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An assessment of the suitability of captive-bred founders for lizard restoration projects using Duvaucel's geckos (*Hoplodactylus duvaucelii*).

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Abstract

Sourcing founders for species restoration projects can be problematic, especially when using rare or endangered animals. Harvesting from small natural populations could be detrimental to those populations. A possible solution is to use captive-bred founders as this would reduce harvesting pressure on natural source populations. In the summer of 2013, a combination of captive-bred and wild-sourced Duvaucel's geckos (*Hoplodactylus duvaucelii*) were released on two islands in Auckland's Hauraki Gulf. To assess the suitability of captive-bred founders for species restoration projects, short-term survival, condition, reproductive performance, dispersal and activity patterns, and habitat use were investigated using mark-recapture surveys and radio telemetry over a 12 month period following the release, and comparisons were made between captive-bred and wild-sourced geckos.

Captive-bred geckos were encountered more often than wild geckos one year after the release, and had greater increases in body condition index. They also had better overall health, but more partial tail losses. Gravid females from both groups were encountered during the first post-release breeding season and at least 50% of juveniles were encountered alive during the first year. Less than 15% of radio tracked geckos moved further than 100 m away from their release locations. The size of activity areas reduced with time after release. Areas of activity were largest for wild geckos during both radio tracking periods and were much larger than the activity areas of captive-bred geckos during the second radio tracking period. *Hoplodactylus duvaucelii* did not appear to utilise available habitats randomly and rearing history did not appear to influence habitat use. Flax had considerably high use during both radio tracking periods. Overall, captive-bred geckos performed similarly to their wild counterparts, demonstrating that they are suitable for species restoration projects.

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Chapter 1

Literature Review: Assessing translocation success and the suitability of captive-bred founders for restoration projects.



Plate 1.0: *Hoplodactylus duvaucelii* captured on Motuora Island in February 2014.

1.1 Translocations - a conservation tool

Translocations are defined as the movement of species from one area to another with the intention of introducing, re-introducing or supplementing existing populations (IUCN/SSC, 2013). Many species have suffered population declines as a result of several factors including habitat destruction, competition from invasive species and predation by introduced predators. A primary aim of many conservation based translocation projects is to help reduce the threat of extinction by increasing the distribution of rare and endangered species. Although translocations are now increasingly common, they are often biased towards mammalian and avian species (Germano & Bishop, 2008).

Herpetofauna account for 46% of terrestrial vertebrates worldwide, yet they are underrepresented in wildlife studies (Christoffel & Lepczyk, 2012) and translocation projects (Fischer & Lindenmayer, 2000). For example, in a review by Fischer & Lindenmayer (2000), 93% of the translocation studies they examined involved either mammals or birds, whereas just 7% involved herpetofauna and invertebrates. Furthermore, very few herpetofauna translocation studies have focused on lizards (Towns, 1994). A possible reason for this underrepresentation is that there is often limited funding available for research projects and thus, allocation of funding can tend to be biased towards more iconic species (Small, 2011). Additionally, success rates have also been shown to vary among species. For example, when compared with mammalian and avian translocations, those involving herpetofauna suffer lower success rates worldwide (Dodd & Seigal, 1991). The translocation process involves countless complex interactions between several biological, environmental and behavioural factors (Germano *et al.*, 2014), which is what makes it risky. Thus, translocations do not guarantee success. Yet despite this inherent risk, translocations are a popular management tool utilised by conservationists. Although translocations will always involve some degree of risk, a translocation that is properly planned and executed can minimise some of that risk.

1.2 Factors influencing translocation success

Determining the reasons behind low success rates can often be problematic, due to a lack of post-release monitoring or failure to publish research findings, especially when translocations have failed or the outcomes are uncertain (Miller *et al.*, 2014). It is important that research findings are published to better inform translocation efforts and share possible solutions (Germano *et al.*, 2014). A number of more general factors have been found to influence the likelihood of translocation success, such as unsuitable habitat at release sites and dispersal away from release locations (Germano & Bishop, 2008).

Habitat quality is crucial, as unsuitable or inadequate habitats could prevent the successful establishment of translocated founders in new environments. For example, rainforest reptiles only appeared in 12.8% (5/39) of reforested sites in the subtropics of eastern Australia, compared with 44.4% (16/35) in the tropics, after translocation (Kanowski *et al.*, 2006). Unsuitable habitat structure was identified as one of the factors likely to have resulted in this outcome (Kanowski *et al.*, 2006). Poor habitats may have insufficient or unsuitable food resources, which could limit growth and reduce survival rates (Letty *et al.*, 2007), whereas unsuitable shelter resources could increase exposure to predators. Additionally, habitats that are scarce in resources or insufficient in size, may force animals to disperse in search of better habitats elsewhere. Unsuitable habitat is a commonly cited reason for translocation failure (Griffith *et al.*, 1989; Dodd & Seigal, 1991; Semlitsch, 2002; Germano & Bishop, 2008). Therefore, pre-release habitat assessments are essential if researchers are to determine whether or not the intended release locations are capable of sustaining the translocated animals in the long-term (Cheyne, 2006).

Post-release dispersal can influence the likelihood of translocation success in a number of ways (Richardson *et al.*, 2015). For example, dispersal may lead some animals into unsuitable habitats that lack appropriate food and shelter resources. It could also result in translocated animals becoming lost or isolated from other conspecifics. For example, post-release dispersal resulted in four gopher tortoises (*Gopherus polyphemus*) becoming lost within the first 15 days following their release into a government reserve in South Carolina (Tuberville *et al.*, 2005). Dispersal may also result in unnecessary energy expenditure, which could reduce growth and survival rates. Dispersal away from predator free or protected areas could also increase mortality rates (Kramer & Chapman, 1999). Furthermore, dispersal alters the composition of translocated populations, potentially exposing those populations to Allee effects, such as limited access to mates (Deredec & Courchamp, 2007; Baling *et al.*, 2013; Richardson *et al.*, 2015). Post-release dispersal could also limit the amount of post-release data researchers are able to collect, especially if translocated animals disperse into inaccessible locations. For example, Duvaucel's geckos (*Hoplodactylus duvaucelii*) translocated to Motuora Island in 2006 were released into a monitoring site surrounded by steep vertical cliffs on three sides (van Winkel, 2008). Any individuals that chose to move down those cliffs were likely to have been missed by monitoring efforts as the cliffs were too steep to traverse in some areas.

Animals may disperse away from certain areas for a number of reasons, such as insufficient or missing resources at the release locations, interspecific and intraspecific competition, a higher risk of predation, exploration, or as a result of homing. Understanding the factors that can cause an animal to disperse following a translocation can help researchers to develop more appropriate and effective

translocation strategies. For example, when planning translocations for species that exhibit strong homing tendencies, the distance between the capture location and the intended release location could have a significant impact on whether or not the translocation is likely to succeed. Animals that are released too close to their capture locations have been shown, in some studies, to return to their former homes. For example, 44% of Agassiz's desert tortoises (*Gopherus agassizii*) returned home after being translocated 2 km away; whereas none of the *G. agassizii* translocated 8 km away were re-encountered at their original source locations (Hinderle, *et al.*, 2015). In contrast, 14 out of 15 eastern fence lizards (*Sceloporus undulatus*) returned to within 6.81 m of their original capture sites after being relocated an average of 46 m away (Hein & Whitaker, 1997).

In addition to habitat quality and dispersal away from release sites, other factors such as the release of an insufficient number of animals (Germano & Bishop, 2008), stress (Teixeira *et al.*, 2007; Dickens *et al.*, 2010) and unusual post-release behaviour (Letty *et al.*, 2007) can also influence the likelihood of translocation success. For example, releasing an insufficient number of animals limits the available genetic diversity of the translocated population and could also restrict breeding opportunities if translocated individuals are unable to locate other conspecifics. Stress can occur at any stage of the translocation process and can have varying effects (Teixeira *et al.*, 2007); such as increasing an animal's susceptibility to diseases and impeding reproductive behaviours (Dickens *et al.*, 2010). For example, stressed sea turtles release corticosterone, which has been linked with inhibiting their immune system, increasing their susceptibility to infectious diseases (George, 1996). In male rough-skinned newts (*Taricha granulosa*), increases in corticosterone concentrations have been shown to reduce the occurrence of courtships (Moore & Miller, 1983). Abnormal post-release behaviour can include inappropriate habitat use and dispersal away from release sites. Homing can also pose a problem when animals are relocated to habitats that are relatively close to their original homes. For example, 40 days after being experimentally relocated on land, 92.9% (52/56) of European pond turtles (*Emys orbicularis*) were rediscovered within their original home ranges (Lebboroni & Chelazzi, 2000). Translocations that are carefully thought through during the planning stages can increase the chance of success by addressing some of these issues in advance, such as selecting release sites with appropriate habitat types (Germano *et al.*, 2014) or incorporating methods that could reduce post-release dispersal away from monitoring sites, such as food supplementation at release locations (Ebrahimi & Bull, 2012).

1.3 Suitability of captive-bred founders for species restoration projects

Species restoration projects can incorporate the release of both wild-caught and captive-bred animals. However, the use of captive-bred animals in restoration projects is often met with criticism,

as translocations involving captive-bred animals have been shown to have lower success rates when compared with those involving wild-sourced animals (Snyder *et al.*, 1996). For example, Griffith *et al.* (1989) found that just 38% of translocations involving animals sourced exclusively from captivity were successful compared to 75% of translocations involving wild-caught animals.

Sourcing founders for species restoration projects can be problematic, particularly when the species of concern is rare. Harvesting from small natural populations could be detrimental to those populations. The use of captive-bred animals in restoration projects provides a solution to this problem as it reduces the harvest pressure on natural source populations. In order to establish a captive-breeding programme, animals will initially need to be harvested from natural source populations. Once a captive population has been established, it provides an alternative or an additional source population. Individuals can then be sourced from the captive population rather than, or in combination with the natural source population, thus reducing the overall harvesting pressure on natural source populations. Sourcing individuals from captive populations has a number of other benefits. For example, researchers can be more selective with their choices of which animals to translocate. When sourcing animals from the wild, researchers are only able to choose from animals that have been caught and if catch numbers are low, there may be no choice at all. There is also more knowledge about the traits and history of captive stock compared with that of wild stock. Additionally, captive-bred animals may find the pre-translocation processes less stressful as they are used to being handled by humans (Mathews *et al.*, 2005).

Captive breeding has existed for centuries and occurs when animals are bred in human-controlled, artificial conditions that are under altered selection pressures from those present in their natural environments (IUCN/SSC, 2014). Yet, releasing captive animals back into the wild was not initially a main priority of captive breeding programmes (Spalton *et al.*, 1999) until successful projects such as “Operation Oryx” (Grimwood, 1962) highlighted the potential of captive-breeding programs for species reintroduction projects. Thus, conservation-based captive breeding programmes are relatively new. Despite their potential, captive breeding programmes continue to cause controversy with regards to their value as a conservation tool (Griffiths & Pavajeau, 2008).

Drawbacks of using captive-bred animals include the maintenance and logistics of self-sustaining captive populations (i.e. the associated spatial and monetary costs), reduced genetic diversity and domestication (Snyder *et al.*, 1996). The option of using captive-bred animals in restoration projects is only possible for species that are able to breed successfully in captivity (Snyder *et al.*, 1996). Unfortunately for some species, establishing captive populations can be problematic due to reproductive issues associated with breeding animals in captivity, such as inbreeding and

outbreeding depression (Lacy *et al.*, 1993), infertility and premature reproductive aging (Hermes *et al.*, 2004). For those species that are able to be bred successfully in captivity, achieving a suitable level of genetic and phenotypic diversity within the captive population and maintaining that diversity is a constant issue (Rahbek, 1993). For example, in the early 1990s, a captive-breeding population of tuatara (*Sphenodon punctatus*) was established on Little Barrier Island (Hauturu), situated off the north-eastern coast of New Zealand's North Island, using eight rediscovered adults (1:1 male to female sex ratio) (Moore *et al.*, 2008). The group was initially split into male/female pairs, with each pair housed separately to maximise genetic representation (Moore *et al.*, 2008). Unfortunately, breeding failed to occur, which resulted in all eight *S. punctatus* later being housed together (Moore *et al.*, 2008). The founding captive population has subsequently produced more than 120 offspring; however, it is unknown how many of the four original males have sired offspring (Moore *et al.*, 2008). Domestication is another problem associated with animals bred in captivity. Captive environments differ substantially from wild environments and have an impact on everything from species interaction to learned behaviours, foraging habits, refuge habits and migration habits (Snyder *et al.*, 1996). For example, Otago skinks (*Oligosoma otagense*) that have been bred in captivity have been shown to weigh on average, 36% more than wild-caught *O. otagense* of the same size (i.e. snout-to-vent length) (Connolly & Cree, 2008). Captive-bred *O. otagense* have also been found to be slower than their wild counterparts, which could make them more susceptible to predation (Connolly & Cree, 2008). Following translocation, captive-bred northern water snakes (*Nerodia sipedon sipedon*) spent a larger proportion of their active season occupying terrestrial habitats rather than aquatic habitats, in contrast to the behaviours of resident and translocated wild-sourced *N. sipedon sipedon*, and demonstrated little or no preferences for or against available habitat types (Roe *et al.*, 2010). Another criticism often associated with captive-bred animals is a failure to recognise predators. In some cases though, individuals may exhibit an instinctive recognition of many native predators, but must learn to avoid introduced predators. For example, declines have been observed in several wild populations of hellbender salamanders (*Cryptobranchus alleganiensis*), with juveniles experiencing a disproportionately higher number of mortalities (Wheeler *et al.*, 2003). Larval *C. alleganiensis* have been shown to exhibit strong responses to native predators, but were less responsive to scent cues of non-native predators such as rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) (Gall & Mathis, 2010). Domestication is often a key factor in the failure of many translocations (Griffin *et al.*, 2000).

However, these drawbacks may have less relevance for herpetofauna (Santos *et al.*, 2009) as several studies have shown that herpetofauna are often not as negatively affected by captive environments. For example, in central-northern Spain, introduced captive-bred juvenile large *psammodromus*

lizards (*Psammodromus algirus*) displayed similar survival and growth rates to wild-caught *P. algirus* and higher activity rates (Santos *et al.*, 2009). Captive-bred rattlesnakes were found to be just as competent as their wild counterparts in terms of hunting ability (Chiszar *et al.*, 1993). Additionally, Germano & Bishop (2008) found no significant differences in the success rates of captive and wild herpetofauna translocations. Furthermore, Griffiths & Pavajeau (2008) found examples of 13 amphibian reintroductions, using captive-bred founders, which have successfully achieved self-sustaining populations. Herpetofauna are also generally small in comparison to mammals, thus, they are often cheaper to feed and care for and require less space (Bloxam & Tonge, 1995; Santos *et al.*, 2009). In addition, unlike many mammals and birds, herpetofauna often lack parental care, making them less dependent on learnt behaviours, which are often negatively impacted on in captivity (Bloxam & Tonge, 1995; Santos *et al.*, 2009). However, in cases where animals are reliant on learnt behaviours to survive in the wild, some form of predator avoidance training is recommended (Griffin *et al.*, 2000). For example, in the case of hellbender salamanders (*C. alleganiensis*), Crane & Mathis (2011) suggest trout recognition training.

The suitability of captive-bred founders for species restoration projects is often debated due to reports of lower success rates when compared with translocations using founders sourced from wild populations. However, a fair assessment of the suitability of captive-bred founders has often not occurred. For example, as mentioned previously, Griffith *et al.* (1989) found a stark contrast in the success rates of translocations involving either captive-bred or wild-sourced founders. However, their study compared translocations using founders that had either been exclusively sourced from captivity, or exclusively sourced from wild populations. Unless a combination of both captive-bred and wild-sourced individuals are released simultaneously, within the same release sites, it is difficult to determine whether rearing condition is responsible for the failure of a translocation rather than other causes (Letty *et al.*, 2007). For example, availability of food and shelter resources may change with the seasons, thus if one group has been released at a different time to the other group, seasonal variations may have contributed to differences observed in the performance of each group. Likewise, differences in the quality of the habitats at different release locations could also result in variations in the performance of each group.

1.4 Assessing translocation success and monitoring populations post-translocation

A translocation is commonly defined as having succeeded if a stable (Dodd & Seigal, 1991) self-sustaining population has been established (Griffith *et al.*, 1989) that includes locally born animals (Towns & Ferreira, 2001). Determining success based on this definition can be challenging, as many translocations are only short-term projects that do not follow population demography for an

extended period. Assessing translocation success is further complicated by species that exhibit extreme longevity, are slow to reach maturity or have a low annual reproductive output, as is the case with many of New Zealand's native species. Additionally, success status may change over time (Seddon, 1999). Therefore, it is not surprising that the outcomes of many translocations are often reported as uncertain. For example, between 1993 and 2008, most translocations involving New Zealand herpetofauna concluded with uncertain outcomes, when success was determined using the traditional criteria defined above (Miller *et al.*, 2014). Thus, Miller *et al.* (2014) have developed a revised set of criteria for assessing success, which take into consideration species life history and the time after release. Success has been broken down into four key stages and includes firstly, the survival and growth of translocated individuals; secondly, evidence of reproduction; thirdly, population growth and finally whether the population is viable (Miller *et al.*, 2014). Indicators of the achievement of each stage are summarised as follows: increases in body condition and survival of a pre-defined number of founders (stage 1); presence of locally born individuals, excluding those from females gravid at the time of the release (stage 2); presence of a larger number of individuals than were released, which can include original founders (stage 3); and presence of a larger number of individuals than were released, with regular captures of juvenile individuals and a smaller number of original founders contributing to the total number of captures during each monitoring period (stage 4).

To assess translocation success, post-release monitoring is essential and there are several methods available, such as mark-recapture surveys (Lettink & Armstrong, 2003) and fluorescent powder tracking (Mellor *et al.*, 2004; Birchfield & Deters, 2005). Radio telemetry is another useful tool that allows researchers to determine the fates of animals that may have otherwise remained unknown (Millsaugh & Marzluff, 2001). In addition to the post-release dispersal and home range patterns of a species, radio telemetry can provide valuable information about behaviour, habitat use and population demographics (Kenward, 2001; Goodman *et al.*, 2009). It can also be used to monitor the degree and impact of possible threats such as predation, competition and poaching, allowing researchers to develop more practical and appropriate techniques for the management and conservation of threatened species (Goodman *et al.*, 2009). Furthermore, advances in radio telemetry have made it an especially effective technique for monitoring cryptic species (Greene, 1994). A variety of tags and attachment methods exist, however, the most suitable design and attachment method will vary depending on the study species and the type of information being investigated (Species Inventory Unit, 1998; Withey *et al.*, 2001; Goodman *et al.*, 2009). For example, implanted transmitters have the benefit of concealment and eliminate the possibility of animals becoming snagged on vegetation, whereas externally fitted transmitters are considered less invasive

and are easier to recover and reuse (Species Inventory Unit, 1998). Radio telemetry can be used to study a broad range of species, including lizards. In New Zealand, it has been used to study both geckos and skinks, for example, the Marlborough green gecko (*Naultinus manukanus*) (Hare *et al.*, 2007), the southern North Island forest gecko (*Mokopirirakau* ‘Southern North Island’) (Romijn *et al.*, 2014) and chevron skinks (*Oligosoma homalonotum*) (Neilson *et al.*, 2006). Radio telemetry has also been used in previous *H. duvaucelii* studies (Christmas, 1995; Hoare, 2006; van Winkel, 2008). In all of these studies, transmitters were fitted externally. In Christmas’s (1995) study, the transmitters were attached to the dorsal side of the geckos above the rear legs using surgical tape, whereas Hoare (2006) and van Winkel (2008) both used ‘backpack’ designs.

Home range analysis can also provide useful information about a translocated population. The home range of an animal is defined as the area in which it regularly travels in search of food, shelter and mates (Burt, 1943; Rose, 1982). The size of an animal’s home range and whether or not it overlaps with the home range of another conspecific or multiple conspecifics can provide valuable information about individual social status and the type of social system present (Stone & Baird, 2002). For example, there is more overlap in the home ranges of individuals that are part of a social dominance hierarchy, whereby social rank and competitive edge determine access to limited resources, than there is for individuals in territorial systems, in which individuals aggressively monopolise prime territories preventing conspecifics from gaining access to limited resources (Stone & Baird, 2002). However, the type of social system present in a group is not fixed and can change as a result of resource availability, population density and access to mates, in addition to various other reasons (Lott, 1984). For example, although naturally territorial, green anole lizards (*Anolis carolinensis*) will adopt a social dominance hierarchy if placed in high density populations or into areas where resources are limited (Greenberg & Crews, 1990; Bush, 2014). Therefore, in addition to individual mating success, patterns in home range size and overlap can also provide information about population density and resource availability at particular sites (Stone & Baird, 2002).

1.5 Overview of New Zealand herpetofauna translocations

In New Zealand, translocations are a common conservation tool, with more than 400 conservation-based translocations having taken place (Armstrong & McLean, 1995). Although terrestrial birds have featured predominately (Armstrong & McLean, 1995), herpetofauna have not been excluded. The first known herpetofauna translocations to occur in New Zealand took place before 1960 and included one frog translocation and four tuatara translocations (Sherley *et al.*, 2010). A lizard translocation is also known to have occurred but it was excluded as the identity of the species was not recorded (Sherley *et al.*, 2010). No translocations involving herpetofauna occurred between

1960 and 1984; but between 1985 and 2008, nine frog translocations, 13 tuatara translocations, 46 skink translocations (15 species) and 22 gecko translocations (13 species) have taken place (Sherley *et al.*, 2010). More than half of these translocations have either undergone post-release monitoring or it has been planned for them (Sherley *et al.*, 2010).

Conservation and conflict between humans and wildlife have been the driving factors behind most lizard translocations in New Zealand (Romijn, 2015). Lizard translocations have involved six of New Zealand's eight lizard genera, with the most commonly translocated genus being New Zealand's only native skink genus, *Oligosoma* (Romijn, 2015). *Woodworthia* geckos are the third most commonly translocated genus along with the only species in the *Hoplodactylus* genus, *H. duvaucelii* (Romijn, 2015). *Toropuku* and *Tukutuku* are the only two gecko genera that have yet to be involved in any translocations (Romijn, 2015). Most lizard translocations in New Zealand have utilised individuals sourced exclusively from the wild, with only seven translocations supplementing wild founders with captive-bred founders, and only four translocations using individuals sourced exclusively from captivity (Romijn, 2015). Lizard translocations most often involve the movement of individuals from one island to another island, but can also involve moving individuals from an island to the mainland, the mainland to an island or between different mainland locations (Sherley *et al.*, 2010; Romijn, 2015). A key advantage of translocating animals to offshore islands, as opposed to the mainland, is that they are generally free of threats such as introduced predators and are easier to control to prevent re-invasions (Towns & Daugherty, 1994).

1.6 Examples of herpetofauna translocations

In 1988, fourteen robust skinks (*Oligosoma alani*) (3:9:2 – males/females/unknown), 30 Suter's skinks (*Oligosoma suteri*) (10:20 – males/females) and 23 Whitaker's skinks (*Oligosoma whitakeri*) were translocated to Korapuki Island, which is part of the Mercury Islands group (Towns & Ferreira, 2001). *Oligosoma alani* and *O. suteri* were sourced from wild populations on Green Island, whereas *O. whitakeri* were sourced from Middle (Atiu) Island (Towns & Ferreira, 2001). Green Island and Middle Island are both part of the Mercury Islands group. An additional five *O. whitakeri* joined the translocated population in 1988 and 1990 (28, 10:13:5 – males/females/unknown) (Towns & Ferreira, 2001). Post-release monitoring showed population increases for all three translocated species (Towns & Ferreira, 2001). All three translocated populations have been described as stable and self-sustaining (Towns & Ferreira, 2001).

In 1995, 68 tuatara (*Sphenodon punctatus*, previously *Sphenodon guntheri*) comprising a combination of both wild-sourced and captive-reared individuals were translocated to Titi Island,

near Stewart Island (Nelson *et al.*, 2002). The translocated population included 18 adults (7:11 – males/females) all of which were sourced from the wild population on North Brother Island in the Cook Strait and 50 juveniles reared in captivity (Nelson *et al.*, 2002). Following five years of post-release monitoring, a minimum of 57% of *S. punctatus* are known to have survived all of which increased in size and weight (Nelson *et al.*, 2002). There was also evidence of breeding success (Nelson *et al.*, 2002).

Also in 1995, 103 legless lizards known as slow-worms (*Anguis fragilis*) were captured at an urban location in Kent in the south-east of England and translocated 1 km away (Platenberg & Griffiths, 1999). Two years of subsequent post-release monitoring resulted in the recapture of 62 translocated *A. fragilis* (Platenberg & Griffiths, 1999). Gravid females were only encountered during the first year of post-release monitoring and only included five individuals, whereas no juveniles were encountered (Platenberg & Griffiths, 1999). Additionally, seven *A. fragilis* are known to have died during the monitoring period (Platenberg & Griffiths, 1999). Platenberg & Griffiths (1999) concluded that the translocated population of *A. fragilis* was not thriving in the short-term and seemed unlikely to become sustainable in the long-term. Subsequent post-release monitoring has not occurred.

1.7 Summary of *Hoplodactylus duvaucelii* translocations

Translocations of *H. duvaucelii* have been conducted on five islands, the first of which took place between 1997 and 1998. Between 1997 and 1998, a total of 40 (1:2:1 ratio – male/female/sub-adult, includes gravid females) *H. duvaucelii* were translocated from North Brother Island to Mana Island, situated off the west coast of Wellington (Flannagan, 2000). Initial post-release monitoring was carried out between November 1998 and December 1999 (Jones, 2000). Further post-release monitoring was conducted from 2009 to 2012 (Bell & Herbert, 2012). Monitoring revealed that the population had almost tripled in size. Juveniles accounted for 25.4% of the population and founder survival was at least 25% (Bell & Herbert, 2012). In 2006, *H. duvaucelii* were translocated from Korapuki Island to Motuora Island (20, 1:1 ratio – male/female, includes gravid females) and Tiritiri Matangi Island (19, approx. 1:1 ratio – male/female, includes gravid females), both of which lie in Auckland's Hauraki Gulf (van Winkel, 2008). Initial post-release monitoring was conducted for the first 13 months on both islands (van Winkel, 2008) followed by on-going annual volunteer-based population monitoring. At the conclusion of van Winkel's study (2008), founder body condition had increased and at least 20% and 5% of founders had survived on Motuora Island and Tiritiri Matangi Island, respectively. In 2011, 61 (approx. 1:1 ratio – male/female) *H. duvaucelii* were translocated from North Brother Island to Long Island in the Marlborough Sounds (Cash, 2011, unpublished report DOC DM-865117). Population monitoring was not conducted post-release, but has been

planned for five years after the release (Cash, 2011). The most recent translocation was carried out late March 2014 and involved the translocation of 86 (approx. 2:1 ratio – female/male) *H. duvaucelii* from Stanley (Kawhitu) Island, part of the Mercury Islands group, to Motuihe Island in the Hauraki Gulf (M. Baber, pers. comm., 2015). Post-release monitoring has not been conducted and is not planned for the near future (M. Baber, pers. comm., 2015).

In February and March 2013, 186 *H. duvaucelii* (1:1 ratio – male/female and 6 neonates) were translocated to Tiritiri Matangi Island and Motuora Island. The 2013 translocations were conducted as part of an ecological restoration initiative aimed at supplementing the existing resident populations established in 2006. The 2013 translocations implemented two release methods utilised in previous *H. duvaucelii* translocations, specifically, the release of gravid females and the release of a mix of adults and sub-adults. The release of gravid females will help to maximise genetic diversity and initiate early population growth, whilst the release of a mix of adults and sub-adults will help to maximise the reproductive potential of the translocated population. The 2013 translocations have also provided an opportunity to investigate the effects of rearing condition on translocation success; to further study the habitat choices, dispersal and range patterns of translocated *H. duvaucelii*; and to compare those habitat choices and movement patterns with those of the resident populations. The 2013 translocations involved the release of 60 captive-bred *H. duvaucelii* and 120 wild-caught *H. duvaucelii*, 60 of which were sourced from Korapuki Island and 60 from Stanley Island. It also included the release of six neonates that were born during the quarantine period prior to the release. It is the 2013 translocations that form the basis of my study.

1.8 Purpose of this research

The purpose of this study is to help address gaps in the literature that have been identified above. The primary aim of this study was to assess the suitability of captive-bred founders for restoration projects by investigating the effects of rearing condition on translocation success in the short-term. To better understand factors influencing the success of herpetofauna translocations using captive-bred founders I compared the short-term post-release survival, body condition, reproductive performance, dispersal and range patterns, and habitat use of captive-bred founders with wild-sourced founders. I assessed translocation success using the adjusted success criteria discussed by Miller *et al.* (2014) that take into account the translocation challenges associated with many of New Zealand's native species, such as extreme longevity, delayed sexual maturity and low annual reproductive output. The results from this research will have important implications for wildlife management practice and could be extrapolated to cover other lizard species in New Zealand. This

research will also help to increase public awareness about New Zealand's reptiles, which are not as well-known as our avian species.

1.9 Brief chapter overviews

Chapter 2 introduces the study species (Duvaucel's geckos, *Hoplodactylus duvaucelii*), the study sites (Tiritiri Matangi Island and Motuora Island) and the 2006 and 2013 translocations. It also describes the general methods used in this study.

Chapter 3 compares short-term post-release survival, body condition index, general condition and reproductive performance of captive-bred and wild founders; and between translocated and resident *H. duvaucelii* in relation to origin, sex and island of release. It also describes and reviews the capture methods used.

Questions:

- Do captive-bred and wild *H. duvaucelii* perform similarly, in terms of survival, body condition and reproductive performance, in the first year following translocation?
- Do translocated and resident *H. duvaucelii* show similar trends in population health and breeding success?
- Do the translocated populations of *H. duvaucelii* show signs of short-term translocation success?

Chapter 4 documents dispersal events and compares the average maximum linear distances moved from the release sites between captive-bred and wild founders. It also compares movement patterns and activity areas of captive-bred and wild founders; and between translocated and resident *H. duvaucelii* in relation to origin, sex and time after release. It also documents the nocturnal movement and activity patterns of *H. duvaucelii*.

Questions:

- Do captive-bred and wild *H. duvaucelii* differ in their dispersal and activity patterns during the first year after release?
- Do translocated and resident *H. duvaucelii* exhibit similar activity patterns one year after release?

Chapter 5 describes and compares the microhabitat use patterns of captive-bred and wild founders during the first year after the release. It also compares the habitat use of translocated and resident

H. duvaucelii and it documents the spatial distribution of *H. duvaucelii* in relation to microhabitat type.

Questions:

- Do captive-bred and wild *H. duvaucelii* use available habitats differently?
- Do translocated and resident *H. duvaucelii* differ in their habitat use?

Chapter 6 summarises the main conclusions drawn from each results chapter and includes recommendations for future research.

Question:

- Are captive-bred founders suitable for *H. duvaucelii* restoration projects?

Chapter 2

General Methods



Plate 2.0: *Hoplodactylus duvaucelii* captured on Tiritiri Matangi Island in May 2013.

2.1 Study species

Hoplodactylus duvaucelii, commonly known as Duvaucel's gecko, is New Zealand's largest living gecko species (Whitaker, 1968). It is one of 43 known endemic gecko species in New Zealand and one of 110 known reptile species (Hitchmough *et al.*, 2013).

Fossil evidence suggests that *H. duvaucelii* were once widely distributed throughout New Zealand (Worthy, 1987). This species is now believed to be extinct on the mainland (Towns & Daugherty, 1994). Remaining populations of *H. duvaucelii* are restricted to offshore islands scattered around New Zealand's North Island (Towns & Daugherty, 1994). Their current distribution extends mostly along the east coast of the North Island, but also reaches as far south as the Cook Strait (Towns & Daugherty, 1994).

Hoplodactylus duvaucelii are classified on the IUCN Red List (2014) as 'lower risk' and 'least concern'; however, it is noted that there is insufficient knowledge about their history (Groombridge, 1993). New Zealand's Threat Classification System lists *H. duvaucelii* as 'relict-at-risk', which includes taxa that occupy less than 10% of their original range (Hitchmough *et al.*, 2013).

Leading factors in the decline of *H. duvaucelii* include habitat destruction and predation by introduced mammals. Fossil evidence indicates that introduced predators, such as rats, played a significant part in the reduction of *H. duvaucelii*'s previous distribution (Worthy & Holdaway, 1995).

2.2 Biology

Hoplodactylus duvaucelii are comparably long-lived, with some individuals achieving 50 years (Wilson, 2010). In addition to their extreme longevity, they also mature slowly taking approximately seven years to reach sexual maturity (Barwick, 1982). They have a low annual reproductive output, with females giving birth to just one or two live young, i.e. they are viviparous, after a gestation period of about seven to eight months (Barwick, 1982; Cree, 1994). The northern populations of *H. duvaucelii*, which appear to be slightly larger than the southern populations, can attain a total length of up to 320 mm (160 mm for snout-to-vent length (SVL)) and weigh as much as 118 g (Whitaker, 1968). *Hoplodactylus duvaucelii* are predominately nocturnal and are able to remain active during cooler temperatures (Cree, 1994). However, they also sun-bask near shelters during the day to thermoregulate (Whitaker, 1968). *Hoplodactylus duvaucelii* have been described as both arboreal and terrestrial (Barwick, 1982). They are habitat generalists and thus can occupy a wide range of habitat types in both coastal environments (e.g. flax (*Phormium tenax*), shore, cliffs, etc.) and forest interiors (Hoare *et al.*, 2007), although they are commonly found along forest fringes (Whitaker, 1968). They have also been found to seek shelter in rocky crevices, cavities in trees and under

boulders and in seabird burrows (Barry *et al.*, 2014). *Hoplodactylus duvaucelii* can adapt their habitat use in the presence of introduced predators. For example, in the presence of Pacific rats (*Rattus exulans*), *H. duvaucelii* on Ōhī-nau, which is situated to the east of the Coromandel Peninsula, North Island, New Zealand, were found to exhibit a preference for arboreal habitats over terrestrial habitats (Hoare *et al.*, 2007). Their diet is largely made up of insects (Barwick, 1982; Christmas, 1995), but they will also eat nectar (Whitaker, 1987; Towns, 2002), fruit (Whitaker, 1987; Barwick, 1982) and on some occasions, small lizards (Barwick, 1982). Like all gecko species, they regularly shed their skin and can regenerate their tails.

