Spatial ecology, habitat use, and the impacts of rats on chevron skinks (*Oligosoma homalonotum*) on Great Barrier Island

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Fact: Chevron skinks make everyone happy

Abstract

The chevron skink (*Oligosoma homalonotum*) is one of the largest, yet least observed skink species in New Zealand. The species was thought to have once been widespread in Northern New Zealand, however currently it is only found on Great Barrier and Little Barrier Islands. Great Barrier Island is the apparent stronghold for the species although it appears to be in decline there, despite a net increase in habitat. Recent studies have increased the understanding of the general ecology of the species, however little is known about the threats to the survival of this species.

This study had two main objectives; the first was to establish if rats are a threat to chevron skinks, and the second was to increase current knowledge of the species ecology. The research was undertaken in an area of extensive rodent control (Glenfern Sanctuary) and an adjacent unmanaged reserve in Port Fitzroy, on Great Barrier Island in 2008. The first objective of this study involved confirming that rat densities in the treatment (Glenfern Sanctuary) were sufficiently different to allow meaningful comparisons of chevron skink population characteristics between sites. This was achieved by determining absolute rat densities using Zippin's removal method at four sites, and correlating these with a relative abundance measure (tracking rates) to give confidence in the observed trends. Rat densities were high (1.94 - 3.00 rats ha^{-1}) in the control, and low (0.00 and 0.06 rats ha^{-1}) in the treatment sites, and these correlated well with tracking rates. In light of these clear differences between the treatment and control, the population structure and condition of chevron skinks were compared between sites. The population structure showed erosion of juvenile and sub-adult size categories, which indicated differences in vulnerabilities between size categories. Physical evidence of failed rat predation was also observed in adult skinks in the unmanaged control, which confirmed that rats were interacting with chevron skinks. Although the adults survived the attacks they suffered injuries including eye damage, punctures, cuts and tail loss. Smaller skinks would be unlikely to survive such attacks due to the severity and scale of the injuries, supporting the assertions of the population structure that smaller skinks may be more vulnerable than adults. The extent of tail loss was converted to a condition index to determine if failed rat predation was more widespread in the population, than was observed by conspicuous injuries. This condition index (body-tail condition index) was stable through all size categories in the treatment, but significantly reduced in adults in the unmanaged sites. That there was no reduction in the condition of smaller skinks in the unmanaged control sites despite high rat densities suggests that interactions between rats and smaller skinks are fatal, and thus not represented in the data.

Nine chevron skinks were radio-tracked to determine habitat use, home range and ranging behaviour. Habitat use of chevron skinks was similar to a previous study and demonstrated that trees, crevices and logs were important refuge sites. Chevron skinks were more likely to be found at sites with trees, crevices and debris dams. Chevron skink home ranges indicated that adults moved further away from streams than previously anticipated at this time of year, and skinks demonstrated site fidelity. There was also overlap in home ranges between individuals, and skinks with overlapping home ranges shared common refuges. During flooding events, chevron skinks exhibited an arboreal response that appears to be a behaviour specific to stream associated animals, which allows them to avoid being taken by floodwaters.

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Chapter 1 General Introduction

1.1 INTRODUCTION

The niho taniwha or chevron skink (*Oligosoma homalonotum*) is one of the rarest and most cryptic lizards in New Zealand. It is also the largest skink and one of the largest lizards in New Zealand. It is currently only known from two islands in the Hauraki Gulf, Great Barrier and Little Barrier Islands. Before the 1990s, fewer than 80 chevron skinks had ever been reported (Neilson et al. 2006). To date there has only been approximately 300 confirmed reports (DOC unpubl. data), making the chevron skink one of the most secretive and least observed lizard species in New Zealand.

Under the New Zealand threat classification system, the chevron skink is classified as 'Nationally Endangered' (Hitchmough et al. 2007) and is believed to be in decline (Neilson et al. 2006). Internationally it is considered as 'Vulnerable' (VU D2) by the IUCN redlist (IUCN 2008). Because of the rarity and cryptic nature of the species, there were significant knowledge gaps in relation to both the species ecology and the reasons for its decline. Following the establishment of a species recovery plan in 1993, research efforts have provided significant insight into the species' general ecology, but much remains unknown, particularly with regard to threats to the species. Introduced rodents have been identified as a possible factor in the decline of chevron skinks (Baling 2003; Towns et al. 2002) but this remains a significant unresolved research question, and was recommended as a research priority in the 2002 North Island *Oligosoma* spp. skink recovery plan. This study investigates the potential impacts of rats on chevron skinks, and aspects of chevron skink ecology.

1.2 CHEVRON SKINK MORPHOLOGY

The common European name is derived from the distinctive "chevron" shaped markings on its dorsal surface (Figure 1). The Māori name, niho taniwha, meaning 'dragons teeth' also refers to these distinctive teeth shaped markings. Another characteristic feature of the chevron skink is the pale teardrop markings below the eye and on the lower mandible (Figure 1). The chevron skink is the longest skink in New Zealand and is also one of the largest lizards. The snout-vent length (SVL) of chevron skinks can reach up to 143mm (Gill & Whitaker 1996), and the total length can exceed

300mm (pers. obs.). Wild adult chevron skinks can weigh up to 40g (Barr unpubl. data), while gravid females can be substantially heavier weighing as much as 50g (Baling 2003). The chevron skink has a particularly long tail relative to its body size, which can be nearly 1.5 times its SVL. The tail appears to display prehensile qualities (pers. obs.) and it has been suggested that the chevron skinks tail could assist it with climbing (Halema Jamieson, pers. comm.). The chevron skink is also unusual among New Zealand skinks for its vocalisations when disturbed or handled (Towns & McFadden 1993). Adults, sub-adults, juveniles and neonates all demonstrate these distinctive chirps (pers. obs.).

Figure 1. The ‘teardrop’ marking on the upper and lower mandibles (top left), chin markings (bottom left) and the distinctive chevron markings seen on the dorsal side of the chevron skink (right). Note the tail length relative to the body. Photographs by author.

1.3 DISTRIBUTION – PAST AND PRESENT

The chevron skink was first described in 1906 (Boulenger 1906), from Flat Island in the Mokohinau group. When re-describing the species, McCann (1955) noted that the chevron skink type specimen was mislabeled as being from Great Barrier Island. It became apparent that Boulenger (1906) had inadvertently mixed the location information on the type specimens between Suter’s skink and chevron skink, which were described simultaneously. Accordingly, the chevron skink was geographically lost until its rediscovery in the 1970's on Great Barrier Island (Hardy 1977).

Chevron skinks appear to be distributed widely across the Great Barrier island, from the south around the Tryphena and Rosalie Bay areas (Towns & McFadden 1993) towards the north with several records from the Northern "Te Paparahi" block (Newman & Towns 1985). Sightings are generally concentrated in the west of the island, with very few sightings occurring on the eastern side, particularly areas east of Mt Hobson (Newman 1985, DOC unpubl. data). Sightings of chevron skinks around Tryphena and Port Fitzroy have been relatively numerous, with a number of records resulting from roadkill and domestic cats bringing skinks to their owners. Tryphena and Port Fitzroy are also the most populated areas on Great Barrier Island, therefore it is unclear whether this concentration of records is due the greater likelihood of encounter with cats, cars and people (and thus records) or whether the decreased pressure from pigs and goats around these more populated areas corresponds to an increased population of skinks (Towns & McFadden 1993).

Little Barrier Island is the only other location where chevron skinks are currently known to occur. A single specimen of chevron skink was discovered on the Island in 1991 on a tuatara survey trip in the northwest of the Island. Subsequent searches (Gibbs 1996; Whitaker 1993, 1995; DOC unpubl. data) have failed to find additional chevron skinks on the island. In 2007, a second confirmed chevron skink was found on Little Barrier by Ben Barrow after releasing captive tuatara (Helen Dodson pers. comm.). This second chevron skink was found approximately 100m from the location of the first chevron skink record, however based on size they were considered to be two different individuals (Halema Jamieson pers. comm.).

Towns and Robb (1986) considered that the current distribution of chevron skinks on Great Barrier and Little Barrier Islands is a fragment of what once would have been a more widely distributed population, and therefore the chevron skink is an "island pseudoendemic". There is some anecdotal evidence that chevron skinks were formerly present on the mainland. Worthy (1991) suggested that subfossil records from a large indeterminate *Leiolopisma* in Northern New Zealand – now called *Oligosoma* in New Zealand (Patterson & Daugherty 1995) – could possibly be from chevron skinks.

1.4 CHEVRON SKINK ECOLOGY

Chevron skinks are diurnal (Gill & Whitaker 1996; Neilson et al. 2006) and are most often found in damp and humid areas such as wet rotten logs, water seepages, and packs of damp leaf material (Towns & McFadden 1993). In particular chevron skinks have a close association with streams and stream margins in native forest (Neilson et al. 2006; Newman & Towns 1985). Catchments with narrow, rocky streams are more likely to contain chevron skinks than catchments with silty streams (Neilson et al. 2006). This close association with streams has been demonstrated for adult skinks (Neilson et al. 2006) and appears to be particularly strong for juvenile skinks (Newman & Towns 1985). The relatively high rates of evaporative water loss of chevron skinks compared to semi-arid skinks (Neilson 2002b) supports the observations that this species is most often found in high humidity areas such as stream environments. Towns and Robb (1986) suggested that juvenile chevron skinks could even be semi-aquatic. This species has been known to jump into streams trying to evade capture (Newman & Towns 1985). In fact, chevron skinks have been observed entering a stream and hiding underwater between rocks during an attempted capture (pers. obs.). Similarly, a lizard species in Nicaragua that occupies stream environments in dense forest is also known to jump into streams when disturbed (Vitt et al. 1995). There is no evidence however, that chevron skinks voluntarily demonstrate aquatic behaviour in the absence of a threat.

Chevron skinks are more frequently found in old forest than young or medium aged forest (Neilson et al. 2006). However it is unclear whether this is due to habitat or the recovery time since land clearance. Neilson et al. (2006) radio-tracked eight chevron skinks and found they were more likely to be found at sites that had crevices, debris dams and trees than where these microhabitats were absent. Sites with logs, stones and boulders were also used by chevron skinks more often than they were available (Neilson et al. 2006). Chevron skinks are also occasionally found inside burrows (Newman 1985; pers. obs.). In captivity, chevron skinks have been observed using self-made burrows (Baling 2003) and it is possible they display this behaviour in the wild. Newman and Towns (1985) suggested this could be possible although it has never been observed in wild chevron skinks.

Arboreality has been observed in captive (Baling 2003) and wild (Neilson et al. 2006) chevron skinks. In the wild, chevron skinks have been located in Puriri trees (*Vitex lucens*), tree ferns, and in the crowns of nikau palms (*Rhopalostylis sapida*) (Neilson et al. 2006). In addition, chevron skinks have been seen climbing and basking on vertical walls and roofs (Whitaker 1993). Chevron skinks have also been found in the walls of derelict buildings, in waste water pipes of plumbing systems, culverts (Towns et al. 2002) and inside cars (DOC unpubl. data).

Baling (2003) demonstrated that active behaviour in chevron skinks is associated with temperature, light and sun with peaks around midday; and that inactivity is often correlated with cold temperatures, with a peak of inactivity in August. In *apparent* contrast, many of the confirmed records of wild chevron skinks on Great Barrier Island occur during the winter months. Neilson et al. (2006) indicated that the majority of these records were in non-forested habitats and therefore dispersal of chevron skinks between fragments is most common during these wetter months. It is possible that chevron skinks are more likely to be seen in non-forested areas during winter as they are less constrained by evaporative water loss in cold and wet conditions, or they bask in the open more frequently as a response to lower ambient temperatures. In captivity chevron skinks occasionally bask during winter, particularly on the edge of captive enclosures (Marleen Baling, pers. comm.). However, basking was shown to be a relatively uncommon behaviour of chevron skinks in captive situations, and it is thought it would likely occur even less frequently in natural forest systems (Baling 2003).

Towns and McFadden (1993) stated that chevron skinks are clearly not heliothermic (obtain their heat directly from the sun), because they are so infrequently seen in the open. They suggested that if chevron skinks were heliothermic they would need to spend large amounts of time basking to attain heat due to their size and would accordingly be more conspicuous. However, Baling (2003) observed chevron skinks covert basking, whereby skinks basked within refuges. This indicates that basking skinks will not necessarily always be conspicuous. Chevron skinks have occasionally been observed basking in sun patches in the forest (Robb 1986), and is suspected that chevron skinks run over on the road may have been basking for warmth (Halema Jamieson, pers. comm.).

Chevron skinks are known to feed on invertebrates including small land snails, beetle larvae (Towns et al. 2002), *Miturga* sp. spiders (Keri Neilson, pers.comm.) and cave weta (*Gymnoplectron sp.*) (pers. obs.). In addition, chevron skinks have been observed in tunnel web spider (*Porrhothele antipodiana*) holes and presumably ate the inhabitants (pers. obs.). Wingcases of winged bush cockroaches (*Parellipsidion* spp.) have also been observed in the faeces of chevron skinks (pers. obs.).

The longevity of chevron skinks is only known from the captive records of one animal, which was at least 20 years old (Baling 2003). Little is known about the growth rates of chevron skinks, although it has been suggested they take 3-5 years to reach sexual maturity (Towns & McFadden 1993). Up to eight young are born in summer (Robb 1986), and are first observed in March (Neilson et al. 2006).

1.5 THREATS

There is very little empirical information on the threats to chevron skinks. The only known predator of chevron skinks is introduced cats (*Felis catus*), and this has been confirmed through domestic cats bringing chevron skinks to their owners. Several of these have been rehabilitated and re-released to predator-controlled areas on Great Barrier Island. A recently deceased chevron skink was found decapitated on an open track on Great Barrier Island. It was suspected a feral cat preyed on the skink and was disturbed while eating it (DOC unpubl. data). To date, the extent of the impacts of feral cats to chevron skinks has not been investigated.

Introduced pigs (*Sus scrofa*) are known predators of lizards (Thomson & Challies 1988), and it is likely that they opportunistically take chevron skinks. In addition to direct predation, pigs are likely to threaten chevron skinks through habitat destruction. Pigs feed intensively along stream margins where chevron skinks live, and cause extensive habitat degradation (Towns et al. 2002) including turning and removing leaf litter, which acts as a refuge to chevron skinks when they are active on the forest floor. Areas of loosened and turned soil are also more vulnerable to erosion during heavy rainfall and flooding, which causes destruction of essential habitat and refugia, and causes the silting of stream habitats. Introduced goats were present on Great Barrier Island until 2006. Similarly to pigs, goats were probably a threat to chevron skinks through the extensive erosion they caused through the removal of shrubs and ground cover (Ogle 1981). Their subsequent eradication is likely to have had benefits for chevron skinks.

Rats are often considered to be a threat to chevron skinks (Baling 2003; Towns et al. 2002) on the basis that they are linked to significant declines, localised extinctions and range contractions of other New Zealand lizards (Towns 1991; Towns & Daugherty 1994; Whitaker 1978). Furthermore, New Zealand reptiles respond extremely well to eradications of rats on islands (Hoare et al. 2007; Towns 1991; Towns et al. 2007). Despite these assumptions, there is no empirical evidence confirming rats are a threat to chevron skinks.

Chevron skinks are also likely to have native avian predators, which rely on visual cues. Although native predators have not been observed taking chevron skinks it is likely that species known to predate lizards also take chevron skinks, such as kingfisher (*Halycon sancta*; Fitzgerald et al. 1986), banded rail (*Rallus philippensis*; Whitaker 1968), and possibly morepork (*Ninox novaeseelandiae*; Ramsay & Watt 1971) and pukeko (*Porphyrio porphyrio*; Carroll 1966).

In addition to both introduced and native predators, human activities such as farming (Clough 2004), fire (Wheeler 2004) and logging (Sewell 2004) have caused the loss of significant areas of habitat as well as habitat fragmentation. Habitat fragmentation has caused significant declines in New Zealand’s biodiversity (Brockerhoff et al. 2008), and has possibly led to impacts on chevron skinks through reduced heterozygosity (Baling 2003).

1.6 CONSERVATION MEASURES AND RESEARCH TO DATE

1.6.1 Recovery plans and achievements

Chevron skinks have been included in two recovery plans. The species had a dedicated recovery plan from 1993-2002 - ‘The chevron skink recovery plan’ (Towns & McFadden 1993) and then became part of the North Island *Oligosoma* spp. skink recovery plan 2002-2012 (Towns et al. 2002). The latter plan superseded the former and amalgamated recovery objectives for all other North Island *Oligosoma* spp. lizards (Towns et al. 2002).

The focus of the 1993 chevron skink recovery plan (Towns & McFadden 1993) was to initiate advocacy on Great Barrier Island with regard to potential pest threats, in addition to raising the profile of chevron skinks on the island. Furthermore, it called for initiation of pest control on existing pest species and measures to prevent incursions of further pest species onto GBI, in particular Norway rats (*Rattus norvegicus*) and mustelids. The recovery plan recommended that comprehensive surveys be undertaken on Little Barrier Island and that research be undertaken on the Little Barrier Island chevron skinks.

The recovery objectives for chevron skink in the 2002 North Island *Oligosoma* spp. skink recovery plan (Towns et al. 2002) included the continued prevention of new pest species incursions onto GBI. The plan also contained specific plans for managing some existing pests on both islands, including the eradication of kiore from Little Barrier Island, and the eradication of goats, localised pig control and the establishment of a ‘mainland island’ site on GBI. The research priorities of the *Oligosoma* spp. skink recovery plan were to identify the habitat use of chevron skinks including microhabitat and substrate preferences and understanding the role of evaporative water loss. Furthermore the plan sought to establish the vulnerability of chevron skinks to predation and measure the cost effectiveness of rodent control.

Achieved

- A two-year intensive advocacy programme was initiated, and GBI maintained its Norway rat, mustelid and possum (*Trichosurus vulpecula*) free status (Towns et al. 2002).
- The profile of chevron skinks on GBI was raised through information brochures, posters and talks at conferences and to community groups (Halema Jamieson, pers. comm.).
- Goats were controlled in the Northern block of GBI from the 1980's (Towns 1989) and were successfully eradicated from the entire Island in 2006.
- Chevron skink evaporative water loss study was completed (Section 1.4) and habitat use and preferences is ongoing.
- Three intensive surveys were conducted on Little Barrier Island in 1993, 1995, and 1996 however no chevron skinks were found despite 12820 trap days of search effort (Gibbs 1996; Whitaker 1993, 1995).
- Kiore were successfully eradicated from Little Barrier Island (Griffiths 2006)

Not achieved

- No orchestrated pig control has been initiated on DOC land on GBI
- The vulnerability of chevron skinks has not been successfully quantified for any potential pest species. A study into the effects of rodents was attempted but not achieved, and therefore the cost effectiveness of rodent control is undetermined.
- There has been no research conducted on chevron skinks on Little Barrier Island as only one further skink has been located there.

