and standard error) for the average invertebrate density and richness per CFR per check session for each monitoring grid and Tiritiri Matangi and Motuora Islands separately.

Island or Grid	Density				Richness			
	Min	Max	Mean	SE	Min	Max	Mean	SE
Motuora	0.25	1007.56	149.25	23.87	0.25	4.67	2.53	0.09
M1	0.25	11.25	4.23	0.79	0.25	3.00	1.30	0.17
M2	82.11	1007.56	448.19	55.10	2.11	4.67	3.22	0.10
M3	5.89	381.56	78.13	16.24	1.44	4.00	2.83	0.14
M4	3.78	101.78	37.44	4.74	1.44	3.44	2.53	0.10
Tiritiri Matangi	0.25	25.56	5.43	0.52	0.13	2.67	1.40	0.06
T1	1.22	25.56	10.39	1.45	0.67	2.67	1.57	0.11
T2	0.44	10.56	4.89	0.53	0.44	2.67	1.63	0.12
T3	0.89	13.11	4.04	0.62	0.56	2.22	1.37	0.09
T4	0.25	6.63	2.41	0.36	0.13	2.38	1.05	0.11