2.3 The 2006 and 2013 translocations

In December 2006, 39 wild-caught *H. duvaucelii*, sourced from Korapuki Island, were translocated to Tiritiri Matangi Island, hereafter Tiritiri Matangi (36°60' S, 174°89' E) and Motuora Island, hereafter Motuora (36°30' S, 174°47' E) (19 geckos and 20 geckos, respectively) (van Winkel *et al.*, 2010). In February and March 2013, an additional 186 *H. duvaucelii* (90 males, 90 females and 6 neonates) were translocated to supplement the populations established in 2006. Ninety *H. duvaucelii* comprising 60 wild-caught and 30 captive-bred geckos were translocated to each island. A combination of age classes, including adults (SVL ≥ 110 mm), sub-adults (SVL 101 to < 110 mm) and juveniles (SVL < 101 mm) were released. The captive-bred population was comprised of individuals from four different age cohorts, i.e. 2007 (7 geckos), 2008 (15 geckos), 2009 (18 geckos) and 2010 (20 geckos). Six neonates were born during the quarantine period and released on Tiritiri Matangi (2 geckos) and Motuora (4 geckos). Wild-caught geckos were sourced from two islands: Korapuki Island (36°39.5' S, 175°51' E) and Stanley (Kawhitu) Island (36°37' S, 175°52' E). Both of these islands are pest-free and belong to a chain of islands, collectively known as the Mercury Islands (36°35' S, 175°55' E). The Mercury Islands are situated off the north-eastern coast of New Zealand's North Island, approximately 8 km from the Coromandel Peninsula (Fig. 2.1). Captive-bred geckos were sourced from the Massey University Reptile Facility (MURF) in Auckland. The MURF captive population was established using 30 *H. duvaucelii* (9 males and 21 females) sourced from Korapuki Island in 2006.



Figure 2.1: Map of the Mercury Islands in New Zealand showing the locations of Korapuki Island (◀) and Stanley (Kawhitu) Island (↔) where a total of 120 (60 from each island) *Hoplodactylus duvaucelii* were sourced for translocation. Map retrieved from <http://www.teara.govt.nz/en/map/30348/north-east-peninsula-and-mercury-islands>.

Two separate translocations took place on each island. The first set of translocations occurred in February 2013. Combinations of captive-bred and Korapuki-born geckos, hereafter Korapuki geckos, were released into two separate release sites on each island, called Sites 2 and 3 on Tiritiri Matangi and Sites 2 and 4 on Motuora. The second set of translocations occurred in February on Tiritiri Matangi and March 2013 on Motuora and involved the release of wild Stanley Island geckos, hereafter Stanley geckos. The Stanley geckos were released into separate release sites from the captive-bred and Korapuki geckos, called Site 1 on Tiritiri Matangi and Site 3 on Motuora. The release sites were subsequently used as monitoring sites. Each monitoring site was a 60 m by 60 m square with five parallel transects and 25 monitoring stations, consisting of an artificial tree shelter and tracking tunnel, situated approximately 15 m apart (Fig. 2.2). In total, three release sites were used on each island for the 2013 translocations. The 2013 release sites were not in the same locations as the original 2006 release sites. The closest of the 2013 release sites was approximately 435 m on Tiritiri Matangi and approximately 295 m on Motuora. The furthest sites were approximately 630 m on Tiritiri Matangi and 465 m on Motuora.

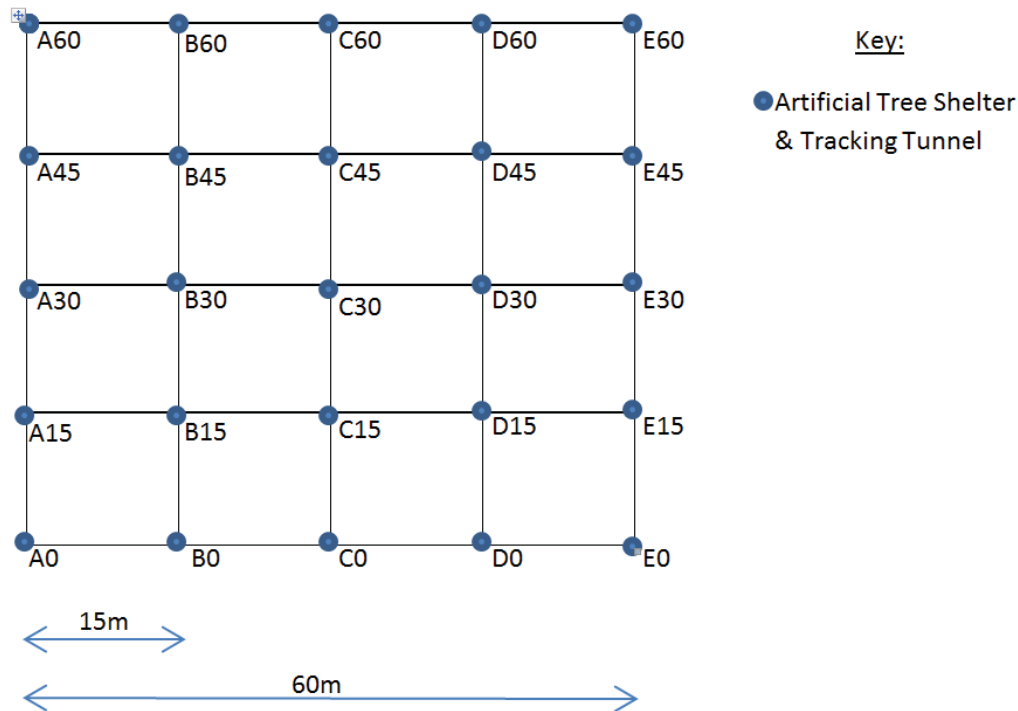


Figure 2.2: A diagram showing the design of the release and monitoring sites used in this study.

Twenty females (7 captive-bred, 12 Korapuki and 1 Stanley) were gravid (i.e. pregnant) at the time of the translocations, four (3 captive-bred and 1 Korapuki) of which gave birth before they were released. All six of the neonates released were from captive-bred females as the Korapuki female gave birth to only one neonate that was stillborn.

2.4 Study sites

Tiritiri Matangi and Motuora are both located within Auckland's Hauraki Gulf (Fig. 2.3). Tiritiri Matangi is located about 4 km from the Whangaparaoa Peninsula and about 30 km from central Auckland. Motuora is situated approximately 5 km off the eastern side of the Mahurangi Heads, north of Auckland. Tiritiri Matangi, covering an area of about 220 hectares, is more than double the size of Motuora, which covers an area of approximately 80 hectares. The Department of Conservation (DOC) categorises Tiritiri Matangi as a scientific reserve and open sanctuary, while Motuora is listed as a recreational reserve. Tiritiri Matangi is jointly managed by DOC and the Supporters of Tiritiri Matangi Incorporated (SoTM), a non-profit conservation-orientated volunteer group established in 1988. Motuora is also jointly managed by DOC and the Motuora Restoration Society Incorporated (MRS), a conservation-orientated charity recognised since 2007. Both islands are pest-free, although it is important to note that mammalian predators have never been present

or introduced to Motuora (MRS). In order to maintain pest-free status, visitors are required to check all luggage, clothing and shoes as part of a biosecurity measure, for the presence of pests, seeds and soil before they arrive on the islands. Checks are also mandatory for all boats accessing the islands. Both islands have a history of farming and have therefore had to undergo extensive re-planting to restore forest habitats. On Tiritiri Matangi, 94% of the native bush had been cleared (SoTM, 2010). Both islands are accessible to the general public; however, Tiritiri Matangi is visited by a significantly larger number of people. It has also been the focal location of more native species reintroductions.



Figure 2.3: Map of the Hauraki Gulf in Auckland showing the locations of Tiritiri Matangi Island (◀) and Motuora Island (↶) where a total of 186 *Hoplostactylus duvaucelii* were translocated in February and March 2013. Map retrieved from <http://www.thebarrier.co.nz/maphaurakigulf.htm>.

2.5 Flora

Both Tiritiri Matangi and Motuora are covered mostly in regenerating forests with patches of original forest, open grassland and water sources such as streams and ponds, as well as a number of sandy and rocky beaches. Neither island is completely flat, which is the same for Korapuki Island and Stanley Island. Instead, all four islands are mostly defined by flat-topped hills, sloping valleys and steep sea-facing cliffs (Taylor & Lovegrove, 1997; Towns & Atkinson, 2004). A long history of human

activity on both islands left Motuora with only 25% of its original forest (Gardner-Gee *et al.*, 2007) and Tiritiri Matangi with just 6% (SoTM, 2010). A similar situation occurred on Korapuki Island and Stanley Island, where most of the original vegetation was removed leaving just a few remnant forest patches behind. On Motuora, the aim is to have about 93% of the island covered by coastal broadleaf forest by 2040 and to leave the remaining 7% as open grassland (Gardner-Gee *et al.*, 2007). In comparison, 60% of Tiritiri Matangi has already been used for forests and the remaining 40% has been left as open grassland (SoTM, 2010). A similar assortment of plant species can be found on both islands with some of the seeds used on Motuora having been sourced from Tiritiri Matangi (Gardner-Gee *et al.*, 2007). Examples of some of the most dominant plant species present on both islands include pohutukawa (*Metrosideros excelsa*), cabbage trees (*Cordyline australis*), karo (*Pittosporum crassifolium*), mahoe (*Melicytus ramiflorus*), manuka (*Leptospermum scoparium*), coprosma (*Coprosma* spp.), *Muehlenbeckia* (*Muehlenbeckia astonii*) and flax. Many of these species also dominate the vegetation composition on Korapuki Island and Stanley Island, in particular pohutukawa, mahoe and flax (Taylor & Lovegrove, 1997; Towns & Atkinson, 2004). Additional plant species of interest, present on Tiritiri Matangi and Motuora, include kawakawa (*Macropiper excelsum*) and ngaio (*Myoporum laetum*), which in addition to pohutukawa and flax flowers are known food sources for *H. duvaucelii* (Whitaker, 1987).

2.6 Fauna

On Motuora, species reintroduction projects have focused primarily on invertebrates, reptiles and seabirds. The 'Motuora Native Species Restoration Plan' provides a list of all intended species reintroduction projects for the island starting from 2007 to 2017 (Gardner-Gee *et al.*, 2007). Such projects have seen the release of wetapunga (*Deinacrida heteracantha*) (MRS), common geckos (*Woodworthia maculata*) (MRS), whiteheads (*Mohoua albigilla*) (Graham *et al.*, 2008), *H. duvaucelii* (first released in December 2006) (van Winkel, 2008), shore skinks (*Oligosoma smithii*) (Baling *et al.*, 2010), common diving petrels (*Pelecanoides urinatrix urinatrix*) (Gummer *et al.*, 2008), Pycroft's petrels (*Pterodroma pycrofti*) (MRS) and most recently, Pacific geckos (*Dactylocnemis pacificus*) (MRS). Motuora is also home to other lizard species, including copper skinks (*Oligosoma aeneum*) and moko skinks (*Oligosoma moco*) as well as other native (and non-native) avian species, such as tui (*Prosthemadera novaeseelandiae*), New Zealand wood pigeon/kererū (*Hemiphaga novaeseelandiae*) and the endemic North Island brown kiwi (*Apteryx mantelli*). Motuora acts as a crèche for kiwi chicks as part of a project known as 'Operation Nest Egg: Kiwis for Kiwi', which commenced on the island in 1999 (MRS). Predatory species of *H. duvaucelii* are present on Motuora and include morepork/ruru (*Ninox novaeseelandiae*) and pukeko (*Porphyrio porphyrio melanotus*). In

comparison, Tiritiri Matangi has primarily focused on avian translocations. Approximately 71 bird species, native and non-native, can be seen on the island (SoTM, 2010), subsequently resulting in more intensified competition for food, especially invertebrates, on Tiritiri Matangi when compared with Motuora. Tiritiri Matangi is also home to the same reptilian species present on Motuora with the exception of *D. pacificus* and the addition of tuatara (*Sphenodon punctatus*) (SoTM, 2010). As tuatara are known to occasionally consume smaller lizards, they are another potential predator of *H. duvaucelii* (Dawbin, 1949). As with Motuora, kiwi are also present on Tiritiri Matangi, specifically little spotted kiwi (*Apteryx owenii*).

2.7 General methods

Prior to their release, each gecko was sexed, weighed and measured. The following measurements were recorded: snout-to-vent length (SVL), vent-to-tail tip length (TL) and tail regeneration length. All measurements were taken using a standard ruler and recorded in millimetres (mm). Weights were measured in grams (g) using a 100 g Pesola spring-scale. Female reproductive state (gravid, not gravid or postpartum/spent) was also recorded and was determined using abdominal palpation (Cree & Guillelte, 1995; Girling & Cree, 1995). I followed the definition described by Cree & Guillelte (1995), which differentiates between three stages, i.e. gravid (eggs or embryos present), not gravid (detectable follicles, but no eggs or embryos present) and recently given birth/postpartum/spent (no eggs, embryos or enlarged follicles) (Cree & Guillelte, 1995). The number of missing toes was also noted prior to release. As *H. duvaucelii* can be identified by unique patterns visible on their backs, dorsal photos were taken of all of the geckos for future identification (Plates 2.1a, 2.1b & 2.1c). For quicker identification, their abdomens were labelled with their ID using a non-toxic pen (Sharpie). Their IDs were placed on the ventral side so that they would remain visible after transmitter attachment and also so that the markings did not obscure the unique dorsal patterns used to identify each gecko, or make the geckos stand out more to potential predators. These were temporary labels as they were lost each time the geckos shed their skins. Pre-release measurements were recorded at the source locations of each release group. The number of missing toes and photo IDs were recorded during the quarantine period. All translocated *H. duvaucelii* were disease screened for *Salmonella* (three tests) and *Cryptosporidium* (one test) prior to their release and returned negative results. Post-translocation, the same information was recorded every time a gecko was captured. Scars and injuries were also recorded. Other information relating to the capture, including the date, time, and location of the capture and a brief description of the habitat were also recorded. In addition, the GPS position was recorded using a Garmin handheld GPS (Garmin models: GPSMAP® 62 and GPSMAP® 62s, accuracy ± 3 m). If the captured gecko was no longer

labelled with its temporary pen mark (ID), it was labelled with a new temporary pen mark (ID) that was either a number or a letter and then properly identified later by comparing the pre-release and post-release ID photos and measurements. *Hoplodactylus duvaucelii* released in 2006 were fitted with PIT tags (van Winkel, 2008), so all geckos found at the 2006 release sites were checked for the presence of a PIT tag using a handheld PIT tag reader. If the unknown gecko was a new gecko, i.e. belonged to a cohort born post-release or a 2006 gecko that did not have a PIT tag present, a new ID was created. This procedure did not occur if the captured gecko was wearing a transmitter or was known to have recently been weighed and measured within that same month.



Plates 2.1a, 2.1b & 2.1c: Photo IDs for C55F show how the dorsal patterns of *Hoplodactylus duvaucelii* remain the same as an individual grows. Plate 2.1a was taken at MURF (Massey University Reptile Facility) in 2009, about two months after C55F was born (age: juvenile, SVL: 58 mm). Plate 2.1b was taken during the quarantine period at MURF prior to the release in February 2013 (age: sub-adult, SVL: 102 mm). Plate 2.1c was taken one year after the release on Tiritiri Matangi Island in March 2014 (age: adult, SVL: 121 mm). (Photos by M. Barry).

Fifty six *H. duvaucelii* were fitted with 'backpacks' containing radio transmitters (SOPR-2038 crystal controlled magnum multi-vibrator 2 stage, 20 mm x 80 mm x 60 mm, with a 200 mm whip antenna, 1.8 g to 2.1 g; Wildlife Materials, Inc., USA) (Plate 2.2a) 24 to 48 hours prior to release. The reason for this was to allow the geckos time to adjust to the backpacks and to make sure that there were no adverse health effects with having a transmitter attached, with regards to the added weight and potential chafing. Half (28) were released on each island. Thirty were released into the artificial tree

shelters and the other 26 were released into 'natural' shelters. Large variations between the body weights of captive-bred and wild, and male and female geckos (Table 2.1) meant that it was not possible to attach transmitters to an equal number of geckos from each group. Transmitters were only fitted onto adult geckos weighing 50 g or more (46 g or more for captive-bred geckos). Gravid females were excluded. Twelve captive-bred (8 males and 4 females), 22 Korapuki (16 males and 6 females) and 22 Stanley geckos (10 males and 12 females) were fitted with transmitters. The average combined weight of the backpack and transmitter was 4.5 g (N = 39) equating to an average of 7.7% of the body weight of *H. duvaucelii* (Tables 2.2a & 2.2b, Appendix), which does not exceed the recommended limit of 10% (Beaupre *et al.*, 2004). A smaller transmitter (PIP3 AG393 single celled tag, 16 mm x 8 mm x 6 mm, with a 151 mm antenna, 1.7 g; Sirtrack Ltd., New Zealand) (Plate 2.2b) was used later in the study (approximately 8 months after the release), which reduced the average overall weight to 2.8 g (N = 19) equating to an average of 5.1% of the body weight of *H. duvaucelii* (Tables 2.2c & 2.2d, Appendix).



Plate 2.2a: A male *Hoplodactylus duvaucelii* fitted with a backpack containing the original, larger radio transmitter (SOPR-2038). (Photo by M. Barry).



Plate 2.2b: A female *Hoplodactylus duvaucelii* fitted with a backpack containing the second, smaller radio transmitter (PIP3 AG393).

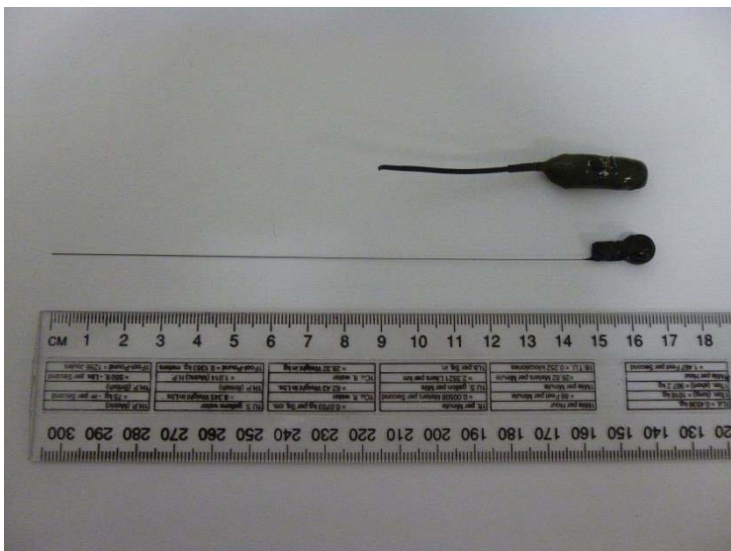


Plate 2.3: The two types of radio transmitters used during this study. Top: the original, larger radio transmitter (SOPR-2038) used from February to May 2013. Bottom: the second, smaller radio transmitter (PIP3 AG393) used from September to December 2013.

Table 2.1: The average weight \pm standard error (SE) and the weight range for male and female *Hoplodactylus duvaucelii* from each origin, i.e. captive-bred, Korapuki-sourced and Stanley-sourced, during the quarantine period prior to translocation in February 2013. Weights are in grams (g). Gravid females have been excluded.

Origin	N	Males		N	Non-Gravid Females	
		Mean \pm SE (g)	Range (g)		Mean \pm SE (g)	Range (g)
Captive	31	37.3 \pm 2.0	18.0 to 60.7	22	34.4 \pm 2.2	20.4 to 54.0
Korapuki	31	51.8 \pm 2.0	28.4 to 73.9	17	47.0 \pm 2.2	32.6 to 61.1
Stanley	28	59.4 \pm 2.6	26.7 to 79.6	31	62.1 \pm 2.0	29.1 to 78.3

2.8 Transmitter attachment

Transmitters were attached following a slightly modified version of the backpack design and method used during the 2006 translocations (van Winkel & Ji, 2014). The backpack harnesses were made out of Co-Flex bandage, which is a soft and stretchy material that allows for fluctuations in body fat and reduces the likelihood of abrasions. The backpack harness was comprised of a central pad from which two shoulder straps extended out. The central pad was glued using an all-purpose adhesive (UHU Glue) onto a square piece of elastic adhesive bandage tape. The transmitter was glued onto the central pad using cyanoacrylate glue (Super Glue) with the antenna extending down towards the tail. The backpack harness was then attached across the individual's shoulders with the straps extending out on either side of the head. The straps were folded over the shoulders and crossed over the chest in an 'X' pattern and then brought up behind the opposite foreleg and glued (using Super Glue) onto the transmitter. Any excess strapping was cut off. A square piece of elastic adhesive bandage tape was then stuck over the transmitter to further secure and conceal the transmitter. The straps crossing over the chest were glued (using Super Glue) together at the centre point to reduce movement. A non-toxic black marker pen was used to colour the backpack black in order to reduce its visibility. This was only done if black Co-Flex bandage material and black elastic adhesive bandage tape could not be acquired. Two modifications were made to the backpack design during the monitoring period to reduce the elasticity of the backpacks, as several transmitters were discarded in the initial weeks following the release (Chapter 4). The first modification was the use of a double layer of Co-Flex bandage material to make the backpack harness less stretchy, rather than the initial single layer. The second modification was the addition of a small square of elastic adhesive bandage tape, which was placed on the individual's chest where the straps crossed over. Care was taken to prevent glue getting on the skin of any of the geckos during transmitter attachment.

2.9 Analyses

All data analyses were performed using IBM SPSS Statistics 21 and 22 (IBM Corporation, 2013). All means were reported with a standard error (SE) of ± 1 unless otherwise stated.

Chapter 3

Short-term indicators of translocation success: Comparing survival, condition and reproductive performance of captive-bred and wild *Hoplodactylus duvaucelii*.



Plate 3.0: A gravid *Hoplodactylus duvaucelii* captured on Motuora Island in February 2014.

3.1 Introduction

Adjusting to novel environments

The initial months following a translocation can be especially demanding for translocated animals, whether they have been sourced from the wild or captivity as they must all learn to adapt to an unfamiliar environment (Letty *et al.*, 2007). Wild-sourced animals are generally thought to have an advantage over captive-bred animals in restoration projects (Snyder *et al.*, 1996) as they are accustomed to living in a wild environment and have not been affected by problems often associated with breeding animals in captivity, such as domestication. Common problems following translocation include predation (Letty *et al.*, 2007), stress (Teixeira *et al.*, 2007; Dickens *et al.*, 2010) and unconventional behaviours, such as wandering behaviour (Letty *et al.*, 2007). Each of these factors can lead to reduced survival, declines in body condition and limited breeding success, which ultimately influence the likelihood of a translocation succeeding. Assessing whether captive-bred animals are equally suited for reintroduction into wild environments requires comparing how well captive-bred animals adapt when faced with these factors, in relation to their wild counterparts. This requires the simultaneous release of both captive-bred and wild animals within the same release sites, but comparative studies such as this are rare, especially with reptiles.

Predation can be particularly devastating following a release. Captive-bred animals may never have encountered predators before, whereas wild-sourced animals may be unfamiliar with non-native predators, such as rats. In 2007 captive-bred woma pythons (*Aspidites ramsayi*) were reintroduced into the Arid Recovery Reserve in South Australia (Moseby *et al.*, 2011). Just one month after the release, more than half of the translocated population of *A. ramsayi* had been killed by a native predator, the mulga snake (*Pseudechis australis*) (Moseby *et al.*, 2011). Within four months of release, predation had eradicated the entire translocated population (Moseby *et al.*, 2011). Breeding failed to occur due to the rapid mortality rate (Moseby *et al.*, 2011).

Stress is considered an inevitable part of translocations (Dickens *et al.*, 2010). Stress can occur throughout the translocation process, including post-translocation (Teixeira *et al.*, 2007), however, its impacts vary. For example, following translocation, mountain yellow-legged frogs (*Rana muscosa*) suffered declines in body mass (Matthews, 2003), whereas timber rattlesnakes (*Crotalus horridus*) altered their behaviour and suffered from reduced survival rates (Reinert & Rupert Jr, 1999).

Transmitter attachment could also be a source of stress for an animal. Green iguana (*Iguana iguana*) hatchlings fitted with transmitters exhibited a lower growth percentage for body mass and had reduced climbing speeds (Knapp & Abarca, 2009). Black ratsnakes (*Elaphe obsoleta*) with implanted

transmitters also experienced a lower yearly growth rate for body mass and female *E. obsoleta* had egg clutches that were lighter relative to their body size (Weatherhead & Blouin-Demers, 2004). Conversely, implanted transmitters were found to have no impact on body condition or baseline concentrations of corticosterone (a stress hormone) of *E. obsoleta* in Sperry *et al.*'s study (2009). Knapp & Abarca (2009) found no significant differences in survival rates and Weatherhead & Blouin-Demers (2004) were also unable to conclusively link transmitter attachment with increased mortality rates. Habitat quality has also been found to have an effect on stress levels. For example, male spotted salamanders (*Ambystoma maculatum*) exhibited increased baseline concentrations of corticosterone when migrating across pavement when compared with *A. maculatum* that migrated through forest habitats (Newcomb Homan *et al.*, 2003).

Unconventional behaviour following translocation can also be detrimental to the initial survival and future reproductive success of a translocated population. For example, translocated captive-bred northern water snakes (*Nerodia sipedon sipedon*) displayed reduced movement and unusual habitat use when compared with resident snakes; whereas wild-sourced snakes would frequently disperse away from the monitoring sites (Roe *et al.*, 2010). Dispersal into unfamiliar areas could isolate translocated individuals from other conspecifics, restricting breeding opportunities. Dispersal could also reduce survival if the habitat in which the animal has dispersed into is unsuitable. In addition, unusual habitat use, such as the selection of inappropriate shelter sites, could increase exposure to predators, and habitats that lack suitable or sufficient food resources could lead to declines in body condition, which could further reduce an animal's chance of survival.

Assessing translocation success: recapture methods

Determining whether or not a translocation has succeeded requires some form of post-release monitoring (Seddon, 1999). A popular population monitoring technique is the mark-recapture survey. This method can be applied for any species, which can be captured and identified or marked for future identification (Lettink & Armstrong, 2003). Mark-recapture surveys enable researchers to estimate survival, abundance and reproductive success (Lettink & Armstrong, 2003). Other factors can also be assessed, such as the post-release condition of translocated animals. Several capture methods can be utilised, however, the effectiveness and appropriateness of each method will vary depending on the study species and the study sites.

Although commonly used in aquatic environments, funnel traps such as g-minnow traps, can also be used to capture terrestrial species and are considered the most effective method for capturing geckos (Hare, 2012). Jenkins *et al.* (2003) compared the effectiveness of funnel traps with that of

pitfall traps and found that in addition to regularly catching a greater number of individuals, funnel traps also captured a greater diversity of species. Funnel traps have also been found to be more effective at capturing larger herpetofauna species (Greenberg *et al.*, 1994). However, a disadvantage of trapping methods is that some animals may become trap-shy.

Visual encounter surveys, such as spotlighting, artificial cover object (ACO) searches (Monti *et al.*, 2000) and vegetation searches are another method that can be applied to capture lizards. Although trapping methods have been found to be more successful than visual encounter surveys (Crosswhite *et al.*, 1999), visual encounter surveys have a number of advantages. For example, unlike trapping methods, which can be biased towards lizards occupying ground-level shelters and denser vegetation where traps can be hidden, visual encounter surveys can be used to search those same habitats as well as arboreal shelters and small crevices and burrows. For species that are habitat generalists such as *H. duvaucelii*, search methods that cover a broader range of habitat types will improve the likelihood of encountering individuals. Another advantage of visual encounter surveys are that they can provide insights about behaviour as researchers are able to observe exactly what an animal is doing during the search period. For species that are active at night, nocturnal visual encounter surveys such as spotlighting could provide valuable information about foraging and general activity patterns. However, it is important to consider what effect the presence of an observer may have on the animal's behaviour (Bell, 2009). A disadvantage of visual encounter surveys is that they are subject to environmental conditions (Bell, 2009). Observer experience is also important as inexperience and observer bias can negatively impact the success rate of visual encounter surveys (Hare, 2012).

Chapter aim:

The aim of this chapter is to compare the performance of captive-bred and wild *Hoplodactylus duvaucelii* by assessing short-term indicators of translocation success, including survival, condition and reproductive performance in the first 14 months following their release on Tiritiri Matangi and Motuora Islands.

Specific chapter objectives:

- Compare short-term survival of captive-bred and wild Korapuki *H. duvaucelii* by assessing the minimum number alive and the number of known mortalities.
- Compare the population health 12 months after the release of captive-bred and wild Korapuki *H. duvaucelii* by assessing body condition indices and other indicators of general condition, including tail losses and wounds.

- Compare the reproductive performance of captive-bred and wild Korapuki *H. duvaucelii* by assessing the number of gravid females encountered during the first breeding season post-release and by assessing the number of juveniles encountered.
- Compare the condition and reproductive performance of translocated captive-bred and wild Korapuki *H. duvaucelii* with that of resident *H. duvaucelii*.

Criteria for short-term translocation success:

To achieve 'Stage 1' of translocation success, according to Miller *et al.*'s (2014) translocation success criteria, the following must be observed: increases in body condition and survival of a pre-defined number of founders. During the 2006 *H. duvaucelii* translocations on Tiritiri Matangi and Motuora, van Winkel (2008; van Winkel *et al.*, 2010) encountered $\geq 70\%$ of founders during the first three months post-release, body condition indices increased and island-born juveniles were encountered. As the 2013 translocations involved the same study species and the same island release sites, the results obtained from van Winkel's study (2008; van Winkel *et al.*, 2010) were used as a guideline for defining this study's survival, condition and reproductive performance success criteria.

- There is evidence of the persistence and establishment of translocated *H. duvaucelii*, i.e. at least 70% of the translocated founders are encountered (survival) during the monitoring period.
- There is evidence of growth, and body condition index is at least stable or has increased during the monitoring period (condition).
- There is evidence of breeding, i.e. through the detection of gravid females in the first breeding season post-release (reproductive performance).
- There is evidence of the persistence of juveniles, i.e. offspring of the translocated founders are encountered during the monitoring period (reproductive performance).

3.2 Methods and Analyses

Comparing the effectiveness of the different monitoring methods utilised during this study was not an objective of this study. The purpose of this study was to capture as many *H. duvaucelii* as possible to monitor their condition post-translocation and to assess the suitability of captive-bred founders by comparing them with wild Korapuki-sourced founders, so data from both systematic surveys and ad hoc captures were used. Sampling effort differed due to logistic constraints and sampling methods were adjusted over time. Therefore comparisons cannot be made between seasonal variations in capture rates or differences in the number of captures across each of the release

islands and monitoring sites for the first 12 months after the release. Future post-release monitoring of these populations will incorporate a standardised monitoring method (M. Barry, pers. comm. 2013).

Mark-recapture surveys

Mark-recapture surveys were carried out twice on each island and were the main monitoring technique utilised to capture *H. duvaucelii*. The initial surveys took place in November 2013. The second survey was done in February 2014 on Motuora and across March and April 2014 on Tiritiri Matangi. *Hoplodactylus duvaucelii* were captured using double-ended g-minnow funnel traps, which were placed at suspected gecko locations that were selected based on radio telemetry data, tracking tunnel footprint data (Holdom, 2015) and suitable vegetation types. Funnel traps were set during the day, left overnight and then checked every morning. Each funnel trap was baited with one slice of banana. The bait was topped up or replaced as necessary. Funnel traps were set over a maximum of four consecutive nights. Up to 26 funnel traps were set at each of the eight monitoring sites, including the 2006 monitoring sites (Table 3.1, Appendix). Funnel traps were set at locations both within and outside of each of the monitoring sites.

Visual encounter surveys: spotlighting

In an extra effort to capture *H. duvaucelii* visual encounter surveys (VES, i.e. spotlighting) were conducted twice on Motuora and three times on Tiritiri Matangi at all of the 2013 monitoring sites as well as the 2006 monitoring sites. VES were incorporated as they provided an opportunity to encounter *H. duvaucelii* that may have been missed during mark-recapture surveys; for example, trap-shy individuals or individuals occupying trap-free areas within and outside of the monitoring sites. To minimise disturbance to other wildlife such as ground breeding birds, the number of VES conducted was restricted due to the occurrence of day and night radio tracking sessions. Very dense vegetation at some of the monitoring sites also limited the visual field. On Motuora, VES were done in July 2013 and in February 2014 (12 and 6 searchers, respectively). On Tiritiri Matangi, VES were done in September and November 2013 and in April 2014 (2, 5 and 6 searchers, respectively). Each trip included one or two nights of VES. All sessions started at around 8 pm and concluded after 10 pm. Thirty minutes were spent at each monitoring site, with 20 minutes dedicated to searches within the monitoring sites and 10 minutes set aside for searches outside of the monitoring sites. Headlamps were used to search for geckos in all forms of arboreal and terrestrial vegetation, including along the ground and amongst leaf litter. When consecutive VES occurred, the order in which each of the monitoring sites were visited was changed. Searchers also varied their search

areas to avoid observer bias. During the 2014 VES on Motuora, the search area at the 2006 monitoring site was extended to include more of the original 2006 monitoring area.

Opportunistic encounters

Body measurement data was also obtained through opportunistic encounters with geckos located during vegetation searches, additional g-minnow funnel trapping sessions, radio tracking sessions, artificial tree shelter checks and ad hoc encounters. Vegetation searches were occasionally done at suspected gecko locations at Sites 2 and 3 on Motuora and at Site 2 and the 2006 monitoring site on Tiritiri Matangi between October and December 2013. Searches were restricted to flax (*Phormium tenax*) and involved visually scanning flax for *H. duvaucelii* or signs of *H. duvaucelii* such as shed skin or faeces. If signs of *H. duvaucelii* were observed, then the flax was more thoroughly searched by moving fronds and searching the interior of the flax. Vegetation searches never exceeded 30 minutes. Double-ended g-minnow funnel traps were set on other occasions during the monitoring period in order to catch geckos for transmitter attachment (Chapter 4). If a gecko was captured, its measurements were always recorded prior to transmitter attachment. Measurements were also collected when transmitters were removed. All eight monitoring sites incorporated 25 artificial tree shelters into which some of the geckos were released (Chapter 2). These artificial shelters were checked regularly as part of another study on *H. duvaucelii* by Holdom (2015) that was conducted concurrently with this study. Artificial tree shelters were not checked as part of this study. However, the measurements (Chapter 2) collected from individual *H. duvaucelii* found in artificial tree shelters were used in this study.

Analyses

Body condition index was calculated according to the method used by Barry *et al.* (2010); i.e. body condition index (BCI) equals the cubic root of body mass divided by snout-to-vent length (SVL) multiplied by 100. In accordance with this method, any geckos with a tail length less than 75% of the mean original tail length were excluded (Barry *et al.*, 2010). Gravid females and juveniles were also excluded to avoiding potential confounding effects of female reproductive state and age-related variation in growth patterns on BCI. In addition, the six *H. duvaucelii* that are known to have died during the study were also excluded.