1.7 RESEARCH STUDIES

1.7.1 Habitat use of chevron skinks

Between 1997 and 2002, a scientist from DOC Science and Research Unit (Keri Neilson) undertook a dedicated study of chevron skinks on Great Barrier Island. One of the main focuses of her studies was to increase the understanding of chevron skink ecology and physiology to assist management decisions and future survey methods. An outcome of these studies was identifying that chevron skinks have relatively high rates of evaporative water loss, supporting hypotheses that skinks are associated with humid environments such as streams (Neilson 2002b). In addition, these studies determined habitat use of chevron skinks by analysing preferences of eight adult radio-tracked skinks (Section 1.4). Furthermore, comparisons were made between 12 catchments to determine which variables were important in determining the presence of chevron skinks (Neilson et al. 2006).

1.7.2 New monitoring techniques

Trapping systems and lures were trialed for chevron skinks in captivity and field tested to determine efficacy (Jamieson & Neilson 2007). G-minnow fish traps baited with banana or raspberry lure have increased the capture rate substantially from standard monitoring techniques such as pitfall traps and hand searching. G-minnow fish traps have achieved capture rates of between 1.3 and 5.5 skinks/100 trap days (DOC, unpubl. data). In contrast, pitfall trap capture rates during habitat use studies averaged 0.13 skinks/100 trap days, which is among the lowest for any skink species in New Zealand (Neilson et al. 2006).

1.7.3 Captive and genetic studies

A postgraduate MSc student examined the habitat use and behaviour of chevron skinks in captivity and the possible effects of habitat fragmentation on the population genetic structure of the species (Baling 2003). Habitat use was investigated using four captive adult skinks and found that skinks display a high level of refuge site fidelity, and refuge selection determines micro and macrohabitat use. This study also found that the change in microhabitat use and behaviour of chevron skinks is associated with change in daily and seasonal climate, and that skink activity is highest at midday, which is associated with climatic factors. Examining mitochondrial DNA and microsatellite loci between fragmented populations of chevron skinks and two model species determined the effects of habitat fragmentation. The unique locality of two haplotypes and the possible reduction in genetic variation within populations suggested that genetic fragmentation of populations had occurred, although larger sample sizes were needed to confirm the pattern.

1.7.4 The effects of control of introduced rats on chevron skink on Great Barrier Island

A study initiated by DOC (Science and Research Unit) in 1998 sought to determine the effects of rodent predation (and the cost effectiveness of rodent control) on the population dynamics and habitat use of chevron skinks. Two 100ha areas that contained chevron skinks were selected as experimental sites; rodents were controlled at one of the sites by snap-trapping on a grid (100 x 25m) while the other site was left unmanaged (Neilson 2002a). Rodents and lizards (chevron skinks and other) were monitored at both sites to confirm efficacy of rodent control and to detect responses in the lizard populations.

Pre-treatment monitoring using pitfall traps revealed that lizard abundances were low in both areas and relative rodent abundances using tracking rates were very high (often greater than 90%; Neilson 2002a). Rats were controlled in the treatment sites between December and May in 2000/2001 and 2001/2002. The project was abandoned in 2002 as the method of rat control was expensive and trapping could not control rodents to an acceptable level, and there was no detectable positive response of lizards to the rodent control; in fact there was a decline in overall lizard numbers during the operation.

The outcomes of this research resulted in recommendations that the project would benefit from being moved to Glenfern Sanctuary where predator control was being undertaken using poison bait-stations. The reasons behind this suggestion were that the total area of control at Glenfern Sanctuary was sufficiently large, and would encompass an entire peninsula (Neilson 2002a). The experimental limitations of moving the study to Glenfern Sanctuary were considered to be a lack of confidence in the effectiveness of the rodent control due to lack of monitoring. In addition there was no pre-treatment data for chevron skinks, although Neilson (2002a) argued it would still be possible to examine trends in the population of skinks between Glenfern Sanctuary and a non-treatment site.

1.8 KNOWLEDGE GAPS

The *Oligosoma* recovery plan (Towns et al. 2002) outlined the priorities for chevron skink recovery over a five-year period until 2007. The top three priorities were to eradicate kiore from Little Barrier Island, determine habitat use of chevron skink and to determine the effectiveness of predator control. To date, kiore have been successfully eradicated from Little Barrier Island (Griffiths 2006), and a study of chevron skink habitat use has been undertaken (Neilson et al. 2006).

There is still a great need to further study the general ecology and habitat preferences of chevron skinks, considering only eight skinks have been radio-tracked in one relatively modified catchment (K. Neilson, pers. comm). Important unknown information such as home range, general habits, ranging behaviour, and interactions with conspecifics can be gleaned from further radio-tracking studies. There is also a clear need to quantify the threats of introduced predators, in particular to determine the effects of rodent control. This objective is clearly expressed by the *Oligosoma* recovery plan (Towns et al. 2002) and supported by Neilson et al. (2006), who stated the threats to chevron skinks must be established by manipulating them independently. The most substantial obstacle in establishing the threats to chevron skinks and carrying out robust scientific studies to date has been the cryptic nature of chevron skinks and the incredibly low capture rates.

1.9 NEW RESEARCH OPPORTUNITIES

The habitat use studies undertaken by Neilson et al. (2006) coupled with the trapping technique outline by Jamieson and Neilson (2007) have greatly increased the trappability and therefore the detectability of chevron skinks. As a result, there are new opportunities to utilise this novel trapping method to undertake research. Glenfern Sanctuary, the suggested site for studying the impacts of rodents on chevron skinks (Neilson 2002a), has now had extensive rodent control (160ha) since 2002, which in 2004 was extended to encompass the entire Kotuku peninsula (230 ha).

1.10 THESIS OBJECTIVES AND STRUCTURE

There were two main objectives in this study. The first was to determine if rats are a threat to chevron skinks, which was done in two parts. Rat densities were investigated to confirm that the chosen treatment sites (Glenfern Sanctuary) and control sites had real differences in rat densities, which would yield meaningful comparisons. This information was then used as a basis for the second component; comparing chevron skink populations between the treatment and control sites to determine if rats were impacting on them.

The second objective of this study was to investigate habitat use, home range and ranging behaviour to expand current knowledge of chevron skink ecology.

Although all parts of this study are related, the research has been broken down into three data based chapters relating to the three components outlined above, and these are written as stand alone documents. Accordingly, the methods are contained within each chapter, as opposed to a general methods section. As a result, some repetition is unavoidable as well as some cross-referencing between chapters.

Chapter 2: Confirming the effects of extensive rodent control: rat densities from absolute and relative abundances.

Chapter 2 determines absolute and relative rat densities between the study sites to confirm that extensive rodent control has been effective in reducing rat numbers. Absolute and relative densities are correlated to confirm population trends between methods and the response of kiore (*Rattus exulans*) to the removal of ship rats is investigated.

Chapter 3: The impact of rats on chevron skinks: population structure and condition, and physical evidence of rat predation.

Chapter 3 examines differences in the population structure and condition of chevron skinks between sites of extensive rat control and unmanaged sites. Rat densities obtained in chapter 2 are used to make this comparison. Sublethal injuries observed are used to elucidate findings.

Chapter 4: Habitat preferences, home range and ranging behaviour of chevron skinks.

Chapter 4 investigates the habitat preferences of chevron skinks through a radio-tracking study to augment current knowledge. It also presents the first home range information for chevron skinks in addition to ranging behaviour.

Chapter 5: General summary and conclusions

Chapter 5 provides a synthesis of all the chapters and draws general conclusions based on the results of the combined research. Future research is suggested with a focus on conservation application.

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Chapter 2 Confirming the effects of extensive rodent control: rat densities from absolute and relative abundances.

2.1 ABSTRACT

Zippin's removal method of population estimation, and footprint tracking tunnels were undertaken at four 9ha grids on Great Barrier Island to compare rat densities between an unmanaged area (control) and an area with extensive rodent control (treatment). Two 9ha treatment removal grids were established in a 270ha predator control area, and two 9ha control removal grids in an adjacent unmanaged area with three objectives. 1) To confirm that rodent control was successful in reducing the rat populations and that there was a real difference between treatment and control sites by obtaining absolute rat density estimates, 2) to determine whether these absolute densities corresponded to a relative abundance measure (tracking tunnel rates) and 3) to establish empirically whether kiore (*Rattus exulans*) were subjected to interference competition from ship rats (*R. rattus*). In the treatment removal grids only one ship rat was trapped, while 52 rats (51 ship, 1 kiore) and 46 rats (33 ship and 13 kiore) were caught in the two unmanaged control grids respectively. Pre-trapping tracking rates were 0% in both treatment grids, and were 75% and 89% in the unmanaged control grids. Kiore became more trappable as ship rats were progressively removed, so were not included in density estimates. These findings support previous suggestions that kiore are susceptible to interference competition from ship rats, and this mechanism may be responsible for ship rats excluding kiore throughout their former range in New Zealand. The estimated minimum densities of ship rats derived from the removal grids were between 0.00 and 0.06 rats ha^{-1} in the treatment grids, and 1.94 and 3.00 rats ha^{-1} in the unmanaged control grids, confirming that the rodent control was successfully reducing rat densities. Tight linear relationships between tracking rates and estimated densities indicate that relative indices correspond well to absolute abundance estimates in this instance, and give confidence in the density trends seen between the treatment and unmanaged control areas. Since density estimates can only be given for the dominant rat species, the total rat population (ship rat plus kiore) is underestimated in these density estimates. This needs to be considered for future studies of multi-species assemblages using Zippin's removal method, and when associating the rat densities with potential impacts on fauna.

2.2 INTRODUCTION

2.2.1 Introductions and impacts of rats in New Zealand

The human aided introductions of three rat species (*Rattus exulans, R. norvegicus and R. rattus*) to New Zealand have caused serious and ongoing ecological impacts to the native flora and fauna (Atkinson & Moller 1990; Innes 1990; Moors 1990). The first rat species to arrive in New Zealand was the kiore (*R.exulans*), which came with early Māori settlers in approximately 1280AD (Wilmhurst et al. 2008). Kiore have been held responsible for the wave of extinctions that occurred shortly after their arrival (Holdaway 1999). Arriving with sailing ships from Europe and North America in the late eighteenth century, Norway rats (*R. norvegicus*) were much larger than kiore and caused further extinctions of animals that had survived kiore predations (Moors 1990; Towns et al. 2006). Ship rats (*R. rattus*) were the last of the rat species to arrive in New Zealand and it is suspected they established in the North and South Islands around 1860 and 1890 respectively (Innes 1990). The ship rat is particularly arboreal (Innes 1990) and their arrival caused a further wave of extinctions, including the greater short-tailed bat (*Mystacina robusta*) and a wren (Towns et al. 2006). The ship rat has also been implicated with declines and localised extinctions of many forest birds (Innes 1990; Towns et al. 2006). In addition to the more obvious and documented impacts on terrestrial birds, introduced rats are known to impact lizards (Hoare et al. 2007; McCallum 1986; Newman & McFadden 1990; Towns 1991; Towns et al. 2003), tuatara (Cree et al. 1995; Jones 2002; Towns et al. 2007) and invertebrates (Kuschel & Worthy 1996).

In response to these impacts, rodent management and abundance estimation have become a key part of conservation and research activities in New Zealand. Estimating rodent abundances is often essential to identify threats and understand species declines. In addition, they allow researchers and conservation managers to assess management efforts and guide management decisions. Relative rodent density measures are the most widely used in New Zealand and are often undertaken as the sole measure of rodent density because they are cheap, easy and well known in New Zealand conservation. However, relative measures of rodent abundance are known to have significant limitations and biases. Consequently, there have been calls for relative measures to be correlated with a second density measure (Blackwell et al. 2002), ideally an absolute density. Absolute density estimates are obtained infrequently in New Zealand due to the difficulty, costs and logistics involved, however they generally provide more robust and easily understood information.

2.2.2 Rodent abundance estimation methods

2.2.2.1 Relative indices

Footprint tracking tunnels (King & Edgar 1977) are the most widely used method for determining relative densities of rodents in New Zealand (Armstrong et al. 2006; Murphy et al. 2008; Ratz 1997). Tracking tunnels are equipped with a white card with ink and pad at the centre; the target animal is attracted with bait, and leaves ink footprints on the card. The abundance of rats in the area is extrapolated from the tracking tunnels and expressed as the proportion of tunnels tracked (Blackwell et al. 2002). Kill trapping is also used as a relative measure of rodent abundance as outlined by Cunningham and Moors (1983) (for example, Innes 1995; James 1996). Many contemporary studies have shown a preference for measuring relative abundances of rats as they can provide sufficient amounts of information (Caughley 1977) with less effort (Brown et al. 1996) and less cost (Blackwell et al. 2002). However, a number of studies have revealed that relative abundances such as tracking tunnels and kill trapping are susceptible to biases. These include saturation of the index technique at high densities causing non-linear relationships between the actual density and the density estimate (Sandlandt & Moller 1989; Tanaka 1960), modification of the target species response by competitors or predators (Brown et al. 1996), and their liability to measure activity in addition to density (King & Edgar 1977). Furthermore, Ruscoe et al. (2001) identified that differences in relative abundances are not necessarily real, as they may be related to other factors such as behaviour of the species being indexed.

2.2.2.2 Absolute density estimations

Absolute rodent densities are obtained far less often in New Zealand due to the cost, time and logistical difficulty involved (Blackwell et al. 2002) particularly when dealing with large areas. Absolute density is usually calculated by dividing the number of rats estimated to be in an area (N) by the effective trapping area (A); A equals the trapped area plus a boundary strip equal to half the average home-range radius (Dice 1938). In New Zealand the method of obtaining *N* and *A* values has varied. Hickson (1986) calculated *N* using live-trapping and tracking to establish the minimum number of rats known to be alive (MNA) (Krebs 1966), and calculated the home range for *A* by trapping and tracking tunnel fixes. Daniel (1972) also calculated the MNA using live trapping and calculated *A* by adding a border strip equal to half the mean distance moved between successive captures. Hooker and Innes (1995) calculated *N* by live and kill trapping and calculated *A* by radio-tracking live rats to obtain home range. Wilson et al. (2007) used a capture-mark-recapture (CMR) protocol to calculate density without the need to estimate effective area (*A*) although they found the precision of their density estimates was not satisfactory.

2.2.2.2.1 Zippin's removal method

Zippin's removal method (Zippin 1958) calculates N by systematically removing animals from a defined area, then uses the nightly catch plotted against cumulative catch to estimate the number of animals (through extrapolation) that were in the defined area before trapping began. Zippin's removal methods assumes 1) the joint effect of births, deaths, emigration and immigration is negligible during the experiment, 2) the probability of capture remains constant throughout the experiment and trapping conditions remain the same and 3) the probability of capture during the experiment is the same for each animal exposed to capture (Zippin 1958).

Both Blackwell (2002) and Brown (1996) have used Zippin's removal method to calculate N in the New Zealand setting, and used the home range generated by Hooker and Innes (1995) to determine the effective trapping area (*A*).

There are also potential weaknesses of absolute abundance estimations. Wilson et al. (2007) suggested that MNA and Zippin estimates of *N* are underestimates, because the entire population will very rarely be caught and it is not robust to heterogeneous capture probability between individuals. Wilson et al. (2007) also argues that methods using a constant boundary strip to determine *A* will be unreliable because home range varies over time and between habitats.

2.2.2.3 Calibrating relative density indices and absolute abundances

Due to the potential biases, inaccuracies and uncertainties of both relative density indices and absolute density estimates, calls have been made advocating the use of two or more index methods as a calibration when comparing abundances. This is to determine if the index being used is directly related to the absolute abundance, and to give greater confidence in observed trends (Blackwell et al. 2002).

In New Zealand, Brown et al. (1996) and Blackwell et al. (2002) have tested relative rodent indices against absolute abundance estimates derived from Zippin's removal method. Brown et al. (1996) utilised a single removal grid and found a tight relationship between tracking tunnels rates and estimated rat densities. Blackwell et al. (2002) found that densities from tracking tunnels and the removal grid followed a similar trend but the relationship was not significant at the 0.05 level. This was probably due to immigration on the last night of trapping.

2.2.3 Interactions between rat species

In addition to the difficulties inherent in population estimation of single species, it has been suggested that any researcher attempting to determine the population densities of sympatric rodent species will encounter problems due to interference competition between species thus biasing capture rates (Harper & Veitch 2006) i.e. less dominant species will become more trappable as the dominant species declines. Over short term trapping periods, this response is behavioural and has been observed in mice as a response to the removal of ship rats (Brown et al. 1996), and in kiore as a response to the removal of Norway rats (Harper & Veitch 2006). The longer-term response, which manifests as a real population increase of the subordinate species is termed the "competitor release effect" and has been modeled between mice and ship rats (Caut et al. 2007).

Currently, there is only circumstantial evidence to suggest that kiore are subordinate to ship rats (Atkinson & Moller 1990; Russell & Clout 2004; Yom-Tov et al. 1999). Yom-Tov (1999) found that kiore are generally smaller in the presence of ship rats, and consider that because ship rats and kiore are rarely found sympatric that there is competition between the two. Russell and Clout (2004) found that the distribution of kiore was negatively related to ship rat presence, and to a lesser extent Norway rats. They also found that kiore presence was not affected by the presence of mice (Russell and Clout 2004). Despite this evidence by deduction, the actual response of kiore to ship rat removal has not been studied within free-living rat populations in New Zealand.

2.2.4 Research objectives

In this study, absolute ship rat densities were calculated in four separate catchments using Zippin's (1958) removal method to 1) confirm rodent control was successful and there was a true difference between treatment and control sites. Rodent tracking tunnel rates and absolute densities were calibrated following the methods of Brown et al. (1996) to 2) determine whether the relative measure of tracking tunnel rates corresponded well with absolute abundances to increase the confidence in the observed trends. Finally, catch rates of ship rats and kiore were examined temporally to ascertain if there was a behavioural response of kiore to ship rat removal to 3) establish empirically if kiore were subjected to interference competition from ship rats. This is part of a wider study to determine how rodent densities affect the endangered chevron skink (*Oligosoma homalonotum*). Therefore it is critical to clearly determine the effectiveness of the rodent control and have confidence in the measures of rodent density between the treatment and unmanaged control sites.