All BCI data met the assumptions of normality and homogeneity of variances, thus fulfilling the statistical assumptions for parametric tests. A general linear model (GLM) was used to investigate possible differences in BCI prior to the release, in relation to sex, site of origin and the interaction between sex and site of origin. Significant findings were further analysed using *post hoc* tests,

specifically Hochberg's GT2 *post hoc* test, due to unequal sample sizes (Field, 2000). A GLM was also used to investigate possible differences in BCI one year (12 to 14 months) after the release in relation to site of origin. Possible differences in the BCIs of resident and translocated (all 2013 origins pooled) *H. duvaucelii* were investigated using a paired samples t-test. A paired samples t-test was also used to investigate potential changes in the pre-release and (one year) post-release BCIs of captive-bred and wild *H. duvaucelii*.

A Pearson chi-square test was used to investigate whether origin and the proportion of observed wounds were related.

Catch per unit effort (CPUE) was calculated for VES (i.e. spotlighting) by dividing the number of *H. duvaucelii* caught by the unit (person search hours) effort. As unit effort varied due to variation in the number of searchers, the number of person search hours was determined by multiplying the number of search hours by the number of searchers. CPUE has been reported as the number of geckos per (/) person search hours.

3.3 Results

Fourteen *H. duvaucelii* were captured during the 2013 mark-recapture surveys, of which three were re-encountered during the course of the survey. During the 2014 mark-recapture surveys, 62 *H. duvaucelii* were captured, 29 of which were re-encountered during the course of the survey. Visual encounter surveys (i.e. spotlighting) covered a total of 72 person search hours on Motuora and 30 person search hours on Tiritiri Matangi. A total of five *H. duvaucelii* were captured on Motuora, all at the 2006 monitoring site on Motuora over two nights in February 2014. For the first night, CPUE = 0.67 geckos/person search hours. For the second night, CPUE = 1 gecko/person search hours. No *H. duvaucelii* were captured during VES on Tiritiri Matangi. Ten *H. duvaucelii*, three on Tiritiri Matangi and seven on Motuora, were captured during opportunistic vegetation searches and nine *H. duvaucelii*, six on Tiritiri Matangi and one on Motuora, were captured during radio tracking sessions. Seven of the nine *H. duvaucelii* had transmitters attached, so measurements were collected after the transmitters were removed. Twenty six *H. duvaucelii* were captured during opportunistic funnel trapping sessions (Plate 3.1), seven of which were re-encountered during the course of the survey.



Plates 3.1: A wild (originally from Korapuki Island) male (left) and captive-bred female (right) *Hoplodactylus duvaucelii* captured in a double-ended g-minnow funnel trap during an opportunistic funnel trapping session on Tiritiri Matangi Island in October 2013.

Encounters of 2013 translocated H. duvaucelii (excluding founder offspring)

Seventy seven (42.8%) *H. duvaucelii* (females: 47, 61.0%; males: 30, 39.0%) were encountered during the 12 month post-release study across both islands. Thirty two (41.6%) of those geckos (females: 18, 56.3%; males: 14, 43.8%) were re-encountered on more than one occasion between March 2013 and April 2014.

More *H. duvaucelii* were encountered on Motuora (47.7%, 43/90) than on Tiritiri Matangi (37.8%, 34/90). However, re-encounters were higher on Tiritiri Matangi (50%, 17/34) than on Motuora (34.9%, 15/43).

Of the 77 *H. duvaucelii* encountered post-release, 29 (37.7%) were captive-bred geckos, 32 (41.6%) were Korapuki geckos and 16 (20.8%) were Stanley geckos. Thirteen (44.8%) of the 29 captive-bred geckos were re-encountered one to four times, 17 (53.1%) of the 32 Korapuki geckos were re-encountered one to four times and only 2 (12.5%) of the 16 Stanley geckos were re-encountered once.

Overall, 48.3% (29/60) of captive-bred geckos, 53.3% (32/60) of Korapuki geckos and 26.7% (16/60) of Stanley geckos were encountered throughout the entire one year monitoring period.

Translocated *H. duvaucelii* were encountered throughout the monitoring period, although seasonal variations were observed (Fig. 3.1). Encounters of captive-bred and Korapuki geckos peaked in the first two months after the release (Fig. 3.1). In comparison, the highest number of Stanley gecko encounters occurred one year after the respective releases, between January and April 2014 (Fig. 3.1). This is also when re-encounters of captive-bred and Korapuki geckos were at their highest (Fig. 3.1). In comparison, the only re-encounters of Stanley geckos occurred between April and May 2013 (Fig. 3.1).

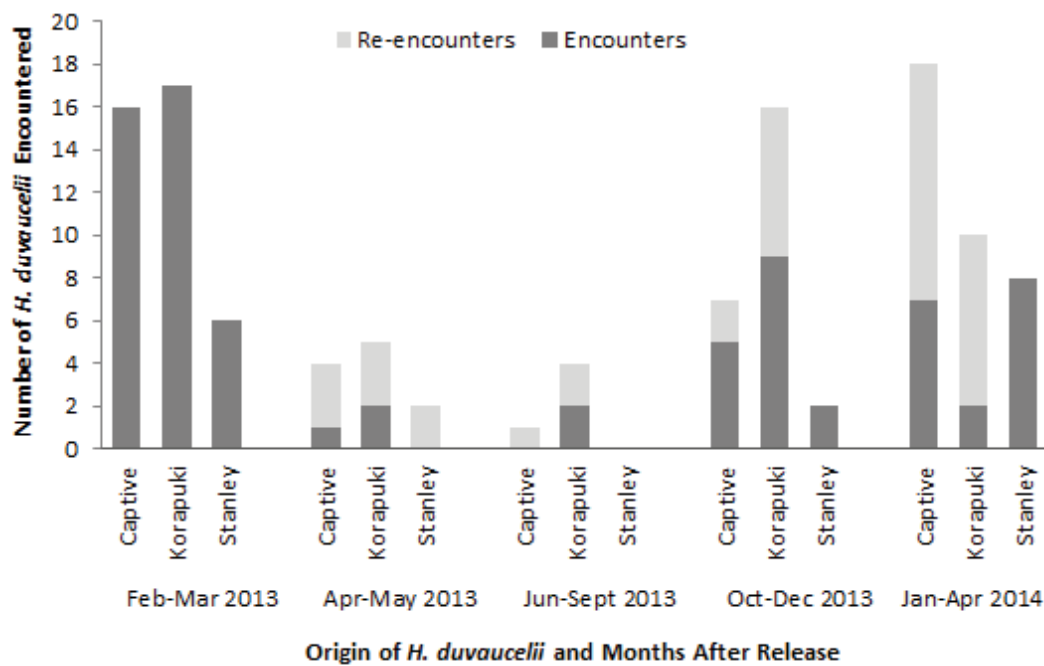


Figure 3.1: The total number of captive-bred, Korapuki and Stanley founder *Hoplodactylus duvaucelii* encountered and re-encountered collectively on Tiritiri Matangi Island and Motuora Island from February 2013 to April 2014.

Thirty-nine of the 180 (21.7%) *H. duvaucelii* (excluding the 6 juveniles born during the quarantine period) were re-encountered during the first two months after the release, i.e. February and March 2013 (Fig 3.2). In comparison, just 18 (10%) *H. duvaucelii* were re-encountered during the first mark-recapture survey in November 2013 (Fig 3.2). During the second mark-recapture survey, one year later between February and April 2014, 36 (20%) *H. duvaucelii* were re-encountered (Fig 3.2).

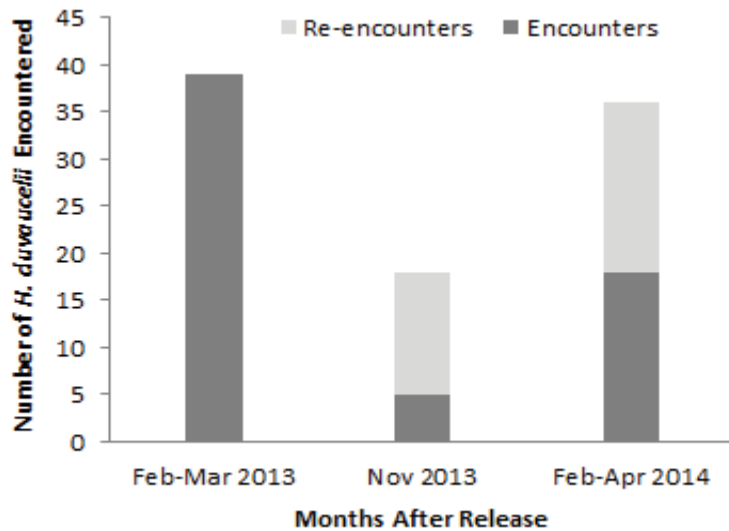


Figure 3.2: The total number of translocated *Hoplodactylus duvaucelii* re-encountered on Tiritiri Matangi Island and Motuora Island during the initial two months after the release (i.e. February and March 2013), compared with the total number of captures and recaptures during the two mark-recapture surveys in November 2013 and across February, March and April 2014.

Encounters of resident H. duvaucelii

A total of 48 resident geckos, including eight (5 females and 3 males) of the original 39 *H. duvaucelii* translocated in 2006 (Plate 3.2) were encountered at the 2006 monitoring sites between May 2013 and April 2014. All eight of the originally translocated *H. duvaucelii* were identified by the presence of PIT tags. One of the male founders was misclassified as a female (original 2006 ID: "018F", new ID: "Jack"). Five of the eight founders were encountered on Tiritiri Matangi and three were encountered on Motuora.



Plate 3.2: Lou (2006 ID: 007F), one of the original founding female *Hoplodactylus duvaucelii* released on Motuora Island in 2006, recaptured in November 2013 and February 2014.

Twenty eight of the 48 resident geckos were encountered on Tiritiri Matangi and 20 were encountered on Motuora. Another *H. duvaucelii* was encountered on Motuora, however, it escaped before any measurements or photos could be taken and therefore has been excluded from the total number of encounters. Two of the geckos encountered on Motuora were not found at the 2006 monitoring site. Both were adult females and were caught in February 2014 at the 2013 captive/Korapuki monitoring sites, one at Site 2 and the other at Site 4. PIT tags were not present for either of the geckos and photos of their dorsal patterns did not match any of the 186 newly translocated *H. duvaucelii*. Furthermore, both females were too large (ID: 28F, Site 4, SVL: 117.5 mm and ID: 29F, Site 2, SVL: 127 mm) to be offspring of the newly translocated founders.

Of the 48 resident geckos encountered, 38 were adults and sub-adults (females: $N = 22$, $\bar{x} = 124.4 \pm 1.1$ mm, SVL range: 113 to 132 mm; males: $N = 16$, $\bar{x} = 117.7 \pm 2.3$ mm, SVL range: 101 to 129 mm) and ten were juveniles ($\bar{x} = 81.6 \pm 3.2$ mm, SVL range: 60 to 95 mm). Ten of the 48 resident geckos (20.83%) were re-encountered one to three times.

Evidence of gravid females

In the first post-release breeding season between November 2013 and April 2014, 33.3% (9/27) of recaptured translocated females and 54.5% (12/22) of the resident females encountered were either gravid or had recently given birth (i.e. spent). Four of the translocated females were captive-bred

females, three were Korapuki females and two were Stanley females. Three of the four captive-bred females and one of the three Korapuki females had also been gravid at the time of the release. Overall, 21 either gravid or spent translocated females were encountered, 12 on Tiritiri Matangi and nine on Motuora.

Evidence of founder offspring

Nineteen juveniles were encountered within or on the perimeters of the release sites during the monitoring period between March 2013 and April 2014, of which seven were encountered on Tiritiri Matangi and 12 were encountered on Motuora (Fig. 3.3). Another juvenile was encountered on Motuora, however, as photos and measurements were not taken it has been excluded from the total number of encounters. Eight of the 19 juveniles (42.1%) were re-encountered on more than one occasion. Of the six juveniles born prior to the release, the two juveniles released on Tiritiri Matangi were both encountered post-release, on multiple occasions. Most encounters of juveniles occurred in the first three months following the release. Re-encounters occurred between April and November 2013 and in April 2014 (Plate 3.3). Juveniles were re-encountered at all four captive/Korapuki monitoring sites. All juveniles re-encountered in 2013, with the exception of two, were encountered in trees with artificial shelters. The other two were caught in funnel traps, one at Site 2 on Tiritiri Matangi and the other at Site 4 on Motuora. Only one juvenile was re-encountered in 2014 when it was captured in a funnel trap at Site 2 on Tiritiri Matangi.

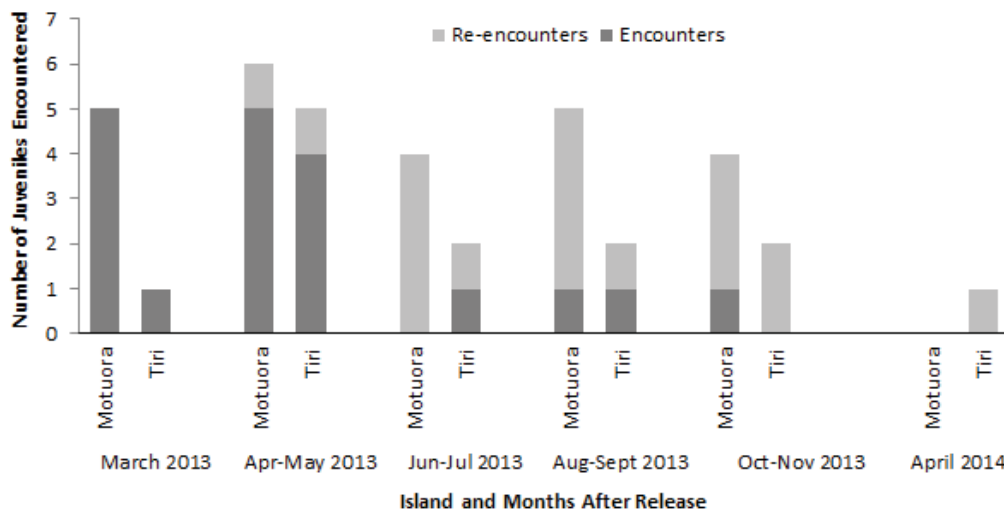


Figure 3.3: The number of encounters and re-encounters of juvenile *Hoplodactylus duvaucelii* on Tiritiri Matangi Island and Motuora Island from March 2013 to April 2014.



Plate 3.3: Two island-born juvenile *Hoplodactylus duvaucelii* encountered together on at least three occasions on Motuora Island during 2013.

Body condition index (BCI)

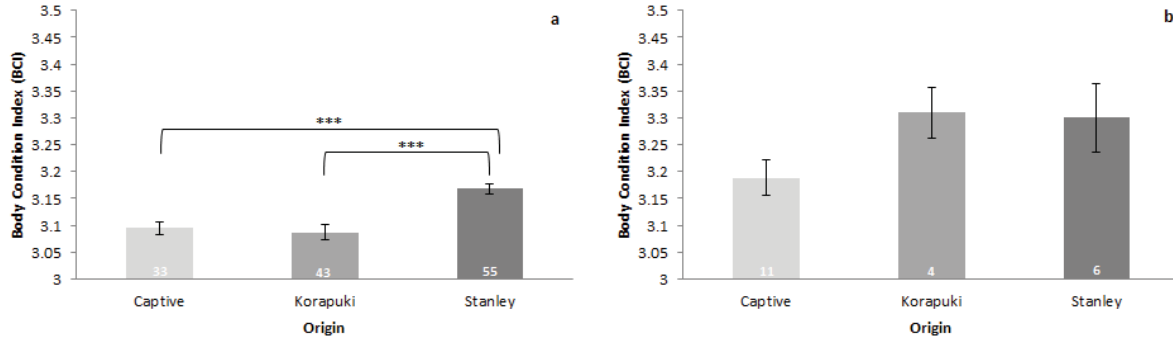
A two-way Anova was used to investigate possible differences in BCI prior to the release in relation to sex, site of origin and the interaction between sex and site of origin. The BCIs of *H. duvaucelii* (Table 3.2) varied significantly in relation to site of origin ($F_{2,125} = 17.27$, $p < 0.001$), but not in relation to sex ($F_{1,125} = 1.65$, $p = 0.202$) or the interaction between site of origin and sex ($F_{2,125} = 0.38$, $p = 0.685$).

Variation in BCIs for site of origin was further investigated with *post hoc* tests and showed that *H. duvaucelii* from Stanley Island had significantly higher BCIs than captive-bred (Hochberg's GT2: $p < 0.001$) and Korapuki (Hochberg's GT2: $p < 0.001$) *H. duvaucelii* (Fig 3.3a). As no differences in BCIs in relation to sex were observed, males and females were pooled for further analyses (Fig 3.3a).

Table 3.2: Pre-release (February 2013) mean \pm standard error and range for body condition indices (BCI) of male and female captive-bred, Korapuki and Stanley *Hoplodactylus duvaucelii*.

	Males			Females		
	<i>N</i>	Mean \pm SE	Range	<i>N</i>	Mean \pm SE	Range
Captive	20	3.09 \pm 0.02	2.88 to 3.24	13	3.07 \pm 0.02	2.96 to 3.18
Korapuki	28	3.10 \pm 0.02	2.93 to 3.24	15	3.06 \pm 0.02	2.73 to 3.37
Stanley	27	3.17 \pm 0.02	3.04 to 3.31	28	3.17 \pm 0.02	3.01 to 3.33

One year after the release, no significant differences in BCI were observed between any of the groups with respect to origin (Anova: $F_{2,18} = 3.17$, $p = 0.066$) (Fig. 3.4b).



Figures 3.4a & 3.4b: Mean body condition indices (BCI) of captive-bred, Korapuki and Stanley *Hoplodactylus duvaucelii* prior to the release (a) and one year after the release (b). Sample sizes (N) are given in each bar. Error bars represent standard errors. ***Represents a significant difference: $p < 0.001$.

No differences in BCI were evident (paired samples t-test: $t = -0.57$, $df = 39$, $p = 0.58$) between resident *H. duvaucelii* ($N = 20$, $\bar{x} = 3.22 \pm 0.02$) and translocated (all 2013 origins pooled) *H. duvaucelii* ($N = 21$, $\bar{x} = 3.24 \pm 0.03$) one year after the release.

Overall, mean BCIs increased for all groups one year after the release (Fig. 3.5). The difference in BCI was significant for captive-bred *H. duvaucelii* ($N = 11$, paired samples t-test: $t = -3.39$, $df = 10$, $p = 0.003$), but not for Korapuki ($N = 4$, paired samples t-test: $t = -3.07$, $df = 3$, $p = 0.055$) or Stanley *H. duvaucelii* ($N = 6$, paired samples t-test: $t = -1.75$, $df = 5$, $p = 0.140$).

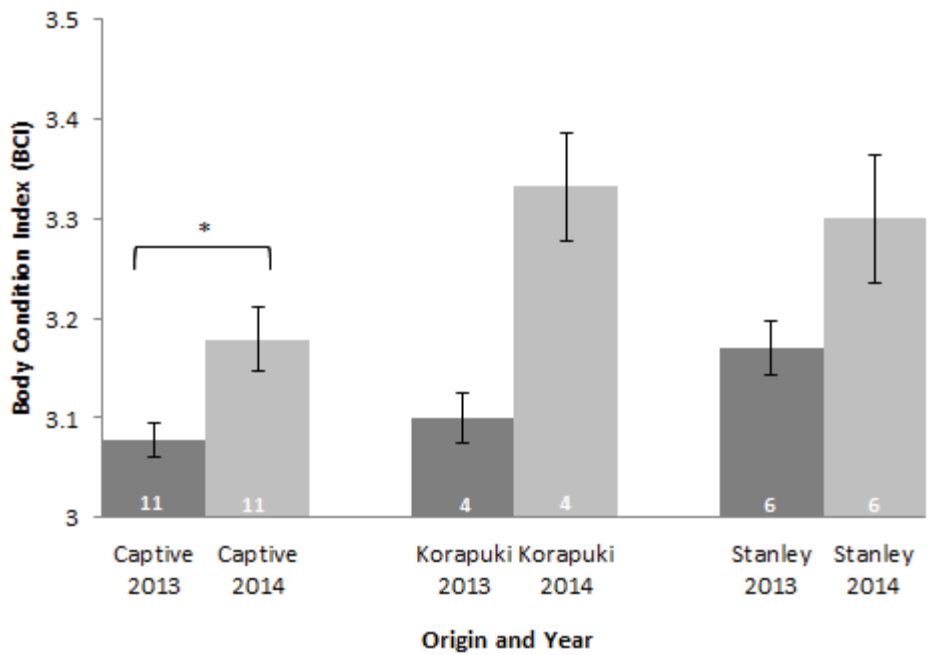


Figure 3.5: Mean body condition indices (BCI) of captive-bred, Korapuki and Stanley *Hoplodactylus duvaucelii* prior to release (2013) and one year after the release (2014). Sample sizes (N) are given in each bar. Error bars represent standard errors. *Represents a significant difference: $p < 0.05$.

General condition

Partial tail losses were recorded for five captive-bred geckos (approx. 18 mm, 20 mm, 22 mm, 34 mm, 49 mm), one Korapuki gecko (approx. 7 mm) and three Stanley geckos (approx. 6 mm, 12 mm, 15 mm) post-release, of which six were females and three were males. Seven of those geckos were from Tiritiri Matangi and two were from Motuora. One partial tail loss was recorded at the start of the monitoring period in March 2013. Two were recorded in November 2013 and the remaining six were recorded one year after the release, across March and April 2014. Six of these geckos also had scars and/or gecko bite marks. Two other geckos experienced partial tail losses. However, both were the result of handling error, one of which occurred during the release (a Stanley female) and the other, which occurred during a measuring session (a 2013 juvenile).

Fifteen captive-bred geckos, 24 Korapuki geckos and 12 Stanley geckos were found with some type of minor wound or scarring post-release, compared with 29 resident geckos (Pearson chi-square test: $\chi^2 = 4.685$, $df = 1$, $p = 0.096$) (Tables 3.3a & 3.3b).

Table 3.3a: The percentage (%) of captive-bred, wild (i.e. Korapuki-sourced and Stanley-sourced) and resident *Hoplodactylus duvaucelii* encountered with wounds or scarring post-release between February 2013 and April 2014.

Origin	Number of <i>H. duvaucelii</i> captured	Percentage of <i>H. duvaucelii</i> with injuries
Captive	29	51.7%
Wild	48	75%
Resident	48	60.4%

Table 3.3b: The number of *Hoplodactylus duvaucelii* from each origin encountered with gecko bites, abrasions (includes transmitter wounds), discolouration and/or scars post-release between February 2013 and April 2014.

Origin	Gecko bites	Number of <i>H. duvaucelii</i>		
		Abrasions	Discolouration	Scars
Captive	10	4	3	6
Korapuki	12	7	3	15
Stanley	7	1	1	7
Resident	18	3	1	15
Total	47	15	8	43

Gecko bite marks were observed on all parts of the body, but were most often found along the tail. Two male Korapuki geckos, one from each island, were found with gecko bite marks all over their bodies. Only one juvenile was found with gecko bite marks. Two Korapuki geckos on Tiritiri Matangi and one resident gecko on Motuora were found with scarring from possible bird bites. In addition, one resident gecko on Tiritiri Matangi was found missing its left eyelid and its left eye was slightly swollen. As it was first captured at the conclusion of the monitoring period (i.e. April 2014) it is not known whether its wound healed.

Toe losses were recorded for two captive-bred geckos, four Korapuki geckos and one Stanley gecko, of which six were males and one was a female.

Eight out of 85 radio tracked *H. duvaucelii* (9.4%) were found with abrasions from the transmitters, which had broken their skin (Plate 3.4a, Appendix). These wounds were only observed after the transmitters had been removed, approximately six weeks (for one gecko from the first radio tracking

period) and between nine and 11 weeks (for the remaining seven geckos that were radio tracked during the second radio tracking period) after transmitter attachment. For six of the geckos, the wounds were located on their backs between the shoulders, whereas for the other two geckos the wounds were on their shoulders. The abrasions were treated with Vetadine Iodine Wash when the transmitters were removed. Six were re-captured in 2014 and five were re-captured in 2015 (M. Barry, pers. comm., 2015; Table 3.4, Appendix). Two geckos have not been re-encountered since their transmitters were removed. For all of the geckos that were re-encountered, their wounds had healed well (Plates 3.4b & 3.4c, Appendix).

Mortalities

Six translocated *H. duvaucelii* were found dead during the monitoring period. Three were captive-bred geckos and three were Korapuki geckos (3/60, 5% each). All of the deceased geckos were adult males (6/90, 6.67%) and had been fitted with transmitters. One of the Korapuki geckos had been fitted with a transmitter twice. Four of the deceased geckos were found on Tiritiri Matangi and two were found on Motuora. The first two geckos, both captive-bred, were found deceased in February, two days after the release. The first Korapuki gecko was found deceased in March, 20 days after transmitter attachment. Two geckos were found deceased in April. One was a captive-bred gecko that was found deceased one day after transmitter attachment and the other was a Korapuki gecko that was discovered 51 days after transmitter attachment. The last Korapuki gecko was found deceased in December, 27 days after transmitter attachment. Overall, five *H. duvaucelii* were found deceased during the first radio tracking period and one *H. duvaucelii* was found deceased during the second radio tracking period. All three captive-bred geckos were sent to Massey University's Institute of Veterinary, Animal and Biomedical Sciences in Palmerston North for post-mortem pathology reports, the results of which were inconclusive (Plates 3.5a, 3.5b & 3.5c, Appendix). Post-mortem pathology reports were not done for any of the Korapuki geckos as all of their bodies were decomposing when they were discovered.

3.4 Discussion

*Encounters of 2013 translocated *H. duvaucelii* (excluding founder offspring)*

At the conclusion of this study, a minimum of 20% (36/180) of translocated *H. duvaucelii* were confirmed to be alive. Captive-bred founders had a higher percentage of encounters (30%, 18/60) than both wild groups (Korapuki: 16.7%, 10/60 and Stanley: 13.3%, 8/60) one year after the release, indicating that they may be more likely to remain within designated monitoring areas and settle sooner than their wild counterparts following translocation. As dispersal away from the monitoring

areas can negatively impact the likelihood of translocation success, using individuals that are more likely to settle within allocated monitoring sites could help alleviate this problem. As captive-bred animals are accustomed to living within smaller spaces, they may be less likely to travel far distances making them suitable candidates for restoration projects.

On Motuora and Tiritiri Matangi, a minimum of 18.9% and 21.1% of translocated *H. duvaucelii* were confirmed to be alive, respectively. Although this figure seems low, it is comparable with other similar studies. On Mana Island, only 17.5% (7/40) of translocated *H. duvaucelii* were encountered alive during Jones (2000) 13 months study, and van Winkel (2008) reported a minimum number alive of at least 12.8% (5/39) of translocated *H. duvaucelii* across Motuora and Tiritiri Matangi at the conclusion of his 13 months study. On Motuora, at least 20% of founders were recaptured alive compared with at least 5% of founders on Tiritiri Matangi (van Winkel, 2008).

Although there is evidence of both the persistence and establishment of the newly translocated populations, the 70% encounter rate established as a measure of the success of the translocation was not achieved. However, this estimate was perhaps unrealistic as it was based on the number of encounters made during the first three months after release for van Winkel's study (2008; van Winkel *et al.*, 2010), rather than one year after the release. This estimate was also based on a smaller founder population (i.e. 39 versus 186) and on a different distribution of animals within the release sites (i.e. 19 and 20 versus 30+). Additionally, different sampling techniques were utilised and sampling effort varied between this study and van Winkel's study (2008; van Winkel *et al.*, 2010).

The minimum number of *H. duvaucelii* confirmed to be alive is likely to have been underestimated due to dispersal (Chapter 4), changes in habitat use (Chapter 5) and the cryptic appearance and behaviour of this species. When monitoring populations, effort is primarily focused within dedicated monitoring sites. Therefore dispersal by individuals away from those monitoring sites will impact detectability (Lettink, 2007). Fitting animals with transmitters can help alleviate this problem, as monitoring sites can be expanded based on radio telemetry data to increase the chance of re-encountering as many individuals as possible. However, some individuals may travel too far away or into habitats that are inaccessible and thus will still be missed during mark-recapture surveys. During this study, dispersal out of the monitoring sites occurred across both islands. Although the monitoring sites were expanded, a number of individuals are known to have dispersed to areas that could not be included in the adjusted search areas. In the initial months following the releases, many *H. duvaucelii* utilised more exposed vegetation types. For example, several *H. duvaucelii* were found resting on the trunks of trees, and thus were easier to sight (Chapter 5). However, towards the end

of this study, *H. duvaucelii* were repeatedly found occupying denser vegetation such as flax (*Phormium tenax*) and were subsequently harder to sight (Chapter 5). Even radio tracked *H. duvaucelii* whose locations could be determined were not always sighted (Chapter 4) due to their habitat use.

Encounters of resident H. duvaucelii

Forty new *H. duvaucelii* and eight of the original founders were encountered across the 2006 monitoring sites. Based on the translocation success criteria of Miller *et al.* (2014), the resident population, collectively, has achieved 'Stage 3', i.e. there is evidence of population growth. However, when examining individual islands, only Tiritiri Matangi has achieved 'Stage 3' (28 encountered versus 19 released). On Motuora, 20 *H. duvaucelii* were encountered in total, which is the same number that were released, thus this study only provided evidence that 'Stage 2', i.e. there is evidence of survival and growth of translocated individuals and there is evidence of reproduction, was achieved on Motuora.

It is likely that the number of resident geckos on both islands is higher than what was observed during this study for several reasons. First, although the 2006 monitoring sites surveyed during this study covered the core 2006 release sites, they did not incorporate the entire monitoring area. During the 2014 mark-recapture surveys and visual encounter surveys on Motuora, the 2006 monitoring site was expanded to encompass more of the original monitoring area used during van Winkel's (2008) study, which resulted in the only captures made during visual encounter surveys. Thus, it seems likely that more geckos may have been encountered if the search effort covered more of the original monitoring area. Second, as the primary focus of this study was on the newly translocated geckos, less search effort was directed at the 2006 monitoring sites. Furthermore, detection rates are likely to have been lowered as a result of dispersal away from the monitoring sites, especially on Motuora. On Motuora, steep cliffs surrounding the monitoring site on three sides meant that any individuals that had dispersed down the cliffs are likely to have been missed during search efforts as the terrain becomes inaccessible further down the cliffs. Additionally, the presence of two resident geckos at two of the 2013 monitoring sites shows that resident *H. duvaucelii* on Motuora have expanded their former range. Approximately 300 m and 410 m (Site 4 and Site 2, respectively) separate the 2006 monitoring site from the two sites on Motuora where two resident geckos were encountered. Search efforts during the course of this study did not encompass the area between the 2006 monitoring site and those two 2013 monitoring sites. Thus, any geckos occupying shelters between these sites will have been missed.

Although Motuora might not have achieved 'Stage 3' yet, both islands show evidence that they are progressing through the stages of success as defined by Miller *et al.* (2014). The current success achieved by the resident populations can be used as an indicator for the likelihood of the 2013 translocations also achieving translocation success.

Evidence of gravid females

The release of gravid females aims to help initiate early population growth following translocation. However, further population growth could fail to occur if conspecifics become isolated from one another as a result of post-release dispersal. Thus, the presence of gravid females on both islands in the first post-release breeding season provides evidence that at least some individuals have remained within the vicinity of other conspecifics. Nine of the 27 females encountered during the first post-release breeding season were gravid. Of those nine females, four were captive-bred and five were wild, which shows that both captive-bred and wild *H. duvaucelii* are capable of locating conspecifics in unfamiliar environments, and that both groups are able to reproduce successfully post-translocation. Among the resident populations, more than half (8/12) of the females encountered on Tiritiri Matangi were either gravid or spent, compared with just under half (4/10) of the females on Motuora. The breeding success of the resident populations could act as an indicator of the future reproductive potential of the newly translocated populations. During Jones's (2000) study, just five of the original 20 females translocated to Mana Island were re-encountered, of which three were gravid. However, Bell & Herbert (2012) captured a total of 115 *H. duvaucelii* between February 2009 and 2012.

Evidence of founder offspring

Although the estimated annual reproductive output of *H. duvaucelii* is 1.12 young per female (Cree, 1994), they are capable of having a maximum of two live young per year. Based on the assumption that all of the translocated gravid females gave birth to two live young (with the known exception of the Korapuki female that only gave birth to one stillborn neonate; Chapter 2), a maximum of 38 juveniles could theoretically have been encountered. Therefore, this indicates that at least 50% of juveniles were encountered alive during the monitoring period. Juvenile survival is crucial as a high mortality rate will restrict future population growth. Determining juvenile survival rates can be problematic though, as juveniles can be difficult to locate and are rarely captured using typical mark-recapture methods (Pike *et al.*, 2008). In this study, for example, only one juvenile was captured in a funnel trap during a mark-recapture survey and two were captured during opportunistic trapping sessions. All other juvenile encounters occurred during artificial tree shelter checks. Thus, juvenile

survival would have appeared much lower if only the mark-recapture survey data were considered. Therefore, it is important to use a variety of detection and capture methods. Although only one juvenile was encountered in a funnel trap at the conclusion of this study, encounters at artificial shelters indicate that survival was actually much higher.

Body condition index (BCI)

Although *H. duvaucelii* from other populations show sexual dimorphism (Barwick, 1982), no significant differences were observed in the pre-release body condition indices of males and females used in this study. Sample sizes of suitable individuals (i.e. adults and sub-adults with $\geq 75\%$ tail length, excluding gravid females) were too low to compare the post-release body condition indices of males and females. However, based on the pre-release results, a significant difference between males and females was not expected.

Pre-release mean body condition indices of *H. duvaucelii* varied significantly in relation to origin. Lizards bred in captivity can often be heavier than wild-sourced lizards (Connolly & Cree, 2008), however, in this study no significant differences were observed between captive-bred and Korapuki *H. duvaucelii*, possibly because the captive population was established using *H. duvaucelii* sourced from Korapuki Island. This may also explain why Stanley *H. duvaucelii* differed significantly from both groups. The absence of a significant difference between captive-bred and wild Korapuki *H. duvaucelii* allows for a fairer comparison of the two groups as neither origin had a potential advantage over the other, with regards to body condition.