2.3 METHODS

2.3.1 Study area

This study was carried out at Port Fitzroy (36° 16′ S, 175° 36′) on Great Barrier Island (27 760 ha) in the Hauraki Gulf, New Zealand (Figure 2). Port Fitzroy is located approximately 90km NE from Auckland city. Unlike mainland New Zealand, Great Barrier Island is free from introduced mustelids, brushtail possums (*Trichosurus vulpecula*), hedgehogs (*Erinaceus europaeus*) and Norway rats. The island's vegetation cover is predominantly regenerating manuka (*Leptospermum scoparium*) and kanuka (*Kunzea ericoides*) although it contains pockets of lowland mixed coastal broadleaf forest and lower and upper montane forest (Ogden 2004).

2.3.1.1 Treatment area; Glenfern Sanctuary and Kotuku peninsula – history of rodent control

Kotuku peninsula is the geographical feature that has become known as Glenfern Sanctuary. The peninsula totals 230ha and consists of two parcels of private land and a small public reserve administered by the Department of Conservation (DOC) (Kotuku Scenic Reserve, 69ha). One parcel of private land is owned by Tony and Mal Bouzaid (Bouzaid's property, 83ha), and the other by Orama Christian Community (OCC, 78ha) in Karaka Bay.

Rodent control was initiated on the peninsula in May 2001 on Bouzaid's property. In May 2002, rodent control was extended to OCC and encompassed 161 ha. In September 2004, predator control began in the Kotuku scenic reserve giving the entire peninsula (230ha) some level of rodent control (Figure 3). At Bouzaid's property and OCC, broadifacoum was supplied in pellet form for an entire year (May 2001 to May 2002 inclusive at Bouzaid's; May 2002 to May 2003 inclusive at OCC) to achieve an initial rodent knockdown. In all subsequent years the poison regime for Bouzaid's property and OCC has been broadifacoum blocks checked monthly (September to May inclusive). In Kotuku scenic reserve, the warfarin based bait Racumen® was supplied every 3 weeks during September to May from 2004-2007. Since 2007, diphacinone has been supplied in Kotuku scenic reserve September to February inclusive. In all three areas poison is presented in Philproof rodent bait stations approximately 100mm above ground level on a tree at stations 50m apart. A 1km section (approximately) on the SE perimeter of the control area has bait stations at 25m intervals to limit incursions into the area (Figure 3). Tracking tunnels have been implemented since 2005 (Appendix 1).

The exact history of land clearance at Glenfern Sanctuary is difficult to determine, however early photographs suggest extensive clearance as early as 1904 (Figure 5). Ogden et al. (2006) indicated that after 1940 the island began to regenerate to native manuka and kanuka, and indeed large areas of regeneration were apparent on the Kotuku peninsula by the 1950's (Figure 5). Areas of Glenfern Sanctuary were never completely cleared of vegetation, although the riparian strip was almost certainly grazed by farm animals (Tony Bouzaid pers. comm.).

2.3.1.2 Control area. Great Barrier Forest Conservation Area (GBFCA).

The GBFCA (DOC reserve 118) is an area of native forest above Port Fitzroy (DOC 1995). It is 368ha in area although it is contiguous with a much larger area of bush. The vegetation is a mixture of secondary hardwood/tall kanuka/kauri regeneration with some areas of secondary coastal broadleaf forest (DOC 1995). The GBFCA has no history of rodent control.

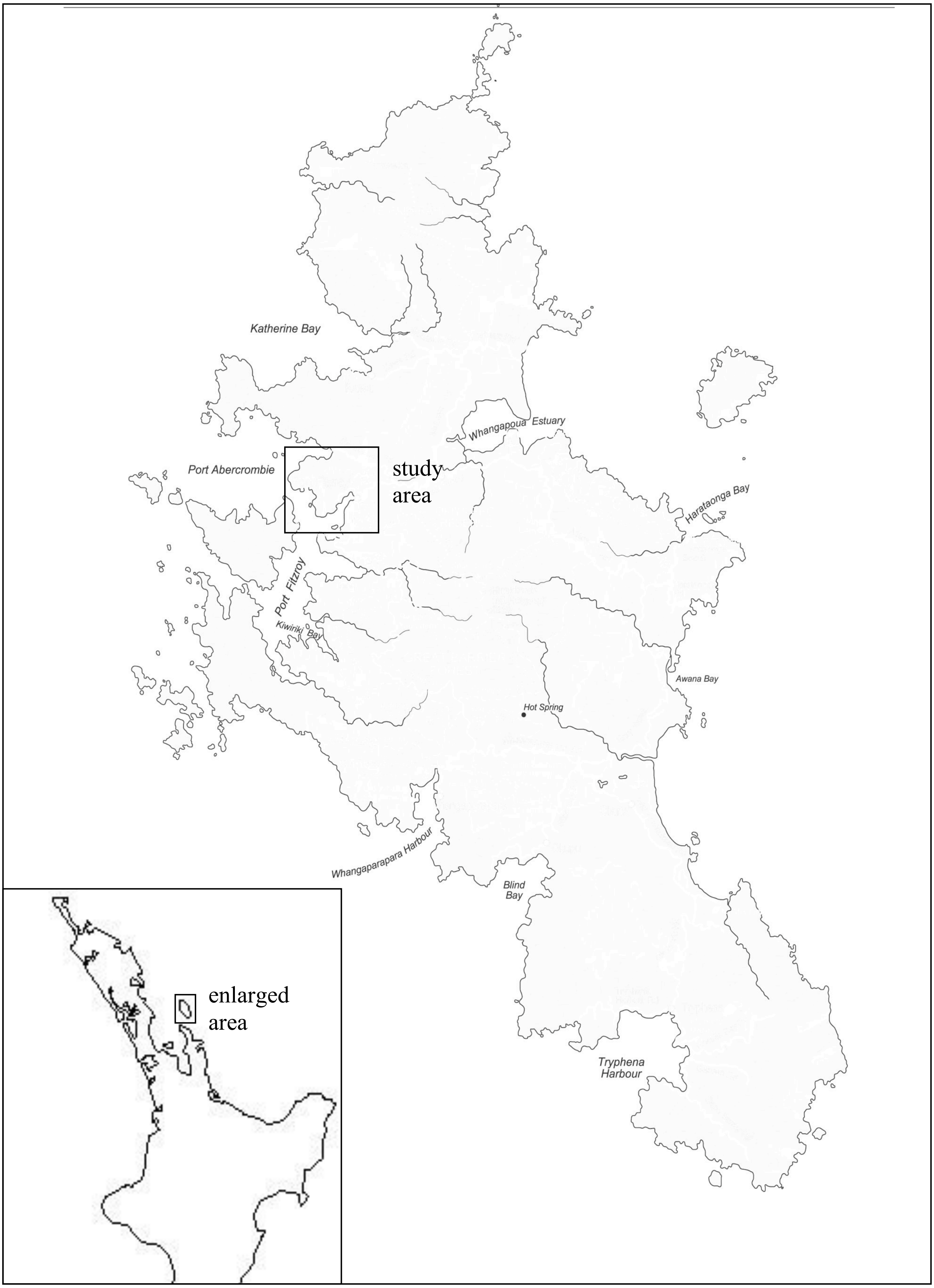

Figure 2. The location of Great Barrier Island (27 760 ha) in the Hauraki Gulf of New Zealand. The study area is shown in greater detail in Figure 3 & Figure 4 (Map modified from DOC).

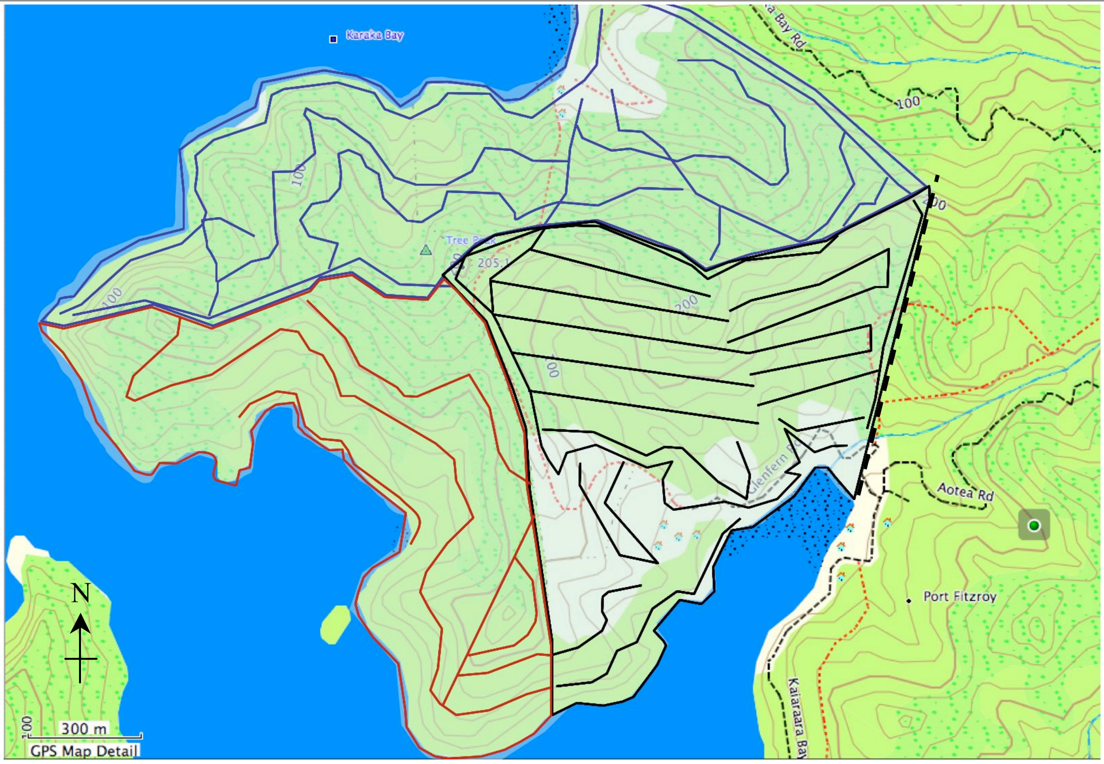

Figure 3. Map of the rodent control network on Kotuku peninsula, Port Fitzroy, Great Barrier Island. Black lines are poison lines on Bouzaid's property, dashed black line is poison on 25m interval, and blue lines are poison lines on OCC. Red lines are poison lines on Kotuku scenic reserve.

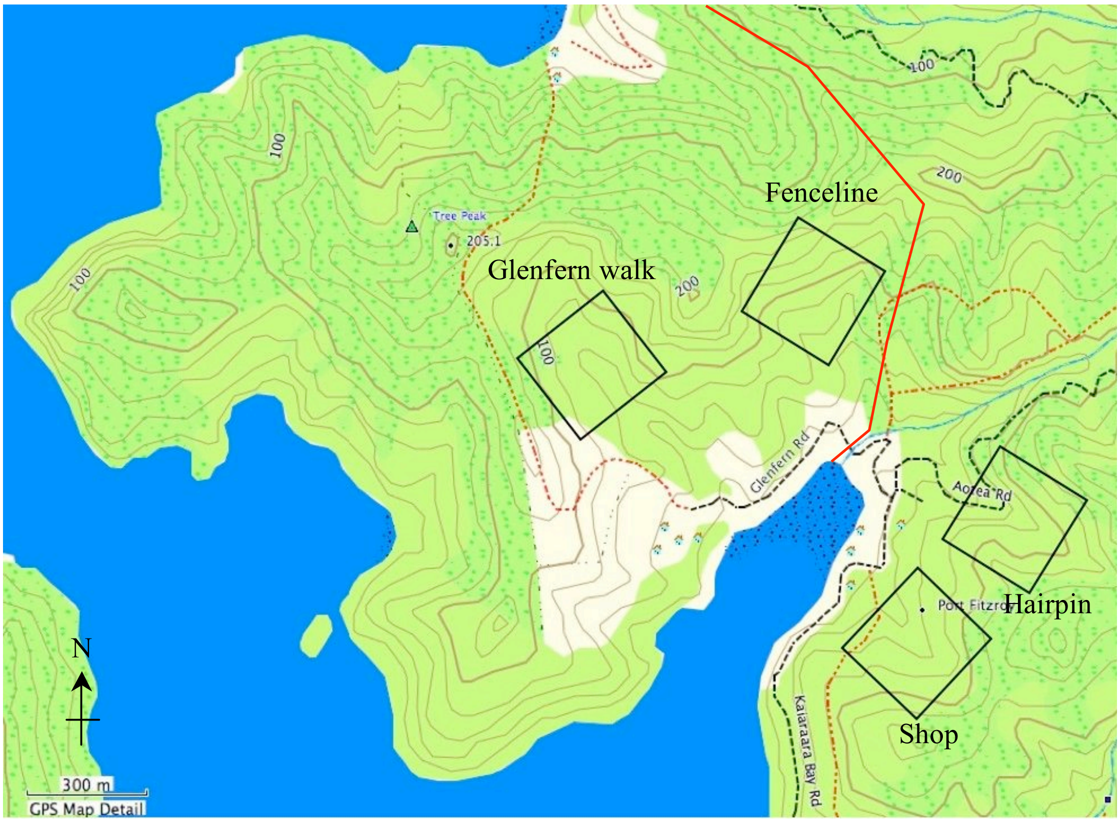

Figure 4. Map of the study area at Port Fitzroy, Great Barrier Island. Treatment (Glenfern walk and Fenceline) and control (Shop and Hairpin) removal and tracking grids were run in August 2008. Rodent control occurred west of bold red line (Figure 3).

Figure 5. Historic photos of Kotuku peninsula showing early land clearance.

Top photo shows Kotuku peninsula looking from the South-east.
Great Barrier. Port Fitzroy. Rarohara Bay. H. Winkelmann 1904. Used with permission from Auckland War Memorial Museum.
Bottom photo shows Kotuku peninsula looking from the south. 1950's Used with permission from Tony Bouzaid.

2.3.2 Study Design

Four 9 ha removal grids, two treatment grids and two unmanaged control grids were established using a compass and hipchain. The treatment grids were located on private land on Kotuku peninsula (230ha), and the unmanaged control grids were located within the Northern Great Barrier Forest Conservation Area (368ha, DOC reserve 118) adjacent to Port Fitzroy and administered by DOC (Figure 4). Both areas were contiguous with much larger bush areas, however the Kotuku peninsula was fenced off with a predator proof Xcluder™ fence in June 2008, prior to this study. Trapping was targeted specifically for rats and was not designed to selectively target certain rat species. Tracking was targeted at rodents and did not select for certain species of rodents. Trapping and tracking data were collected during August 2008 when rat densities and movements are considered to near their lowest (Innes 1990) and comparisons were made between the treatment and control.

2.3.2.1 Extinction trapping

The methods of Brown et al. (1996) were followed using Zippin's removal method (section 2.2.2.2.1; Zippin, 1958) to calculate rat densities and to calibrate these densities with rat tracking rates on the four removal grids. Each grid was situated within a defined catchment to estimate the rat density within it. The location of the trapping corresponded with catchments where chevron skinks were monitored. All grids were 300m x 300m (9ha) with stations at 50m intervals within the grids; creating 7 transect lines consisting of 7 stations (Figure 6). Victor® Easy Set® rat traps were installed at each station and covered with a corflute box (100 x 175 x 300mm, with a 100 x 100mm opening) held down with a no. 8 wire peg. The cover was implemented to reduce the threat to non-target species (Brown et al. 1996). The rat traps were fastened to the cover peg so that trapped rats (and their traps) were not removed by cats and pigs. Both unmanaged grids (Shop and Hairpin) and the Glenfern walk grid were oriented so the transect lines were perpendicular to the stream (Figure 3). This meant traps were at least 10m away from the stream to avoid accidental bycatch of chevron skinks. The Fenceline grid was oriented diagonal to the stream to avoid the predator proof fence that was installed in June 2008, although all traps were positioned at least 10m away from the stream (Figure 3). The effective trapping area was calculated by adding a buffer to the total grid area (after Dice 1938) equal to half the total home range radius of ship rats taken as 56m (Hooker & Innes 1995). The buffer strip was restricted to 30m on the SE side of the Fenceline grid where it was bounded by the fence. This gave an effective trapping area of 17 ha, and 15.9 ha for the restricted Fenceline grid.

The traps were baited nightly with peanut butter applied to the heel of the trap treadle to increase the trap efficacy. Trapping was undertaken until 1) trapping rates dropped below a threshold close to extinction (5 rats/100 trap nights) or 2) for at least three nights if trapping was always below this threshold. Consequently, trapping occurred for three consecutive nights in the treatment grids (14-16th August 2008) and six consecutive nights in the unmanaged control grids (14 – 20th August 2008). Trapping concluded earlier in the treatment grids because trapping was always below the trapping threshold. All trapping grids were installed at least three days before trapping began.

2.3.2.2 Tracking tunnels

Black trakka™ tracking tunnels were run simultaneously with the extinction trapping to calibrate the two methods and to correlate tracking tunnel rates with the estimated rat densities. In each of the removal grids, a total of twenty-eight tracking tunnels were installed within 1m of the rat traps (as per Brown et al. 1996) at 50m intervals along four transect lines 100 m apart (Figure 6). Tracking tunnels were baited with peanut butter. The tracking rates were recorded the night before trapping commenced (13th August 2008) and for three consecutive nights in the treatment grids, and six consecutive nights in the unmanaged control grids. Tracking concluded earlier in the treatment grids because of the very low rat trapping and tracking rates. Tracking rates were expressed as the proportion of tunnels tracked with rat footprints, and represent a one-night tracking index (Blackwell et al. 2002). Tracking tunnels were in place three months before tracking commenced.

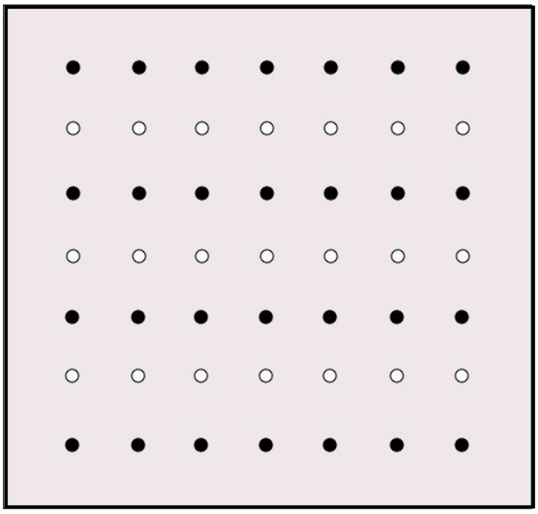

Figure 6. Layout of tracking tunnels and snap-traps used to estimate rat densities and calibrate estimate indices at Port Fitzroy, Great Barrier Island in August 2008. Filled circles indicate a snap trap and a tracking tunnel; open circles indicate only a snap trap (50m spacings). The shaded area is the effective trapping area (17ha) with a 56m buffer (half the diameter of the average ship rat home range; Hooker and Innes 1995) added to the actual trapped area after Dice (1938).

2.3.2.3 Rat morphometrics and identification

All carcasses were kept and measured according to Cunningham and Moors (1983) to determine their breeding condition, sex, species and approximate age. Sex was determined by the presence of an open or closed vagina below the urethral opening for females and the absence of a vagina for males (Figure 7; Cunningham and Moors 1983). Maturity was determined as adult or juvenile based on sexual maturity; perforate or imperforate vagina respectively for females, testes scrotal or nonscrotal respectively for males (Figure 7). This was cross-referenced with weight estimations derived from Daniel (1972) for ship rats; males over 120g and females over 80g were classed as adults. All adult female rats were checked for lactation as an indication of breeding condition.

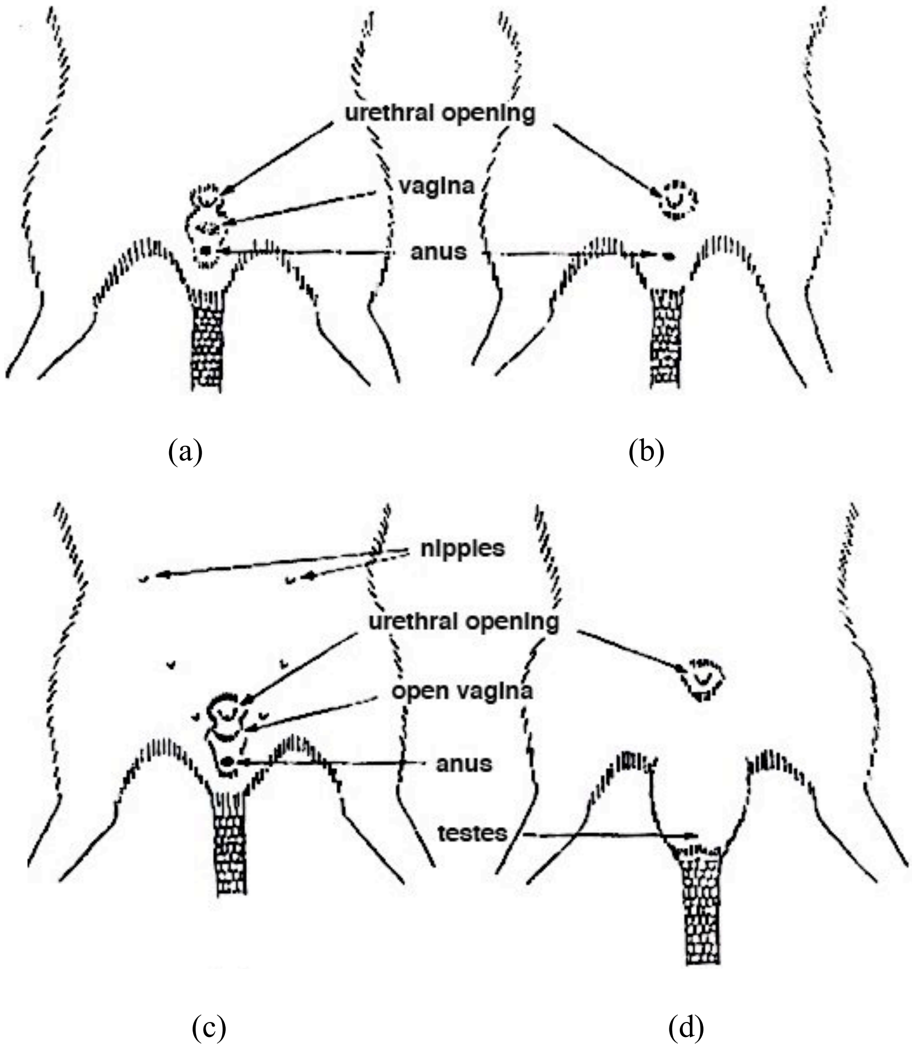

Figure 7. Comparison of external sexual features of immature and mature rats.

(a) Immature female. The urethral opening is close to the anus and the vagina is covered with a hairless patch of translucent skin.
(b) Immature male. The urethral opening is further form the anus than in immature females and there is no hairless patch. In both sexes the urethral opening is on a small protrusion.
(c) Mature female. The vagina is open or secondarily closed. Nipples are present but may be hidden in the fur if the animal is not breeding.
(d) Mature male. The testes are in the scrotum, which hides the anus and is bald at the rear. Modified from Cunningham and Moors (1983).

Rats were identified to species level by diagnostic features from Cunningham and Moors (1983). It was found that belly fur and the presence of dark fur on the outside edge near the ankle on the hind feet were the best diagnostic feature to identify kiore (Figure 8). Other methods to distinguish between ship rat and kiore outlined by Cunningham and Moors (1983) proved unsatisfactory so additional morphometrics were investigated to ensure accuracy of identification.

Figure 8. External features of kiore that distinguish them from ship rat, found at Port Fitzroy, Great Barrier Island in August 2008. Left photo shows white tipped grey fur of the belly of kiore that appears mottled. Right photo shows the pelage colouration of the kiore hind foot. Note the distinctive dark strip near the ankle indicated by the red line. Photographs by author.

All ship rats were identified to their respective colour morphs corresponding to their former subspecific names (viz *frugivorus* = agouti/white, *alexandrinus* = agouti/grey, and *rattus* = black) using dorsal and ventral colouration from Tomich and Kami (1966). Examples of the three morphs observed in this study, which were used as a reference for further colour morph identification are shown in Figure 10.

2.3.3 Data analysis

All statistical tests were conducted in Graphpad Prism 5.0 for Macintosh, Graphpad software, Sandiego, California, USA, unless otherwise stated.

2.3.3.1 Population dynamics

The catch rates of ship rat colour morphs over all nights were compared within grids using a *G*-test with the Williams' correction factor. The proportions of ship rat morphs caught were compared in each grid between nights 1-3 and 4-6 using a chi-square test. The total proportions of gender and age class were compared within grids for kiore and ship rat using chi-square test with Yates' correction for continuity, where there were sufficient data. The capture rates between nights (1-3, 4-6) were compared for gender, and age class using chi-square tests corrected with Yates' correction for continuity.

Figure 9. The three colour morphs of ship rat found during the removal experiment at Port Fitzroy, Great Barrier Island in August 2008. From left "*alexandrinus*", "*frugivorus*" and "*rattus*". Photograph by author.

2.3.3.2 Rat density estimation

Trapping data were corrected according to Nelson and Clark (1973) for occasions where traps were tripped without capture (sprung empty), where bait was removed without the traps being tripped (bait-gone) and where mice (*Mus musculus*) were caught. As “sprung”, “bait-gone”, and “mice” traps reduce overall trap availability to rats (Nelson and Clark 1973), this calibration reduces the number of trap nights to account for this effect. The numbers of each rat species recovered per day were converted to the unit “catch per/100 trap nights” using the formula;

$$\text{Rats caught/100 nights} = \frac{\text{number rodents caught x 100}}{\text{corrected trap effort}}$$

A simple linear regression between the numbers of rats caught per night and the cumulative number of rats removed was calculated with 95% confidence intervals. The regression gave 95% confidence estimates of rats present in the grid before trapping began at the y intercepts i.e. no animals had yet been removed. These confidence estimates were divided by the effective trapping area (17ha and 15.9ha) to calculate density estimates with 95% confidence. In addition, the minimum rat density estimates were calculated for each grid by dividing the total number of rats caught by the effective trapping area. The minimum density estimates and the upper 95% confidence intervals were considered to be the range of rats present in each grid. The rat densities on each subsequent night of trapping were calculated as the average of the density at the end of trapping on the previous night, and the density at the end of the current night (Brown et al. 1996), so the changing densities could be calibrated with the changing tracking tunnels rates. The proportions of rats caught between nights (1-3, 4-6) were compared for core vs. edge traps (to test for immigration into the grid) using chi-square tests corrected with Yates’ correction for continuity.

2.3.3.3 Tracking tunnel calibration

Rat tracking rates and estimated ship rat densities were calibrated by plotting the nightly tracking rates against the absolute ship rat densities estimated to be present on each subsequent night of the removal experiment (as per Brown et al. 1996). Rat species were grouped for tracking rates as we could not differentiate between species using prints. Because capture and tracking were almost nil in both treatment grids, it was not possible to correlate the tracking rates with estimated densities in these grids. A simple linear regression describes the best fit of data for this relationship.

2.3.3.4 Response of kiore

The proportions of ship rat and kiore caught were compared between grids using a Fishers exact test due to the small numbers of kiore in the Hairpin grid. The proportions of kiore and ship rats caught were compared between nights 1-3, and 4-6 in the Shop grid using chi-square tests with Yates' correction for continuity to test if more kiore were caught as ship rats were progressively removed.

2.4 RESULTS

2.4.1 Rat morphometrics, identification and population dynamics

2.4.1.1 Kiore identification

The ratio of tail length to head-body was measured for rats as described by Cunningham and Moors (1983), although it was not definitive as an identification tool. Since Ruscoe (2004) and Golding (2008) highlighted that there can be confusion and misidentification between ship rats and kiore, further morphometrics were investigated for this study. It was discovered that the ratio between the length of hind foot (HF) and head body length (HBL) separated kiore from ship rats when graphed against the HBL (Figure 10). Accordingly, the external diagnostic identity features were cross-referenced with this novel morphological approach.

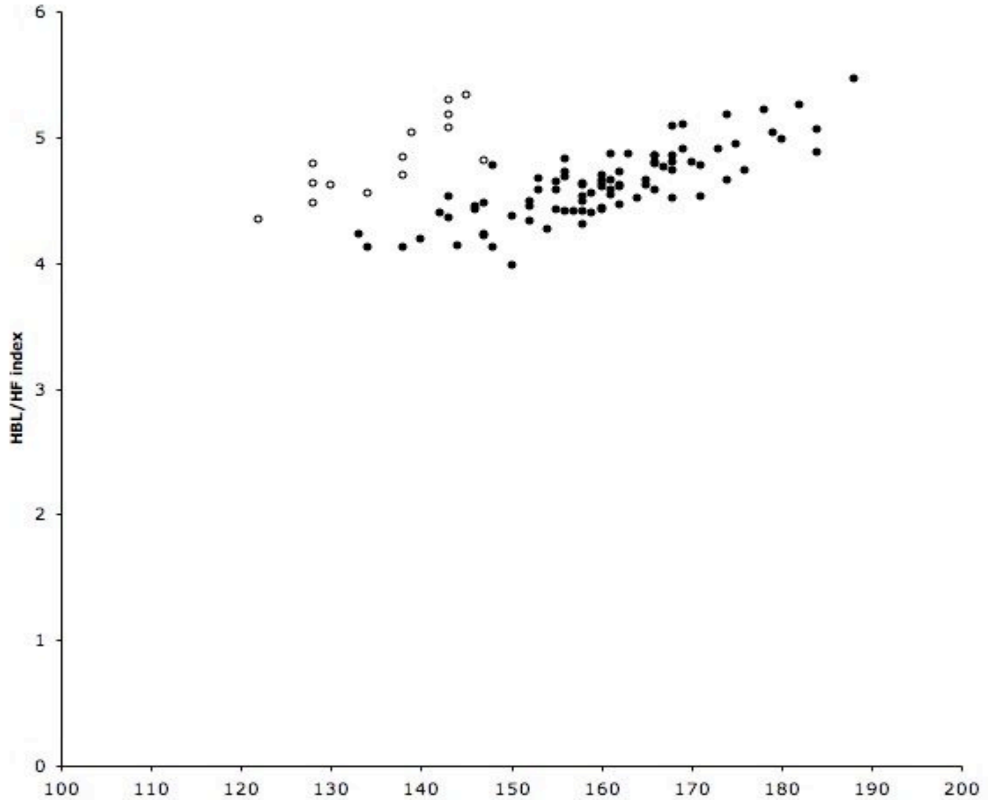

Figure 10. The relationship between the head body length (HBL) and the proportion of HBL/hind foot length (HF) found during the removal experiment at Port Fitzroy, Great Barrier Island in August 2008. Kiore and ship rat have a different relationship between these two measures, which was used to cross reference against the external feature identifications. Open circles: kiore; filled circles: ship rats.

2.4.1.2 Ship rat population dynamics

Only one mature female ship rat was caught in the treatment grids during the entire removal experiment. In the unmanaged grids, 33 ship rats were caught in the Shop grid and 51 ship rats were caught in the Hairpin grid. In the unmanaged grids the overall sex ratios (male:female) were 1.2:1 and 0.82:1 in Shop and Hairpin respectively. Chi-square analysis revealed that sex ratios were not significantly different from unity at either Shop or Hairpin ($\chi^2_1 = 0.12$ & 0.31 respectively, $P > 0.05$), and the proportions did not vary over the trapping period ($\chi^2_1 = 0.03$ & 0.11 respectively, $P > 0.05$).

There were more adults caught than juveniles in both unmanaged grids (94% and 6% respectively in Shop grid; 86% and 14% respectively in Hairpin grid). Chi-square analysis indicated these were significantly different in both the Shop and Hairpin grids ($\chi^2_1 = 22.78$ & 25.41 respectively, $P < 0.01$). Adults and juveniles remained equally trappable throughout the trapping period in Shop and Hairpin grids ($\chi^2_1 = 0.33$ & 0.62 respectively, $P > 0.05$).

The percentages of colour morphs (*frugivorus, alexandrinus, and rattus*) caught in the unmanaged grids were 49%, 30% and 21% for Shop grid respectively, and 43%, 22% and 35% for Hairpin grid respectively. Chi-square analysis indicated these proportions of morph did not differ significantly from unity in either Shop or Hairpin ($\chi^2_2 = 3.68$ & 3.78 respectively, $P > 0.05$), nor did the proportions vary throughout the trapping period (days 1-3, and 4-6) ($\chi^2_2 = 1.65$ & 0.50 respectively, $P > 0.05$). No female ship rats caught during the removal experiment were lactating.

2.4.1.3 Kiore population dynamics

Kiore were caught in both unmanaged grids during the removal experiment although only one mature female was caught in the Hairpin grid. No kiore were caught in the treatment grids. The overall sex ratio (male:female) of kiore in the Shop grid was 0.86:1. Chi-square analysis revealed sex ratios were not significantly different from unity ($\chi^2_1 = 0.00$, $P > 0.05$) in the Shop grid. The sex ratios in the Shop grid were similar throughout the trapping period; 2 males and 3 females caught on days 1-3, and 4 males and 4 females caught on days 4-6 although the sample size was too small to compare statistically. All kiore appeared to be adult based on external features. No female kiore caught during the removal experiment were lactating.

2.4.2 Rat density estimation

In both unmanaged control grids, ship rat catch rates declined over time as was predicted (Figure 11). This allowed sound density estimates of ship rats. There was only one ship rat capture in the treatment grids, which suggest that the densities were very low throughout the removal experiment and continued trapping would have had limited value for density estimates (Figure 11).

The estimated ship rat densities derived from the regression between nightly catch of ship rats and cumulative number removed (Figure 12) were different between the treatment and control (Table 1), and were highest in the Hairpin grid. The absolute density range in the Hairpin grid was between 3.00 and 3.26 rats ha^{-1}, and between 1.94 and 1.97 rats ha^{-1} in the Shop grid. Estimated ship rat densities obtained in the treatment grids were essentially zero, although rats are known to occur at both sites albeit at low numbers (Barr unpublished data).

The proportions of ship rats caught in the core vs edge traps did not change throughout the trapping period (between days 1-3 and 4-6) in either unmanaged grids; Shop grid (chi-square $\chi^2_1 = 1.38$, $P > 0.05$) and Hairpin (chi square $\chi^2_1 = 0.004$, $P > 0.05$).

Table 1. Total number of ship rats caught (*n*) and density estimates, based on removal trapping at four sites on Great Barrier Island in August 2008. The range of ship rats is considered to be between the minimum density and the upper 95% confidence interval estimates (in bold).

Treatment	*n*	Minimum density (rats ha^{-1})	Estimated density (rats ha^{-1})	Lower 95%	Upper 95%
Glenfern walk	1	0.06	0.00	0.00	0.00
Fenceline	0	0.00	0.00	0.00	0.00
Unmanaged control					
Shop	33	1.94	1.79	1.61	1.97
Hairpin	51	3.00	2.94	2.61	3.26

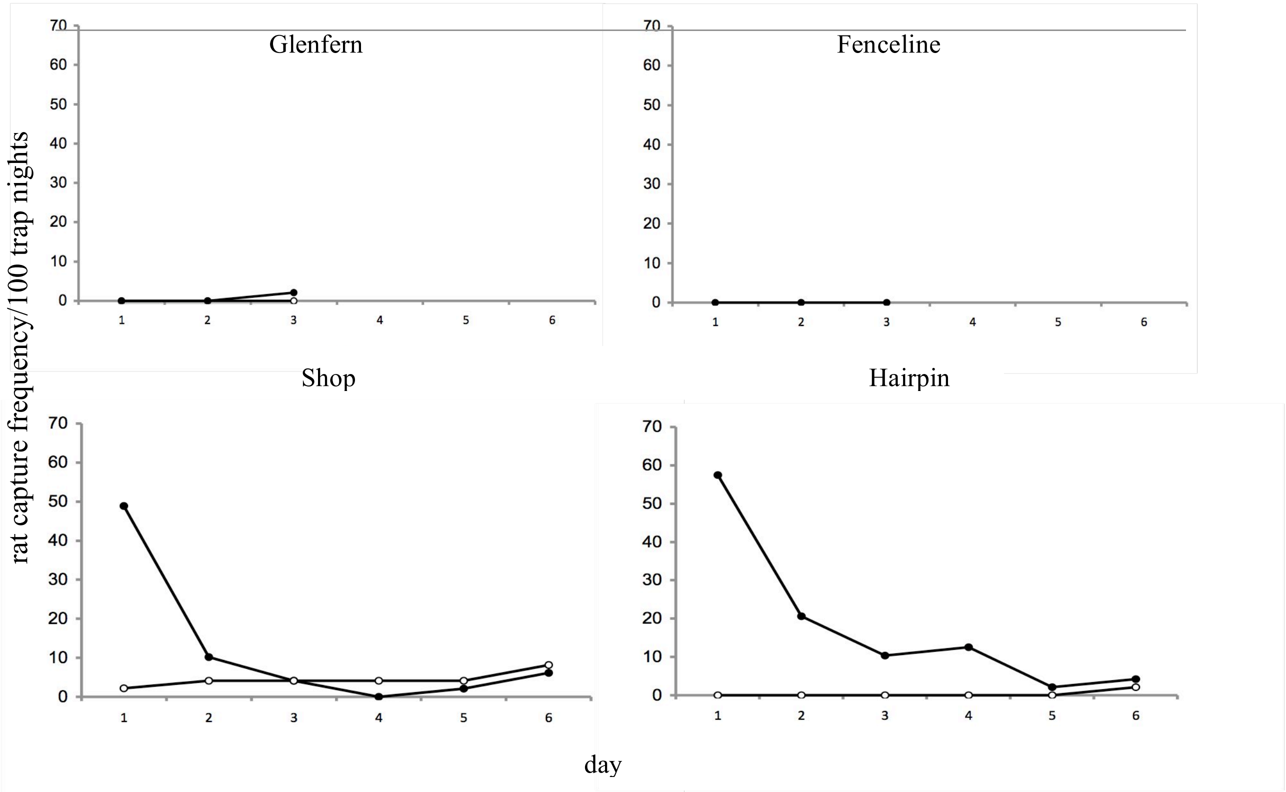

Figure 11. Catch rates/100 nights for kiore (open circles) and ship rats (closed circles) on four experimental removal grids in Port Fitzroy, Great Barrier Island in August 2008.