One year after the release, no significant differences in body condition index were observed between any of the groups with respect to origin, potentially indicating that captive-bred founders are as suitable as wild-sourced founders for restoration projects. However, samples sizes were very low, so statistical power might be compromised. Furthermore, no differences in body condition index were evident between resident *H. duvaucelii* and all 2013 translocated *H. duvaucelii*, although again sample sizes were low. This suggests that all origins were able to successfully locate necessary resources and that possible differences between each of the monitoring sites did not disadvantage any of the groups. Although no significant differences were observed, captive-bred *H. duvaucelii* had the lowest mean body condition index, which could suggest that they may take longer to adjust to finding their own food or locating new food sources. However, the presence of gravid females, which provides another gage of condition, generally indicates good body condition. As a similar number of captive-bred and wild gravid females were encountered (i.e. 4 versus 5, respectively) the condition of the captive-bred founders appears comparable with that of the wild-sourced founders

further suggesting that captive-bred individuals are capable of finding essential resources in unfamiliar habitats.

Mean body condition indices increased for all origins one year after the release. The difference between pre-release and post-release body condition indices was more pronounced for captive-bred *H. duvaucelii* than for Korapuki and Stanley *H. duvaucelii*, although sample sizes were low so statistical power may be compromised. This further suggests that all origins were able to successfully adapt to their new environments and that any possible differences between the monitoring sites did not disadvantage any of the groups. Although captive-bred *H. duvaucelii* were the only group to show a considerable increase between their mean pre-release and post-release body condition indices, both wild groups had larger increases in body condition index overall, i.e. BCI increase = 0.23 (Korapuki), 0.13 (Stanley) and 0.10 (captive-bred). Low sample sizes and large variations in individual body condition indices for both wild groups (i.e. Korapuki BCI range: 3.19 to 3.43 and Stanley BCI range: 3.15 to 3.60) may explain why the differences between the pre-release and post-release mean body condition indices for these two groups were not considerably different. Large variations in individual body condition indices are not unusual, for example, Barry *et al.* (2010) reported a body condition index range of 2.72 to 3.33 for wild Korapuki *H. duvaucelii*. Animals bred in captivity generally have access to a constant and steady food supply with competition for resources being controlled or prevented. This can often result in captive-bred animals exhibiting higher body condition indices than their wild counterparts, for example, Otago skinks (*Oligosoma ottagense*) (Connolly & Cree, 2008; Hare *et al.*, 2012). For wild-sourced animals, especially those from high density populations, food resources are often limited due to intense competition. Following translocation into lower density populations, wild *H. duvaucelii* may have instinctively taken advantage of the reduced conspecific competition for food, by consuming larger amounts of food. A similar trend was observed during the 2006 translocations. Body condition indices increased considerably after the first year (van Winkel, 2008).

General condition

As lizards store some of their energy reserves in their tails, (Bustard, 1967; Clark, 1971; Derickson, 1976; McDiarmid, 2012), tail loss can influence condition. For example, common side-blotched (*Uta stansburiana*) lizard hatchlings with partial tail losses grew at significantly slower rates when compared with *U. stansburiana* hatchlings that had fully intact tails (Niewiarowski *et al.*, 1997). Tail loss can also affect measurements of body condition (Barry *et al.*, 2010). Partial tail losses were recorded for eleven *H. duvaucelii* post-release. Tail autotomy is a defence mechanism that facilitates escape from predators (Downes & Shine, 2001). As more tail losses were observed on Tiritiri

Matangi, where there is a higher abundance and diversity of potential avian predators, predator avoidance is a conceivable cause of the observed tail autotomy. The presence of scars on four of the geckos also hints at predation, although the scars could also suggest intra-species competition. A lack of prior experience with predators may explain why captive-bred geckos lost larger proportions of their tails. Studies have shown that some captive-bred lizards have slower sprint speeds in comparison to wild lizards (Garland Jr., 1985; Connolly & Cree, 2008; Hare *et al.*, 2012), suggesting that they may be less successful at evading predators. Alternatively, due to a lack of experience with predators, captive-bred geckos may autotomize a larger proportion of their tail to ensure their escape. The observed tail losses could also have been the result of aggressive interaction between conspecifics (Jones, 2000), as eight of the geckos were captured at known sheltering aggregations of *H. duvaucelii* and four were also observed with gecko bite marks.

Several *H. duvaucelii* were observed with wounds following the release. Captive-bred *H. duvaucelii* were observed with fewer wounds than wild-sourced *H. duvaucelii*. Most wounds were minor and did not appear to have had a noticeable impact on overall condition. Bite marks from other geckos were particularly common, showing that several geckos have remained within the vicinity of other conspecifics. Two male geckos had more serious gecko bite marks that extended the length of their bodies. These bites may have been linked to competition for mates. For example, the male on Motuora was sheltering about 30 m from another larger male that was sheltering in flax with a female. They could also suggest that competition for resources is already a factor, despite the relatively low numbers of *H. duvaucelii* at each of the monitoring sites. When animals are relocated, they are forced to establish new homes. Some areas may have better resources than others, which can result in intraspecific aggression as individuals compete for territories with the best resources. Stamps (1977) suggests that the extent of aggressive behaviour is linked to the amount of overlap in resources between different individuals. Intraspecific competition may also have accounted for the toe losses observed during the monitoring period. Yet exactly how much of an impact toe losses have on an individual's ability to survive continues to be debated. For example, the removal of up to three toes was found to have no significant impact on either the average or the maximum running speeds of Australia's eastern water skinks (*Eulamprus quoyii*) (Borges-Landa'ez & Shine, 2003). However, the loss of just two toes was found to severely impact the clinging ability of the Carolina anole (*Anolis carolinensis*) (Bloch & Irschick, 2005). As *H. duvaucelii* can occupy both terrestrial and arboreal habitats, toe losses could therefore potentially have a negative impact on their ability to use arboreal shelters. However, several geckos with missing toes were observed occupying arboreal shelters during this study, including one gecko with six missing toes.

Eight geckos out of the 85 fitted with transmitters were found with deep abrasions, which had been caused by the transmitters. This type of wound was also observed during the 2006 translocations (van Winkel, 2008). Schorr *et al.* (2011) also reported chaffing at the site of transmitter attachment for several long-nosed leopard lizards (*Gambelia wislizenii*); however, only slight chaffing was observed. Van Winkel (2008) suspected that the abrasions observed during his study were caused by the use of rubber harnesses, thus the rubber was subsequently substituted for Co-Flex bandage material. During van Winkel's (2008) study, abrasions were observed after three weeks of transmitter attachment, whereas in this study, abrasions were only observed after six weeks of transmitter attachment, as the wounds were only visible after the transmitters were removed. *Hoplodactylus duvaucelii* were always visually assessed, if sighted, for indicators of reduced health, such as sunken eyes and light skin colouration. As all of these geckos appeared healthy, their transmitters were not removed. Using Co-Flex bandage material may allow for geckos to be radio tracked for a longer time period than if other materials such as rubber are used. However, as these abrasions were only visible after the transmitters were removed, they may have been present for several weeks before they were first observed. This suggests that the length of time transmitters are attached for should be restricted, as chaffing can occur regardless of the type of material used.

Growth was observed in *H. duvaucelii* from all origins during the monitoring period. Captive-bred and Stanley *H. duvaucelii* both increased in weight and snout-to-vent length. Korapuki *H. duvaucelii* also increased in weight, but remained relatively consistent in snout-to-vent length, displaying the same trend as the then-founder populations, which were also from Korapuki Island, during the 2006 translocations (van Winkel, 2008). Growth rate is affected by age, with older animals exhibiting slower growth. Thus, differences in growth rates could result from variation in the age groups of the founders. The captive-bred founders ranged in age from three to six years old and were smaller on average (N = 60, SVL = 108.2 ± 1.2 mm, range: 89 to 122 mm) than both the Korapuki (N = 60, SVL = 119.3 ± 0.9 mm, range: 102.5 to 132 mm) and Stanley geckos (N = 60, SVL = 124.6 ± 1.1 mm, range: 97 to 136 mm) suggesting that older individuals were sourced from the wild populations.

Mortalities

At the conclusion of this study, 3.3% of translocated *H. duvaucelii* are known to have died. No differences were observed in the mortality rates of captive-bred and wild Korapuki *H. duvaucelii*. Post-mortem pathology reports for the three captive-bred geckos were inconclusive as to a cause of death.

It seems unlikely that predation was a factor in any of the observed deaths, even though both release islands are home to potential predators of *H. duvaucelii*. All three captive-bred geckos were found without injuries and completely intact in artificial tree shelters. As all three Korapuki geckos were only discovered after they were well into the decomposition process, it is difficult to conclusively rule out predation, however, it seems unlikely as none of the transmitters or backpack harnesses showed any signs of damage.

Reduced body condition indices were also not a factor in any of the observed deaths, as all six *H. duvaucelii* had higher body condition indices than the pre-release averages for their origin groups, at the time of their respective captures. Captive-bred and Korapuki males also had slightly higher mean body condition indices than females prior to the release, although differences between males and females were not significant. The Korapuki *H. duvaucelii* found deceased in December also had a higher body condition index at the time of transmitter attachment than the average body condition index for Korapuki geckos one year after the release.

The discovery of only deceased males could be related to differences in aggression levels between males and females. For example, testosterone implants have been used to test whether increased aggression reduced survivorship of male lizards (Marler & Moore, 1988). Their results showed that male *Sceloporus jarrovi* with testosterone implants were more active, did a greater number of displays and experienced significantly lower survival rates when compared with control males (Marler & Moore, 1988). However, more males were radio tracked than females, so there was a greater chance of re-encountering male *H. duvaucelii*. Likewise, there was a greater chance of re-encountering radio tracked *H. duvaucelii*.

Stress associated with the translocation process, release into a foreign environment or having a transmitter attached could have been a factor in some or all of the observed deaths. However, as none of the recovered geckos were tested for hormonal indicators of stress, it is unknown whether or not stress was a contributing factor.

Limitations of capture methods

Double-ended g-minnow funnel traps

Funnel traps create an illusion where the trap entrance appears too small to exit from the inside, thus confusing animals by giving the impression that there are no exits (Hare, 2012). Therefore, it is possible for animals to escape as there is nothing physically preventing them from getting out of the traps. During the November 2013 mark-recapture survey on Motuora, a gecko at the 2006 monitoring site was witnessed jumping out of a funnel trap while the trap was still closed. Escapes

have also been documented for other reptiles. For example, 74% of snakes that were deliberately released in aquatic funnel traps, escaped within 24 hours (Willson *et al.*, 2005). There were several occasions during this study when empty traps were found with the bait completely gone. This was unusual as the traps were checked every day and the bait was usually found either untouched, partially consumed by invertebrates or dried out. This suggests that some individuals may have escaped and so were not sampled.

In addition to *H. duvaucelii*, other species were also occasionally caught in the funnel traps. Funnel traps have been shown to catch non-target species such as large insects, spiders, small mammals, toads, frogs and even small birds (Fitch, 1951). In this study, moko skinks (*Oligosoma moco*) accounted for most of the bycatch. Bumble bees and spiders were also occasionally found in the traps and on one occasion, a pukeko chick (*Porphyrio porphyrio melanotus*) was found deceased. Fitch (1951) also reported findings of deceased animals in funnel traps. A moko skink was also found stuck in one of the traps having tried to escape through the wire mesh. It was subsequently freed and appeared to be unharmed.

Visual encounter surveys: spotlighting

Visual encounter surveys (i.e. spotlighting) were predominately conducted within the monitoring sites. However, based on the radio telemetry data (Chapter 4) many of the geckos were known to have moved outside of the monitoring sites. Although brief searches were conducted outside each of the monitoring sites, visual encounter surveys may have been more successful if searches were focused more around known gecko locations. *Hoplodactylus duvaucelii* are known to form social aggregations (Barry, 2010), so increasing search efforts at known locations of certain geckos may have improved the chances of encountering other geckos. However, in a study which examined the effectiveness of spotlighting for arboreal marsupials at known locations, using the greater glider (*Petauroides volans*), success rates were still low even after the search effort was increased (Lindenmayer *et al.*, 2001). Some disturbance during foraging periods may have caused *H. duvaucelii* to change their foraging behaviour, which could have also contributed to low encounter rates. However, effort was always made to minimise disturbance during night radio tracking sessions, for example, by limiting the number of observers to one or two and by moving carefully and quietly. Furthermore, spotlighting is biased towards locating active individuals, thus the low encounter rates could suggest a high rate of inactivity by *H. duvaucelii* during visual encounter surveys (Lettink, 2007).

3.5 Conclusion

Both captive-bred and Korapuki *H. duvaucelii* were encountered throughout the monitoring period indicating that both groups are able to establish and persist in new environments. This is further indicated by evidence of growth and increases in body condition index for both groups, suggesting the captive-bred *H. duvaucelii* are suitable for restoration projects. Although the 70% re-encounter target was not achieved in the first 12 months after the release, increases in body condition, detection of gravid females in the first post-release breeding season, re-encounters with several juveniles and the current state of the resident populations suggests an optimistic outlook for the future growth and establishment of *H. duvaucelii* populations on Tiritiri Matangi and Motuora.

Chapter 4

Dispersal and movement patterns of captive-bred and wild *Hoplodactylus duvaucelii* following translocation.

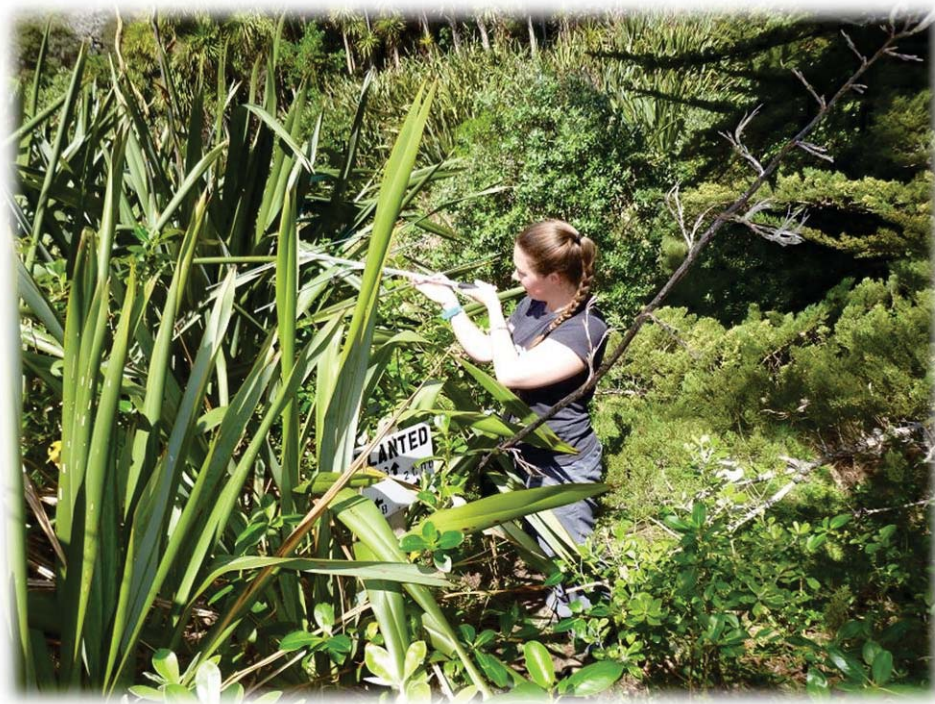


Plate 4.0: Author using radio telemetry to track *Hoplodactylus duvaucelii* on Motuora Island.

4.1 Introduction

Incorporating captive-bred animals into translocation projects can help alleviate harvesting pressure on small natural source populations. Yet their suitability as founders for species restoration projects continues to be debated (Snyder *et al.*, 1996; Mathews *et al.*, 2005). A primary reason for this is their unfamiliarity with wild environments. Captive-bred animals may be more susceptible to predation, due to a failure to recognise predators (Griffin *et al.*, 2000) or suffer higher rates of starvation because of an inability to find or identify natural food sources. Furthermore, captivity can result in phenotypic changes, which may impact the ability of captive-bred animals to survive in the wild (Connolly & Cree, 2008). For example, slower sprint speeds resulting from larger body size (Connolly & Cree, 2008) may negatively influence ability to escape from predators.

As animals must move in search of food, shelter and mates, movement is a significant behaviour that ultimately influences an individual's survival and reproductive success (Germano, 2006). Thus, post-release movements could potentially limit translocation success (Armstrong & Seddon, 2008; Knox & Monks, 2014). For example, dispersal away from the release sites could limit breeding opportunities if conspecifics became isolated from one another and large scale movements could also lead to declines in body condition as a result of excessive energy expenditure. Previous studies have found differences in the movement patterns of translocated and resident reptiles. For example, translocated three-toed box turtles (*Terrapene carolina triunguis*) covered larger total distances and utilised bigger home ranges than resident *T. carolina triunguis* (Rittenhouse *et al.*, 2007). Translocated hognose snakes (*Heterodon platirhinos*) showed larger variation in daily distances travelled, and unlike resident snakes, translocated *H. platirhinos* did not confine their movements to specific areas (Plummer & Mills, 2000). Additionally, translocated male timber rattlesnakes (*Crotalus horridus*) used larger home ranges, travelled greater total distances during active seasons, and moved further per day than resident males (Reinert & Rupert Jr, 1999).

Rearing history might also influence movement patterns (Roe *et al.*, 2010). Captive-bred animals may travel shorter distances or disperse less as they are accustomed to living in more confined spaces (Jarvie *et al.*, 2015). However, previous studies have found that rearing history can have varying influences on the post-release movement and activity patterns of reptiles. For example, translocated captive-reared northern water snakes (*Nerodia sipedon sipedon*) were less active and utilised smaller areas than both resident snakes and wild translocated *N. sipedon sipedon* (Roe *et al.*, 2010). Whereas, introduced captive-bred juvenile large psammomys lizards (*Psammomys algirus*) exhibited higher activity and dispersal rates than wild *P. algirus*, dispersing more often and covering greater distances (Santos *et al.*, 2009). Translocated captive-reared juvenile Ozark

hellbenders (*Cryptobranchus alleganiensis bishopi*) utilised small home ranges and exhibited fairly high rates of site fidelity, yet this was consistent with the movement patterns of wild *C. alleganiensis bishopi* (Bodinof *et al.*, 2012). Additionally, no significant differences were observed in the average dispersal distances and home range areas of captive-bred and wild-caught juvenile tuatara (*Sphenodon punctatus*) released at Orokonui Ecosanctuary, 20 km from Dunedin (Jarvie *et al.*, 2015).

Movement patterns of Hoplodactylus duvaucelii

The movement patterns of individual *H. duvaucelii* can vary widely. For example, the average minimum distance travelled in one night by resident *H. duvaucelii* across Ruamahua-iti Island and Mauitaha Island ranged between 6.3 m and 25.9 m and the maximum distance observed was 44 m (Christmas, 1995). In comparison, movements per night averaged at 8.2 m on Tiritiri Matangi and 11.5 m on Motuora for translocated *H. duvaucelii* (van Winkel, 2008). On Aorangi Island, one resident gecko moved 27.4 m (90 ft.) in a single night, whereas another was re-encountered 67.2 m (250 ft.) from its previous location after three nights (Whitaker, 1968). Activity area has also been found to vary, ranging from 5 m² to 210 m² for resident *H. duvaucelii* in Christmas's (1995) study and 33 m² to 1634.5 m² on Tiritiri Matangi and 256.5 m² to 2006 m² on Motuora for translocated *H. duvaucelii* in van Winkel's (2008) study. However, no significant differences were observed in the dispersal distances, activity patterns or home range areas of male and female *H. duvaucelii* on Tiritiri Matangi and Motuora (van Winkel, 2008). Although *H. duvaucelii* can be wide ranging (Whitaker, 1968), they often have overlapping home ranges (van Winkel, 2008) and have also been found to show site fidelity. For example, on North Brother Island, a female *H. duvaucelii* was re-encountered 30 years after she was first captured within 5 m of her original capture location (Thompson *et al.*, 1992). On Mana Island, a gecko that had escaped during the translocation process was re-captured nine months later just 60 m from where it had escaped (Flannagan, 2000).

Investigating possible variations in gecko movements

In New Zealand there have been several translocations involving reptiles that were either bred or raised in captivity, for example, forest geckos (*Mokopirirakau granulatus*), shore skinks (*Oligosoma smithi*), brown skinks (*Oligosoma zelandicum*) and tuatara (*S. punctatus*; formally two separate species including *S. guntheri*) (Reintroduction Specialist Group). However, few translocations have involved the simultaneous release of both captive-bred and wild individuals, thus limiting opportunities for comparisons of post-release movement patterns between the two groups.

The objective of this chapter is to assess the suitability of captive-bred founders for species restoration projects by investigating the influence of origin on the dispersal and movement patterns

of captive-bred and wild *H. duvaucelii*. Comparisons were primarily made between captive-bred and wild Korapuki *H. duvaucelii* to prevent possible bias related to source origin (Chapter 2).

Furthermore, as part of the translocation design, captive-bred and wild Korapuki *H. duvaucelii* were released simultaneously and within the same respective release sites to minimise possible differences in movement patterns linked with variation in habitat quality at the different release sites. The 2013 translocations also provided an opportunity to collect additional post-release movement and activity data about *H. duvaucelii* from translocated wild Stanley-sourced geckos. Furthermore, the presence of resident populations of *H. duvaucelii* on both islands allowed for comparisons between the movement and activity patterns of translocated and resident *H. duvaucelii*, which may assist in determining the likelihood of translocation success for this species.

Chapter aim:

The main aim of this chapter is to compare dispersal, range and movement patterns of translocated captive-bred and wild *H. duvaucelii* of the same origin during the first year after release to determine whether there were any significant differences between the groups. A further aim is to assess whether *H. duvaucelii* have settled in and established home ranges by comparing movement patterns between resident geckos and translocated geckos six to 14 months after release.

Specific chapter objectives:

- Document dispersal events and compare the average maximum linear distances moved from the release sites between captive-bred and wild Korapuki geckos and in relation to sex within the first five months after translocation.
- Analyse activity patterns in relation to rearing status (captive-bred versus wild Korapuki) and sex, zero to five months and eight to 15 months after translocation.
- Compare the average home range size between captive-bred and wild Korapuki geckos and in relation to sex, eight to 15 months after translocation.
- Compare activity patterns and the average home range size between 2013 translocated and resident *H. duvaucelii*, eight to 15 months after translocation.
- Document the night activity and movement patterns of *H. duvaucelii*.

4.2 Methods and analyses

Radio telemetry

Hoplodactylus duvaucelii with radio transmitters attached (Chapter 2) were located using a hand-held TRX-1000 telemetry receiver tuned to 150MHz operating frequency and a 3-element folding antenna (Wildlife Materials International Inc.).

To determine possible differences in habitat use between captive-bred and wild *H. duvaucelii*, a subset of captive-bred and wild Korapuki geckos (Table 4.1) were radio tracked immediately after the release for up to three months (February to April 2013) and again, nine to 11 months following their release (October to December 2013). In addition, 22 adult Stanley geckos were radio tracked during the first radio tracking period and eight resident geckos (from the 2006 release sites) were radio tracked during the second radio tracking period (Table 4.1). One resident *H. duvaucelii* on Tiritiri Matangi was radio tracked from September 2013. A total of 65 and 27 *H. duvaucelii* were radio tracked during the first and second radio tracking periods, respectively (Table 4.1).

Table 4.1: The total number of male and female *Hoplodactylus duvaucelii* from each origin radio tracked during each of the radio tracking periods.

	February to April 2013			September to December 2013		
	Male	Female	Total	Male	Female	Total
Captive	9	5	14	1	5	6
Korapuki	19	10	29	7	6	13
Stanley	10	12	22	—	—	0
Resident	—	—	0	3	5	8

Two radio telemetry periods were incorporated in this study so that both the initial dispersal and activity patterns, and subsequent activity areas and movement patterns of translocated *H. duvaucelii* could be investigated and compared with resident *H. duvaucelii*, as well as in relation to origin and sex.

Day radio tracking

Day tracking was conducted between 8 am and 6 pm (5 pm after the conclusion of daylight savings time). The logistics of monitoring on two separate islands and the large sample size meant that it

was not always possible to get a similar number of fixes for each individual every week (range: 0 to 6). Radio telemetry was not conducted during moderate or heavy rain to avoid damaging the radio telemetry equipment.

Whenever a gecko was located during a radio telemetry session, its position (accuracy ± 3 m) was recorded using a handheld GPS device (Garmin 62S). The date, time, monitoring site and whether or not the gecko was sighted was also noted for analysis purposes. Additional information that could help with relocating previous gecko positions, such as the proximity of artificial tree shelters and paths was also recorded. Flagging tape or a coloured clothes peg was used to mark each of the location fixes, so that they could be easily located later for microhabitat surveys (Chapter 5) and photos were taken at each point in case the flagging tape or pegs fell down or got lost.

Each individual was radio tracked until their transmitter was recovered after the animal had lost it, or until the end of the radio tracking period at which point their transmitter was removed. These repeated location fixes collected from the point when the transmitter was lost to when it was recovered were not included in the analysis. As many of the transmitters were discarded after only a few days or weeks during the first radio tracking period, five double-ended g-minnow funnel traps were sporadically set in March and April 2013 within the monitoring sites and at suspected gecko locations, which were based on available radio tracking data, in an effort to catch additional geckos for transmitter attachment. Funnel traps were only set at the captive-bred and Korapuki gecko monitoring sites (i.e. Site 2 and Site 4 on Motuora and Site 2 and Site 3 on Tiritiri Matangi). Stanley *H. duvaucelii* were excluded as the primary focus of this chapter was to compare the dispersal and movement patterns of captive-bred and wild Korapuki *H. duvaucelii*, but tracking results were included wherever possible. Discarded transmitters were re-used on any recaptured captive-bred and Korapuki *H. duvaucelii* that met the weight and condition requirements (Chapter 2). This included any *H. duvaucelii* encountered during artificial tree shelter checks conducted by Holdom (2015). In addition, two modifications were made to the backpack design to reduce the elasticity of the backpacks so that they would stay attached for longer (Chapter 2).

Funnel trapping sessions specifically aimed at capturing *H. duvaucelii* for transmitter attachment for the second radio tracking period were carried out in September and October 2013. On Tiritiri Matangi, funnel traps were only set within and around the captive/Korapuki and resident gecko monitoring sites (i.e. Sites 2 and 3 and the 2006 Site). Whereas on Motuora, funnel traps were set around all of the monitoring sites, including the Stanley gecko monitoring site (i.e. Site 3), as some Korapuki *H. duvaucelii* were known to have dispersed into that area during the first radio tracking period. Transmitters were also attached to *H. duvaucelii* encountered during opportunistic

vegetation searches and artificial tree shelter checks (Chapter 3). Three *H. duvaucelii* captured during mark-recapture surveys on Motuora in November 2013 were also fitted with transmitters.

Gecko movements were categorised either as stationary points (0 m), small scale movements (< 3 m) or new locations, hereafter relocation points (\geq 3 m). Small scale movements were not investigated in this study, so for the purpose of analysis, stationary points and small scale movements were pooled.

Only movements away from the release sites were considered dispersal events. Therefore, to account for the size of the release sites (i.e. 60 m by 60 m) and the ability of *H. duvaucelii* to travel large distances (e.g. 44 m; Christmas, 1995) within a single night, dispersal events were defined as any movements of 100 m or more. If a gecko returned to within 100 m of the release site, its movement was categorised as 'exploring'.

Location data from five geckos that died during the first or second radio tracking periods (Chapter 3) were excluded from the analysis of movement patterns from the respective sampling periods.

Night radio tracking

Night tracking sessions were conducted in March and April 2013 during the first radio tracking period and in September, October, November and December 2013 during the second radio tracking period. Six (1 captive-bred, 5 Korapuki; Tiritiri Matangi N = 3, Motuora N = 3) and 25 (6 captive-bred, 11 Korapuki, 8 resident; Tiritiri Matangi N = 12, Motuora N = 13) *H. duvaucelii* were night tracked during the first and second radio tracking periods, respectively. Stanley geckos were not night tracked during either of the two radio tracking periods, as the primary focus of this study was to assess the suitability of captive-bred *H. duvaucelii* by comparing them with wild *H. duvaucelii* from the same origin (i.e. Korapuki).

Night tracking sessions were divided into five two-hour sessions. During the first radio tracking period each gecko was initially night tracked around 6 pm, 8 pm, 10 pm, 12 am and 2 am. This was later changed to 5 pm, 7 pm, 9 pm, 11 pm and 1 am to accommodate for daylight savings time ending. During the second radio tracking period, the 6 pm night tracking session was excluded as it was not dark at that time.

Hoplodactylus duvaucelii were only night tracked if their day position had been recorded on that same day and all *H. duvaucelii* that were tracked during the night were relocated the following day to determine if they had moved again during the period after night radio tracking sessions had ended. Night positions were initially triangulated to avoid getting too close to the geckos and

disturbing them while they were foraging. Triangulation involved circling the area where the gecko was suspected to be. Three or four location fixes were recorded at different positions surrounding the gecko's suspected location and then a compass was used to determine the direction of the gecko at each location fix based on the signal strength. The compass directions were then used to determine where all of the GPS positions intersected to pinpoint the gecko's actual location. During the second radio tracking period, most night positions were pinpointed. Night positions that were not triangulated were pinpointed using the receiver and cable only, or just the receiver without the cable and antenna. The reason for this change was to reduce the overall amount of time spent in the area where the gecko was foraging. Although pinpointing requires getting closer to the gecko, it is quicker than triangulating the gecko's position. However, triangulation was still used when it was not possible to pinpoint a gecko's location.

Separate GPS positions were not recorded for small scale movements, i.e. those that occurred within the same flax bush or on the same tree, etc. Instead, these movements were visually estimated.

Analyses

Geographic GPS coordinates (i.e. latitude and longitude) were viewed using the program BaseCamp™ (Garmin Ltd., 2013). Geographic coordinates were converted to universal transverse mercator (UTM) coordinates using the program MapSource (Garmin Ltd., 2013) for use in the program Ranges8 (Anatrack Ltd., 2008). Dispersal distances and activity areas were calculated in Ranges8. Figures displaying activity areas were created using Ranges8.

As some but not all geckos were radio tracked during the first and the second monitoring periods, a generalised estimating equation (GEE) approach (Liang & Zeger, 1986; Zeger *et al.*, 1988) was chosen to investigate possible differences in the average proportion of stationary radio tracking fixes in relation to gecko rearing history and time after release. The average proportion of stationary fixes for geckos were used as the response variable (linear with identity link function) and the two predictor variables were gecko rearing history (captive-bred versus wild Korapuki) and tracking period (first versus second). The interaction between the two predictor variables was also included in the model. Gecko ID was set as subject variable and tracking period was set as within-subjects variable to account for the repeated measurements of some individuals. An exchangeable working correlation matrix structure and robust estimator of the covariance matrix was used. The Wald chi-square statistic for main model effects as well as model based estimated marginal means were reported. An independent samples t-test was used to explore possible differences in the proportion of stationary fixes for resident and translocated (captive-bred and Korapuki pooled) *H. duvaucelii*

during the second radio tracking period. All data met the assumptions of normality and homogeneity of variances, thus fulfilling the statistical assumptions for parametric tests. To investigate a potential effect of sex on activity levels, all 2013 translocated groups (i.e. captive-bred, Korapuki and Stanley) were pooled for the analysis of the first radio tracking period, and 2013 released (excluding Stanley geckos) and resident *H. duvaucelii* were pooled for the analysis of males and females during the second radio tracking period.

To calculate home range size, Seaman *et al.* (1999) recommend a minimum sample size of 30 fixes per individual, as small sample sizes have been found to overestimate actual home range size. Less than 30 location fixes (range: 1 to 25) were collected for all individuals (Tables 4.2a & 4.2b, Appendix), therefore, the home range size of translocated and resident *H. duvaucelii* could not reliably be calculated. Instead, gecko range areas based on a minimum of five location fixes and three (maximum: 25) relocation fixes were investigated and termed 'activity areas'. An activity area was defined as the area utilised by *H. duvaucelii* from seven months (September 2013) after the release. Geckos with less than five location fixes and less than three relocation fixes were excluded from the analysis of activity areas. Data includes all location fixes collected using radio telemetry and other methods described above, e.g. funnel trap locations.

An independent samples t-test was used to investigate possible differences in the average distance from release site to activity area (used during the second radio tracking period) for captive-bred and wild Korapuki *H. duvaucelii*. The data did not meet the assumptions of normality and homogeneity of variances, thus the analysis was conducted using log₁₀-transformed data, which complied with the statistical assumptions.

Activity areas were estimated for both radio tracking periods using 95% and 100% minimum convex polygons (MCP). Activity areas that were used during the second radio tracking period were further examined using the 95% fixed kernel density estimator (FKD). These methods were chosen because they are both widely used (Harris *et al.*, 1990; Kernohan *et al.*, 2001), which enables comparisons with other reptile studies (e.g. van Winkel, 2008; Gerner, 2008; Wastell & Mackessy, 2011; Buckland *et al.*, 2014). All MCP activity area data met the assumptions of normality and homogeneity of variances, thus fulfilling the statistical assumptions for parametric tests. However, FKD activity area data did not meet the assumptions of normality and homogeneity of variances, thus the analysis was conducted using log₁₀-transformed data, which complied with the statistical assumptions. Significant findings were further analysed using Hochberg's GT2 *post hoc* test, due to unequal sample sizes. An independent samples t-test was used to explore potential differences in the activity areas of captive-bred and wild Korapuki *H. duvaucelii* during each of the radio tracking periods.

An independent samples t-test was used to explore potential differences in the activity areas of males and females (captive-bred, Korapuki and residents pooled) during the second radio tracking period. All MCP and FKD activity area data for males and females did not meet the assumptions of normality and homogeneity of variances, thus the analysis was conducted using \log_{10} -transformed data, which complied with the statistical assumptions.

Statistical test results, means and standard errors (SE) of \log_{10} -transformed data have been reported, where applicable. However, untransformed data were presented in figures or tables to facilitate interpretation. Where applicable, the median and range have been reported for data that was not normally distributed.

The main focus of this chapter was to compare the dispersal and activity patterns of captive-bred and Korapuki *H. duvaucelii*. However, when general population trends were explored, data from the Stanley and resident geckos were included in statistical analyses where applicable and summary statistics for these groups were presented. If they were included it was stated in the results sections.

4.3 Results

Hoplodactylus duvaucelii were radio tracked for an average of four to seven days between February and April and 11 to 13 days between September and December 2013 (Table 4.3). Transmitters were attached for an average of 22.2 ± 2.6 days ($N = 61$, range: 3 to 70 days) during the first radio tracking period (Table 4.2a, Appendix) and 49.8 ± 3.8 days ($N = 26$, range: 15 to 78 days) during the second radio tracking period (Table 4.2b, Appendix). Three *H. duvaucelii* were fitted with a second transmitter after they lost the first one during the first radio tracking period on Motuora (Table 4.2a, Appendix). Within the first three days after the respective releases, two *H. duvaucelii* on Tiritiri Matangi and eight *H. duvaucelii* on Motuora had discarded their transmitters (Plate 4.1).