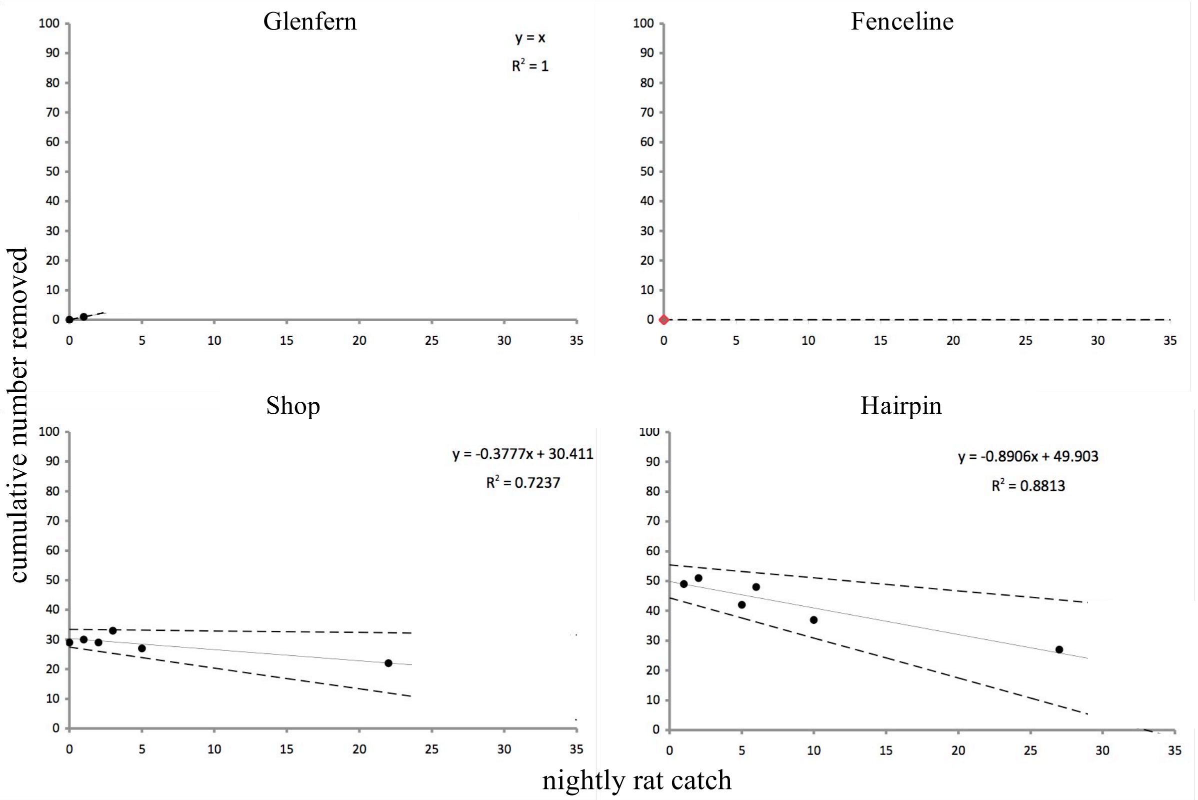

Figure 12. The relationship between nightly catch of ship rats and cumulative number removed in four experimental removal grids at Port Fitzroy, Great Barrier Island in August 2008. The solid lines give the simple linear regressions, and the dashed lines give the upper and lower 95% confidence intervals.

2.4.3 Tracking tunnel calibration

The nightly rat tracking rates were plotted against estimated densities of ship rat on each successive night of the removal experiment for all grids (Figure 13), and a regression was run in Excel to define the relationship. The regressions in the unmanaged control explained 93% of the variance in the Shop grid and 92% for the Hairpin grid (Figure 13). Generally correlations of this nature are forced though zero on the assumption that both indices should register zero in the absence of rats.

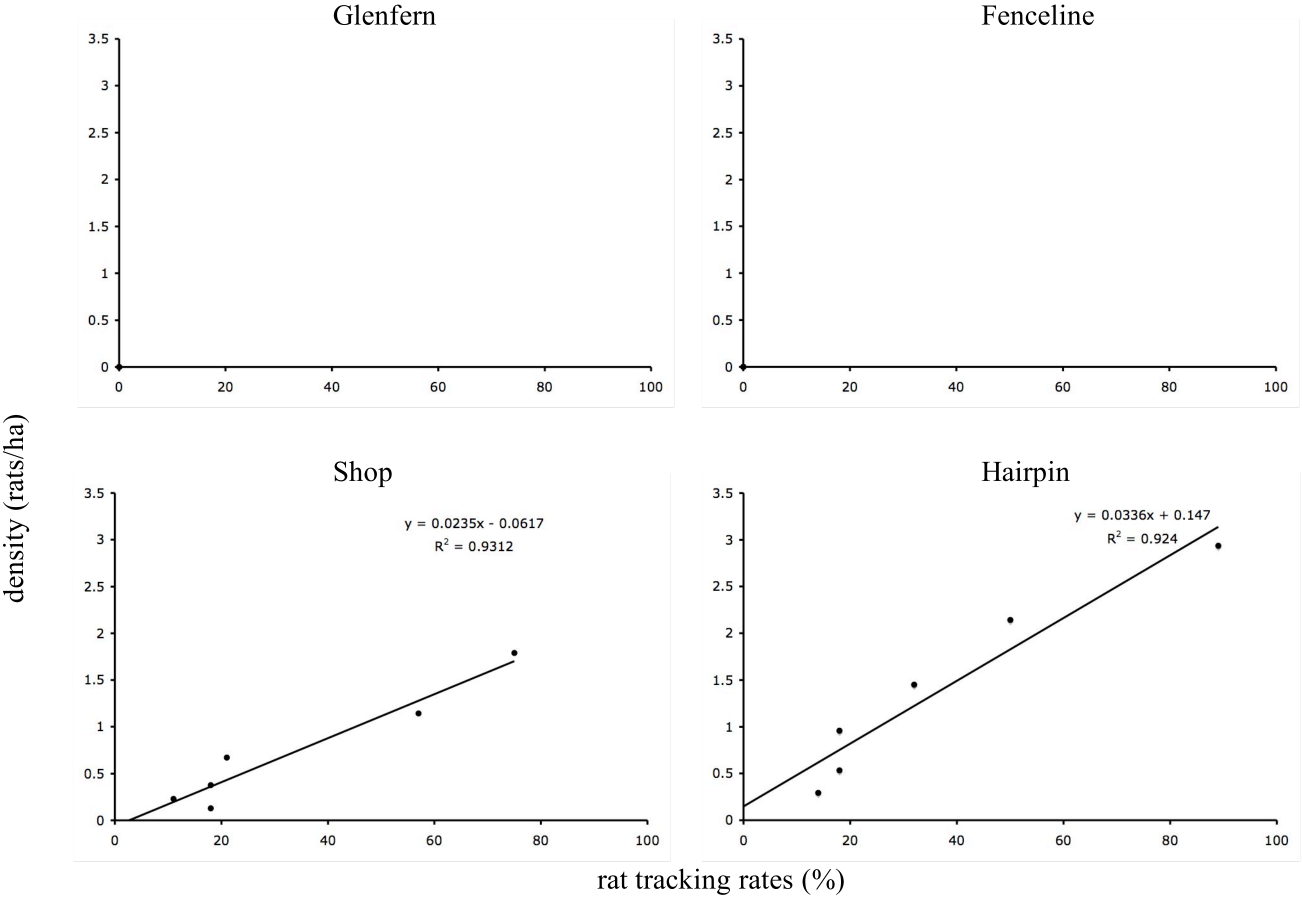

Figure 13. Correlation of nightly rat tracking rates and absolute densities for four experimental removal grids at Port Fitzroy, Great Barrier Island in August 2008.

2.4.4 Response of kiore

Ship rats and kiore were caught in both unmanaged control grids. Only one ship rat was caught in the treatment grids during the entire removal experiment. In total, 33 ship rats and 13 kiore were caught in the Shop grid; 51 ship rats and 1 kiore were caught in the Hairpin grid. Significantly more ship rats were caught than kiore in both unmanaged grids; Shop and Hairpin (chi-square; $\chi^2_1 = 7.85$ & 46.17 respectively, $P < 0.01$). Proportionally more kiore were caught in the Shop grid than in the Hairpin grid, and the difference was highly significant ($P < 0.01$). In contrast to ship rats, the catch rates of kiore increased over time in the Shop grid (Figure 11) and the difference in proportion caught relative to ship rats throughout the trapping period was highly significant (chi-square; $\chi^2_1=9.388$, $P < 0.01$). This confirms that kiore were more trappable as ship rats were removed. Accordingly, they were excluded from density estimates as Zippin's removal method (Zippin 1958) assumes constant probability of capture.

2.5 DISCUSSION

2.5.1 Rat density estimation

The density estimates obtained from this study using Zippin's removal method (Zippin 1958) confirm that extensive rodent control has been successful in reducing rat densities in Glenfern Sanctuary and there is a clear difference between the treatment and control in terms of ship rats. Capture rates of rats in the treatment area gave density estimates that were zero or very close to (as only one rat was caught between both grids), although rats are known to be present there in low densities based on previous tracking (Barr unpublished data). Assuming there is a small remnant population of rats in both treatment grids, it is probable that the actual density (expressed as rats/ha) is very close to zero but cannot be adequately defined using the removal method due to sensitivity of the method. Similarly, tracking tunnels were not sensitive enough to register these low densities. This study is the first (as far as is known) that has attempted to estimate absolute rat density in an area where predator control has been undertaken so comparisons cannot be made with other studies.

The chief assumptions of this method are: 1) the population must be stationary, i.e., the joint effect of births, deaths, emigration and immigration must be negligible during the experiment, 2) the probability of capture remains constant throughout the experiment and trapping conditions remain the same and 3) the probability of capture during the experiment is the same for each animal exposed to capture (Zippin, 1958).

It is unlikely that births and deaths had an impact on our results due to the short time frame of the experiment. It is possible that immigration (as opposed to emigration) could have impacted these results due to a "vacuum effect" described by Brown et al. (1996). Innes and Skipworth (1983) and Hickson et al. (1986) demonstrated that rats expanded their territories as quickly as two nights after the adjacent area was vacated due to trapping. Conversely it is unlikely that rats would leave an area that was becoming less dense due to trapping, as there is more resources available and less competition. However, the fact that ship rat captures reached very low levels in the unmanaged control grids, and that there were tight confidences in the density estimates (at least for ship rats), suggest that the effect of immigration was limited. This was supported by the results comparing the proportions of rats caught in the edge and core traps between days 1-3, and 4-6. If immigration was occurring, the proportion of rats caught in edge traps would have been higher on days 4-6.

Weather conditions remained reasonably constant throughout this experiment (mixture of fine, drizzle and showers on most days with light to moderate SW winds), although it was slightly finer on night six. It is possible that the slightly elevated capture rates in the unmanaged control grids on night six were due to the finer weather. Again it was considered that the tight confidences of our density estimates suggest the effect of weather factors was minimal.

The probability of capture for males and females, age classes, and morphs was the same throughout the experiment for ship rats, as was the probability of capture of male and female kiore (no juveniles were caught and there are no kiore morphs). Considering there was a concomitant decrease in ship rat capture rate as trapping continued in the unmanaged control grids, which corresponded to the decreasing tracking rates, it can be assumed that capture probability for ship rats as a whole was constant. Therefore density could be correctly estimated. In contrast, the capture rates of kiore increased in both unmanaged control grids (although only 1 was caught in the Hairpin grid). In addition, the proportion of kiore caught relative to ship rats increased throughout the experiment, which demonstrates that kiore became more trappable as ship rat density decreased. Since the assumption of constant capture probability was broken for kiore, density estimates could not be determined for this species.

The results of this study are comparable with other studies using Zippin's removal method (Blackwell et al. 2002; Brown et al. 1996), as the assumptions were met and robust density estimates were achieved. The estimates of ship rat density in the unmanaged control grids in this study were lower than the two published estimates of unmanaged ship rat densities in New Zealand forest (4.8 rats/ha - Brown et al. 1996; corrected in Brown et al. 2004, 7.1 rats/ha Blackwell et al. 2002), although the difference might be due to a seasonal effect. Rat densities in New Zealand forest are known to differ throughout the year from low numbers in spring to a peak around autumn (Daniel 1972), so this study is estimating densities near their lowest ebb. It is also possible that the differences in density could be due to differences in the forest type, or the presence of other predators. Brown et al. (1996) and Blackwell et al. (2002) both conducted their experiments on the mainland in the presence of mustelids, and in differing forest types (broadleaf/hardwood forest with isolated podocarps in Brown et al.1996; tawa-podocarp forest in Blackwell et al. 2002). As so few studies have been completed using this technique, it is unclear what effect forest type and predator assemblage would have on rat density.

Care needs to be taken when associating the densities of rats obtained in this study with impacts to biota (in this case chevron skinks). The rat densities calculated in this study are an underestimate of the total rat densities as they exclude kiore. Furthermore, the results of this study suggest that kiore are distributed unevenly between catchments on Great Barrier Island, since the proportions of kiore and ship rats were significantly different between unmanaged catchments. Since densities of both rat species cannot be accurately quantified simultaneously, the actual impacts of rats (kiore and ship rats combined) should be considered in the knowledge that some areas will have greater kiore densities than others. Therefore the differences in rat densities between Shop and Hairpin grid are probably not as great as suggested by the ship rat densities alone as there were more kiore present in Shop grid.

In addition, the density estimates calculated in this study were gathered at a time of year when densities are known to be near their lowest. Therefore, when considering the impacts of rats to biota at this site, the densities of rats should be regarded as a minimum, and would probably higher during summer and autumn. The variation between peaks and troughs in the population in this population are unknown, but it is suspected to follow the relatively muted population peaks and variation patterns observed throughout New Zealand (Daniel 1978; Moors 1978).

2.5.2 Tracking tunnel calibration

The correlation of the two index methods used in this study allows greater confidence in the observed density trends between the treatment and control sites. In the treatment grids, tracking rates were zero in both grids, which corresponds with the estimated densities observed in those grids. In the unmanaged control grids, the linear regressions explained 93% and 92% of the variance between ship rat densities and tracking rates, signifying that absolute density estimates corresponded well with relative densities. The regression passes through both axes very close to the origin, which suggests that both indices are registering the real population relatively accurately on the basis that both should read zero when no rats are present (the mathematical origin). The close relationship between tracking rates and densities shown in this study however could be a seasonal phenomenon. Research suggests that rats, and in particular males have smaller home ranges during winter (Dowding & Murphy 1994). During breeding, males will move more frequently and further presumably for mating purposes, therefore tracking tunnels may be prone to multiple tracking by single rats during studies coinciding with breeding, therefore measuring activity levels as opposed to relative density (Wilson et al. 2007). The fact that no rats were lactating (similar to Daniel (1978)) suggests that the onset of breeding had not yet occurred in this study, therefore males would have been more sedentary than studies during summer.

One further factor that could have impacted on the correlation is that this study could not differentiate between kiore and ship rat footprints. Therefore the tracking rates probably represented a higher density than what was accounted for in the absolute density estimates, particularly in the Shop grid. Since the population of kiore is proportionally quite low, this effect is likely to be quite minimal particularly in light of the tight regressions between absolute ship rat densities and tracking rates.

2.5.3 Correctly identifying kiore

Historically there has been some confusion distinguishing between ship rat and kiore, particularly from inexperienced observers (Ruscoe 2004). In this study, the external diagnostic characteristics recommended by Cunningham and Moors (1983) were not always definitive. The tail lengths in relation to body length of kiore were similar to that of ship rat. Furthermore, tail damage was noted in some instances, which could lead to false identification of ship rat as kiore. This study found ventral and hind foot pelage colour to be the most useful, however wet and muddy animals presented problems in some cases. Using morphological measurements of HF and HBL proved to be helpful as a cross-reference in this study, and this technique is recommended if uncertainty is encountered in other studies. This feature may however be specific to the

GBI population of kiore and should be tested in other populations. This novel method also assumes accurate measurement and that HBL is not distorted by the method of capture.

2.5.4 Response of kiore

Many studies have suggested there is an interaction between kiore and ship rats (Atkinson & Moller 1990; Russell & Clout 2004; Yom-Tov et al. 1999). In this experiment the overall increase in kiore captures in the Shop grid, and the shift of capture proportions from predominantly ship rats early in removal to predominantly kiore late in the removal, suggest a response to ship rat removal. This study is the first to empirically demonstrate a response of kiore to ship rat removal, which supports the anecdotal observations suggested by these previous studies. The mechanism behind this response is likely to be interference competition from ship rats. A similar response was seen with kiore when Norway rats were trapped extensively on Raoul Island (Harper and Veitch 2006), and in mice when rats were progressively removed from a forest remnant in the central North Island of New Zealand (Brown et al. 1996). In addition Harris and MacDonald (2007) demonstrated interference competition between ship rats and Galapagos rice rats on the Galapagos archipelago.

Interference competition occurs primarily through territorial defence or aggressive encounter (Harris and MacDonald 2007). If kiore were being excluded from resources by ship rats through these mechanisms, then the reduction of ship rats should result in kiore using habitat and resources (in this case traps) more liberally thus increasing capture rates, as demonstrated in this study. It is unclear why kiore would range and forage differently when ship rat density decreases. It is possible that ship rats were spending more energy establishing new hierarchies and territories within their species following the removal of dominant individuals; or the pressure from each individual ship rat was the same, but there were insufficient ship rats to inhibit kiore behaviour completely.

Interference competition could also explain why there were significantly more kiore in the Shop grid compared with Hairpin grid. Since the estimated density of ship rats was higher in the Hairpin grid than the Shop grid (1.94-1.97 vs. 3.00-3.26 rats/ha), it is possible that interference competition from ship rats was limiting kiore numerically as well as behaviourally. This could explain why the response from kiore in Hairpin was muted i.e. there were so few kiore due to the higher ship rat densities that a behavioural response could not be observed. Extrapolating this idea, there could be a threshold of ship rat density above which interference competition excludes kiore completely. On a national scale, this could explain why kiore persist only in isolated areas of the mainland like the South West of the South Island (Ruscoe 2004; Golding 2008). The mere coexistence of kiore and ship rat on Great Barrier Island could be a function of ship rat density, which from this study appears comparatively low to other sites in New Zealand. Further research into densities of ship rats where kiore are present vs. where kiore are *no longer* present should be undertaken to clarify this concept.

2.6 SUMMARY AND CONCLUSIONS

Robust density estimates of ship rat were obtained, and confirmed that extensive rodent control in the treatment was successful in reducing rat densities; there was a clear difference in rat abundance between the treatment and control. The absolute density estimations (Zippin's removal method) and the relative density index (tracking tunnels) showed an strong positive correlation. Accordingly there is confidence in the observed trends between the treatment and control. Furthermore, this study demonstrated empirically that kiore are subordinate to ship rats and respond behaviourally to their removal, which is likely to be indicative of interference competition by ship rats towards kiore. The implication of this is that even though density estimates may be satisfactorily obtained for one rat species in a mixed species assemblage, this estimate will be an underestimate of the actual rat density, as there will be no estimate for the subordinate species. The inaccuracy will be smaller where the subordinate species population is low, and greater where the subordinate species population is high. In this study, the population of the subordinate species (kiore) was low, and didn't appear to greatly influence the outcomes of the study; as evidenced by the significant correlation when calibrating the two indexing methods. Regardless, this finding emphasises that caution needs to be taken when interpreting rat densities and their impacts on fauna in mixed rodent populations. The dominant species should adhere to the assumptions of density estimation, and catch rates will be a function of cumulative trapping effort. The subordinate species will not necessarily adhere to the assumptions of density estimation and catch rates will be a function of dominant species density. This study showed that kiore behave as a subordinate species to ship rat, although they can coexist with ship rats at some level. Kiore may only be able to coexist with ship rats below a certain ship rat density threshold above which interference competition is too great.

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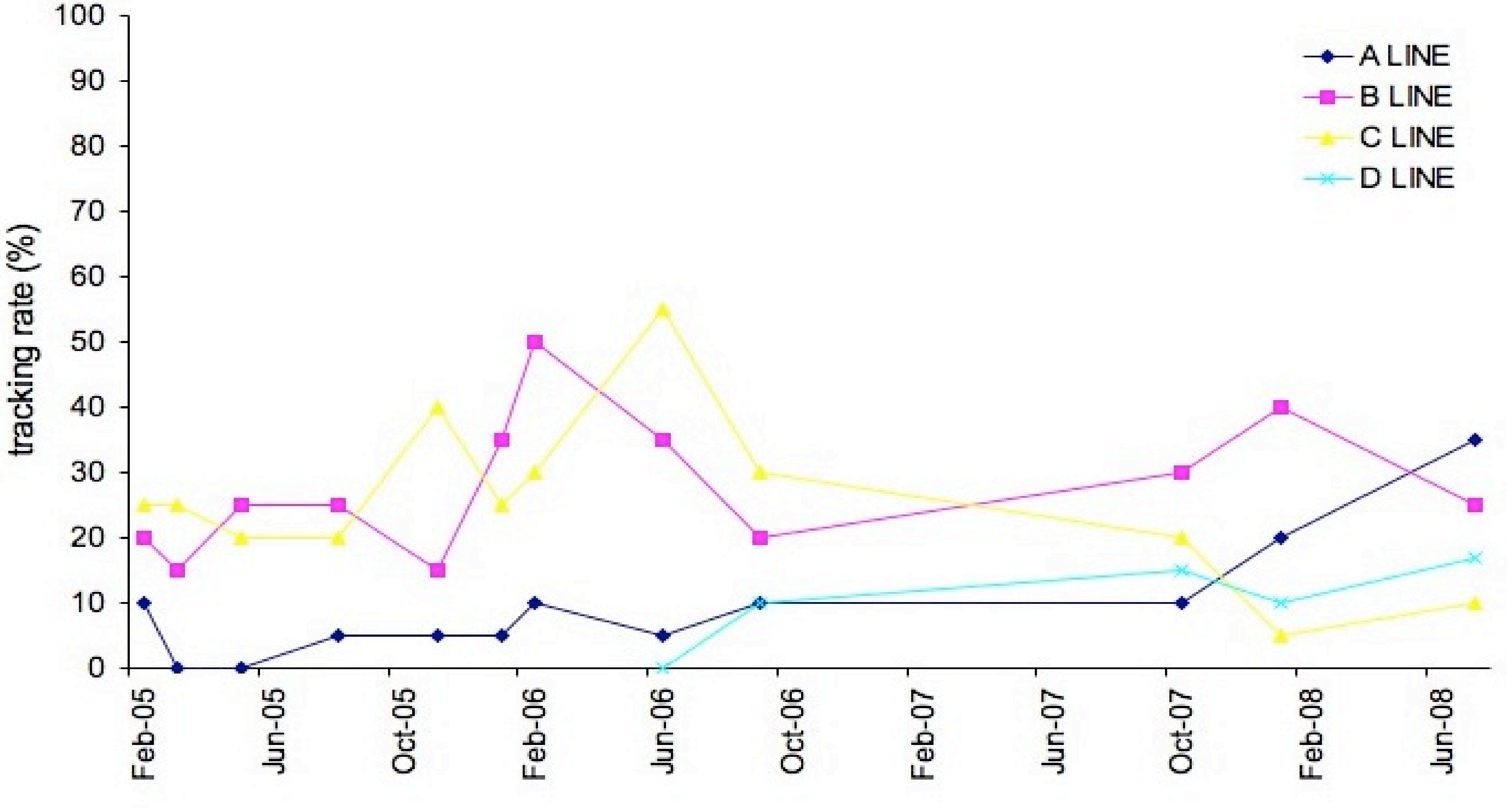
2.8 APPENDIX

Appendix 1. Rat tracking rates (% of tunnels tracked) at four separate tracking lines between February 2005 and August 2008 at Glenfern Sanctuary in Port Fitzroy, Great Barrier Island.



Chapter 3 The impacts of rats on chevron skinks: population structure and condition, and physical evidence of rat predation.

3.1 ABSTRACT

The precise nature of the threats to much of New Zealand's lizard fauna are currently unresolved. Patterns of population decline, range contractions and extinctions suggest introduced rats have had significant impacts on the reptile fauna of New Zealand. However, in many cases the mechanisms of these impacts are inferred but unproven. The chevron skink (*Oligosoma homalonotum*) is one such lizard where the precise threats, and the extent of their impacts, have not yet been established. This study endeavoured to determine the impacts of rats on chevron skinks. The population structure and condition of chevron skinks were compared between an area of extensive rodent control with low rat densities, and an unmanaged area with high rat densities. The population structure showed erosion of juvenile and sub-adult size categories in the areas of high rat density, resulting in reduced recruitment. Rats also appeared to impact the condition of chevron skinks. A novel method was investigated which quantified the extent of tail loss using a ratio of tail length to snout-vent length (SVL) – the body-tail condition (BTC) index. In the presence of high rat numbers, adult chevron skinks were found to have a significantly lower BTC index than smaller size categories, while this condition index remained stable across all size categories when rat numbers were low. In addition to the differences observed in population structure and condition, sublethal injuries were observed in two adult chevron skinks. These sublethal injuries were consistent with rat attack, and provided physical evidence that rats are probable predators of chevron skinks. The observed survival of these two adult chevron skinks suggests that at least a proportion of adults can survive attempted rat predation. The cost of these attacks to adults appeared to be tail loss, and other non-specific damage including eye damage, minor cuts and punctures. Smaller skinks are not expected to survive these attacks. Improved recruitment into the treatment population should see the population recovering in the medium term. In the unmanaged area, the erosion of juvenile and sub-adult size classes combined with reduced condition of adult skinks could impact the overall fitness of the population, and may result in its decline.

3.2 INTRODUCTION

3.2.1 Impact of rats to New Zealand lizards

3.2.1.1 Extinctions, range contractions and recruitment failure

The introductions of rats appear to have had extensive impacts on the unique reptile fauna of New Zealand (Towns 1994). On a national scale, Towns and Daugherty (1994) have shown that the patterns of extinctions (both localised and complete) and range contractions of New Zealand's herpetofauna coincided with the arrival of humans, and in particular their commensal species, rats. These impacts dictate that when rats are present in an area, the diversity of lizards will be lower and the overall densities of lizards will be significantly reduced when compared to an area free of rats (Whitaker 1978).

The broad impacts of rats on New Zealand reptiles (extinctions, range contractions and population declines) has often been implied through examining the differences in lizard abundances between 'rat islands' and 'non-rat islands' (Towns & Daugherty 1994; Whitaker 1978). However, there are only a few examples that identify the causal mechanism of these impacts (Towns et al. 2007). Cree et al. (1995) demonstrated that kiore inhibit recruitment in tuatara (*Sphenodon punctatus*) populations by competing for food, and preying on eggs and juveniles. They suggested that the low recruitment observed in the population structure of tuatara would eventually lead to their localised extinction on rat-inhabited islands. Similarly, Hoare et al. (2007) observed the population structure of Duvaucel's geckos (*Hoplodactylus duvaucelli*) was skewed towards adults on islands with kiore (*Rattus exulans*), when compared with kiore free islands, and recruitment was very low. They suggested that larger geckos were probably surviving rat predation attempts due to their size where juveniles were not. However, despite the survival of large geckos it was possible that recruitment failure could drive the geckos to extinction (Hoare et al. 2007).

3.2.1.2 Condition and sublethal injuries

Beyond the broad scale patterns of population declines and extinctions, there are even fewer published examples of the sublethal impacts of introduced fauna on reptile populations in New Zealand, such as sublethal injuries and reduced condition. Cree et al. (1995) measured the body weight of tuatara to determine if they were being out-competed for food in the presence of rats, but found no difference. In contrast, Towns et al. (2007) found that tuatara improved in condition after the eradication of kiore from some islands.

Published work in New Zealand that compares sublethal injuries between differing rat densities is also scant. Tyrell et al. (2000) attempted to look at tail loss and eye damage in tuatara between 'rat' and 'non-rat' islands however their results were probably confounded by seabird densities, which appeared to be a causal factor in the injuries. Jo Hoare (unpubl. data) noted that Duvaucel's geckos had significantly higher incidences of tail loss in the presence of rats (Ōhīnau Island) than in the absence of rats (Korapuki Island). High rates of tail loss were also found in the Duvaucel's gecko population on Green Island although they seemed to be confounded by failed tuatara predation (Jo Hoare pers. comm.).

3.2.1.3 Caudal autotomy in lizards

In lizards, tail loss or 'caudal autotomy' refers to the voluntary shedding of the tail (Bateman & Fleming 2009) and is common to many species of skink, including the chevron skink. The tail is dropped quickly at a breakage plane, which is thought to be controlled either hormonally or by the central neural system (Bateman and Fleming 2009). The regenerated tail lacks fracture planes, therefore subsequent autotomies occur at the same breakage point or more proximally (Chapple & Swain 2004). Tail loss generally occurs as a response to attempted predation (Diego-Rasilla 2003), and can therefore be a useful indicator of condition in relation to predation attempts; although other triggers exist including intraspecific competition (Jennings & Thompson 1999) and possibly interspecific competition.

Escaping predation through tail loss is considered to be the primary tactic lizards use to escape predators (Downes & Shine 2001). The shedding of a tail allows the lizard to break away from a predator, particularly if it has been grasped by the tail (Bateman and Fleming 2009). The lizard tail is often an important reserve of lipids and energy that sustains an animal through lean times (Avery 1970). To minimise loss of energy reserves but to ensure escape, the tail is dropped between one and three vertebrate anterior to the grasping point (Arnold 1984). To further distract the predator, the tail may wriggle and squirm while the lizard makes a retreat (Pafilis et al. 2005). Perhaps the most extreme and fascinating example of a lizard tail distracting predators is the chameleon gecko (*Carphodactylus laevis*), whose dropped tail makes audible sounds similar to a rodent distress call (Wilson & Swan 2003).

When faced with an impending attack, some lizards will divert attention to the tail as it is considered dispensable. By curling, vibrating or undulating their tail in the presence of predators, lizards will focus the attack away from vital areas such as the head and body (Cooper 1998; Mori 1990). This behaviour has been observed in the chevron skink when the tail is touched lightly during handling (pers. obs.).

3.2.2 Research objectives

Conservation pracititioners have identified a need to quantify the impact of rats on indigenous fauna to supply evidence to support large-scale control programmes and eradications of rats (Towns et al. 2006). Specifically to chevron skinks, two of the key objectives for chevron skink recovery outlined in the Department of Conservation *Oligosoma* Species Recovery Plan (Towns et al. 2002) are to provide information on their vulnerability to predation and to measure the cost effectiveness of rodent control. Accordingly, this study endeavoured to quantify the vulnerability of chevron skinks to rats by examining the difference in the population structure and a condition index (related to tail loss) of chevron skinks between an area of intensive rodent control with low rat densities, and an unmanaged area with high rat densities.

3.3 METHODS

3.3.1 Study area

This study was carried out at Port Fitzroy (36° 16′ S, 175° 36′) on Great Barrier Island (27 760 ha) in the Hauraki Gulf, New Zealand (Chapter 2; Figure 2). Port Fitzroy is located approximately 90km NE from Auckland city. Unlike mainland New Zealand, Great Barrier Island (GBI) is free from introduced mustelids, hedgehogs (*Erinaceus europaeus*), Norway rats (*Rattus norvegicus*) and brushtail possums (*Trichosurus vulpecula*) (Towns & McFadden 1993) and goats (*Capra hircus*) were eradicated in 2006. Pigs (*Sus scrofa*), cats (*Felis cattus*), and three rodent species (ship rat, *Rattus rattus*; kiore, *R. exulans*; and mice, *Mus musculus*) are all relatively common on the island (pers. obs). Native lizard predators are widely distributed on GBI including kingfisher (*Halycon sancta*), banded rail (*Rallus philippensis*) and morepork (*Ninox novaeseelandiae*). The vegetation of GBI is predominantly scrub forest with manuka (*Leptospermum scoparium*) and kanuka (*Kunzea ericoides*) that has been regenerating since the 1940's (Ogden et al. 2006). It contains pockets of lowland mixed coastal broadleaf, and lower and upper montane forest (Ogden 2004).

3.3.2 Study design

Comparisons of chevron skink populations were made between two treatment catchments and two control catchments. The treatment catchments were located on private land (Glenfern Sanctuary) on Kotuku peninsula (230ha) in an area that has undergone extensive rodent control since 2001 (section 2.3.1.1). Haphazard cat control was intermittent at Glenfern Sanctuary, although it is doubtful this has had a significant or lasting impact on the resident cat population. The control catchments were located within the Northern Great Barrier Forest Conservation Area (368ha, DOC reserve 118), where rats were unmanaged. Catchments were chosen on the basis that chevron skinks were known to be present within them (see section 3.3.3.1). Further prerequisites for the study sites were: the stream system had to contain sufficient microhabitat (as described in Neilson et al. 2006) and be long enough to accommodate the monitoring units. Data were collected between January and May 2008.

3.3.3 Study sites

3.3.3.1 Pilot study

A pilot study was conducted in the region of Port Fitzroy, Karaka Bay and Akapoua Bay (Figure 14) in January 2008 to locate suitable study sites where chevron skinks were present. Initially catchments were scouted to locate streams with suitable microhabitat (mainly debris dams, suitable vegetation), stream characteristics (rocky or partially rocky, narrow with running water) described by Neilson et al. (2006) and a length sufficient to accommodate monitoring units (dependent on the number of debris dams). Six streams were chosen (including one that was known to contain chevron skinks) and 10 G-minnow fish traps were installed in debris dams at each stream to detect the presence of chevron skinks (Figure 14). The first two streams in each of the treatment and control grids that were found to contain chevron skinks were chosen as the study areas. Trapping was discontinued at the remaining sites due to the time constraints of the study.