Table 4.3: The mean \pm standard error (SE), minimum and maximum numbers of tracking days per origin during the first and second radio tracking periods are presented.

Origin	February to April 2013 (1st)			September to December 2013 (2nd)		
	<i>N</i>	Mean \pm SE	Range	<i>N</i>	Mean \pm SE	Range
Captive	11	4.7 ± 1.1	1 to 13	6	12.8 ± 1.9	7 to 19
Korapuki	28	6.8 ± 0.9	1 to 18	12	11.6 ± 1.8	1 to 20
Stanley	22	5.7 ± 0.9	1 to 16	0	-	-
Resident	0	-	-	8	11.0 ± 2.4	3 to 19



Plate 4.1: A captive-bred *Hoplodactylus duvaucelii* on Motuora Island encountered in the process of losing his transmitter just two days post-release in February 2013.

Five transmitters from the first radio tracking period were recovered in May and seven, three on Tiritiri Matangi and four on Motuora, were not recovered due to difficulties finding the transmitters in dense vegetation and eventual battery failures. However, four of those individuals were encountered again later during the monitoring period and had successfully discarded the transmitters without any visible injuries. Furthermore, one of the three geckos that had not been re-encountered was recaptured in March 2015 and did not show any signs of injury that may have occurred if the backpack had remained on for an extended period of time (M. Barry, pers. comm. 2015). All of the transmitters from the second radio tracking period were recovered, although two transmitters on Motuora were only recovered in December 2013.

Dispersal patterns

Fewer than 15% of all radio tracked *H. duvaucelii* (8/61) from the first radio tracking period dispersed more than 100 m away from their release sites. Two Korapuki males and one Stanley male also dispersed, but later returned to within 100 m of their release sites. Thus, they were classified as

exploring. However, by the start of the second radio telemetry period, one of the Korapuki males had dispersed again. The initial dispersal events occurred 11 and 17 days post-release for the two Korapuki *H. duvaucelii* and 10 days after the release for the Stanley *H. duvaucelii*. Three (27.3%) captive-bred, seven (25%) Korapuki and two (9.1%) Stanley *H. duvaucelii* dispersed and did not return to within 100 m of their release sites. However, only one captive-bred male and four (1 male, 3 females) Korapuki *H. duvaucelii* dispersed during the first radio tracking period (16 ± 2.8 days, range: 9 to 26 days post-release). Overall, 72.7% (8/11) of captive-bred, 67.9% (19/28) of Korapuki and 86.4% (19/22) of Stanley *H. duvaucelii* that carried transmitters did not disperse.

During the second half of the monitoring period, 75% (36/48) of translocated *H. duvaucelii* that were either radio tracked or had been encountered through other methods had not dispersed. More than half (56.3%, 27/48) of those geckos had also not been previously encountered during the first radio tracking period. Ten *H. duvaucelii* (3 captive-bred, 6 Korapuki, 1 Stanley; 6 males, 4 females) had dispersed, although two of the dispersal events only took place in 2014. One Korapuki male was exploring and a Korapuki female that had dispersed during the first radio tracking period had since returned to within 100 m of her release site and so was also categorised as exploring.

Across the entire monitoring period, the furthest recorded dispersal distance was 293.8 m (Korapuki male, one year post-release) on Tiritiri Matangi and 256.2 m (Stanley female, 2 months post-release) on Motuora. The furthest dispersal distance achieved by a captive-bred *H. duvaucelii* was 223 m (male, one month post-release).

Average maximum weekly distances from release sites were similar for all *H. duvaucelii*, irrespective of origin (Fig 4.1), although distances ranged widely. In general, the average maximum distance from release site gradually increased each week before levelling out around week seven (Fig 4.1). Note that seven geckos only had transmitters attached after the release and six geckos had transmitters re-attached during the radio tracking period.

Median distance from release site to final location was 32.7 m ($N = 11$, range: 4.2 to 223 m) for captive-bred geckos, 33.4 m ($N = 28$, range: 0.1 to 223.4 m) for Korapuki geckos and 40.8 m ($N = 22$, range: 1.5 to 256.2 m) for the Stanley geckos.

The average distance from release site to activity area was slightly greater for captive-bred *H. duvaucelii* ($N = 7$, $\bar{x} = 91.9 \pm 28.3$ m, range: 18.8 to 198.3m) than Korapuki *H. duvaucelii* ($N = 11$, $\bar{x} = 76.1 \pm 12.9$ m, range: 18.9 to 184m), however, differences were non-significant (independent samples t-test: $t = 0.06$, $df = 16$, $p = 0.956$).

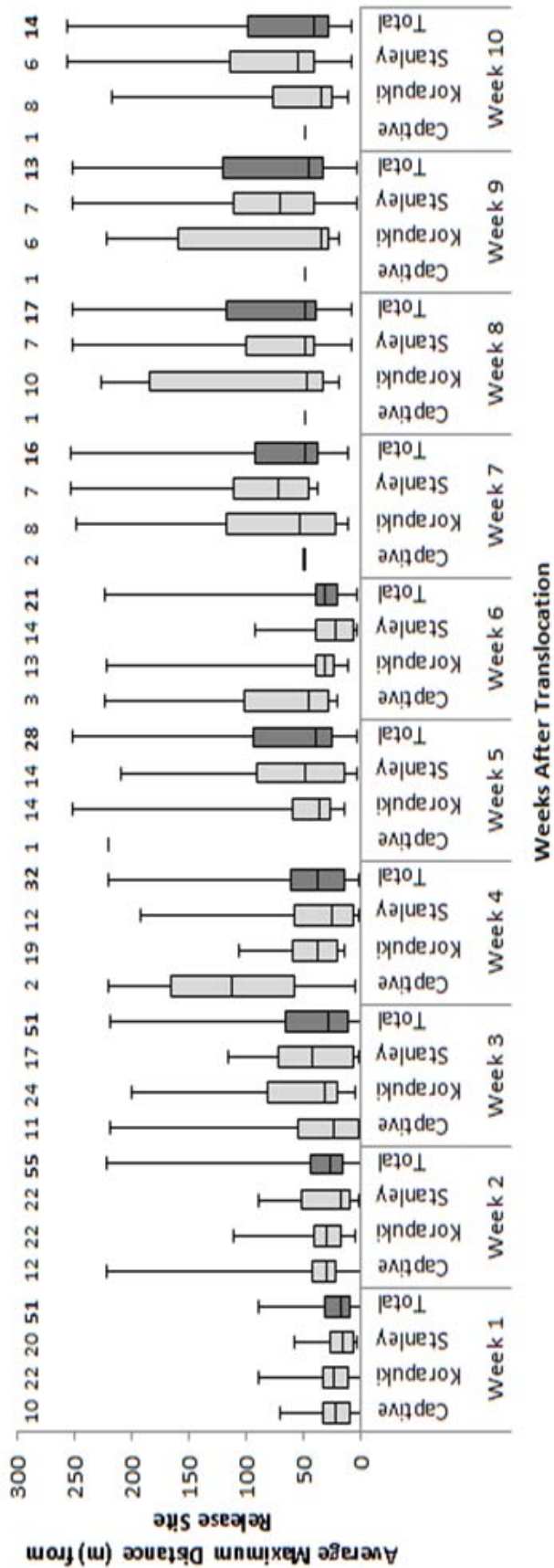


Figure 4.1: Box plots depict the average maximum distances (m) travelled from release sites each week by captive-bred, Korapuki and Stanley *Hoplodactylus duvaucelii* for the first ten weeks post-translocation. Sample sizes (N) are given above each bar. Error bars represent standard errors.

Overall, 40.8% (71/174; Tiritiri Matangi: 35, Motuora: 36) of *H. duvaucelii* were never encountered during the monitoring period. This included 45.6% (26/57; 15 males, 11 females) of captive-bred *H. duvaucelii*, 26.3% (15/57; 8 males, 7 females) of Korapuki *H. duvaucelii* and 50% (30/60; 15 males, 15 females) of Stanley *H. duvaucelii*.

Furthermore, 17 (8 captive-bred, 8 Korapuki, 1 Stanley) *H. duvaucelii* that were either encountered during the first three weeks or were radio tracked, but subsequently discarded their transmitters, were not re-encountered after the first three weeks post-translocation.

Activity areas and patterns

Activity areas reduced with time after the release. In the initial months after the release, wild Korapuki *H. duvaucelii* used the largest activity areas (Table 4.4a). However, no significant differences were found between the sizes of the activity areas of captive-bred ($N = 5$; $\bar{x} = 2.5 \pm 0.5 \text{ m}^2$; \log_{10} -transformed data) and Korapuki ($N = 20$; 100% MCP: $\bar{x} = 2.7 \pm 0.2 \text{ m}^2$; 95% MCP: $\bar{x} = 2.6 \pm 0.2 \text{ m}^2$; \log_{10} -transformed data) geckos (independent samples t-test; 100% MCP: $t = -0.39$, $df = 23$, $p = 0.699$; 95% MCP: $t = -0.26$, $df = 23$, $p = 0.799$).

Wild Korapuki *H. duvaucelii* also used the largest activity areas during the second radio tracking period (Table 4.4b). The activity areas of captive-bred ($N = 6$; 95% FKD: $\bar{x} = 9.1 \pm 1.5 \text{ m}^2$; \log_{10} -transformed data) and Korapuki ($N = 11$; 95% FKD: $\bar{x} = 17.6 \pm 3.6 \text{ m}^2$; \log_{10} -transformed data) geckos were significantly different (independent samples t-test; 100% MCP: $t = -2.41$, $df = 10.2$, $p < 0.05$; 95% MCP: $t = -3.07$, $df = 10.5$, $p < 0.05$; 95% FKD: $t = -2.18$, $df = 12.9$, $p < 0.05$). When the activity areas of captive-bred and Korapuki *H. duvaucelii* were pooled, translocated geckos ($N = 17$; 100% MCP: $\bar{x} = 286.1 \pm 95.3 \text{ m}^2$; 95% MCP: $\bar{x} = 201.4 \pm 51.6 \text{ m}^2$; 95% FKD: $\bar{x} = 319.1 \pm 105.9 \text{ m}^2$; untransformed data) had slightly smaller activity areas than resident *H. duvaucelii* (Table 4.4b).

No significant differences were evident between the activity areas used by males ($N = 9$; 100% MCP: $\bar{x} = 2.4 \pm 0.1 \text{ m}^2$; 95% MCP: $\bar{x} = 2.3 \pm 0.1 \text{ m}^2$; 95% FKD: $\bar{x} = 2.4 \pm 0.2 \text{ m}^2$; \log_{10} -transformed data) and females ($N = 16$; 100% MCP: $\bar{x} = 2.1 \pm 0.1 \text{ m}^2$; 95% MCP: $\bar{x} = 2.0 \pm 0.1 \text{ m}^2$; 95% FKD: $\bar{x} = 2.1 \pm 0.2 \text{ m}^2$; \log_{10} -transformed data; based on pooled data for captive-bred, Korapuki and resident geckos) during the second radio tracking period (independent samples t-tests; 100% MCP: $t = -1.49$, $df = 23$, $p = 0.150$; 95% MCP: $t = -1.66$, $df = 23$, $p = 0.111$; 95% FKD: $t = -1.29$, $df = 23$, $p = 0.209$) (Table 4.5, Appendix).

Table 4.4a: Displayed are the average activity areas (m^2) \pm standard error (SE) and range for captive-bred, Korapuki and Stanley *Hoplodactylus duvaucelii* during the first five months after the release (February to June 2013) excluding *H. duvaucelii* with less than five location fixes. MCP: minimum convex polygon. *Untransformed data presented.

Origin	N	100% MCP*				95% MCP*			
		Mean \pm SE (m^2)	Median (m^2)	Range (m^2)	Mean \pm SE (m^2)	Median (m^2)	Range (m^2)	Mean \pm SE (m^2)	Range (m^2)
Captive	5	2385.3 \pm 1972.0	391.1	5.7 to 10233.4	2373.0 \pm 1975.5	391.1	5.7 to 10233.4		
Korapuki	20	3103.5 \pm 1583.0	710.6	2.9 to 31775.3	2835.7 \pm 1581.0	644.0	1.0 to 31775.3		
Stanley	12	2123.1 \pm 1332.5	464.0	2.9 to 17726.0	2002.3 \pm 1336.7	444.0	2.9 to 17726.0		
2013 Total	37	2745.1 \pm 990.9	612.1	2.9 to 31775.3	2556.3 \pm 990.2	580.2	1.0 to 31775.3		

Table 4.4b: The average activity areas (m^2) \pm standard error (SE) and range for captive-bred, Korapuki and resident *Hoplodactylus duvaucelii* from eight months after the release (September 2013 to April 2014) excluding *H. duvaucelii* with less than five location fixes. MCP: minimum convex polygon. FKD: fixed kernel density estimator. *Untransformed data presented.

Origin	N	100% MCP				95% MCP				95% FKD*			
		Mean \pm SE (m^2)	Median (m^2)	Range (m^2)	Mean \pm SE (m^2)	Median (m^2)	Range (m^2)	Mean \pm SE (m^2)	Median (m^2)	Range (m^2)	Mean \pm SE (m^2)	Median (m^2)	Range (m^2)
Captive	6	72.9 \pm 13.0	81.8	15.3 to 100.5	60.7 \pm 11.5	68.5	8.4 to 87.3	93.6 \pm 22.1	112.4	7.0 to 155.8			
Korapuki	11	402.3 \pm 136.3	230.1	17.5 to 1577.1	278.1 \pm 69.8	192.8	12.1 to 680.8	442.1 \pm 152.6	261.8	10.8 to 1539.3			
2013 Total	17	286.1 \pm 95.3	100.5	15.3 to 1577.1	201.4 \pm 51.6	87.3	8.4 to 680.8	319.1 \pm 105.9	122.6	7.0 to 1539.3			
Resident	8	297.1 \pm 90.1	286.3	30.5 to 808.9	258.4 \pm 88.7	212.9	30.5 to 808.9	367.5 \pm 180.0	212	56.7 to 1591.3			

Captive-bred *H. duvaucelii* were frequently encountered in the vicinity of Korapuki geckos and both groups often had overlapping activity areas. Furthermore, the activity areas of female *H. duvaucelii* were found to overlap with both males and other females (Figs 4.2a & 4.3a (95% MCP); Figs 4.2b & 4.3b (100% MCP), Appendix; Figs 4.2c & 4.3c (95% FKD), Appendix), whereas the activity areas of male *H. duvaucelii* did not appear to overlap.

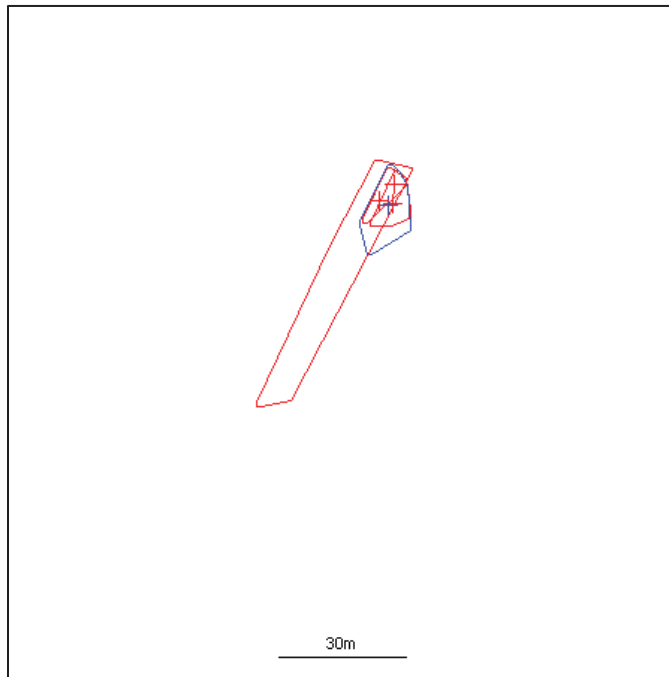


Figure 4.2a: Example of the activity areas (95% minimum convex polygon) of two captive-bred and two Korapuki *Hoplodactylus duvaucelii* (males: 1 and females: 3) on Tiritiri Matangi Island, from eight months after the release (September 2013 to April 2014). The blue area represents the male and the red areas represent females. 'X' represents initial capture locations.

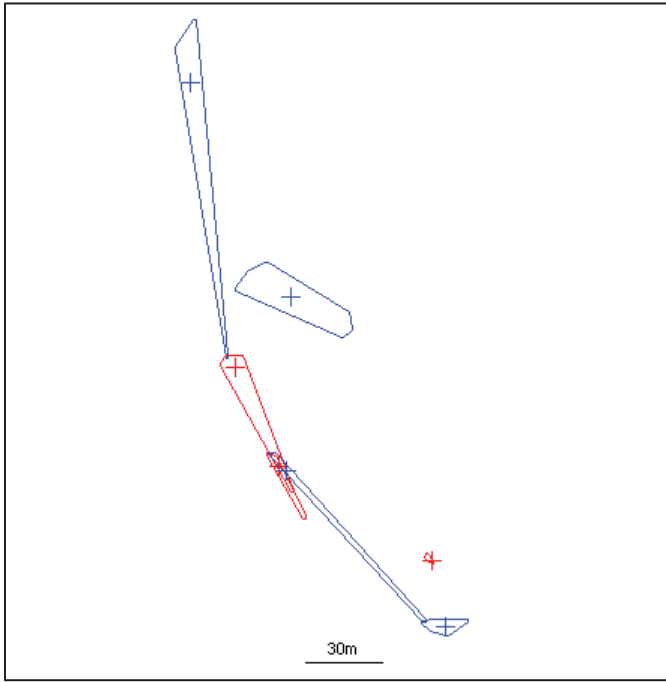


Figure 4.3a: Example of the activity areas (95% minimum convex polygon) of three captive-bred and four Korapuki *Hoplodactylus duvaucelii* (males: 4 and females: 3) on Motuora Island, from eight months after the release (September 2013 to April 2014). Blue areas represent males and red areas represent females. 'X' represents initial capture locations.

Three captive-bred and three Korapuki *H. duvaucelii* (4 males and 2 females) were radio tracked during both radio tracking periods. Two of the geckos (a captive-bred female and a Korapuki male) were re-encountered in the same activity areas they had used during the first radio tracking period. However, the Korapuki male subsequently relocated and settled more than 100 m away after its transmitter was attached. The other four geckos were all found in new locations. One was re-encountered 38 m from its previous last known location and the other three geckos were all found more than 180 m away from their previous last known locations.

Day time location fixes showed that radio tracked *H. duvaucelii* only moved intermittently and often remained stationary during both monitoring periods (Fig 4.4).

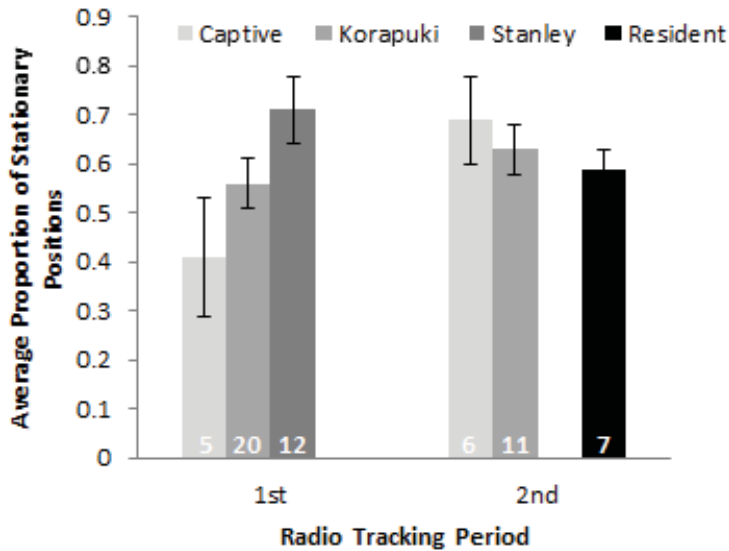


Figure 4.4: The average proportion of stationary positions for captive-bred, Korapuki, Stanley and resident *Hoplodactylus duvaucelii* during the first (February to May 2013) and second (September to December 2013) radio tracking periods. Sample sizes (N) are given in each bar. Sample size represents number of *H. duvaucelii*. Geckos with less than five location fixes were excluded. Error bars represent standard errors.

The mean proportion of stationary fixes increased marginally from 0.53 ± 0.05 , CI: 0.434, 0.632 (N = 25, captive-bred and Korapuki pooled) during the first radio tracking period to 0.63 ± 0.05 , CI: 0.552, 0.747 (N = 17, captive-bred and Korapuki pooled) during the second radio tracking period.

The mean proportion of stationary fixes did not differ significantly between captive-bred and Korapuki *H. duvaucelii* during the first (independent samples t-test: $t = -1.30$, $df = 23$, $p = 0.206$) or second ($t = 0.69$, $df = 15$, $p = 0.499$) radio tracking periods. There were also no significant differences between translocated and resident *H. duvaucelii* (independent samples t-test: $t = 0.68$, $df = 22$, $p = 0.506$) during the second radio tracking period.

No significant differences were found in the proportion of stationary fixes between males (N = 22, $\bar{x} = 0.60 \pm 0.06$) and females (N = 15, $\bar{x} = 0.58 \pm 0.06$) during the first radio tracking period (independent samples t-test: $t = -0.13$, $df = 35$, $p = 0.898$). During the second radio tracking period males were found to be more mobile than females, which was evidenced by a significantly smaller proportion of stationary fixes for males (N = 9, $\bar{x} = 0.54 \pm 0.04$) in comparison to females (N = 15, $\bar{x} = 0.69 \pm 0.04$; independent samples t-test: $t = 2.42$, $df = 22$, $p < 0.05$).

Nocturnal movements

Radio telemetry data shows that *H. duvaucelii* are active throughout the night. The earliest sighting of a radio tracked gecko at night was at 6:23 pm (March) and the latest was at 2:10 am (December). Three *H. duvaucelii* were also opportunistically sighted at night. A Korapuki male was sighted at 11:15 pm in April in a drain beside a main track and two resident juveniles were sighted licking nectar from flax flowers around 8:30 pm and 2 am in November on Tiritiri Matangi. In addition, five resident *H. duvaucelii* were sighted foraging during visual encounter surveys in February 2014 (Chapter 3). Four of the geckos were sighted on the trunks of karo trees (*Pittosporum crassifolium*) and one gecko was sighted on the ground in kikuyu grass (*Pennisetum clandestinum*). The earliest sighting occurred at 9:49 pm and the latest was at 10:56 pm.

Overall, captive-bred and Korapuki *H. duvaucelii* travelled larger distances during the first radio tracking period, with the largest movements occurring between 12 am and 4 am (Fig 4.5). During the second radio tracking period, translocated geckos travelled similar distances to resident geckos (Fig 4.5). The mean distance travelled per night for translocated *H. duvaucelii* was 37.4 ± 10.3 m (N = 6; 95% CI: 17.2 m, 57.6 m; range: 9.6 to 70.7 m) during the first radio tracking period and 10.7 ± 2.8 m (N = 22; 95% CI: 5.3 m, 16.1 m; range: 0.3 to 61 m) during the second radio tracking period. Resident geckos travelled 9.1 ± 1.6 m (N = 12; 95% CI: 6.0 m, 12.2 m; range: 3.4 to 22.5 m) during the second radio tracking period. A formal statistical comparison was not conducted due to low sample sizes. However, non-overlapping confidence intervals for translocated geckos may indicate that overall distances moved per night are significantly different between the first and second radio tracking periods.

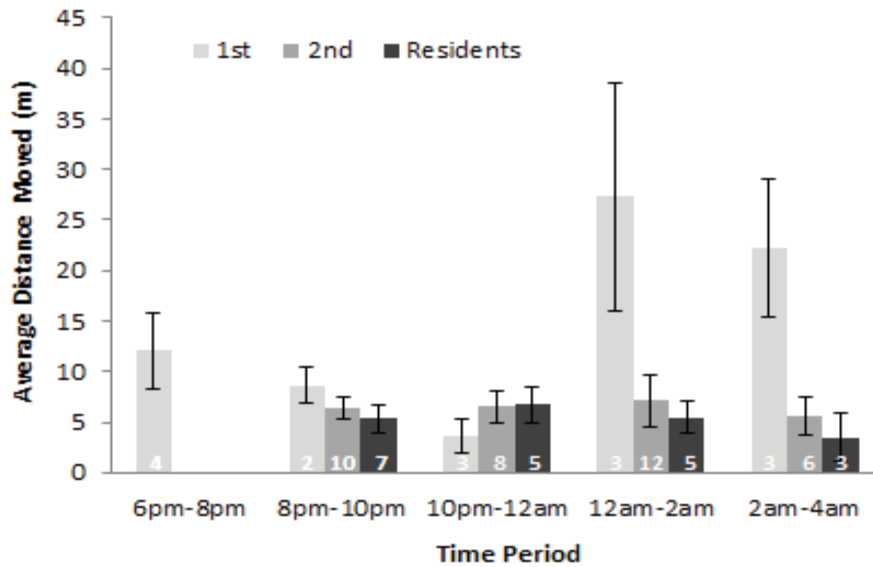


Figure 4.5: The average distance (m) moved by captive-bred and Korapuki (pooled) and resident* *Hoplodactylus duvaucelii* during two hour night radio tracking sessions during the first (March and April 2013) and second (September to December 2013) radio tracking periods. *Resident geckos were only radio tracked at night during the second radio tracking period. Sample sizes (N) are given in each bar. Sample size represents the number of moving locations. Data were collected from five and 20 *H. duvaucelii* from the first and second radio tracking periods, respectively. Error bars represent standard errors. *Note: night radio tracking sessions commenced from 8 pm during the second radio tracking period (see Methods).*

Available data shows that Korapuki *H. duvaucelii* tended to travel further per night than captive-bred *H. duvaucelii* (Table 4.5). However, this trend was not statistically investigated due to low sample sizes.

Table 4.5: The average total distance (m) \pm standard error (SE) travelled per night by captive-bred, Korapuki and resident *Hoplodactylus duvaucelii* during the first (March and April 2013) and second (September to December 2013) radio tracking periods.

Origin	1st Radio Tracking Period				2nd Radio Tracking Period			
	N	Mean \pm SE (m)	Median (m)	Range (m)	N	Mean \pm SE (m)	Median (m)	Range (m)
Captive	1	9.6	–	–	5	3.8 \pm 1.7	3.4	0.3 to 10.1
Korapuki	5	43.0 \pm 10.6	38.9	14.5 to 70.6	17	12.8 \pm 3.4	7.6	0.7 to 61.0
Resident	–	–	–	–	12	9.1 \pm 1.6	7.3	3.4 to 22.5

4.4 Discussion

Overall, dispersal and activity patterns were similar between radio tracked captive-bred and wild Korapuki *H. duvaucelii* following their translocation into a new environment. Most dispersal events occurred during the first month of monitoring and translocated radio tracked *H. duvaucelii* appeared to have settled after nine months as evidenced by smaller activity areas. Later movement and activity patterns were also comparable to radio tracked resident *H. duvaucelii* further indicating that translocated *H. duvaucelii* had settled.

Dispersal patterns

Average maximum weekly dispersal distances were comparable between captive-bred and wild *H. duvaucelii*. Most radio tracked *H. duvaucelii*, irrespective of origin or sex, remained within 100 m of their release locations, although the average maximum distance from release sites gradually increased during the first 10 weeks. Low initial dispersal rates are consistent with van Winkel's (2008) study, where translocated radio tracked *H. duvaucelii* were reported to have travelled less than 50 m in the first month after the release and less than 100 m during the second month. All initial dispersal events (i.e. movements over 100 m) occurred within one month after the release, compared with three to four months after the release during van Winkel's (2008) study. Limited dispersal could suggest that conditions were suitable at the release sites. Animal restoration projects may have a greater chance of success if dispersal rates are low, since dispersal can strongly influence population establishment post-translocation (Armstrong & Seddon, 2008). The average distance from release site to final location was in the 30 m range for captive-bred and Korapuki geckos and 40.8 m for Stanley geckos, further suggesting low initial dispersal and more exploratory behaviour by radio tracked *H. duvaucelii*. Furthermore, the average distance from release site to activity area was not considerably different between captive-bred and Korapuki *H. duvaucelii*. It is important to be aware though that radio telemetry connects location fixes using straight lines, which may underestimate how far an animal has actually travelled (Birchfield & Deters, 2005). Furthermore, the loss of several transmitters early on in the monitoring period means that some geckos may have dispersed further away than what was observed. Additionally, recapture methods were focused within and around the monitoring sites, which targeted geckos that had not dispersed. Thus, geckos that were not recaptured may have dispersed.

Only one radio tracked captive-bred gecko, five Korapuki geckos and one Stanley gecko dispersed during the first radio tracking period, although three *H. duvaucelii* subsequently returned to within 100 m of their respective release sites. However, during the second radio tracking period, three

captive-bred geckos, eight Korapuki geckos and one Stanley gecko had dispersed or were exploring. Low rates of dispersal by captive-bred geckos may make them more suitable candidates for species restoration projects as they may be more likely to settle closer to release sites (Bodinof *et al.*, 2012), especially if translocation managers select ideal habitats for release sites. However, more captive-bred geckos than Korapuki geckos were either never encountered or were not sighted again after the first three weeks of monitoring. Since monitoring efforts were quite extensive within and around the monitoring sites, this suggests that many of these individuals may have dispersed away from the monitoring sites. Dispersal distances of over 200 m were observed on both islands and were reached by *H. duvaucelii* of all origins. Van Winkel (2008) also reported dispersal distances of over 200 m, although only up to 220 m and only on Tiritiri Matangi. Dispersal distances on Motuora were considerably lower, with a maximum dispersal distance of 63 m (van Winkel, 2008).

At least 10 *H. duvaucelii* on Motuora moved into or around different monitoring sites, compared with just one Korapuki male on Tiritiri Matangi. This *H. duvaucelii* had the greatest known dispersal distance during this study. *Hoplodactylus duvaucelii* are capable of detecting and distinguishing between the scents of other conspecifics (Barry, 2010). The closer proximity of the monitoring sites on Motuora may have allowed *H. duvaucelii* to pick up the scents of other conspecifics that were more attractive to them encouraging dispersal towards those areas. However, it is also important to consider that the inclination to disperse may be greater for some individuals than for others (Tuberville *et al.*, 2005).

Radio tracked captive-bred and wild geckos largely exhibited similar dispersal patterns, suggesting that the influence of rearing history on the post-release movement behaviours of *H. duvaucelii* may be less pronounced, thus indicating that captive-bred founders are as similarly suited as their wild counterparts for restoration projects.

Activity areas and patterns

Overall, activity area ranged widely between individuals, irrespective of gecko rearing history, and across both radio tracking periods. Large variations in individual activity areas are consistent with other *H. duvaucelii* studies (Christmas, 1995; van Winkel, 2008) as well as other gecko studies. For example, range areas varied from 4 m² to 116 m² (100% MCP) or 3 m² to 248 m² (95% FKD) for Günther's gecko (*Phelsuma guentheri*) (Gerner, 2008) and 1.9 m² to 158.3 m² (100% MCP) for the Mauritius lowland forest day gecko (*Phelsuma guimbeaui*) (Buckland *et al.*, 2014). However, low sample sizes warranted the inclusion of location fixes collected outside of the radio tracking periods,

so activity areas include location fixes that were collected over a long and varied timeframe, which could also account for the large variations observed.

Korapuki *H. duvaucelii* used the biggest activity areas during both radio tracking periods. Furthermore, the activity areas used by radio tracked Korapuki *H. duvaucelii* during the second radio tracking period were much larger than the activity areas used by radio tracked captive-bred geckos. Captive-bred geckos may have used smaller activity areas as they have been accustomed to living in smaller spaces. However, *H. duvaucelii* on Ruamahua-iti Island and on Mauitaha Island also used similarly small activity areas (Christmas, 1995). Overall, activity areas were smaller for all groups during the second radio tracking period and were also smaller than the average range areas used by resident *H. duvaucelii* on Tiritiri Matangi (563 m²) and Motuora (774 m²) during van Winkel's (2008) study. There was also little variation between the activity areas of radio tracked translocated and resident *H. duvaucelii* and one captive-bred *H. duvaucelii* used the same activity area (which was also used by at least three other *H. duvaucelii* indicating that it was a suitable habitat) during both radio tracking periods, illustrating that translocated *H. duvaucelii* were able to settle and establish core areas within a year of translocation and were able to adapt quickly to new environments. Despite differences in size, the activity areas of radio tracked captive-bred and Korapuki *H. duvaucelii* often overlapped, which is not unusual for gecko species, for example, *P. guentheri* (Gerner, 2008) and *P. guimbeaui* (Buckland *et al.*, 2014) and illustrates that conspecifics had not become isolated. It also suggests similar habitat use between the two groups (Chapter 5). Male *H. duvaucelii* generally do not occupy the same shelters (Barry, 2010), which may account for why male activity areas did not appear to overlap. Social dominance and competition for mates may also have been factors, since male activity areas overlapped with those of females.

Movement and activity patterns also varied between individuals, irrespective of gecko rearing history, although general trends were also apparent. Radio tracked captive-bred and Korapuki *H. duvaucelii* were both less active during the second radio tracking period, as evidenced by increases in the proportion of stationary fixes. The proportion of stationary fixes did not differ significantly between captive-bred and Korapuki geckos during either radio tracking period or between translocated and resident geckos during the second radio tracking period. Most *H. duvaucelii* remained at one core location, with sporadic brief stays at other locations. Other *H. duvaucelii* appeared to have a number of core locations, which they regularly alternated between, whereas a few individuals appeared to still be exploring. Geckos that were repeatedly observed at the same location, but then briefly relocated, may have been drawn to other conspecific scents in search of potential mates or ventured out in search of alternative food sources.

There were also no significant differences in the proportion of stationary fixes between males and females during the first radio tracking period, but there was a significant difference during the second radio tracking period. Males moved more than females, probably due to having slightly larger activity areas than females and also possibly to search for females as the second radio tracking period took place during the mating season. Some reptiles have also been found to exhibit sex-biased dispersal, where males move greater distances than females, for example, slatey-grey snakes (*Stegonotus cucullatus*) (Dubey *et al.*, 2008) and freshwater crocodiles (*Crocodylus johnstoni*) (Tucker *et al.*, 1998).