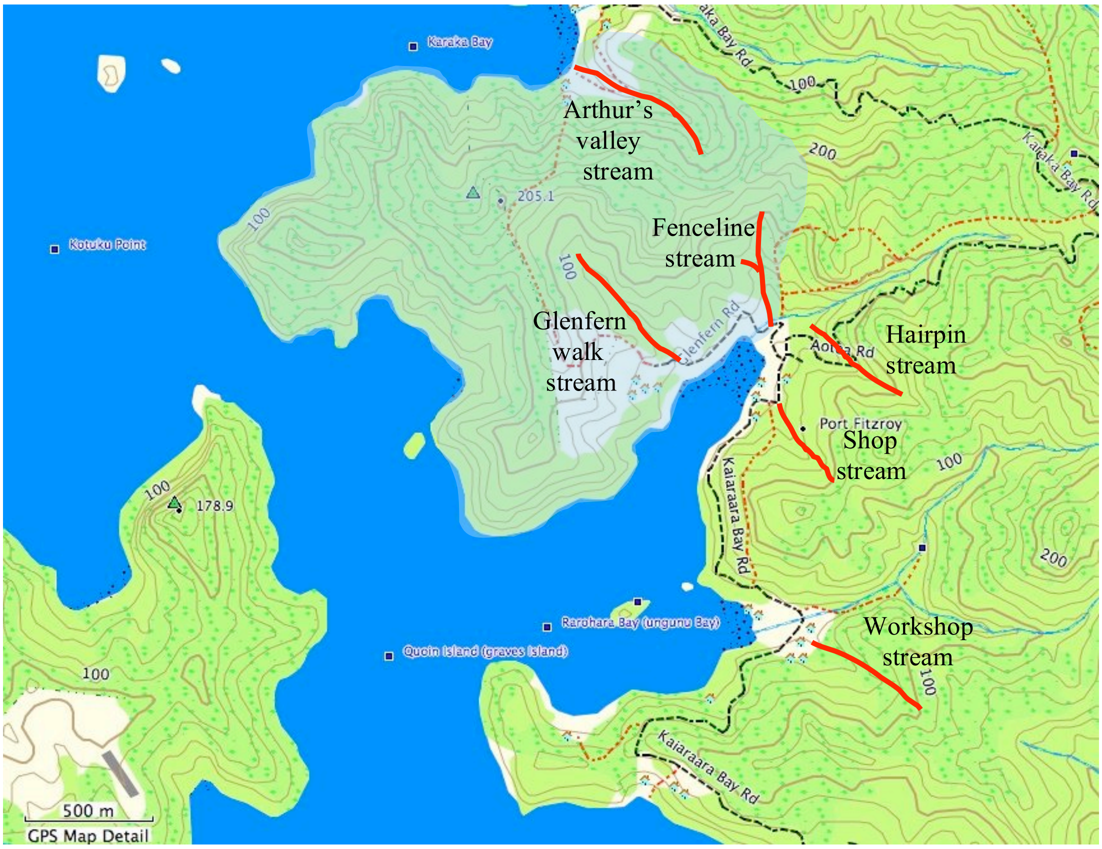


Figure 14. Pilot study stream sites searched for chevron skinks at Port Fitzroy, Great Barrier Island during January 2008. Ten G-minnow traps were installed in each stream (denoted by red line) until the presence of chevron skinks was confirmed. The light shaded blue area is the predator controlled area (Glenfern Sanctuary).

3.3.3.2 Treatment sites (rats managed)

The treatment study sites chosen for the full study were located on private land (Glenfern Sanctuary) on Kotuku peninsula (Figure 15).

Glenfern walk stream site starts from the northern side of Glenfern Rd approximately 70m from the high tide mark (Figure 15). The stream runs approximately SE and flows into Port Fitzroy. A water catchment dam approximately 250m from the high tide mark interrupts the stream. The dam is approximately 30m long and a maximum of 8m wide. A quad bike/pedestrian track crosses the stream via shallow fords and small wooden bridges at several points along the stream, although these do not alter the character of the stream greatly. Glenfern walk stream is predominantly rocky and has smaller tributaries running into it on either side. Below the dam, common plant species include kohehoke (*Dysoxylum spectabile*), tawa (*Beilschmiedia tawa*), puriri (*Vitex lucens*) and rewarewa (*Knightia excelsa*). Above the dam common plant species include kanuka, silver fern (*Cyathea dealbata*), hangehange (*Geniostoma rupestre*), mahoe (*Melicytus ramiflorus*), with intermittent puriri and nikau (*Rhopalostylis sapida*).

Fenceline stream site starts approximately 50m from Old lady stream (Figure 15). This stream has a distinctive fork approximately 180m from Old lady stream although both tributaries run approximately South. The stream feeds into Old lady stream approximately 50m above the high tide mark. The Fenceline stream is predominantly rocky and has some narrow clay gorges. The fork on the true left has some relatively large areas of bare rock, which create sloped waterfalls. Below the fork common plants include kanuka, silver fern, hange hange, mahoe, and pate (*Schlefflera digitata*). Above the fork common plant species include taraire (*Beilschmiedia tarairi*), nikau, rangiora (*Brachyglottis repanda*), mamaku (*C. medullaris*), kanono (*Coprosma grandifolia*), tawa and puriri.

3.3.3.3 Control sites (rats unmanaged)

The unmanaged control sites chosen for the full study were both located in the Great Barrier Forest Conservation Area (GBFCA) (368ha, DOC reserve 118). GBFCA is adjacent to Port Fitzroy and administered by the Department of Conservation (DOC).

Shop stream site starts approximately 50m south of Kaiaraara Bay Rd 120m from the high tide mark at Port Fitzroy (Figure 15). The stream runs NW and flows into Port Fitzroy. The stream is predominantly rocky although it has some areas of small stones and silt. A water catchment dam approximately 250m from the high tide mark interrupts the stream. The dam is approximately 10m long, 3m wide and is heavily silted. The stream has some small tributaries that flow into it from either side. Common plant species in the Shop site include kanuka, mahoe, silver fern, hangehange, mapou (*Myrsine australis*) and mamaku.

Hairpin stream site starts approximately 50m from the Old lady stream. The stream runs NW and flows into the Old lady stream approximately 200m from the high tide mark at Port Fitzroy (Figure 15). Aotea Rd dissects the stream approximately 250m from the Old lady stream. The Hairpin stream is predominantly boulders, although there are small sections of silt and small stones, and some flat rock sloped waterfalls similar to Fenceline stream. Common plant species in the Hairpin stream are kanuka, silver fern, mamaku and kanono.

Differences did occur between study areas, such as vegetation composition and aspect however the general structure of the forest was similar; relatively tall canopy with fern understorey. Although these differences could potentially reflect in different total densities based on resource availability they were considered not to affect the measures used in this study; population structure, skink condition, and sublethal injuries. Rat densities between study sites were considered to be the main factor likely to cause differences in these measures.

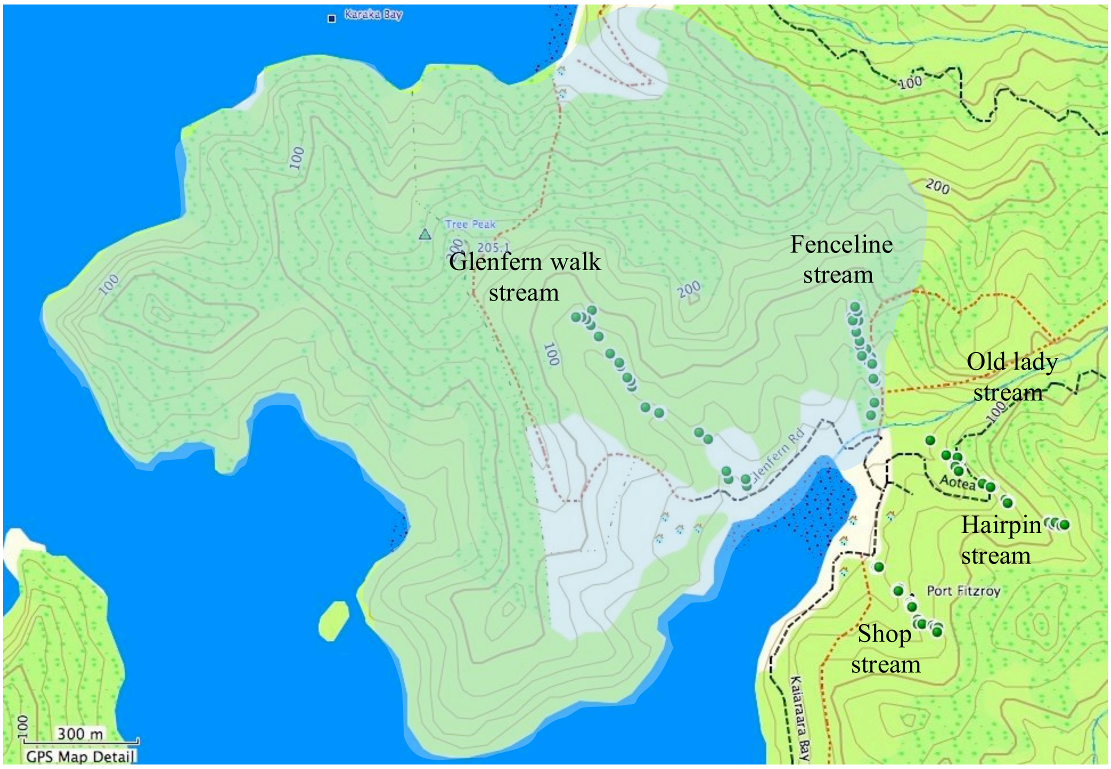


Figure 15. The four chevron skink study sites chosen from the pilot study. Green dots are locations of G-minnow traps established for chevron skinks at each study stream in Port Fitzroy, Great Barrier Island. G-minnow traps were run between January and April 2008. The light shaded blue area is the predator controlled area (Glenfern Sanctuary).

3.3.4 Rat densities[1]

3.3.4.1 *Treatment*

The treatment catchments both contained low densities of rats. Population estimates in Glenfern walk stream catchment were between 0.00 and 0.06 rats ha^{-1} (August 2008). Population estimates in Fenceline stream catchment were 0.00 rats ha^{-1} (August 2008). Despite these low population estimates, rats are known to occur at the sites in autumn and summer (Barr unpubl. data). Accordingly rats probably occur in both treatment catchments all year round albeit at very low (almost undetectable) densities.

3.3.4.2 *Control*

The unmanaged control catchments contained relatively high rat densities. Both catchments supported populations of kiore and ship rat. Ship rat densities in the Hairpin catchment were estimated to be between 3.00 and 3.26 rats ha^{-1}, and between 1.94 and 1.97 rats ha^{-1} in the Shop stream catchment. Kiore were more abundant in the Shop stream although there are no density estimates available for kiore.

3.3.5 Chevron skink sampling

Sampling of chevron skinks was undertaken using G-minnow fish traps (Part number MT 28. Aquatic Eco-Systems, Inc. 2395 Apopka Blvd. Apopka, FL 32703.). The MT 28 fish traps measured 41cm long with 3mm mesh. Mesh of this diameter allowed the containment of neonate chevron skinks (Halema Jamieson, pers. comm.). 25 traps were installed at each of the study stream sites. The locations of the traps were selective i.e. they were only installed in debris dams, as this is a preferred microhabitat for chevron skinks (Neilson et al. 2006) and has proved highly successful in recent trapping experiments (Jamieson & Neilson 2007). The distance between traps was not uniform and in some locations traps were clustered; in particularly large debris dams, or areas where debris dams were close together. Traps were filled with debris dam material and/or leaf litter to approximately one third full and baited with either banana or artificial lure (raspberry syrup; Jamieson and Neilson 2007) or aniseed powder enclosed in a semi-permeable bag). Traps were then placed either within or on debris dams and

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[1] For detailed information on rat densities refer to chapter 2.

covered with vegetation litter so the trap interior was shaded. Traps were tied to a tree or sturdy log to prevent them being washed away during flooding events.

Trapping was carried out between January and April 2008. Trapping periods were January 11 – 21, February 10 – 16, March 10 – 16, and April 18 – 24. Additional trapping was done in Hairpin stream from January 24 - 28, and in the Shop stream from February 24 - 28. Stream levels rose rapidly during heavy rain, so traps were closed to avoid accidental drowning of skinks at these times.

3.3.5.1 Morphological measurements

Morphological measurements were taken from all skinks including snout to vent length (SVL), vent to tail length (VTL), length of tail regeneration (TR) if tail loss had occurred (all measurements taken with standard plastic ruler ± 1mm), and weight (skinks weighed with 30g pesola scales to 0.5g; neonates measured on pocket digital scales to two decimal places). Photographs of the left side of the face and the chin were taken and catalogued to detect recaptures (Figure 17). Facial markings are known to be conserved between years in adult chevron skinks (Jamieson and Barr, unpubl. data), so it is assumed this feature is common to all adult skinks. Facial markings are known to be conserved between months in sub-adult and juvenile chevron skinks (Jamieson and Barr unpubl. data), and it is suspected that the markings are conserved between years.

3.3.6 Growth rates

The growth rates of skinks were calculated for animals recaptured over 3 months from their initial capture. The growth rate of individuals was calculated as;

growth rate(mm/day) = $[(SVL_2) - (SVL_1)] / (t_2 - t_1)$,

where t_1 and t_2 denote successive dates of measurement (after Connolly and Cree 2008).

3.3.7 Population structure

The total catch rates of chevron skinks were not compared. As there was no pre-treatment catch rate data it is possible that unknown differences between the treatment and control prior to treatment, such as predator abundances, caused differences in the total numbers of chevron skinks. In addition, not all biotic and abiotic variables such as vegetation type, aspect and catchment size were standardised between sites. It is possible that different habitats may naturally support different densities of chevron skinks; therefore direct comparisons of total catch rates could lead to false conclusions. Accordingly, to determine how rats impact chevron skink, the population structures in terms of catch per unit effort were compared between the treatment and unmanaged control sites (similar to Bell & Donnelly 2006; Hoare et al. 2007). Although the number of skinks in this study represent almost 30% of the known records, there were still insufficient numbers to statistically compare population structures effectively. Accordingly trends in the population structure were observed with these limitations considered.

3.3.8 Skink condition

The degree of tail loss was used to determine if there was evidence of failed rat predation events in the population. Theoretically the older an individual is the more likely it is to have been exposed to a predation event and to have incurred tail loss (Schall & Pianka 1980; Schoener 1979; Schoener & Schoener 1980). It therefore follows that older animals may incur tail loss multiple times and the effect on total tail length could compound, as an animal gets older. Accordingly, the difference in the extent of tail loss between size categories was tested within the treatment and control separately using a Kruskal-Wallis test. Individual size categories were compared between groups using a Mann-Whitney U test (Graphpad Prism 5.0 for Macintosh, Graphpad software Sandiego California USA). The extent of tail loss was given by the ratio of the total tail length:snout vent length, here after termed the 'body-tail condition index' (BTC) (Figure 16).

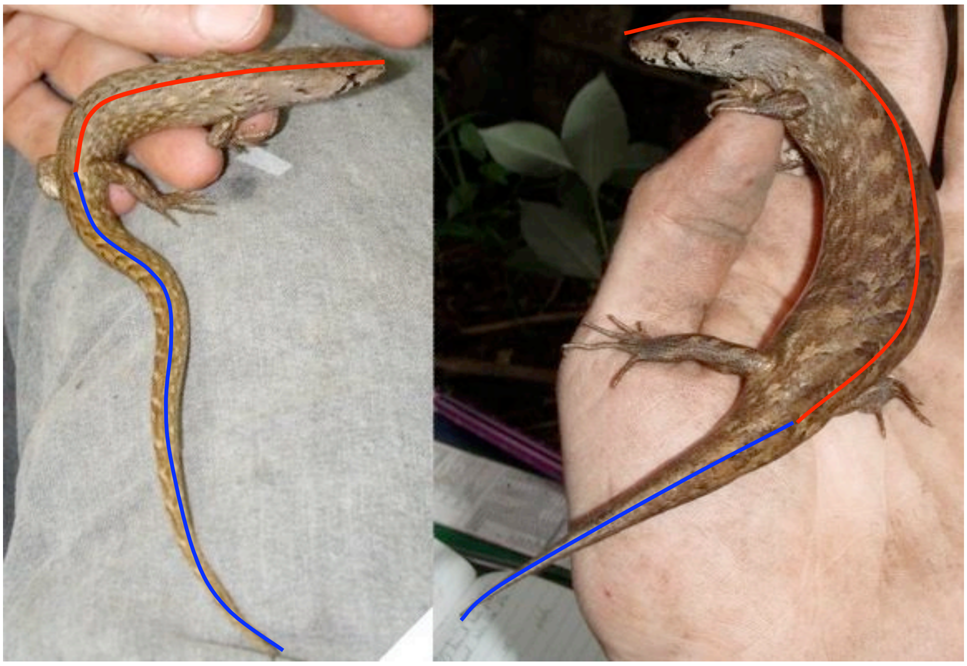

Figure 16. The ratio of total tail length:snout vent length for two chevron skinks. The body-tail condition (BTC) index = tail length(blue) /snout vent length(red). The skink on the left has an optimum condition index (1.47) and the skink on the right has a severely reduced condition index (0.45) due to tail loss.

DATE	SVL	VTL	TR	WEIGHT	LOCATION	TRAP ID
11/3/08	70	102	0	6.5	P-LINE	7

DATE	SVL	VTL	TR	WEIGHT	LOCATION	TRAP ID
22/4/08	74	112	0	8	P-LINE	n/a

Figure 17. Typical facial and chin photos taken of chevron skinks to detect recaptures. Each skink has a unique pattern that can be differentiated between animals.

3.4 RESULTS

3.4.1 Chevron skink captures

Overall, 89 chevron skinks captures were recorded during this study (48 in the treatment sites and 41 in the control sites). Eighty-five of these were individual skinks while 4 were recaptures (including one skink that was recaptured twice). Of the 85 individual skinks, 60 were caught in debris dam G-minnow traps and 24 were captured by hand. A further skink was seen in a puriri cavity and captured by placing a baited G-minnow trap over the hole (Figure 18). In addition to captured animals, 5 chevron skinks were seen but not caught during this study. Four of these were in and around stream debris dams, and one was in fern litter on the stream terrace (Table 2).

Figure 18. Modified trapping method used to opportunistically catch a chevron skink from an arboreal retreat in a Puriri, in Port Fitzroy, Great Barrier Island.

Table 2. Microhabitat and method of chevron skinks caught and seen (and not caught) in four stream catchments at Port Fitzroy, Great Barrier Island from January to April 2008.

Technique	*n*	Debris dam	Puriri tree	Boulder	Leaf litter	Silver fern	Bare
G-minnow	61	60	1				
Hand capture	24	5		1	8	6	4
Total caught	85	65	1	1	8	6	4
Seen	5	4			1		

Neonate chevron skinks were first seen on 19/2/2008 and captured consistently until the end of April when trapping ceased. Two conspicuously gravid females were caught on the 19/2/2008 and 15/3/2008. Two further skinks were caught that were potentially gravid but unconfirmed on the 19/2/2008 and 22/2/2008.

3.4.1.1 Recaptures

There were four recaptures of chevron skinks during this study as indicated by facial identification photos. Two of these were adults and two were sub-adults. The two adults were initially caught in G-minnow traps and were recaptured by hand less than 10m from the original capture location. The time intervals between these captures were 7.5 and 14 weeks[2].

One of the sub-adults was captured by hand in a debris dam and was purposely moved 50m upstream during predator fence construction. It was caught two days later in a debris dam G-minnow trap approximately 40m from the original capture location and 10m from the release location. The other sub-adult was first caught in a G-minnow and was observed eating a cave weta (*Gymnoplectron sp.*) while trapped. This skink was re-caught in the same G-minnow two days later.