Nocturnal movements

Radio tracked *H. duvaucelii* were found to be relatively sedentary at night, rarely moving away from their diurnal shelters during night radio tracking sessions. *Hoplodactylus duvaucelii* may limit large scale movements to avoid exposure to predators or they may require periods of inactivity to recover after nights of high activity. For example, common wonder geckos (*Teratoscincus scincus*) forage by moonlight and so exhibited much longer periods of inactivity during moonless nights (Seligmann *et al.*, 2007). Alternatively, *H. duvaucelii* may intentionally select vegetation such as flax, which can provide shelter during the day and a source of food at night (Chapter 5), allowing *H. duvaucelii* to forage within their diurnal retreats, thus reducing unnecessary energy expenditure. Intermittent movement by geckos may increase their overall endurance and distance capacity. For example, nocturnal frog-eyed geckos (*Teratoscincus przewalskii*) that alternated between periods of activity and periods of inactivity were able to travel almost double the distance of *T. przewalskii* that moved without pausing (Weinstein & Full, 1999).

Previous *H. duvaucelii* studies (e.g. Whitaker, 1968; van Winkel, 2008) have found the first few hours after sunset to have the highest rates of nocturnal activity for *H. duvaucelii*, with activity decreasing after 9 pm. Similar trends were found for 12 other nocturnal gecko species in Western Australia (Pianka & Pianka, 1976). Factors such as temperature, have been linked with reduced foraging and activity. For example, *H. duvaucelii* in captivity are known to reduce foraging activity when temperatures drop (Barry *et al.*, 2010) and the nocturnal activity patterns of other reptiles, such as ratsnakes (*Pantherophis* spp.) have been positively related with temperature (Sperry *et al.*, 2013). However, in this study radio tracked *H. duvaucelii* were sighted at various times throughout the night and radio telemetry data collected during the second radio tracking period shows that the distances moved by both translocated and resident *H. duvaucelii* were fairly consistent throughout the night. Furthermore, the largest movements from the first night radio tracking period, which was

conducted during New Zealand's autumn, occurred between 12 am and 4 am. However, only five individuals' movements were observed and sample sizes were low.

The average distance travelled per night was considerably larger during the initial months after the release, suggesting that night time activity was more orientated towards dispersal and exploratory movements rather than just foraging behaviour. Higher dispersal activity is expected in the initial months after a release as translocated animals explore and become familiar with their new surroundings. However, the range of distances moved was similar for both radio tracking periods. *Hoplodactylus duvaucelii* are known to be naturally wide ranging (Whitaker, 1968) and the average distance travelled per night for both radio tracking periods was consistent with other studies (e.g. Whitaker, 1968; Christmas, 1995; van Winkel, 2008). However, the range of distances travelled by radio tracked *H. duvaucelii* in this study was larger (i.e. 0.3 to 70.6 m) than what has been previously reported, e.g. 3.8 to 27.8 m (van Winkel, 2008) and 6.3 to 44 m (Christmas, 1995), which may suggest a prolonged period of exploration by translocated *H. duvaucelii*.

Korapuki *H. duvaucelii* tended to travel further per night than both captive-bred and resident *H. duvaucelii*. Although sample sizes were uneven and too low to allow for statistical analysis, this data is consistent with Korapuki *H. duvaucelii* having the largest activity areas during both radio tracking periods.

4.5 Conclusion

Overall, the dispersal distances, activity areas and movement patterns of captive-bred and wild Korapuki *H. duvaucelii* were similar. Only the activity areas used during the second radio tracking period showed a pronounced difference between the two groups. Furthermore, there was also a considerable difference in the frequency of movements between males and females during the second radio tracking period. In addition to being more mobile, male *H. duvaucelii* tended to travel further and use larger activity areas than female *H. duvaucelii*. Activity areas and movement patterns were similar between translocated and resident *H. duvaucelii* during the second radio tracking period suggesting that translocated *H. duvaucelii* were able to settle and establish core areas within a year after translocation. Finally, *H. duvaucelii* were observed to be active throughout the night, however, nocturnal activity was found to be sporadic. The results suggest that rearing history does not have a considerable influence on the dispersal, activity and movement patterns of *H. duvaucelii*, indicating that captive-bred geckos are suitable founders for species restoration projects.

Chapter 5

Habitat use by captive-bred and wild *Hoplodactylus duvaucelii* following translocation.



Plate 5.0: An example of the type of habitat used by *Hoplodactylus duvaucelii* on Motuora Island.

5.1 Introduction

Habitat use is defined as the way in which an organism utilises the resources available within a particular environment (Hall *et al.*, 1997). It occurs over numerous spatial scales (George & Zack, 2001) and is specific to a particular individual (Hall *et al.*, 1997). Similarities in the habitat use patterns of multiple individuals could suggest species-specific habitat preferences, as well as provide valuable insights about behaviour since habitat selection is a behavioural process (Krausman, 1999). However, early rearing conditions may have lasting effects on future behaviours (Burghardt & Layne, 1995). Animals sourced from separate locations may subsequently display differing habitat use patterns, i.e. natal habitat preference induction (Davis & Stamps, 2004). For captive-bred animals, these effects could influence future performance and their ability to adapt to wild environments (Burghardt & Layne, 1995).

Habitat use by captive-bred and wild reptiles

The habitat use patterns of captive-bred reptiles, following translocation into wild environments, could differ drastically from those of their wild counterparts as they have been accustomed to a completely different environment. Captive environments provide fewer habitat options and do not offer the same variety of plant species. Roe *et al.* (2010) found that translocated captive-bred northern water snakes (*N. sipedon sipedon*) demonstrated few or no preferences for or against available habitat types, whereas wild-sourced snakes displayed preferences, although they differed from the preferences of resident snakes. Furthermore, captive-bred reptiles may lack experience with prioritising conflicting factors that can influence habitat selection in the wild, such as predator avoidance tactics, thermal conditions and food supply, as these factors are externally controlled in captive environments. This inexperience could result in the selection and use of unsuitable habitats, which could have negative effects on survival, body condition and breeding success. However, since *H. duvaucelii* are considered habitat generalists, this may make them better candidates for translocation projects, as they are able to use a broad range of habitats and so are likely to find acceptable shelters and settle into new environments quicker and more easily than species that exhibit more specific habitat selection. Furthermore, other studies comparing the habitat use patterns of captive-bred and wild reptiles did not find any significant differences between the two groups. For example, juvenile tuatara (*S. punctatus*) were found to use similar habitat resources across three spatial scales, i.e. retreat, local and landscape, irrespective of rearing history (Jarvie *et al.*, 2016). Captive-born Louisiana pine snakes (*Pituophis ruthveni*) also exhibited similar post-release microhabitat and macrohabitat use to repatriated wild snakes (Himes *et al.*, 2006). However, similarities in habitat use patterns between captive-bred and wild founders could also be the result

of one group copying the behaviours of the other, especially if both groups have been released together (Kleiman, 1989) or if the founder species is known to exhibit aggregating behaviour.

Importance of habitat use studies

Habitat use studies are important for developing effective conservation management plans, as they identify and promote the protection of significant habitats (Attum *et al.*, 2011). Protection of high quality habitats is especially important for species restoration projects, as translocations have a greater chance of succeeding when animals are released into good quality habitats (Griffith *et al.*, 1989). Habitat selection is a hierarchical process with each choice becoming more specific (Hutto, 1985). Studies on microhabitat use are particularly beneficial as they also identify key macrohabitat characteristics (Attum *et al.*, 2011).

There have been no prior *H. duvaucelii* translocations involving captive-bred founders, so their habitat use following release into wild environments has been undocumented to date. Thus, this is the first study to examine whether rearing history influences the habitat use patterns of *H. duvaucelii*.

Chapter aim:

The aim of this chapter is to explore habitat use patterns of translocated *H. duvaucelii* during the first year after their release and to determine whether captive-bred and wild geckos (of the same origin) show differences in habitat use.

Specific chapter objectives:

- Characterise the microhabitat (substrate type and percent of ground cover) used by *H. duvaucelii* for foraging activities and as shelter sites in relation to time after release.
- Determine whether microhabitat characteristics at radio tracking locations differ in relation to gecko rearing history (i.e. captive-bred versus wild) zero to three months, and eight to ten months after release.
- Document the spatial distribution of *H. duvaucelii* in relation to microhabitat type.

5.2 Methods

Habitat use was investigated using location fixes collected only from radio tracked *H. duvaucelii*. As the main focus of this chapter was to compare the microhabitat use and spatial distributions of captive-bred and wild Korapuki *H. duvaucelii*, comparisons were primarily made between these two groups. However, the inclusion of the Stanley geckos in the overall translocation project and the

presence of the resident geckos (Chapter 2) allowed for additional assessments of general patterns in microhabitat use by *H. duvaucelii*. Since *H. duvaucelii* are predominately nocturnal, location fixes collected at night were used to represent foraging habitats, whereas location fixes collected during the day were used to represent shelter sites. As the Stanley geckos were not radio tracked at night (Chapter 4) their foraging habitat choices were not investigated.

Microhabitat assessments

At every gecko location fix, substrate type and species, approximate perch height (m) and the species of, and distance (m) to, the next closest tree were recorded.

Substrate types used by *H. duvaucelii* were grouped into four broad categories:

1. Trees (with and without artificial shelters) and shrubs, such as *Muehlenbeckia spp.*
2. Flax (*Phormium tenax*)
3. Ferns and herbaceous species.
4. Other ground covers, such as logs, leaf litter or bare ground.

If a gecko was recorded in a tree (i.e. trunk circumference of 12.6 cm or more) then the height (m) and circumference (cm) of the tree at breast height (DBH, 1.4 m above the ground) was also recorded. Circumference measurements were later converted to diameter for analysis.

Microhabitat variables including type and percent of ground cover as well as presence and size of flax and *Muehlenbeckia spp.* patches surrounding the gecko location fixes were also recorded. The microhabitat assessments were conducted at a later point in time, i.e. between September 2013 and February 2014, due to time constraints during the radio tracking study and also to avoid excess disturbance to the geckos.

All distances were measured using a 50 m measuring tape. All height measurements were measured using a plastic pole approximately 2.1 m in length, which had been marked at 5 cm intervals.

Ground cover surveys

At each gecko location fix, a 5 m by 5 m square grid was marked out using a combination of 2.1 m plastic poles, 1 m wooden sticks and 50 m measuring tapes. Within each square grid there were 25, 1 m by 1 m squares. Location fixes were positioned within the centre square. The percentage of cover within each square was recorded for the following ground cover variables:

- Trunks and logs
- Bare ground
- Leaf litter
- Herbs (includes grasses and plants without woody stems)
- Ferns
- Flax (*Phormium tenax*)
- *Muehlenbeckia* spp.
- Other shrubs (includes plants with woody stems)

In addition, canopy cover (i.e. none, partial or full) and the total number of trees (i.e. trunk circumference of 12.6 cm or more) within each square were also recorded.

Ground cover and tree density were analysed at the 25 m² scale, whereas canopy cover was analysed at the 1 m² scale, i.e. the area directly over each gecko location.

Flax and Muehlenbeckia spp. patch surveys

A patch was defined as a single plant or a dense accumulation of multiple flax or *Muehlenbeckia* spp. plants that exceeded 50 cm by 50 cm in diameter (measured 20 cm above the ground). It was assumed that these plant species are important refuge sites for *H. duvaucelii* and that a minimum size of 50 cm by 50 cm would be sufficiently large enough to serve as a shelter. The outer edge of a patch was defined as any living or dead clump of mostly flax or *Muehlenbeckia* spp. material, which was a minimum of 30 cm above the ground.

If a gecko was recorded in a flax or *Muehlenbeckia* spp. patch, or if a flax or *Muehlenbeckia* spp. patch was located within a 5 m radius of the gecko's position, further variables were collected on the patch dimensions including:

- Maximum height
- North height (measured 20 cm in from the northern outer edge of the patch)
- South height (measured 20 cm in from the southern outer edge of the patch)
- Distance from the centre of the patch to the outer edge of the patch in eight compass directions (i.e. north, north-east, east, south-east, south, south-west, west and north-west) approximately 45° apart.

The average height (m) of each patch was calculated for analysis, using the three height measurements (i.e. maximum, north and south). Since the closest patch and the largest patch were often the same patch, only the height measurements for the closest patch have been reported.

The total basal area of a patch was calculated by dividing the patch into eight separate triangles using the eight distance measurements collected (Fig 5.1). The area of each triangle was calculated and then all eight triangles were summed to get an approximate value for the total basal area. Total basal area was calculated for all patches within a 5 m radius of each gecko location fix and random location fix. Flax patches were divided into five area categories as follows: 0: 0 m², 1: 0.1 to 10 m², 2: 10.1 to 100 m², 3: 100.1 to 300 m² and 4: > 300.1 m².

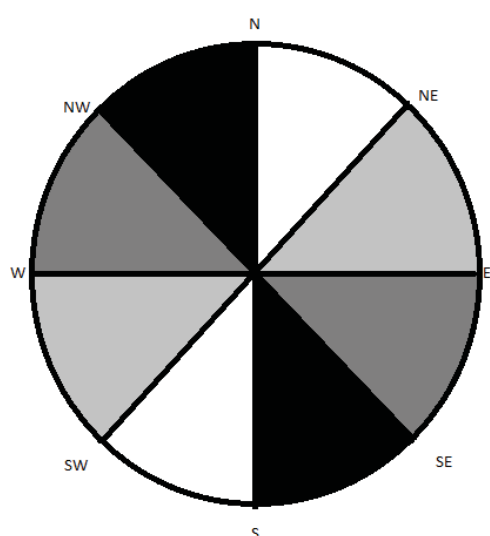


Figure 5.1: An illustration showing how the total basal area of a flax (*Phormium tenax*) or *Muehlenbeckia* spp. patch was calculated by dividing each patch into eight triangles. The area of each triangle was calculated and then all eight triangles were summed to get an approximate value for the total basal area.

Random location fixes

At each of the six 2013 release and monitoring sites and the two 2006 resident monitoring sites, five random location fixes (total: 30) were sampled (i.e. ground cover surveys and patch surveys) to assess available microhabitat types within each of the monitoring sites. Each point was randomly chosen firstly by randomly selecting one of the 25 artificial tree shelters within each monitoring site (Fig. 2.2, Chapter 2) and then walking 5 m from that chosen artificial tree shelter in one of eight

randomly selected compass directions. Artificial tree shelters and compass directions were selected using the random number generator on a calculator.

All random location fixes had to fall within the boundaries of the original monitoring sites as the aim was to assess available microhabitat types within each of the monitoring sites. Therefore, if the chosen direction meant that the random location fix fell outside of the monitoring site, then the opposite direction was used until a point within the monitoring site was selected. Furthermore, locations that had already been sampled (i.e. actual gecko location fixes) were not re-sampled as random location fixes. A new site was selected using the same method as mentioned above. This approach is consistent with other studies. For example, Croak *et al.* (2013) assessed the habitat use of broad-headed snakes (*Hoplocephalus bungaroides*) by comparing the vegetation types utilised by *H. bungaroides* with similar non-used vegetation types in the surrounding area.

Analyses

Substrate use was investigated in relation to availability by comparing substrates used by translocated *H. duvaucelii* with available substrate types at random location fixes using Pearson chi-square tests, separate for each radio tracking period. Possible variations in substrate use (i.e. whether or not a particular substrate was used, not the frequency of use) between captive-bred and Korapuki *H. duvaucelii* were investigated using Pearson chi-square tests, separate for each radio tracking period. Substrate use was also compared between translocated (i.e. captive-bred and Korapuki geckos pooled) and resident *H. duvaucelii* during the second radio tracking period.

Possible differences in the amount of canopy cover directly above gecko locations were explored between captive-bred and Korapuki *H. duvaucelii* using Pearson chi-square tests, separate for each radio tracking period. Comparisons were also made between translocated and resident *H. duvaucelii* during the second radio tracking period. Potential variations in the amount of canopy cover at translocated gecko location fixes and random location fixes were also explored using Pearson chi-square tests, separate for each radio tracking period, to investigate use in relation to availability.

The surrounding ground cover and tree density at gecko location fixes were compared between captive-bred and Korapuki *H. duvaucelii* using Mann-Whitney U tests, separate for each radio tracking period. Comparisons were also made between translocated and resident *H. duvaucelii* during the second radio tracking period. Surrounding ground cover and tree density at translocated gecko location fixes were also compared with random location fixes using Mann-Whitney U tests, separate for each radio tracking period, to investigate occurrence relative to availability.

Sequential Holm-Bonferroni corrections were applied when multiple comparisons were conducted and corrected p-values have been reported.

Data from the Stanley geckos has been included in figures and tables to illustrate similar trends, but has not been statistically analysed as their habitat use was not a primary focus of this chapter.

As resident geckos were not radio tracked during the first radio tracking period, comparisons between translocated and resident geckos refer only to the second radio tracking period.

5.3 Results

General microhabitat trends

Overall, translocated (all 2013 origins pooled) *H. duvaucelii* used 22 different substrates during the monitoring period, of which 13 were different tree species (Fig 5.2). Resident *H. duvaucelii* were only encountered in flax, leaf litter and kikuyu grass (*Pennisetum clandestinum*). Trees used by translocated *H. duvaucelii* had a mean height of 5.1 ± 0.2 m (N = 76, range: 1.35 to 10 m) and an average DBH of 21.8 ± 2.0 cm (N = 71, range: 4.4 to 74.5 cm). Approximate perch height across all substrate types was $\bar{x} = 1.0 \pm 0.12$ m (N = 148, range: 0 to 6.5 m) for captive-bred and Korapuki geckos (pooled) and $\bar{x} = 0.7 \pm 0.13$ m (N = 80, range: 0 to 5.5 m) for Stanley geckos during the first radio tracking period. During the second radio tracking period, perch height was $\bar{x} = 0.5 \pm 0.04$ m (N = 131, range: 0.1 to 2.5 m) for captive-bred and Korapuki geckos (pooled) and $\bar{x} = 0.4 \pm 0.06$ m (N = 60, range: 0.1 to 1.6 m) for the resident geckos.

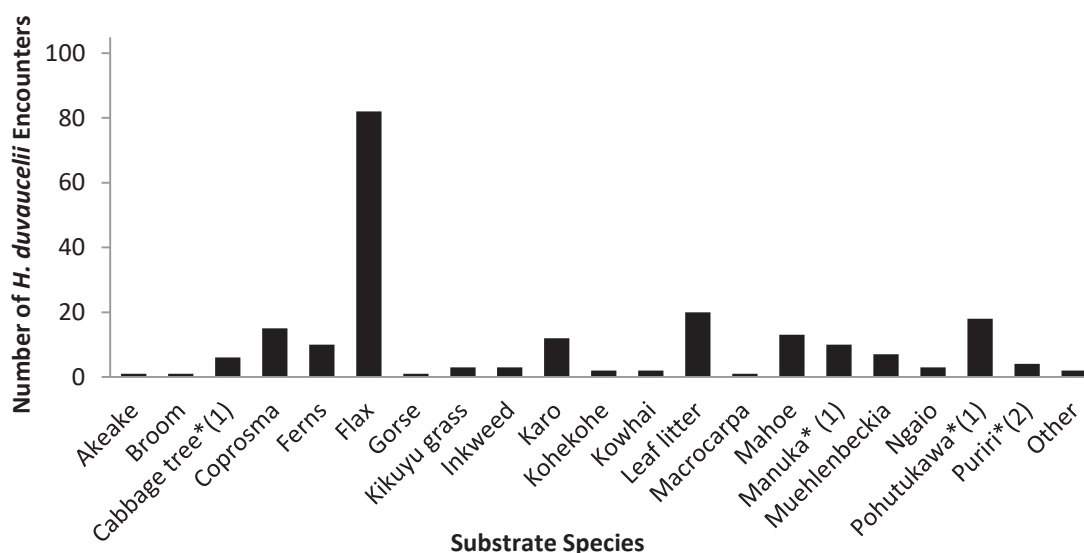


Figure 5.2: Graph depicts the number of *Hoplodactylus duvaucelii* encounters (all 2013 origins pooled) per substrate species across the entire monitoring period. The 'other' category includes one encounter in a drain on a road and one encounter in an artificial refuge (i.e. a plastic tube). *Tally includes encounters in artificial tree shelters, which are given in the brackets.

Surrounding tree species resembled those used by *H. duvaucelii*. During the first radio tracking period, mahoe (*Melicytus ramiflorus*) was the most common species of the next closest tree at captive-bred and Korapuki gecko locations (pooled), whereas coprosma (*Coprosma spp.*) was the most common species of the next closest tree at Stanley gecko locations. During the second radio tracking period, cabbage trees (*Cordyline australis*) were the most common species of the next closest tree at captive-bred and Korapuki gecko locations (pooled), whereas pohutukawa (*Metrosideros excelsa*) was the most common species of the next closest tree at resident gecko locations. Distance to the closest tree was 1.6 ± 0.1 m (N = 111, range: 0.1 to 6.7 m) for captive-bred and Korapuki geckos (pooled) and 1.9 ± 0.2 m (N = 48, range: 0.1 to 6.7 m) for the Stanley geckos during the first radio tracking period. During the second radio tracking period, distance to the closest tree was 2.3 ± 0.3 m (N = 37, range: 0.05 to 6.3 m) for captive-bred and Korapuki geckos (pooled) and 3.3 ± 0.5 m (N = 20, range: 1 to 9.3 m) for resident geckos.

Primary substrate use

All substrate types were used by translocated *H. duvaucelii* during the first radio tracking period, with shrubs and trees having the highest use amongst both captive-bred (10/11) and Korapuki (23/28) *H. duvaucelii* (Plates 5.1 & 5.2). By the second radio tracking period translocated *H.*

duvaucelii, like their resident counterparts (N = 8), sheltered and foraged almost exclusively in flax (Plate 5.3). Shrubs and trees were still used by translocated *H. duvaucelii*, but only by one captive-bred (N = 6) and two Korapuki (N = 13) geckos, whereas two resident geckos used logs and leaf litter.



Plate 5.1: Three examples of 2013 translocated radio tracked *Hoplodactylus duvaucelii* sheltering in trees on Motuora Island during the first radio tracking period.



Plate 5.2: A radio tracked captive-bred female *Hoplodactylus duvaucelii* encountered on a *Coprosma* spp. tree around 8 pm in April 2013 during night radio tracking sessions on Tiritiri Matangi Island.

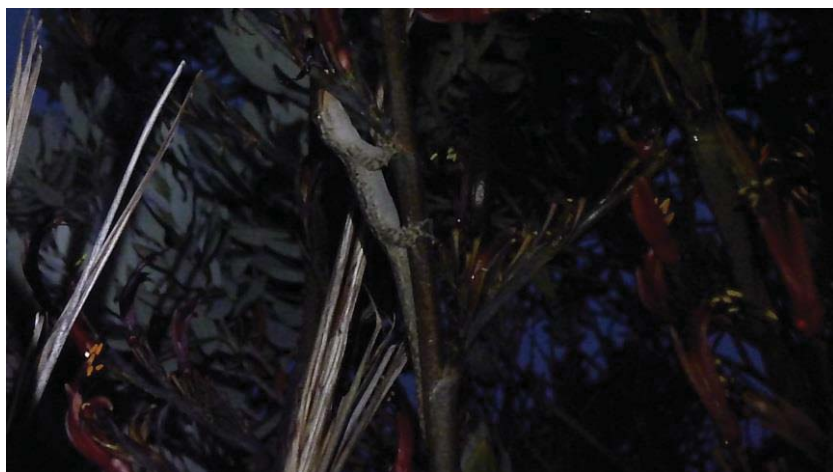
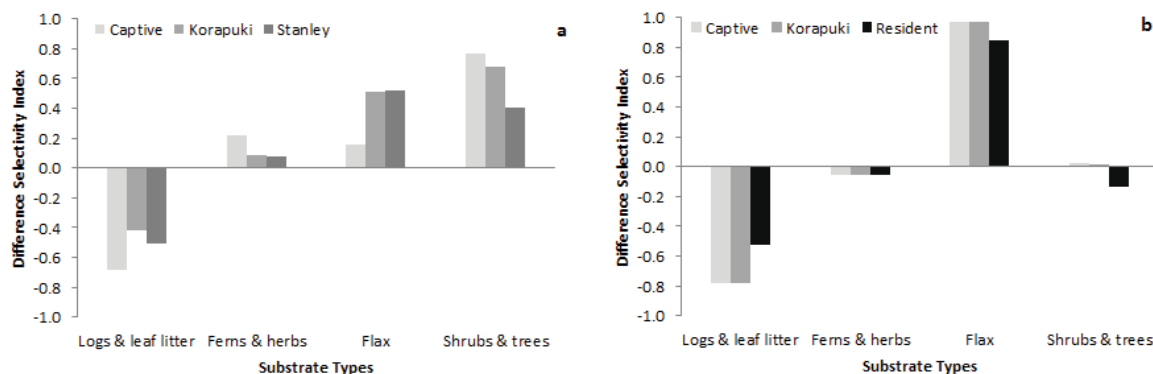


Plate 5.3: A resident juvenile *Hoplodactylus duvaucelii* opportunistically encountered licking nectar from flax (*Phormium tenax*) flowers around 8:30 pm in November 2013 on Tiritiri Matangi Island.

Substrate use did not differ significantly between captive-bred and Korapuki *H. duvaucelii* for shrubs and trees (captive-bred: 10/11, Korapuki: 23/28, Pearson chi-square test: $\chi^2 = 0.466$, $df = 1$, $p = 0.655$), flax (captive-bred: 2/11, Korapuki: 15/28, $\chi^2 = 4.022$, $df = 1$, $p = 0.073$), ferns and herbs (captive-bred: 3/11, Korapuki: 4/28, $\chi^2 = 0.904$, $df = 1$, $p = 0.379$) or logs and leaf litter (captive-bred:

1/11, Korapuki: 10/28, $\chi^2 = 2.764$, $df = 1$, $p = 0.130$) during the first radio tracking period; or for shrubs and trees (captive-bred: 1/6, Korapuki: 2/13, $\chi^2 = 0.005$, $df = 1$, $p = 1.000$) during the second radio tracking period. Statistical tests were not conducted for flax use, ferns and herbs use, or logs and leaf litter use, during the second radio tracking period, since all translocated radio tracked geckos used flax and none used either ferns and herbs or logs and leaf litter. There were also no significant differences in substrate use between translocated and resident *H. duvaucelii* for shrubs and trees (translocated: 3/19, residents: 0/8, $\chi^2 = 1.421$, $df = 1$, $p = 0.532$), flax (residents: 7/8, $\chi^2 = 2.466$, $df = 1$, $p = 0.296$) or logs and leaf litter (residents: 2/8, $\chi^2 = 5.130$, $df = 1$, $p = 0.080$) during the second radio tracking period. Ferns and herbs were not statistically tested as neither group used this substrate type.

Furthermore, during the first radio tracking period, *H. duvaucelii* used the substrate types: shrubs and trees (33/39; Pearson chi-square test: $\chi^2 = 37.463$, $df = 1$, $p < 0.001$) and flax (17/39; $\chi^2 = 17.094$, $df = 1$, $p < 0.001$) significantly more in relation to their availability. In contrast *H. duvaucelii* used logs and leaf litter (11/39; $\chi^2 = 18.431$, $df = 1$, $p < 0.001$) significantly less in relation to their availability (Fig 5.3a). Ferns and herbs were the least used substrate types by translocated *H. duvaucelii* during the first radio tracking period, however, the use of these substrate types were proportional to their availability (7/39; $\chi^2 = 2.723$, $df = 1$, $p = 0.156$) (Fig 5.3a). During the second radio tracking period, *H. duvaucelii* used flax significantly more in relation to flax availability (Pearson chi-square test: $\chi^2 = 50.799$, $df = 1$, $p < 0.001$). Whereas logs and leaf litter were used significantly less relative to availability ($\chi^2 = 30.103$, $df = 1$, $p < 0.001$) (Fig 5.3b). Use relative to availability was not significantly different for shrubs and trees ($\chi^2 = 0.036$, $df = 1$, $p = 1.000$) or ferns and herbs ($\chi^2 = 1.095$, $df = 1$, $p = 0.539$) (Fig 5.3b).



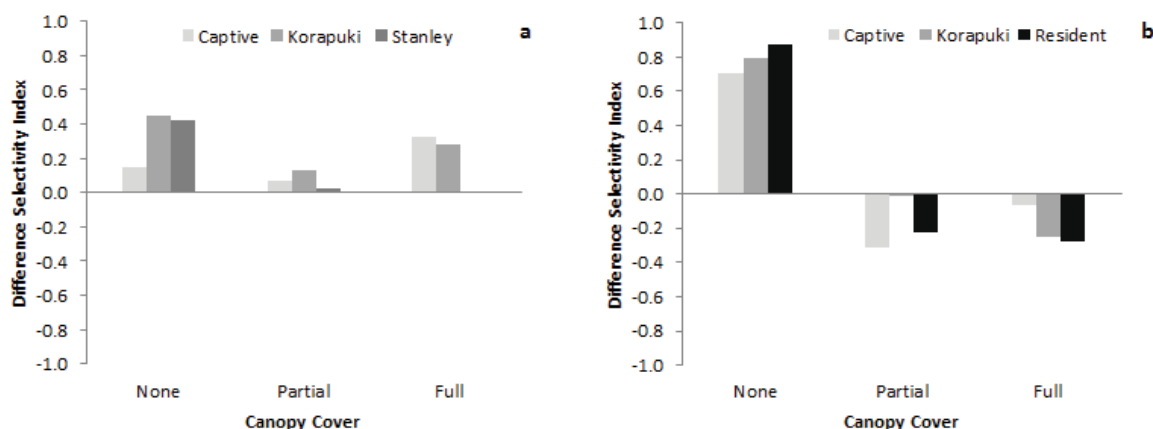
Figures 5.3a & 5.3b: Displayed are selectivity indices for different substrate types calculated for captive-bred ($N = 11$ & $N = 6$, respectively), Korapuki ($N = 28$ & $N = 13$, respectively), Stanley ($N = 22$) and resident ($N = 8$) *Hoplodactylus duvaucelii* for the first (a) and second (b) radio tracking periods. Selectivity index values were derived by subtracting the proportion of substrate used from the proportion of substrate available. Values close to zero indicate use is proportional to availability. Increasing positive values reflect an increasing association and increasing negative values reflect an increasing disassociation with a substrate type.

Primary canopy cover

Radio tracked *H. duvaucelii* used habitats with varying amounts of canopy cover. Locations with full canopy cover, directly above the primary substrate, had the highest use (27/39) amongst captive-bred and Korapuki *H. duvaucelii* during the first radio tracking period, followed by locations with partial canopy cover (23/39) and no canopy cover (19/39). By the second radio tracking period, the trend had reversed, with locations without canopy cover recording the highest use (translocated: 17/19; resident: 8/8), followed by locations with partial canopy cover (translocated: 7/19; resident: 2/8) and full canopy cover (translocated: 4/19; resident: 1/8).

Captive-bred and wild Korapuki *H. duvaucelii* did not differ in their habitat use, with respect to canopy cover, during the first radio tracking period (Pearson chi-square test: no cover: $\chi^2 = 2.820$, $df = 1$, $p = 0.093$; partial cover: $\chi^2 = 0.124$, $df = 1$, $p = 0.725$; full cover: $\chi^2 = 0.088$, $df = 1$, $p = 0.767$; captive-bred: $N = 11$; Korapuki: $N = 28$); or during the second radio tracking period (no cover: $\chi^2 = 0.351$, $df = 1$, $p = 0.554$; partial cover: $\chi^2 = 1.534$, $df = 1$, $p = 0.216$; full cover: $\chi^2 = 0.796$, $df = 1$, $p = 0.372$; captive-bred: $N = 6$; Korapuki: $N = 13$). There were also no significant differences in habitat use, with respect to canopy cover, between translocated ($N = 19$) and resident ($N = 8$) *H. duvaucelii* during the second radio tracking period (no cover: $\chi^2 = 0.909$, $df = 1$, $p = 0.340$; partial cover: $\chi^2 = 0.355$, $df = 1$, $p = 0.551$; full cover: $\chi^2 = 0.273$, $df = 1$, $p = 0.601$).

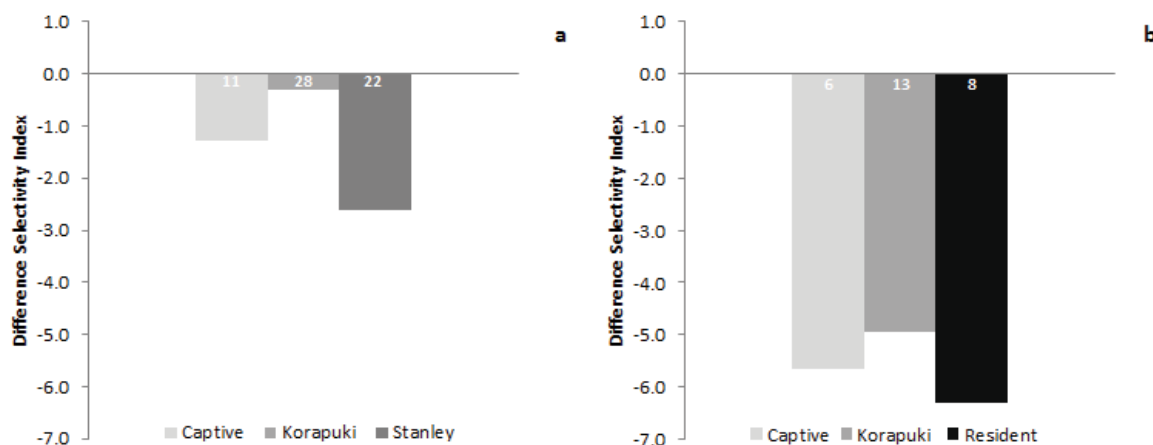
Hoplodactylus duvaucelii used locations with no overhead canopy cover significantly more in relation to availability during both radio tracking periods (Pearson chi-square test: $\chi^2 = 12.247$, $df = 1$, $p < 0.05$; $\chi^2 = 32.638$, $df = 1$, $p < 0.001$, respectively) (Figs 5.4a & 5.4b). Whereas locations with partial overhead canopy cover were used in proportion to their availability during both radio tracking periods ($\chi^2 = 1.044$, $df = 1$, $p = 0.307$; $\chi^2 = 0.594$, $df = 1$, $p = 0.441$, respectively) (Figs 5.4a & 5.4b). *Hoplodactylus duvaucelii* also used locations with full overhead canopy cover significantly more in relation to their availability, but only during the first radio tracking period ($\chi^2 = 6.802$, $df = 1$, $p < 0.05$) (Fig 5.4a). During the second radio tracking period, use was proportional to availability ($\chi^2 = 2.064$, $df = 1$, $p = 0.151$) (Fig 5.4b).



Figures 5.4a & 5.4b: Displayed are selectivity indices for the different canopy cover types at the 1 m² scale directly above each gecko position calculated for captive-bred (N = 11 & N = 6, respectively), Korapuki (N = 28 & N = 13, respectively), Stanley (N = 22) and resident (N = 8) *Hoplodactylus duvaucelii* for the first (a) and second (b) radio tracking periods. Selectivity index values were derived by subtracting the proportion of canopy cover type used from the proportion of canopy cover type available. Values close to zero indicate use is proportional to availability. Increasing positive values reflect an increasing association and increasing negative values reflect an increasing disassociation with a canopy cover type.

Surrounding tree density

Tree density within a 25 m² area surrounding locations visited by captive-bred and Korapuki *H. duvaucelii* (N = 39, $\bar{x} = 6.09 \pm 0.58$, range: 0 to 15) was proportional to availability (N = 40, $\bar{x} = 6.7 \pm 0.9$, range: 0 to 20) during the first radio tracking period (Mann-Whitney U test: $Z = -0.250$, $p = 0.802$) (Fig 5.5a), but was significantly low in relation to availability during the second radio tracking period (N = 19, $\bar{x} = 1.5 \pm 0.3$, range: 0 to 4; $Z = -4.118$, $p < 0.001$) (Fig 5.5b).



Figures 5.5a & 5.5b: Displayed are selectivity indices for the number of trees within a 25 m² area of captive-bred (N = 11 & N = 6, respectively), Korapuki (N = 28 & N = 13, respectively), Stanley (N = 22) and resident (N = 8) *Hoplodactylus duvaucelii* locations for the first (a) and second (b) radio tracking periods. Selectivity index values were derived by subtracting the proportion of trees present from the proportion of trees available. Values close to zero indicate use is proportional to availability. Increasing positive values reflect an increasing association and increasing negative values reflect an increasing disassociation with the number of trees.

Tree density did not differ significantly between locations visited by captive-bred and Korapuki *H. duvaucelii* during either radio tracking period (Mann-Whitney U test: Z = 0.625, p = 0.532; Z = -1.075, p = 0.282, respectively). However, locations visited by translocated *H. duvaucelii* featured significantly higher (Z = -2.068, p < 0.05) surrounding tree density than locations visited by resident *H. duvaucelii* (N = 8, \bar{x} = 0.4 ± 0.2, range: 0 to 2) during the second radio tracking period.

Surrounding ground cover

Captive-bred and wild Korapuki *H. duvaucelii* did not differ in their habitat use, with respect to surrounding ground cover, during the first radio tracking period (Mann-Whitney U test: trunks & logs: Z = -0.906, p = 0.365; bare ground: Z = -0.031, p = 0.975; leaf litter: Z = -1.670, p = 0.095; herbs: Z = -0.453, p = 0.651; fern: Z = -0.365, p = 0.715; flax: Z = -0.772, p = 0.440; *Muehlenbeckia*: Z = -0.310, p = 0.757; other shrubs: Z = -0.390, p = 0.696; captive-bred: N = 11; Korapuki: N = 28). During the second radio tracking period, locations used by Korapuki *H. duvaucelii* (N = 13, \bar{x} = 0.05 ± 0.01) had significantly more bare ground than those used by captive-bred *H. duvaucelii* (N = 6, \bar{x} = 0.01 ± 0.01; Mann-Whitney U test: Z = -2.050, p < 0.05). No other significant differences in ground cover proportions were observed between captive-bred (N = 6) and Korapuki (N = 13) *H. duvaucelii* (trunks

& logs: $Z = -1.067$, $p = 0.286$; leaf litter: $Z = -0.351$, $p = 0.726$; herbs: $Z = -1.492$, $p = 0.136$; fern: $Z = -0.137$, $p = 0.891$; flax: $Z = 0.000$, $p = 1.000$; *Muehlenbeckia*: $Z = -0.360$, $p = 0.719$; other shrubs: $Z = -1.044$, $p = 0.965$) during the second radio tracking period. There were also no significant differences in habitat use, with respect to surrounding ground cover, between translocated ($N = 19$) and resident ($N = 8$) *H. duvaucelii* during the second radio tracking period (trunks & logs: $Z = -0.135$, $p = 0.893$; bare ground: $Z = -0.244$, $p = 0.807$; leaf litter: $Z = -0.053$, $p = 0.958$; herbs: $Z = -0.664$, $p = 0.507$; fern: $Z = -0.220$, $p = 0.826$; flax: $Z = -0.027$, $p = 0.979$; *Muehlenbeckia*: $Z = -0.460$, $p = 0.645$; other shrubs: $Z = -0.372$, $p = 0.710$).

The proportions of flax cover (Mann-Whitney U test: $Z = -2.254$, $p < 0.05$) and herbaceous species cover ($Z = -2.939$, $p < 0.001$) within a 25 m^2 area surrounding locations visited by captive-bred and Korapuki *H. duvaucelii* were significantly higher in relation to availability during the first radio tracking period (Fig 5.6a). All other ground cover types (trunks & logs: $Z = -1.208$, $p = 0.227$; bare ground: $Z = -0.413$, $p = 0.679$; leaf litter: $Z = -1.138$, $p = 0.255$; fern: $Z = -1.036$, $p = 0.300$; *Muehlenbeckia*: $Z = -0.087$, $p = 0.931$; other shrubs: $Z = -0.211$, $p = 0.833$) were proportional to availability during the first radio tracking period (Fig 5.6a).

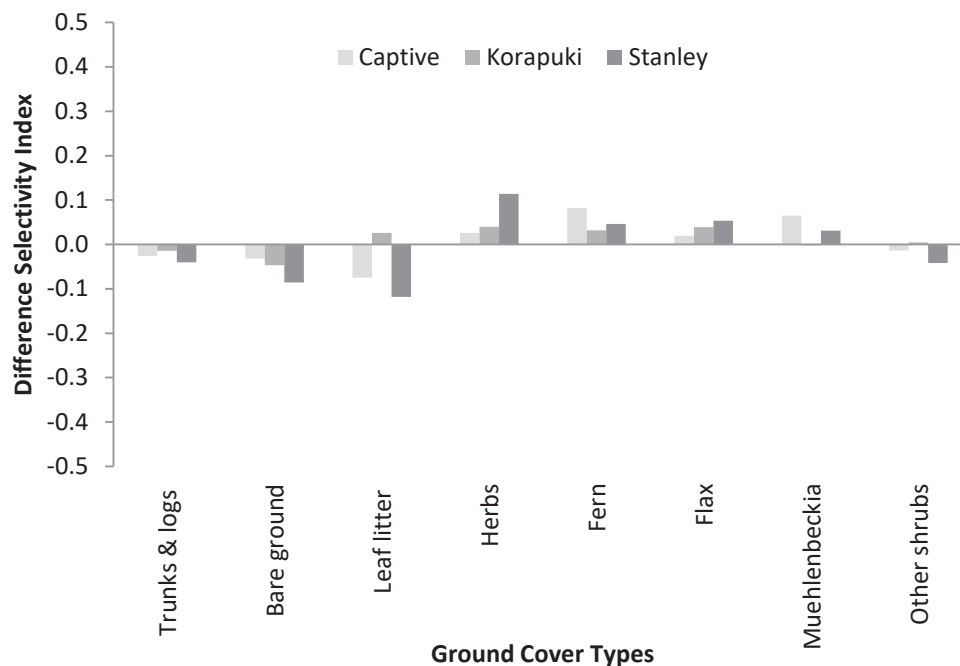


Figure 5.6a: Displayed are selectivity indices for different ground cover types calculated for captive-bred (N = 11), Korapuki (N = 28) and Stanley (N = 22) *Hoplodactylus duvaucelii* for the first radio tracking period. Selectivity index values were derived by subtracting the proportion of ground cover used from the proportion of ground cover available. Values close to zero indicate use is proportional to availability. Increasing positive values reflect an increasing association and increasing negative values reflect an increasing disassociation with a ground cover type.

Locations visited by translocated *H. duvaucelii* during the second radio tracking period also had a significantly higher proportion of surrounding flax cover ($Z = -6.091$, $p < 0.001$) and herbaceous species cover ($Z = -2.998$, $p < 0.05$) in relation to availability (Fig 5.6b). However, the proportions of trunks and logs ($Z = -5.024$, $p < 0.001$) and leaf litter ($Z = -4.390$, $p < 0.001$) within a 25 m² area surrounding locations visited by translocated *H. duvaucelii* were significantly low in relation to availability during the second radio tracking period (Fig 5.6b). All other ground cover types (bare ground: $Z = -1.778$, $p = 0.075$; fern: $Z = -1.254$, $p = 0.210$; *Muehlenbeckia*: $Z = -0.109$, $p = 0.913$; other shrubs: $Z = -1.957$, $p = 0.050$) were proportional to availability during the second radio tracking period (Fig 5.6b).

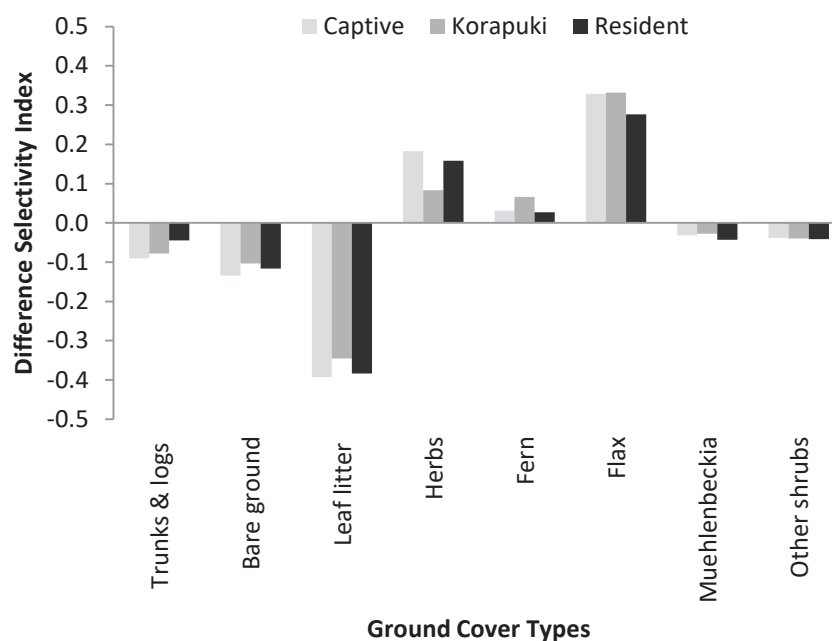


Figure 5.6b: Displayed are selectivity indices for different ground cover types calculated for captive-bred (N = 6), Korapuki (N = 13) and resident (N = 8) *Hoplodactylus duvaucelii* for the second radio tracking period. Selectivity index values were derived by subtracting the proportion of ground cover used from the proportion of ground cover available. Values close to zero indicate use is proportional to availability. Increasing positive values reflect an increasing association and increasing negative values reflect an increasing disassociation with a ground cover type.

Flax and Muehlenbeckia spp. patch use

The total basal area of all flax patches within a 5 m radius of locations used by *H. duvaucelii* increased with time after the release (Figs 5.7a & 5.7b). Statistical tests investigating flax patch use in relation to total basal area were not conducted due to small samples sizes.

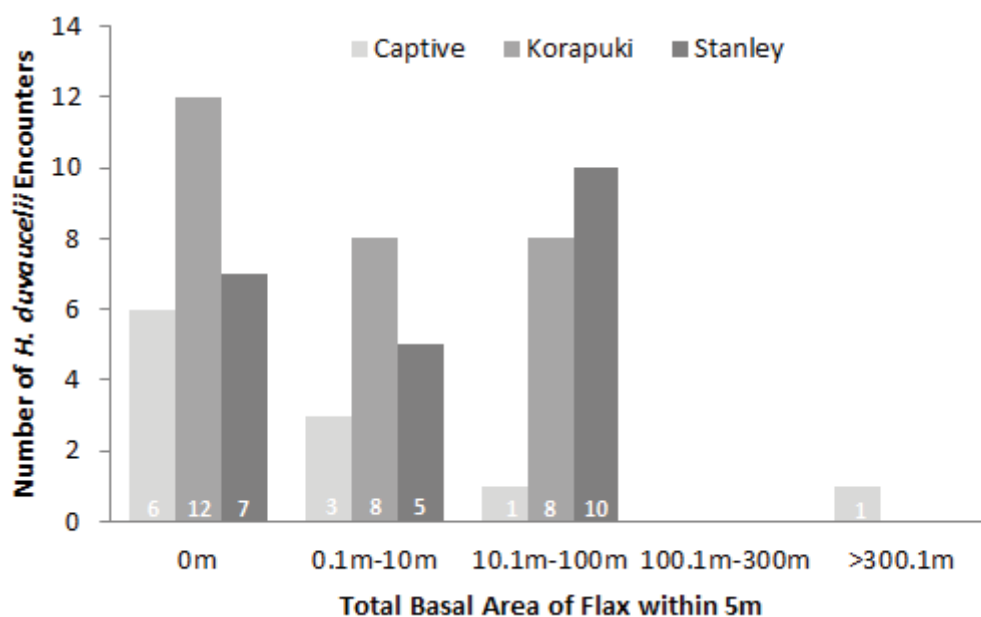


Figure 5.7a: Graph depicts the number of *Hoplodactylus duvaucelii* encountered in flax (*Phormium tenax*) patches of increasing total basal area (m^2) within a 5 m radius of *H. duvaucelii* locations during the first radio tracking period. Sample sizes (N) are given in each bar.

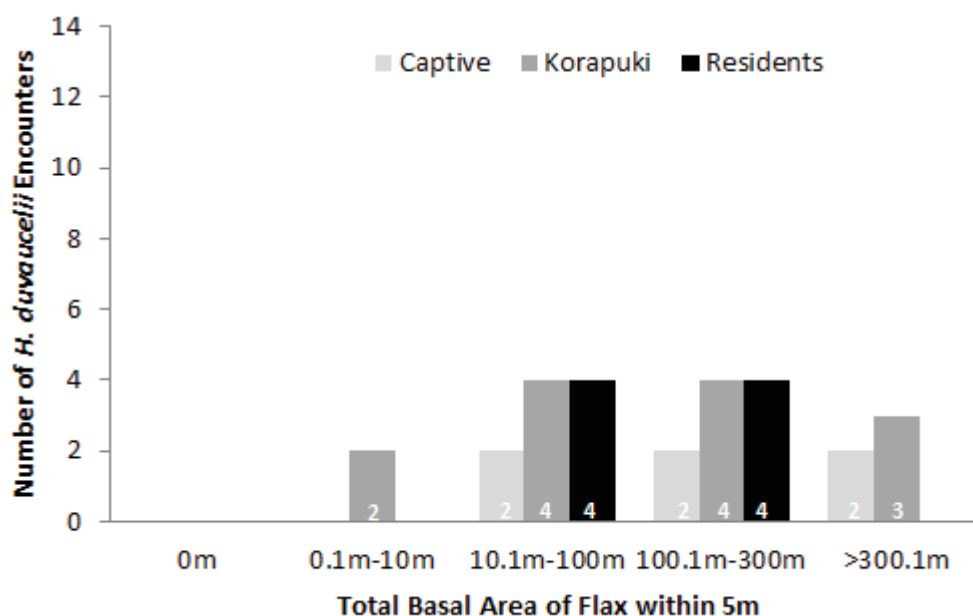


Figure 5.7b: Graph depicts the number of *Hoplodactylus duvaucelii* encountered in flax (*Phormium tenax*) patches of increasing total basal area (m^2) within a 5 m radius of *H. duvaucelii* locations during the second radio tracking period. Sample sizes (N) are given in each bar.

The total basal area of all flax patches within a 5 m radius of *H. duvaucelii* locations ranged from 1.96 to 400 m² (N = 21) for captive-bred and Korapuki geckos (pooled) and from 1.2 to 96.67 m² (N = 14) for Stanley geckos during the first radio tracking period. During the second radio tracking period, the total basal area of all flax patches within 5 m of *H. duvaucelii* locations ranged from 8.94 to 478.5 m² (N = 19) for captive-bred and Korapuki geckos (pooled) and from 19.57 to 269.69 m² (N = 8) for resident geckos. The total basal area of all *Muehlenbeckia spp.* patches ranged from 1.95 to 400 m² (N = 9, all 2013 origins pooled due to small sample sizes) during the first radio tracking period. *Muehlenbeckia spp.* patches were not used by any radio tracked *H. duvaucelii* during the second radio tracking period.

The average height of the closest flax patch was 1.7 ± 0.1 m (N = 47, range: 0.8 to 2.4 m) for captive-bred and Korapuki geckos (pooled) and 1.9 ± 0.1 m (N = 22, range: 1.1 to 2.6 m) for Stanley geckos during the first radio tracking period. During the second radio tracking period, the average height of the closest flax patch was 2.2 ± 0.1 m (N = 40, range: 1.38 to 3.1 m) for captive-bred and Korapuki geckos (pooled) and 2.0 ± 0.1 m (N = 18, range: 1 to 3 m) for resident geckos. The average height of the closest *Muehlenbeckia spp.* patch was 2.1 ± 0.3 m (N = 9, range: 0.4 to 3.1 m, all 2013 origins pooled due to small sample sizes). Patch heights were not investigated further as there was little variation for this variable.

Spatial distributions of H. duvaucelii

Sheltering aggregations were formed by several *H. duvaucelii* during the monitoring period. Earlier aggregations appeared to be temporary, lasting just one or two days, whereas those observed later in the monitoring period appeared to last longer, with several *H. duvaucelii* regularly being re-encountered together. Observed aggregations ranged in size from two to four geckos and included *H. duvaucelii* of differing origins, age and sex.

On Motuora, there were four sightings of *H. duvaucelii* sheltering in pairs. Two sightings were in artificial tree shelters (Holdom, 2015) and both included a Korapuki female with another unidentified *H. duvaucelii*. Two Stanley females were sighted within a metre of each other in a mahoe tree (Plate 5.4) and a captive-bred female and Korapuki male were radio tracked to the same flax bush on five separate occasions. They were also seen basking within 10 cm of each other on one occasion.

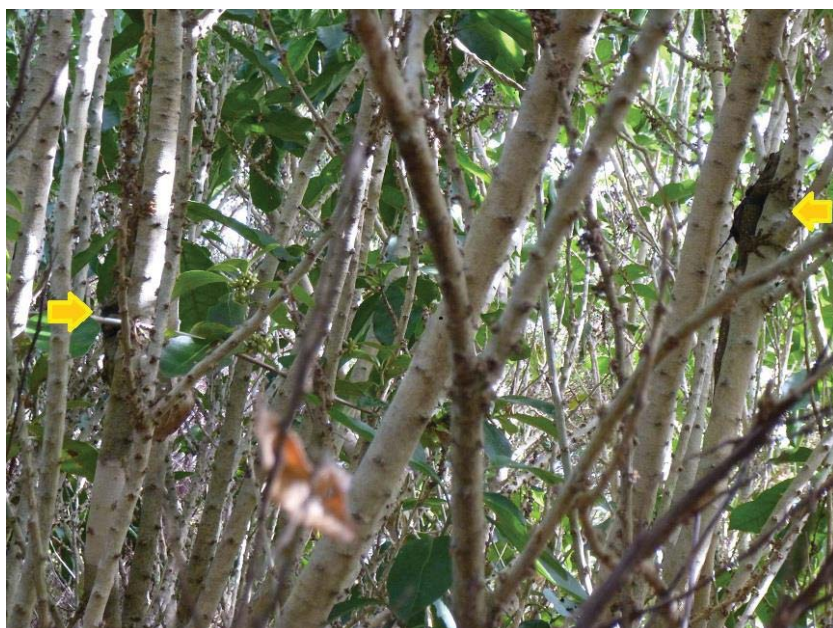


Plate 5.4: Two radio tracked Stanley female *Hoplodactylus duvaucelii* encountered sheltering together in a mahoe tree (*Melicytus ramiflorus*) on Motuora Island in March 2013.

On Tiritiri Matangi, two Stanley females were radio tracked to the same flax patch on two separate occasions; and a captive-bred female and two Korapuki females were located in the same flax bush on 13 separate occasions. Throughout that period, other geckos that were not being radio tracked were also encountered at that location including a Korapuki male, a captive-bred male and female, another Korapuki female and two juveniles (Plate 5.5).

Another sheltering aggregation consisting of two captive-bred females, a Korapuki female and a Korapuki male was also observed on Tiritiri Matangi (Plate 5.6).



Plate 5.5: A radio tracked captive-bred female (upper left), a juvenile (lower left) and an unidentified (right) *Hoplodactylus duvaucelii* encountered sheltering together in the same flax (*Phormium tenax*) on Tiritiri Matangi Island in October 2013.



Plate 5.6: A radio tracked Korapuki male (left) and female (right) *Hoplodactylus duvaucelii* encountered basking together in the same flax (*Phormium tenax*) on Tiritiri Matangi Island in November 2013.

Additionally, a resident male who was one of the original founder *H. duvaucelii* on Tiritiri Matangi, was observed alternating between two separate flax patches, roughly 12 m apart. Two females and two juveniles were captured at one of the flax patches and another two juveniles were captured at the other flax patch.

5.4 Discussion

Substrate use and surrounding microhabitat and patch characteristics

Translocated *H. duvaucelii* initially used a variety of substrate types, but later sheltered and foraged almost exclusively in flax, irrespective of origin, sex, monitoring site or island. *Hoplodactylus duvaucelii* did not appear to utilise available habitats randomly. Translocated and resident *H. duvaucelii* habitually sheltered and foraged directly in flax and also used locations with lots of surrounding flax cover. Whereas logs and leaf litter were rarely used by *H. duvaucelii* during both radio tracking periods. Furthermore, trunks and logs, and leaf litter were sparse around locations used by *H. duvaucelii* during the second radio tracking period. Flax was also widely used by resident *H. duvaucelii* following their respective releases in 2006, however, flax use was considered proportional to availability within the 2006 monitoring sites (van Winkel, 2008).

Flax has several characteristics that make it a more suitable shelter than logs and leaf litter. Its dense structure helps camouflage *H. duvaucelii* and makes it difficult for larger predators to manoeuvre through. Although logs and leaf litter can also provide shelter, logs and leaf litter offer less protection from predators. Multiple flax patches can also become inter-connected creating larger areas for *H. duvaucelii* to travel through in relative safety and can accommodate multiple individuals allowing for social aggregating behaviour. During the first radio tracking period, many locations used by *H. duvaucelii* had no flax patches within a 5 m radius. However, by the second radio tracking period, every location used by radio tracked *H. duvaucelii* had flax patches nearby. The total basal area of flax patches used by *H. duvaucelii* varied greatly throughout the monitoring period, although *H. duvaucelii* appeared to utilise larger flaxes during the second radio tracking period. The average height of flax patches used by captive-bred and Korapuki geckos also increased with time after the release. Since smaller patches (i.e. $< 0.5 \text{ m}^2$) were excluded, it is unknown whether they are also important for *H. duvaucelii*. The smallest measured flax patch covered a total basal area of 1.2 m^2 , which suggests that the suitability of flax may not diminish with reduced size. However, only three geckos were encountered in flax patches that were smaller than 2 m^2 , probably because smaller flax patches had fewer leaves and lacked adequate cavities for geckos to hide in. The total basal area of *Muehlenbeckia* spp. patches also varied greatly and patch areas and heights were similar to the

areas and heights of flax patches. Yet only a few *H. duvaucelii* used locations with *Muehlenbeckia* spp. patches and this only occurred during the first radio tracking period, which suggests that *Muehlenbeckia* spp. are suitable temporary shelter sites, but not as ideal as other species such as flax. Flax also provides favourable basking conditions, especially in forested habitats, as it generally has little or no canopy cover. Flax bushes used by *H. duvaucelii* were often situated along forest edges next to grassy paths or in grassy openings within forests, which may explain why geckos were also more surrounded with herbaceous species during both radio tracking periods. Flax also provides an immediate, although seasonal, food source in the form of nectar (Whitaker, 1987; Eifler, 1995). During this study, flax was observed flowering on both islands in October and November, coinciding with the second radio tracking period. Thus, seasonal attraction to this food source may have accounted for the higher use of flax by *H. duvaucelii* during this time. However, radio tracked *H. duvaucelii* had already been observed using flax prior to the flowering period and continued to use flax after flowering finished. Furthermore, several radio tracked geckos used flax bushes that were not flowering during the flowering period. Only two *H. duvaucelii* (who were opportunistically sighted) were directly observed foraging in flax flowers, possibly due to the low densities of *H. duvaucelii* at each of the monitoring sites. Alternatively, *H. duvaucelii* may have limited visits to flax flowers to reduce the chance of predation from nocturnal predators, such as morepork/ruru (*Ninox novaeseelandiae*), which are present on both islands and were occasionally sighted during radio tracking sessions. Visits to flax flowers have also been shown to be influenced by whether the flowers are male or female, with male flowers attracting greater numbers of geckos (Eifler, 1995).

In addition to flax, translocated *H. duvaucelii* were also regularly encountered sheltering in shrubs and trees, although only during the first radio tracking period. Translocated *H. duvaucelii* may have initially used more arboreal species to better survey and familiarise themselves with their new surroundings. Furthermore, many of the tree species that were used by *H. duvaucelii* are known food sources for this species, such as nectar from pohutukawa (*Metrosideros excelsa*) flowers and fruit from *Coprosma* spp. (Whitaker, 1968; Whitaker, 1987). Pohutukawa, which was the most widely used tree species, was also the most commonly used tree species for foraging *H. duvaucelii* during van Winkel's (2008) study. The flowers of cabbage trees (*Cordyline australis*), manuka (*Leptospermum scoparium*) and kohekohe (*Dysoxylum spectabile*) also produce nectar and have been found to attract other gecko species. For example, Pacific geckos (*Dactylocnemis pacificus*) have been observed foraging on cabbage tree flowers and Northland green geckos (*Naultinus grayii*) have been seen consuming nectar from manuka flowers (Whitaker, 1987). *Dactylocnemis pacificus* have also been seen licking sap exuding from karo (*Pittosporum crassifolium*) trees (Whitaker, 1987). Three resident *H. duvaucelii* on Motuora were seen on the trunks of karo trees that were exuding

sap during visual encounter surveys. Van Winkel (2008) also observed *H. duvaucelii* on sap exuding karo trees on Motuora. Furthermore, karo trees were one of the most frequently visited tree species by *H. duvaucelii* during van Winkel's (2008) study. *Hoplodactylus duvaucelii* and common geckos (*Woodworthia maculata*) have similarly been observed licking sap exuding from the bark of ngaio (*Myoporum laetum*) trees (Towns, 2002). Nectar, fruit and sap producing species also attract invertebrates, which are the primary food source of *H. duvaucelii* diets. *Hoplodactylus duvaucelii* have also been found to adapt their habitat use to minimise risk of predation. For example, in the presence of Pacific rats (*Rattus exulans*), which are predominately ground-dwelling, *H. duvaucelii* on Ōhī-nau used more shelters that were situated above the ground (Hoare *et al.*, 2007). Since both Motuora and Tiritiri Matangi are home to mostly avian predators, this may explain why use of shrubs and trees later declined, as did average perch height. Translocated *H. duvaucelii* used shelter locations with lower tree density during the second radio tracking period and the distance to the next closest tree increased by one metre, indicating a shift to more open habitats. However, habitats utilised by 2013 translocated *H. duvaucelii* were characterised by a higher tree density than locations used by resident geckos.

Captive-bred and Korapuki *H. duvaucelii* did not differ in their habitat use, with respect to substrate use, surrounding tree density or flax patch use during either radio tracking period, suggesting that rearing history does not influence the substrate use of *H. duvaucelii* or the microhabitat characteristics of locations used by *H. duvaucelii*. However, substrate use by captive-bred *H. duvaucelii* may have been influenced by the substrate use of Korapuki *H. duvaucelii* and vice versa as both groups were released within the same areas. Although the differences were not significant, flax use was initially higher for wild *H. duvaucelii*. Familiarity with wild environments and experience with a broader variety of substrate types may give wild-sourced founders an initial advantage as their substrate use is likely to be more directed, whereas captive-bred *H. duvaucelii* may just seek immediate cover, regardless of substrate quality. Later substrate use could have been influenced by attraction to conspecific scents. However, the presence of other conspecifics can also discourage or restrict some individuals from occupying certain habitats. For example, socially dominant male velvet geckos (*Oedura lesueurii*) monopolised shelter sites that were warmer and lacked predator scents during laboratory experiments, forcing subordinate males to occupy cooler shelters with predator scents (Downes & Shine, 1998). Social dominance was found to determine gecko distribution across favourable and less favourable shelter sites (Downes & Shine, 1998). Captive-bred and Korapuki *H. duvaucelii* also did not differ in their habitat use, with respect to the occurrence and proportions of surrounding ground covers, during either radio tracking period with the exception of bare ground, which was more common around locations used by Korapuki *H. duvaucelii* than around

locations used by captive-bred *H. duvaucelii* during the second radio tracking period. Translocated and resident *H. duvaucelii* also showed similar substrate use, flax patch use and surrounding habitat use, with respect to the occurrence and proportions of surrounding ground covers. The similarly high use of flax by translocated and resident *H. duvaucelii* shows that translocated *H. duvaucelii* were able to find and establish suitable shelters within a year of translocation.

Primary canopy cover

Radio tracked *H. duvaucelii* used locations with varying amounts of canopy cover. However, shelters such as flax, which generally lacked canopy cover, were used most often possibly due to better thermal conditions and basking opportunities. Thermal conditions are important for ectotherms as body temperature can impact performance and influence key behaviours and physiological processes (Angilletta Jr. *et al.*, 2002). For example, higher body temperatures in some snake species, such as the Sonoran gopher snake (*Pituophis catenifer affinis*) have been linked with increases in strike speeds (Greenwald, 1974; Webb & Shine, 1998). Thermal conditions at diurnal retreats are especially important for nocturnal ectotherms as conditions at night offer sparse opportunities to behaviourally regulate body temperature (Kearney & Predavec, 2000). However, during the first radio tracking period, translocated *H. duvaucelii* mostly sheltered in shrubs and trees, which often provided fully shaded shelters. Several factors can influence microhabitat selection, which can sometimes lead to conflicting priorities. For example, during laboratory experiments examining shelter selection by male *O. lesueurii*, predator avoidance took priority over thermal conditions (Downes & Shine, 1998). Juvenile broad-headed snakes (*Hoplocephalus bungaroides*) were also thought to prioritise predator avoidance over basking, as the proportion of avian attacks were found to be greatest on model snakes, which had been placed in exposed habitats (13.3%) rather than sheltered habitats (1.6%) (Webb & Whiting, 2005). Overall, captive-bred and Korapuki *H. duvaucelii* did not differ in their habitat use, with respect to canopy cover. Translocated and resident geckos also showed similar habitat use, with respect to canopy cover, further indicating that rearing history does not influence the microhabitat characteristics of locations used by *H. duvaucelii*. However, resident geckos were not radio tracked during the first tracking period; therefore it is unknown whether they would have displayed similar habitat choices as translocated geckos at that time of year. Future studies should investigate the habitat choices of *H. duvaucelii* across different seasons.

Spatial distributions of H. duvaucelii

Several *H. duvaucelii* were directly observed sheltering with other conspecifics. Aggregating behaviour was also observed following the 2006 translocations. On Motuora, a male and female *H.*

duvaucelii were sighted basking within a metre of each other and were believed to have occupied the same shelter for at least eight days (van Winkel, 2008). Sheltering in aggregations can have several benefits including providing access to potential mates and reducing the chance of predation. For example, in captive populations of Australian gidgee skinks (*Egernia stokesii*), *E. stokesii* living in social aggregations spotted potential threats sooner than solitary *E. stokesii* and were also able to bask in a less observant state (Lanham & Bull, 2004). Aggregating behaviour may also have thermal benefits. For example, captive Australian thick-tailed geckos (*Nephrurus miltii*) living in groups were able to behaviourally control changes in body temperatures by huddling closer together during cooler temperatures (Shah *et al.*, 2003). Alternatively, social grouping may increase the potential for inbreeding depression (Visagie *et al.*, 2002).

Earlier aggregations appeared to be temporary and may have occurred as a form of protection from potential predators while translocated *H. duvaucelii* were still becoming familiar with their new surroundings. As the second radio tracking period coincided with the breeding season, social aggregations may have formed to enable breeding opportunities.

Observed sheltering aggregations varied in size. Groups were made up of a mix of males and females and an assortment of age groups, which is not uncommon for this species (Barry, 2010). Captive-bred and Korapuki *H. duvaucelii* were also regularly encountered together. Although males generally do not occupy the same shelters (Barry, 2010), there was one occasion during this study when two males were captured in the same flax. One of the males (Korapuki) had been encountered in that flax on two separate occasions, whereas the other male (captive-bred) was newly sighted there. The Korapuki male was larger than the captive-bred male and was the largest individual (excluding the Stanley geckos) released on Tiritiri Matangi, whereas the captive-bred male had been a sub-adult at the time of the release and had only recently grown large enough to be classified as an adult. As male *H. duvaucelii* can be found in shelters with younger *H. duvaucelii* (Barry, 2010), presumably because they do not compete for mates, larger males may temporarily tolerate smaller males if they do not consider them a competitor. However, the captive-bred male had new scars on his head and the left side of his flank and had also lost two toes and suffered a partial tail loss since his previous encounter; and the Korapuki male had gecko bite marks on his head, new scars on his tail and had lost one toe since his last encounter. This could be evidence of possible aggressive interactions between the two males.

Although only some *H. duvaucelii* were directly observed with other conspecifics, it is suspected that many others formed aggregations or used shelters close to other conspecifics based on the high number of *H. duvaucelii* observed with gecko bite marks and the capture of multiple geckos within

certain areas and shelters, and sometimes within the same funnel traps (Chapter 3). Reduced opportunities for social interaction following translocation, due to low population densities, may promote sheltering in groups. For example, male scents have been found to attract juvenile common lizards (*Lacerta vivipara*) from low density populations, whereas juveniles from high density populations were observed displaying repulsion when exposed to male scents (Cote & Clobert, 2007). Isolation as a result of post-release dispersal can be detrimental for the success of a translocation. Therefore, species that exhibit a strong preference for forming aggregations may improve their chances of achieving translocation success since remaining in the presence of other conspecifics fosters breeding opportunities.

5.5 Conclusion

The habitat use patterns of translocated *H. duvaucelii* did not appear to be influenced by rearing history as captive-bred and Korapuki geckos displayed similar habitat use trends throughout the monitoring period. Translocated and resident *H. duvaucelii* also exhibited similar habitat use trends suggesting that translocated geckos are able to establish suitable shelters and settle within a year of translocation. *Hoplodactylus duvaucelii* did not appear to utilise available habitats randomly. Substrate use shifted from the use of a variety of substrate types early on, to almost exclusive use of flax, suggesting that flax is a highly favourable substrate type for *H. duvaucelii*. Changes in the amount of canopy cover and the proportions of ground covers and tree density were reflective of changes in substrate use. Flax patches had greater use than *Muehlenbeckia* spp. patches and total patch areas increased with time after the release. Aggregating behaviour was exhibited by *H. duvaucelii* from differing origins, age classes and sex groups and occurred during both radio tracking periods with later aggregations lasting longer than earlier aggregations.

Chapter 6

Conclusion and Recommendations



Plate 6.0: *Hoplodactylus duvaucelii* captured on Motuora Island in February 2014.

Overall translocation response

Translocated *H. duvaucelii* were encountered throughout the monitoring period and body condition indices increased for all groups one year after the release, demonstrating that translocated *H. duvaucelii* were able to evade predators and successfully forage for food. Furthermore, gravid females were encountered on both Tiritiri Matangi Island and Motuora Island during the first post-release breeding season, showing that conspecifics had not become isolated following translocation. At least 50% of juveniles were sighted alive during the first year, showing that juveniles were also able to elude potential predators.

The distances travelled by translocated radio tracked *H. duvaucelii* ranged widely, with some individuals from all groups moving further than 200 m away from their original release sites. However, overall dispersal rates were low, suggesting that many radio tracked *H. duvaucelii* settled within or close to the monitoring sites. Furthermore, translocated radio tracked *H. duvaucelii* were less active with increasing time after the release and used smaller activity areas during the second half of the monitoring period, further indicating that they had settled and established core shelter and foraging areas. Translocated *H. duvaucelii* were mostly sedentary at night, only moving intermittently. Nocturnal activity also reduced with time after the release, suggesting more foraging behaviour rather than dispersal behaviour, further indicating that translocated *H. duvaucelii* had settled in their new environments.

Although *H. duvaucelii* are considered habitat generalists, they did not appear to utilise available habitats randomly. Translocated *H. duvaucelii* initially sheltered and foraged in a wide variety of substrates, but were later found sheltering almost exclusively in flax. Canopy cover and ground cover also varied early on in the monitoring period, but by the second half of the monitoring period, *H. duvaucelii* used areas lacking overhead canopy cover and with lots of surrounding flax, suggesting that areas dense in flax and with open canopies are preferable habitats as day time retreat sites for *H. duvaucelii*, possibly due to better basking opportunities and greater protection from predators.

Translocated *H. duvaucelii* formed social sheltering aggregations throughout the monitoring period, although aggregations formed during the second half of the monitoring period lasted longer and generally comprised of a core group of specific individuals, with other geckos briefly joining the group. This shows that conspecifics had not become isolated from one another and that *H. duvaucelii* were able to establish core sheltering sites and social groups within a year following translocation.

Overall, translocated and resident *H. duvaucelii* displayed similar trends in population health and reproductive performance, activity patterns and activity areas and habitat use, illustrating that translocated *H. duvaucelii* were able to adapt and settle into new environments relatively quickly following translocation.

The results obtained in this study met the defined translocation success criteria for body condition and reproductive performance, but did not meet the 70% encounter rate for survival. However, 42.8% of translocated *H. duvaucelii* were encountered throughout the monitoring period and at least 20% of translocated *H. duvaucelii* were encountered alive after one year, which provides evidence of the persistence and the establishment of some individuals. Furthermore, new 2013 released *H. duvaucelii* have been encountered in successive surveys and further long-term monitoring may reveal the survival of more founders. Additionally, the success achieved by the resident populations indicates that long-term translocation success for the newly translocated populations is attainable.

Captive-bred versus wild Korapuki founders

Overall, the post-release performance and responses of captive-bred and wild Korapuki founders were mostly comparable in all aspects with only a few slight differences. Body condition index increased for both groups after one year; however, the increase was more pronounced in captive-bred geckos. General post-release health was also better for captive-bred *H. duvaucelii*, although their overall condition had been better prior to the release as well.

More captive-bred *H. duvaucelii* were encountered one year after the release, suggesting that captive-bred founders may be more likely to settle closer to their original release locations, since post-release monitoring focused more around those areas. As dispersal away from allocated monitoring sites can negatively impact the likelihood of translocation success, the use of captive-bred founders could help alleviate this problem if they are less likely to disperse far distances. This would be dependent upon translocation managers choosing release sites with adequate habitats as captive-bred founders may not know, or may not have learned to identify better quality habitats. However, propensity to disperse appeared to be similar for both groups, as although a larger proportion of wild Korapuki *H. duvaucelii* were known to have dispersed during the radio tracking periods, more captive-bred *H. duvaucelii* that had been radio tracked were not encountered post-release.

Finally, the size of activity areas also differed between the two groups with wild Korapuki *H. duvaucelii* using larger activity areas during both radio tracking periods. However, the activity areas

of captive-bred and Korapuki *H. duvaucelii* often overlapped, resulting in similar habitat use and the formation of social sheltering aggregations.

The results of this study have demonstrated that captive-bred *H. duvaucelii* are capable of performing at a comparable standard to wild-sourced *H. duvaucelii*, and that captive-bred founders are suitable for restoration projects involving *H. duvaucelii* and possibly other lizard species with similar ecological requirements and habits. Ongoing research, particularly in the behavioural ecology of this species, is needed to provide better insights about *H. duvaucelii* activity patterns and habitat use, as this will help translocation managers improve the design of future translocation projects. Post-translocation monitoring is also important as this will help to improve the planning and structure of future species restoration projects. As many of New Zealand's species are long lived, including *H. duvaucelii*, post-translocation monitoring needs to be long-term. Extending the duration of post-translocation monitoring programmes will also allow for more accurate assessments of translocation success. Future studies should also continue to compare the performance of captive-bred and wild-sourced founders, as captive breeding programmes may provide alternative conservation solutions for some species, such as lizards.

Recommendations and further study

- This type of study should be replicated with other native lizards to determine whether captive-breeding programmes offer viable solutions for restoration projects.
- Releasing multiple *H. duvaucelii* directly into flax or into habitats with lots of flax may reduce post-release dispersal away from allocated monitoring sites and prevent conspecifics from becoming isolated following translocation.
- Eight radio tracked *H. duvaucelii* were found with severe abrasions caused by chaffing from the radio transmitter backpacks. These geckos carried transmitters for six or more weeks. Signs of adverse effects were only apparent after the transmitters were removed, as the geckos did not show apparent changes in behaviour and body condition during earlier encounters. In future long-term radio telemetry studies that utilise backpack radio transmitter designs, the backpack should be removed after three weeks, so the animal can be checked, and then the backpack can be re-attached to ensure a good fit.
- Since many lizards store fat reserves in their tails, future studies could investigate whether tail width measurements can provide an alternative measure of body condition index.
- External parasitic mites were observed, but were not focused on in this study. However, they may act as an indicator of overall condition and may also indicate social cohorts and therefore would be worth exploring in future studies.

- Activity areas were found to vary greatly between individuals. Future studies could investigate whether or not there is a relationship between the size of activity areas and the age or snout-to-vent (SVL) of *H. duvaucelii*.
- Large scale movements were the primary focus of this study; however, future studies should investigate small scale movements to further understand the diurnal and nocturnal activity patterns of *H. duvaucelii*.
- Further research on the diurnal and nocturnal microhabitat characteristics of *H. duvaucelii* locations will help researchers to select better quality habitats for use as future translocation release sites.

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Appendix

Table 2.2a: List of all *Hoplodactylus duvaucelii* radio tracked during the first radio tracking period (February to May 2013), including their weights (g) with and without the transmitters attached.

Transmitter 'SOPR-2038'				
Origin	Gecko ID	Sex	Weight without Transmitter (g)	Weight with Transmitter (g)
Captive	C2	M	49.3	52.9
Captive	C3	M	49.7	53.5
Captive	C8	F	48.4	52.2
Captive	C19	M	46.3	50
Captive	C20	F	50	53.8
Captive	C23	F	54	57.6
Captive	C24	M	60.7	64.3
Captive	C25	M	47.4	51
Captive	C58	M	47.3	50.7
Korapuki	K9	M	58.3	62
Korapuki	K13	F	55.2	58
Korapuki	K16	M	66.6	70
Korapuki	K18	M	51.4	54.7
Korapuki	K27	M	59.4	62.4
Korapuki	K33	M	52.5	55.3
Korapuki	K34	M	53.1	56.6
Korapuki	K37	M	59.1	63.1
Korapuki	K38	M	63.6	67
Korapuki	K42	F	50.2	57.3
Korapuki	K47	M	61	64
Korapuki	K48	M	73.9	76.3
Korapuki	K49	M	58.6	61.7
Korapuki	K50	M	51.6	55.6
Korapuki	K51	F	51.7	60.5
Korapuki	K54	M	58.8	62.7
Korapuki	K55	M	64.5	68.3
Korapuki	K57	M	54.7	56.6
Korapuki	K58	M	61.2	65.1
Korapuki	K65	F	61.1	64.9
Stanley	S3	M	73.5	81.2
Stanley	S14	F	63.3	69.1
Stanley	S17	M	72.9	80
Stanley	S18	M	64.2	70.2
Stanley	S20	M	58.8	65.9
Stanley	S28	F	74.2	83.3
Stanley	S42	F	69.8	75.5
Stanley	S52	M	62.7	68
Stanley	S56	F	60.4	66.9
Stanley	S59	F	62.6	70.4

Table 2.2b: The average weight (g) \pm standard error (SE) and the weight range for *Hoplodactylus duvaucelii* before and after transmitter attachment (SOPR-2038) and the equivalent increase in body weight percentage (%). Note that body weight percentage range has been calculated using the average combined backpack and transmitter weight, i.e. 4.5 g.

Transmitter 'SOPR-2038'				
	N	Mean \pm SE (g)	Range (g)	Percentage of Body Weight
Without Transmitter	39	58.5 \pm 1.3	46.3 to 72.2	–
With Transmitter	39	63.0 \pm 1.4	50.0 to 83.3	6.1% to 9.7%

Table 2.2c: List of all *Hoplodactylus duvaucelii* radio tracked during the second radio tracking period (September to December 2013), including their weights (g) with and without the transmitters attached.

Transmitter 'PIP3 AG393'					
Origin	Gecko ID	Sex	Weight without Transmitter (g)	Weight with Transmitter (g)	Combined Weight of Backpack & Transmitter (g)
Captive	C9	F	43.5	45	1.5
Captive	C11	F	53	55.5	2.5
Captive	C14	M	50	54	4.0
Captive	C19	M	49.5	51	1.5
Korapuki	K2	M	53.2	56.2	3.0
Korapuki	K4	F	59	63.9	4.9
Korapuki	K9	M	57	60.5	3.5
Korapuki	K9	M	67	69.5	2.5
Korapuki	K13	F	48	51.8	3.8
Korapuki	K20	F	48	50	2.0
Korapuki	K26	M	58	61	3.0
Korapuki	K27	M	63.5	68	4.5
Korapuki	K41	F	47.5	49.5	2.0
Korapuki	K49	M	59	64	5.0
Korapuki	K56	M	53	55	2.0
Resident	Ben	M	62	63	1.0
Resident	Kay	F	52.5	55	2.5
Resident	Morag	F	55	57	2.0
Resident	Roger	M	65.5	67.5	2.0

Table 2.2d: The average weight (g) \pm standard error (SE) and the weight range for *Hoplostethus medius* before and after transmitter attachment (PIP3 AG393) and the equivalent increase in body weight percentage (%). Note that body weight percentage range has been calculated using the average combined backpack and transmitter weight, i.e. 2.8 g.

Transmitter 'PIP3 AG393'				
	N	Mean \pm SE (g)	Range (g)	Percentage of Body Weight
Without Transmitter	19	55.0 \pm 1.5	43.5 to 67.0	–
With Transmitter	19	57.8 \pm 1.6	45.0 to 69.5	4.2% to 6.4%

Table 3.1: The number of double-ended g-minnow funnel traps set within and outside of each of the monitoring sites during the 2013 and 2014 mark-recapture surveys.

Date	Island	Monitoring Site	Origin of Founders	Number of Funnel Traps		Total
				Within Site	Outside Site	
Nov 2013	Motuora	2	Captive & Korapuki	3	22	25
Nov 2013	Motuora	3	Stanley	5	20	25
Nov 2013	Motuora	4	Captive & Korapuki	12	13	25
Nov 2013	Motuora	2006	Residents	11	14	25
Nov 2013	Tiritiri Matangi	1	Stanley	9	15	24
Nov 2013	Tiritiri Matangi	2	Captive & Korapuki	21	0	21
Nov 2013	Tiritiri Matangi	3	Captive & Korapuki	0	22	22
Nov 2013	Tiritiri Matangi	2006	Residents	0	16	16
Feb 2014	Motuora	2	Captive & Korapuki	0	26	26
Feb 2014	Motuora	3	Stanley	3	22	25
Feb 2014	Motuora	4	Captive & Korapuki	0	24	24
Feb 2014	Motuora	2006	Residents	11	14	25
Mar/Apr 2014	Tiritiri Matangi	1	Stanley	12	12	24
Mar/Apr 2014	Tiritiri Matangi	2	Captive & Korapuki	0	21	21
Mar/Apr 2014	Tiritiri Matangi	3	Captive & Korapuki	5	20	25
Mar/Apr 2014	Tiritiri Matangi	2006	Residents	9	17	26

Table 3.4: A comparison of the weight (g), snout-to-vent length (SVL) (mm) and body condition index (BCI) for six of the eight *Hoplodactylus duvaucelii* with wounds caused by the transmitters. 2013 measurements were recorded at the time of injury. *Indicates gravid females, so BCI measurements are not comparable.

Date	Origin	ID	Sex	Weight (g)	SVL (mm)	BCI
Dec 2013	Captive	C9	F	43.5	117	3.01
Apr 2014	Captive	C9	F	47	119	3.03
Nov 2014	Captive	C9	F	43	115	3.05
Feb 2015	Captive	C9	F	56	126	3.04*
Dec 2013	Captive	C11	F	53	121	3.10*
Apr 2014	Captive	C11	F	55	127	2.99
Nov 2014	Captive	C11	F	62	119	3.33
Feb 2015	Captive	C11	F	65.5	123	3.28
Dec 2013	Korapuki	K9	M	67	129	3.15
Dec 2014	Korapuki	K9	M	70	128	3.22
Mar 2015	Korapuki	K9	M	73	126	3.32
Dec 2013	Resident	Kay	F	52.5	120	3.12*
Nov 2014	Resident	Kay	F	60	122	3.21*
Feb 2015	Resident	Kay	F	71	119	3.48*
Dec 2013	Resident	Morag	F	55	129	2.95*
Nov 2014	Resident	Morag	F	57	121	3.18
Dec 2013	Resident	Roger	M	65.5	131	3.08
Apr 2014	Resident	Roger	M	70.5	129	3.20
Feb 2015	Resident	Roger	M	73.5	127	3.30



Plate 3.4a: Roger (2006 ID: 030M), one of the eight *Hoplodactylus duvaucelii* found with a wound caused by a transmitter in December 2013.



b



c

Plates 3.4b & 3.4c: Roger (2006 ID: 030M), one of the eight *Hoplodactylus duvaucelii* found with a wound caused by a transmitter, re-encountered in April 2014 (b) and February 2015 (c). The transmitter wound healed normally and the scar was barely noticeable in February 2015. (Photos by M. Barry).

Institute of Veterinary, Animal and Biomedical Sciences

PATHOLOGY REPORT

Submitter's Ref.:	Date Sent: 26/02/2013	Accession No.: 49263
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TO: Manuela Barry
Massey University - Albany
Albany
Auckland

Species: Reptile (1)	Sex: Male	Age: ~ 6 Years Old	Breed: Duvaucel's Gecko
ID: C2-M	At Risk: 60	Affected: 2	Dead: 2
Owner: Massey University-Albany Campus	Prev. Accn.:	Type: Post Mortem	

HISTORY

Progeny of wild captured Duvaucel's Geckos from Korapuki Island. Raised at Massey University Reptile Facility. Part of a group of 60 geckos (30 captive bred and 30 wild captured) that were translocated to Tiritiri Matangi Island Feb 17th 2013.

Several geckos including this individual were fitted with radio transmitters (backpacks) 2 days prior to their release-no problems observed with regards to transmitter fitting. Two of these geckos were found dead on the second day post release. The two geckos were submitted in formalin.

GROSS FINDINGS

The gecko was submitted intact in formalin. Length ~245mm and reasonably prominent fat pads. No internal abnormalities noted.

HISTOPATHOLOGY

Liver: hepatocytes contain one or several large, fairly discrete clear intracytoplasmic vacuoles that displace nuclei to the periphery but do not compress them.

Sections of heart, trachea/lung, spleen, kidney, gastrointestinal tract, inactive testis, fat pad and tail show no obvious abnormalities.

DIAGNOSIS

Unknown cause of death

COMMENTS

There was no obvious inflammatory or infectious process seen on histological examination of the internal organs.

Within the liver, most of the hepatocytes (cells within the liver) contained fat/lipid- this can be physiological (such as during vitellogenesis in females or hibernation) or pathological (may occur in obese individuals or those suffering anorexia). I am hesitant to call the lipid accumulation in this gecko's liver pathological (it can be difficult to tell based on histology alone and often requires a combination of liver histology, history and measurement of liver enzymes which can only be done in live animals).

Plate 3.5a: Post-mortem pathology report for C2M, a captive-bred male *Hoplodactylus duvaucelii* found deceased on Tiritiri Matangi Island in February 2013.

Institute of Veterinary, Animal and Biomedical Sciences

PATHOLOGY REPORT

Submitter's Ref.:	Date Sent: 16/05/2013	Accession No.: 49608
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TO: Manuela Barry
Massey University- Albany
Private Bag 102-904
Albany
Auckland

Species: Reptile (1)	Sex: Male	Age: ~5 Years Old	Breed: Duvaucel's Gecko
ID: 107 (C 144) C-144	At Risk:	Affected:	Dead: 1
Owner: Massey University- Albany	Prev. Accn.:	Type: Post Mortem	

HISTORY

Born and raised at reptile facility, Massey (Albany) University, no problems noted during that time. Died one day after radio-transmitter attachment (01/04/2013). Found at same site it was released after attachment. Released onto Tiritiri Matangi Island 17/02/2013. The gecko weighed 40 grams at release. Placed in formalin and submitted for post mortem.

GROSS FINDINGS

The gecko measured 230mm in length and was in moderate to good body condition, with reasonably prominent fat pads. The stomach contained a moderate to large amount of insect material, while the colon also contained a moderate amount of insect/faecal material. No obvious abnormalities were noted on gross post mortem.

HISTOPATHOLOGY

Liver: most hepatocytes contain multiple, small, fairly discrete clear intracytoplasmic vacuoles, likely a combination of lipid and glycogen. Sections of lung, trachea, heart, spleen, kidney, oesophagus, stomach, testis, brain and fat pads show no obvious abnormalities. Sections of intestine are too autolysed to critically interpret.

DIAGNOSIS

Unknown cause of death

COMMENTS

No gross or histological abnormalities were noted; there were no obvious signs of an infectious or inflammatory process.

File Nos.:

Students: Karina Argandona

Date:

Pathologist: S A Hunter

Copy to:

Plate 3.5b: Post-mortem pathology report for C14M, a captive-bred male *Hoplodactylus duvaucelii* found deceased on Tiritiri Matangi Island in April 2013.

Institute of Veterinary, Animal and Biomedical Sciences

PATHOLOGY REPORT

Submitter's Ref.:	Date Sent: 26/02/2013	Accession No.: 49262
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TO: Manuela Barry
Massey University- Albany
Albany
Auckland

Species: Reptile (1)	Sex: Male	Age: 4 Years Old	Breed: Duvaucel's Gecko
ID: C67-M	At Risk: 60	Affected: 2	Dead: 2
Owner: Massey University-Albany Campus	Prev. Accn.:	Type: Post Mortem	

HISTORY

Progeny of wild captured Duvaucel's Geckos from Korapuki Island. Raised at Massey University Reptile Facility. Part of a group of 60 geckos (30 captive bred and 30 wild captured) that were translocated to Tiritiri Matangi Island Feb 17th 2013.

Several geckos including this individual were fitted with radio transmitters (backpacks) 2 days prior to their release-no problems observed with regards to transmitter fitting. Two of these geckos were found dead on the second day post release. The two geckos were submitted in formalin.

GROSS FINDINGS

The gecko was submitted intact in formalin. Length ~260mm and reasonably prominent fat pads. No internal abnormalities noted.

There was a 40mm segment of the mid-tail which was soft and slightly flaccid. Upon opening this section of tail, the soft tissue, including epaxial and hypaxial skeletal musculature was absent and replaced by watery, slightly turbid tan fluid. The vertebral bones were exposed and separated from the proximal part of the vertebral column.

HISTOPATHOLOGY

Liver: hepatocytes contain one or several large, fairly discrete clear intracytoplasmic vacuoles that displace nuclei to the periphery but do not compress them.

Sections of heart, trachea/lung, spleen, kidney, gastrointestinal tract, inactive testis, fat pad and tail show no obvious abnormalities.

DIAGNOSIS

Unknown cause of death

COMMENTS

There was no obvious inflammatory or infectious process seen on histological examination of the internal organs.

Within the liver, most of the hepatocytes (cells within the liver) contained fat/lipid- this can be physiological (such as during vitellogenesis in females or hibernation) or pathological (may occur in obese individuals or those suffering anorexia). I am hesitant to call the lipid accumulation in this gecko's liver pathological (it can be difficult to tell based on histology alone and often requires a combination of liver histology, history and measurement of liver enzymes which can only be done in live animals).

Plate 3.5c: Post-mortem pathology report for C67M, a captive-bred male *Hoplodactylus duvaucelii* found deceased on Tiritiri Matangi Island in February 2013.

Table 4.2a: The number of transmitters, transmitter attachment days, radio tracking days, day location fixes and relocations made on Tiritiri Matangi Island during the first radio tracking period from February to May 2013. Note: the number of day location fixes includes positions acquired through other methods, such as funnel trap locations, etc.

Origin	ID	Sex	Island	Number of transmitters	Number of days transmitter attached	Number of tracking days	Number of day location fixes	Number of relocations
Captive	C3	M	Tiritiri Matangi	1	12	9	9	5
Captive	C8	F	Tiritiri Matangi	1	17	5	5	3
Captive	C11	F	Tiritiri Matangi	1	28	13	12	9
Captive	C20	F	Tiritiri Matangi	1	11	6	6	1
Captive	C25	M	Tiritiri Matangi	1	17	5	8	7
Korapuki	K18	M	Tiritiri Matangi	1	24	6	6	2
Korapuki	K24	F	Tiritiri Matangi	1	8	2	3	2
Korapuki	K27	M	Tiritiri Matangi	1	67	18	17	11
Korapuki	K29	F	Tiritiri Matangi	1	27	6	7	4
Korapuki	K34	M	Tiritiri Matangi	1	3	1	1	0
Korapuki	K37	M	Tiritiri Matangi	1	45	8	8	5
Korapuki	K42	F	Tiritiri Matangi	1	3	14	14	1
Korapuki	K48	M	Tiritiri Matangi	1	24	6	7	3
Korapuki	K49	M	Tiritiri Matangi	1	46	8	8	7
Korapuki	K50	M	Tiritiri Matangi	1	24	9	9	2
Korapuki	K51	F	Tiritiri Matangi	1	53	8	8	4
Korapuki	K53	M	Tiritiri Matangi	1	24	3	5	2
Korapuki	K57	M	Tiritiri Matangi	1	24	8	8	4
Korapuki	K65	F	Tiritiri Matangi	1	4	2	2	0
Stanley	S6	F	Tiritiri Matangi	1	15	7	7	1
Stanley	S10	M	Tiritiri Matangi	1	3	2	2	1
Stanley	S23	M	Tiritiri Matangi	1	3	1	1	1
Stanley	S30	F	Tiritiri Matangi	1	31	3	3	2
Stanley	S43	F	Tiritiri Matangi	1	37	6	6	3
Stanley	S46	M	Tiritiri Matangi	1	9	3	3	1
Stanley	S51	M	Tiritiri Matangi	1	3	2	2	2
Stanley	S54	F	Tiritiri Matangi	1	15	3	3	1
Stanley	SX43	M	Tiritiri Matangi	1	3	2	2	1
Stanley	SX50	F	Tiritiri Matangi	1	9	6	6	0
Stanley	SX59	F	Tiritiri Matangi	1	9	4	4	1

Table 4.2a continued. The number of transmitters, transmitter attachment days, radio tracking days, day location fixes and relocations made on Motuora Island during the first radio tracking period from February to May 2013. Note: the number of day/location fixes includes positions acquired through other methods, such as funnel trap locations, etc.

Origin	ID	Sex	Island	Number of transmitters	Number of days transmitter attached	Number of tracking days	Number of day location fixes	Number of relocations
Captive	C15	M	Motuora	1	4	3	4	2
Captive	C16	F	Motuora	1	3	2	2	2
Captive	C19	M	Motuora	1	13	3	3	1
Captive	C23	F	Motuora	1	3	1	1	0
Captive	C24	M	Motuora	1	12	3	3	2
Captive	C58	M	Motuora	1	3	2	2	2
Korapuki	K2	M	Motuora	2	10	4	5	4
Korapuki	K4	F	Motuora	1	37	13	13	6
Korapuki	K7	F	Motuora	1	50	7	7	5
Korapuki	K9	M	Motuora	2	12	8	8	3
Korapuki	K11	F	Motuora	1	4	1	2	1
Korapuki	K13	F	Motuora	1	70	17	17	8
Korapuki	K16	M	Motuora	1	5	2	2	1
Korapuki	K23	F	Motuora	1	23	2	3	2
Korapuki	K33	M	Motuora	1	69	12	12	3
Korapuki	K38	M	Motuora	1	3	2	1	0
Korapuki	K47	M	Motuora	1	27	13	13	4
Korapuki	K54	M	Motuora	1	12	5	5	1
Korapuki	K55	M	Motuora	1	3	1	1	1
Korapuki	K58	M	Motuora	1	13	3	3	1
Stanley	S3	M	Motuora	2	30	6	7	5
Stanley	S11	F	Motuora	1	62	13	13	5
Stanley	S14	F	Motuora	1	12	3	4	3
Stanley	S17	M	Motuora	1	40	6	6	2
Stanley	S18	M	Motuora	1	12	4	4	3
Stanley	S20	M	Motuora	1	62	10	10	4
Stanley	S28	F	Motuora	1	5	3	3	1
Stanley	S42	F	Motuora	1	4	2	2	1
Stanley	S52	M	Motuora	1	30	11	11	1
Stanley	S56	F	Motuora	1	63	16	16	8
Stanley	S59	F	Motuora	1	62	12	12	5

Table 4.2b: The number of transmitters, transmitter attachment days, radio tracking days, day location fixes and relocations during the second radio tracking period from September to December 2013. Note: the number of day location fixes includes positions acquired through other methods, such as funnel trap locations, etc.

Origin	ID	Sex	Island	Number of transmitters	Number of days transmitter attached	Number of tracking days	Number of day location fixes	Number of relocations
Captive	C7	F	Motuora	1	35	10	13	4
Captive	C19	M	Motuora	1	34	7	8	5
Captive	C23	F	Motuora	1	78	12	14	0
Korapuki	K9	M	Motuora	1	65	7	8	3
Korapuki	K14	F	Motuora	1	55	12	15	3
Korapuki	K31	M	Motuora	1	34	7	8	5
Korapuki	K36	M	Motuora	1	55	10	11	5
Korapuki	K44	F	Motuora	1	33	5	8	4
Korapuki	K47	M	Motuora	1	55	12	14	3
Korapuki	K59	F	Motuora	1	39	9	10	4
Resident	Ellie	F	Motuora	1	19	3	4	2
Resident	Jack	M	Motuora	1	37	5	6	3
Resident	Lou	F	Motuora	1	19	3	5	2
Captive	C9	F	Tiritiri Matangi	1	65	19	25	3
Captive	C11	F	Tiritiri Matangi	1	65	18	20	10
Captive	C60	F	Tiritiri Matangi	1	32	11	14	4
Korapuki	K20	F	Tiritiri Matangi	1	60	19	23	4
Korapuki	K26	M	Tiritiri Matangi	1	57	19	21	11
Korapuki	K41	F	Tiritiri Matangi	1	57	18	20	11
Korapuki	K48	M	Tiritiri Matangi	1	15	1	4	1
Korapuki	K60	F	Tiritiri Matangi	1	60	20	23	3
Resident	Allison	F	Tiritiri Matangi	1	32	9	10	3
Resident	Ben	M	Tiritiri Matangi	1	78	18	19	10
Resident	Kay	F	Tiritiri Matangi	1	70	18	19	9
Resident	Morag	F	Tiritiri Matangi	1	77	13	14	5
Resident	Roger	M	Tiritiri Matangi	1	70	19	22	8



Figure 4.2b: Example of the activity areas (100% minimum convex polygon) of two captive-bred and two Korapuki *Hoplodactylus duvaucelii* (males: 1 and females: 3) on Tiritiri Matangi Island, from eight months after the release (September 2013 to April 2014). The blue area represents the male and the red areas represent females. 'X' represents initial capture locations.

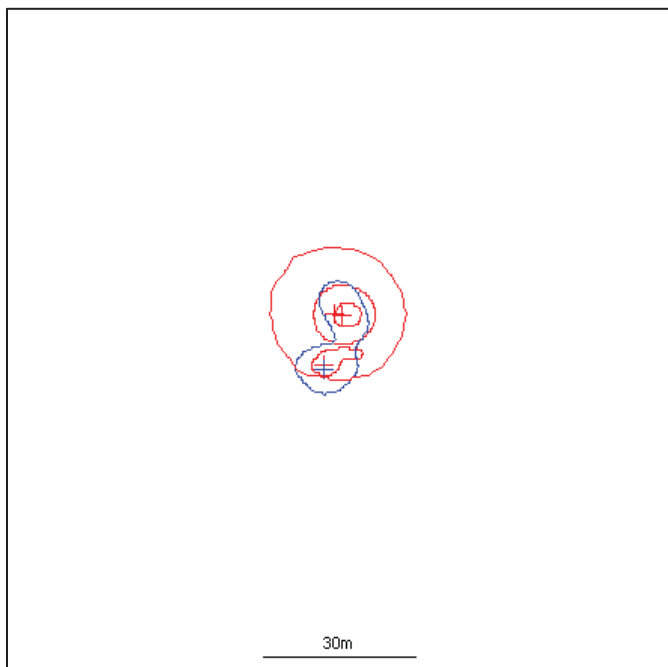


Figure 4.2c: Example of the activity areas (95% fixed kernel density estimator) of two captive-bred and two Korapuki *Hoplodactylus duvaucelii* (males: 1 and females: 3) on Tiritiri Matangi Island, from eight months after the release (September 2013 to April 2014). The blue area represents the male and the red areas represent females. 'X' represents initial capture locations.

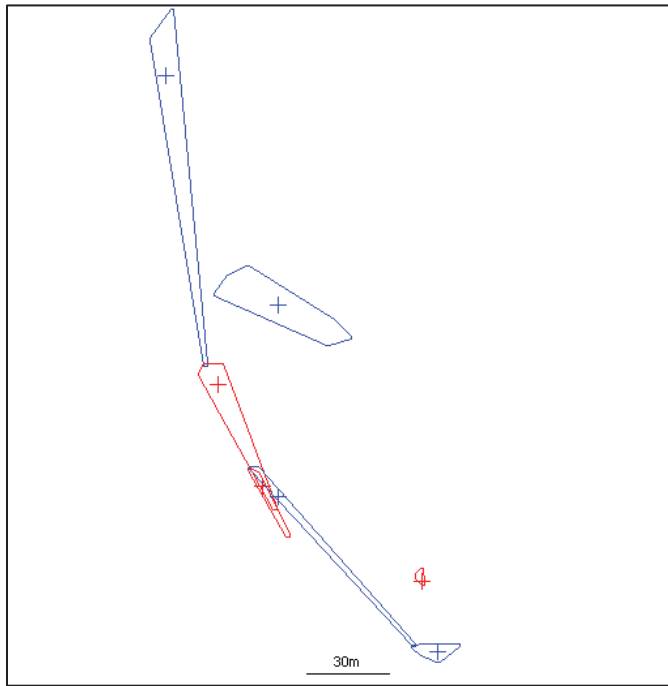


Figure 4.3b: Example of the activity areas (100% minimum convex polygon) of three captive-bred and four Korapuki *Hoplodactylus duvaucelii* (males: 4 and females: 3) on Motuora Island, from eight months after the release (September 2013 to April 2014). Blue areas represent males and red areas represent females. 'X' represents initial capture locations.

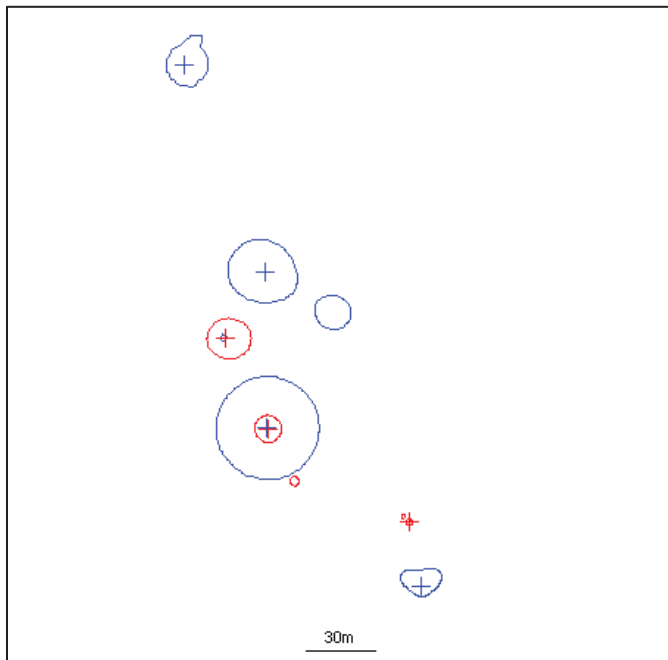


Figure 4.3c: Example of the activity areas (95% fixed kernel density estimator) of three captive-bred and four Korapuki *Hoplodactylus duvaucelii* (males: 4 and females: 3) on Motuora Island, from eight months after the release (September 2013 to April 2014). Blue areas represent males and red areas represent females. 'X' represents initial capture locations.