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[2] Two skinks caught in this study were recaught by Halema Jamieson after the study concluded (DOC unpubl. data). One of the skinks was recaptured 38 weeks later in December 2008. It was caught in a G-minnow trap on both occasions and was within 1m of the initial location. The other was an adult skink caught 41 weeks later in February 2009. It was initially caught in a G-minnow trap and recaught in a silver fern crown less than 10m away. This skink was also caught in 2006 within 10m of both subsequent captures.

3.4.2 Growth rates

Growth rates were calculated for two chevron skinks recaptured over three months after their initial capture (Table 3). The growth rate of the adult skink was low as expected. In contrast, the growth rate of the sub-adult skink was high. At observed growth rates it is expected that chevron skinks would reach adulthood in 4 -5 years.

Table 3. Capture/recapture dates and calculated growth rates of chevron skinks at Port Fitzroy, Great Barrier Island, 2008.

Skink 1						
	Date	SVL (mm)	TL (mm)	TR (mm)	Weight (g)	Growth rate (mm/day)
Initial capture	11/7/06	115	146	9	29.5	
Recapture	14/4/08	119	81	1	29.25	0.006
Skink 2						
Initial capture	14/3/08	76	113	0	9	
Recapture	13/12/08	89	132	0	13.5	0.048

3.4.3 Population structure

There were more chevron skinks caught per unit effort in the treatment sites than the control sites for all size categories except 131mm+, although the magnitude of the difference was not even for all size categories. There were more juveniles (51-70mm SVL) and sub-adults (71-90mm SVL) caught in the two treatment sites than the unmanaged control sites per unit effort (Figure 19). In the treatment sites combined, 50% of the total catch was juvenile (51-70mm SVL) and sub-adult (71-90mm SVL) size categories. In the unmanaged control sites combined, the total proportion of juveniles and sub-adults caught was 38% (Figure 20). There were similar numbers of adults and neonates caught between the treatment and control sites.

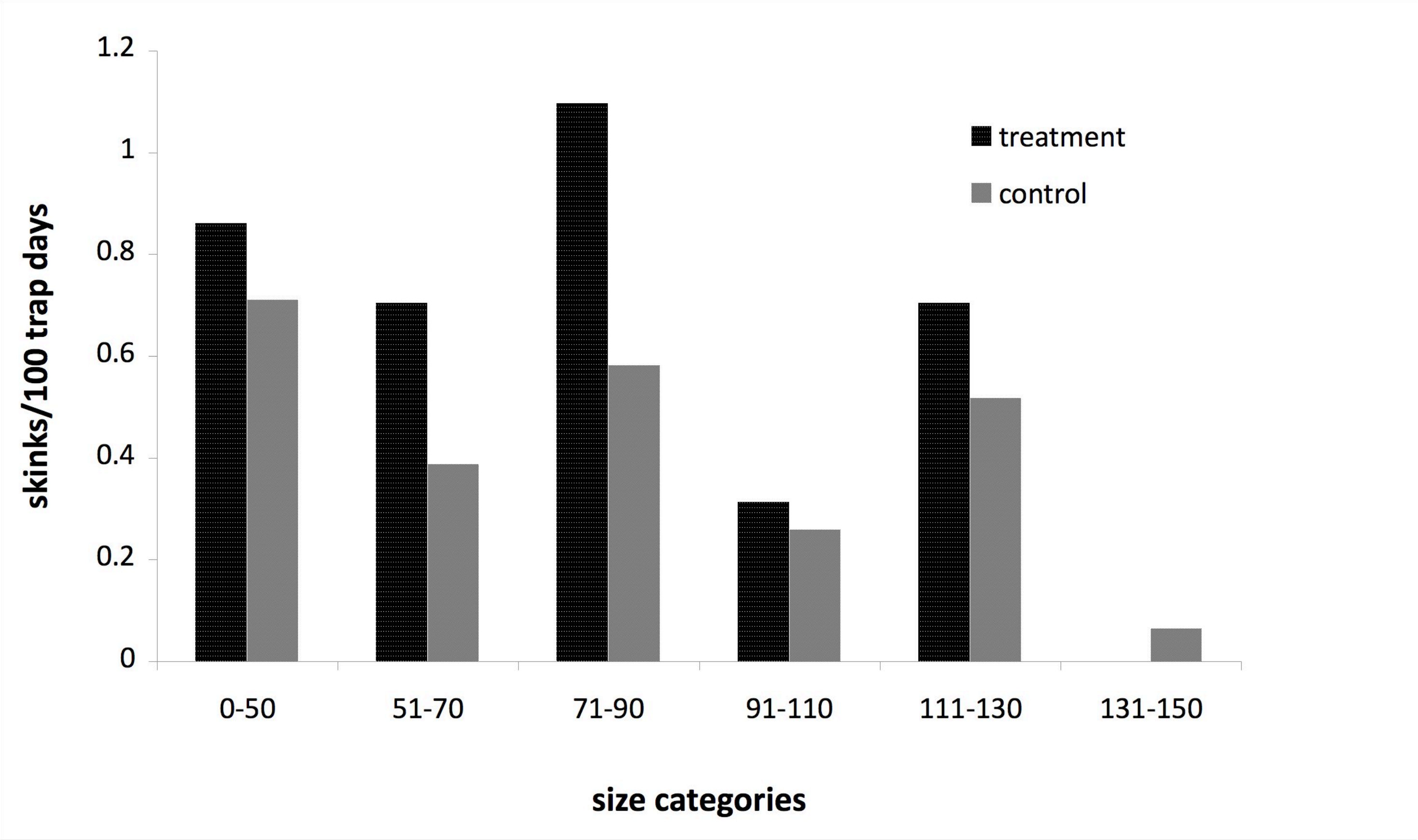

Figure 19. The population structure of chevron skinks in the treatment (*n* = 46) and unmanaged control (*n* = 39) catchments caught on Great Barrier Island during trapping between January and May 2008. Captures of skinks was standardised to skinks caught per 100 trap days.

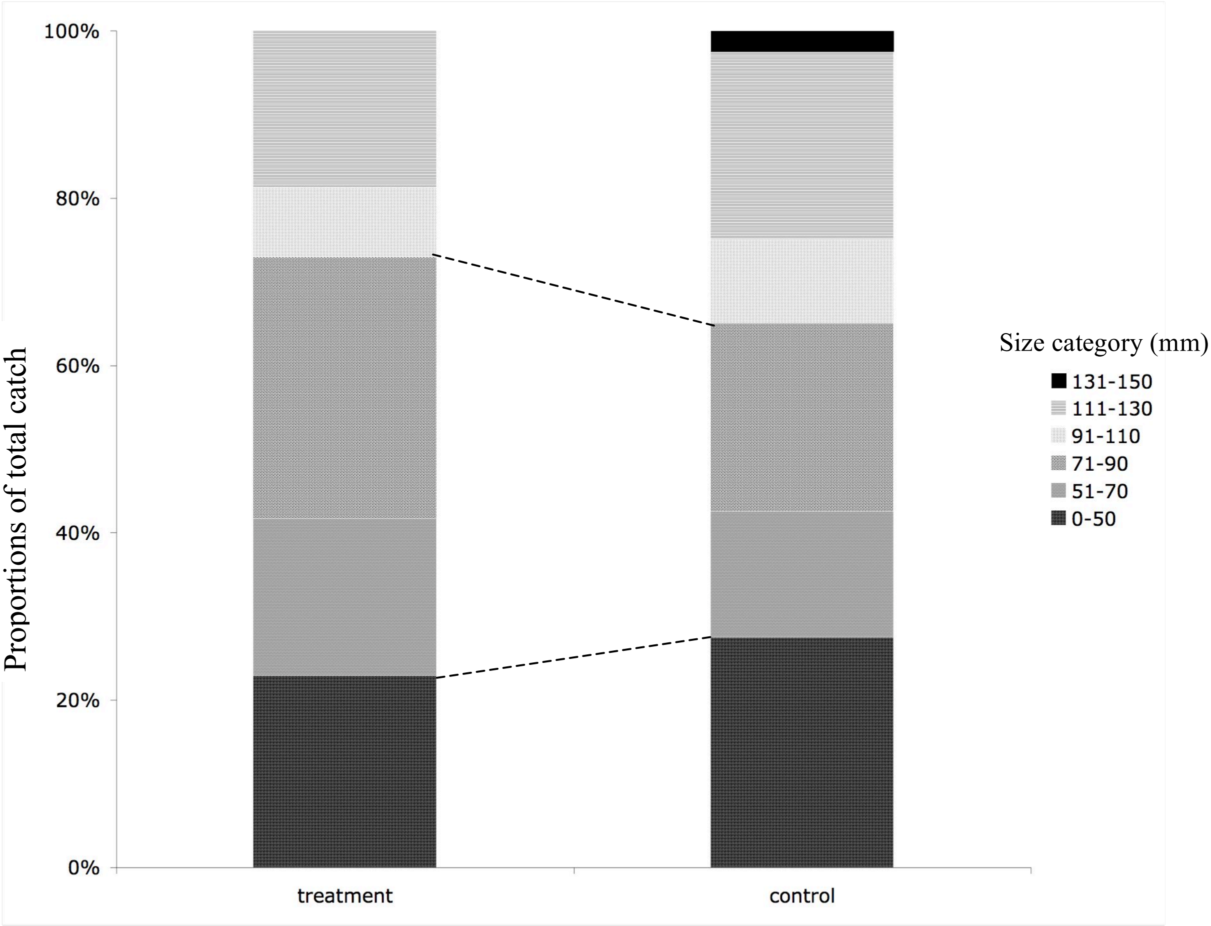

Figure 20. The proportions of chevron skink caught in each size category (mm) in relation to the total catch at Port Fitzroy, Great Barrier Island 2008.

3.4.4 Evidence of attempted rat predation – sublethal injuries

Two skinks were captured in the unmanaged control areas with sublethal injuries. The injuries were indicative of failed rat predation (Craig Gillies pers.comm.).

Skink 1 (Figure 21**)**

Skink 1 was caught on the 15/3/2008. It was a gravid female caught on the stream terrace and was flushed from silver fern litter approximately 2m from the stream. The majority of the injuries to skink 1 were centred around the head region. On the right side of the face there was piercing of the scales in the temporal region including supralabial scales. The holes were less than 1mm wide and 2-3mm long. There were at least 5 separate piercings covering an area of approximately 5mm x 10mm between the eye and ear opening. On the left side of the face there was a single piercing in the temporal region approximately circular, with a diameter of 1.5mm. Immediately anterior to this injury was a vertical cut approximately 3mm long. There was also a rectangular incision on a supralabial anterior to the eye approximately 1mm long. In addition the majority of the tail had been lost, so that only 11mm was original. The tail had regrown to a total length of 62mm. There were no other conspicuous injuries noted.

Skink 2 (Figure 22**)**

Skink 2 was caught on the 14/4/2008. It was caught 1.5m up a silver tree fern on the stream terrace during flooding approximately 4m from the stream. This skink had previously been caught on the 16/1/2008 therefore the injuries were known to be less than 3 months old. The injuries to this skink were most severe to the head region, although there was also damage on the body. The skinks left eyeball had been punctured and disfigured and although it appeared to be healed, it was probably no longer functional. There was a vertical tear immediately anterior to the ear opening on the right side of the face. The tear was approximately 6mm long and was freshly healed. On the left rear leg there was a laceration below the knee joint. This injury didn’t appear to be healed, and there was a small section of scales missing. Between the legs on the dorsal side of the skink there were two small puncture holes. The dorsal injuries were not deep or serious.

Since the last capture in January, skink 2 had lost over 70mm of its tail and 2.75g. None of the tail had re-grown and there was a small unhealed puncture approximately 35mm anterior to the tail fracture on the ventral surface.

This skink was recaptured on 5/2/09 by Halema Jamieson (DOC, unpubl. data). All wounds had healed extremely well and were hardly noticeable, although the eye was still severely damaged. The tail had regrown 36mm, which equated to 0.13mm/day (Figure 23).

Figure 21. Sublethal injuries sustained by chevron skink 1 in the Shop stream at Port Fitzroy, Great Barrier Island. Captured on 15/3/2008. Top left: dorsal view of lateral facial injuries - note dent on left side and punctures on right side. Top right and inset: close up of facial injuries on right side - note widespread punctures and scale damage. Bottom left: close up of facial injuries on left side – note two puncture holes and vertical cut. Bottom right: full body view demonstrating extensive tail loss. Photographs by author.

Figure 22. Sublethal injuries sustained by chevron skink 2 in the Shop stream at Port Fitzroy, Great Barrier Island. Captured on 14/4/2008. Top left: close up of facial injuries - note damage to eyeball. Top right: close up of facial injuries on right side – note semi-healed tear anterior to ear. Bottom left: view of dorsal injuries – note tear below left knee and puncture holes on the dorsal surface. Bottom right: close up of tail demonstrating tail loss – note puncture hole on tail. Photographs by author.

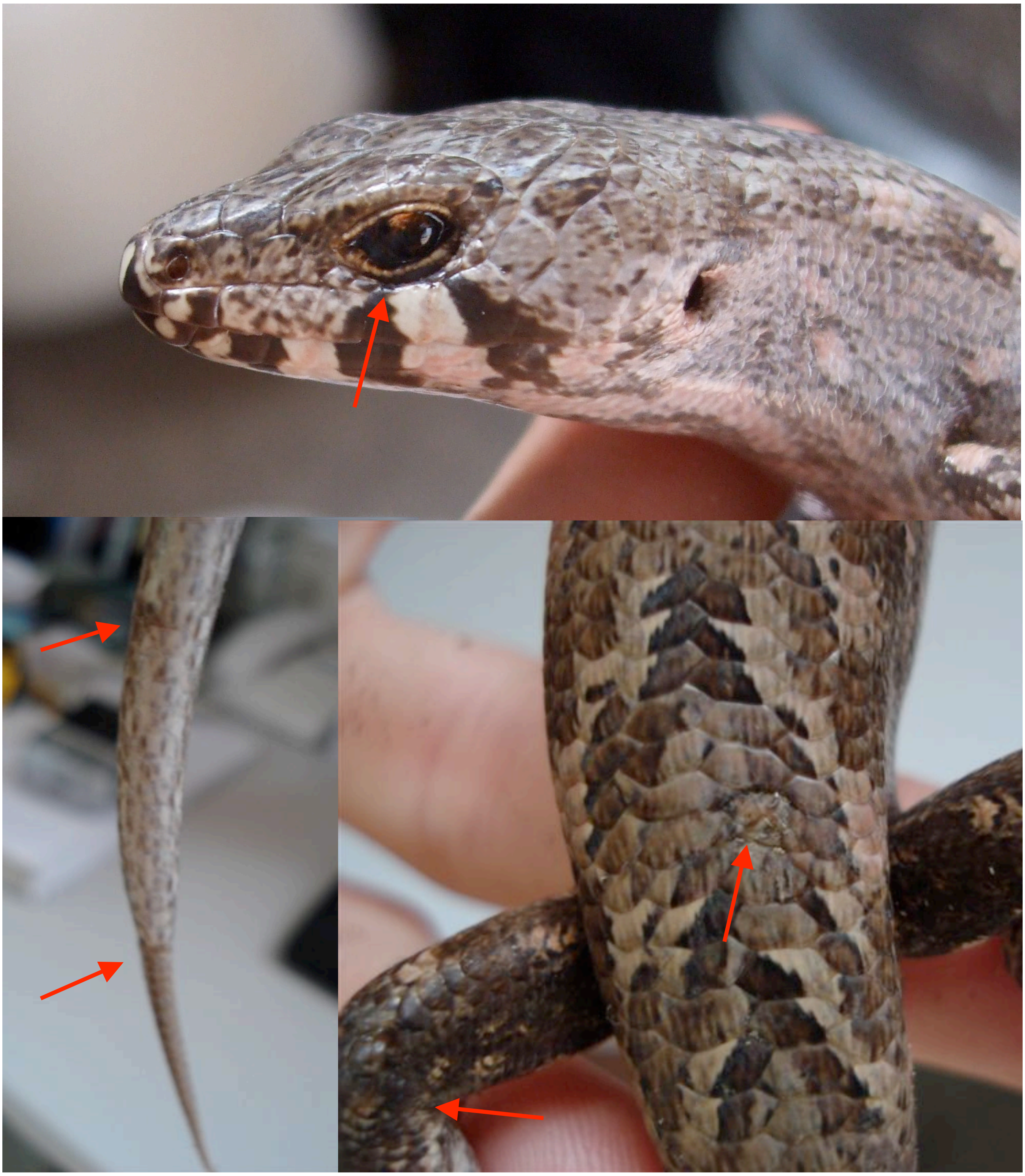

Figure 23. Skink 2 recaptured on 5/2/09 in the Shop stream at Port Fitzroy, Great Barrier Island. Top: close up of facial injuries - note eyeball damage still present. Bottom left: photo of tail demonstrating tail regrowth – note puncture hole healed on tail, and 36mm of tail regeneration. Bottom right: view of dorsal injuries – note tear below left knee has healed and puncture holes on the dorsal surface, healed over but still missing scales. Photographs by Halema Jamieson (used with permission).

3.4.5 Skink condition

In this study, both skinks that survived rat predation had experienced tail loss; severe for one and moderate for the other (Figure 21 and Figure 22). The analysis of skink condition sought to determine if the degree of tail loss provided further evidence of failed rat predation events in the population.

The medians of individual size categories between treatment and control sites were not significantly different for any size category (Table 4).

Table 4. Summary of Mann-Whitney U test statistics of chevron skink body-tail condition (BTC) index between treatment (N_1) and unmanaged control (N_2) sites at Port Fitzroy, Great Barrier Island in 2008.

Size category	U	N_1	N_2	P
0-50	28	10	11	0.24
51-70	2	9	6	0.53
71-90	61	13	9	0.95
91-110	6	4	4	0.69
111+	19	9	8	0.11

However, the medians of the body-tail condition (BTC) index were significantly different compared between size categories in the unmanaged control catchment (Kruskal-Wallis, $K_4 = 11.64$, $P = 0.0203$ using Gaussian Approximation). Examination of the corresponding box plot reveals the median of the BTC index remains stable for all size categories then decreases dramatically for the 111m+ size category (Figure 24). The 71-90mm size category had a large range indicated by the outliers (Figure 24). In contrast the medians of the BTC index were not significantly different between size categories in the treatment sites (Kruskal-Wallis, $K_4 = 4.860$, $P = 0.3020$ using Gaussian Approximation). The corresponding box plot confirms that the medians remain stable over all size categories (Figure 24). The 51-70mm and 71-90mm size categories had large ranges indicated by the outliers (Figure 24).

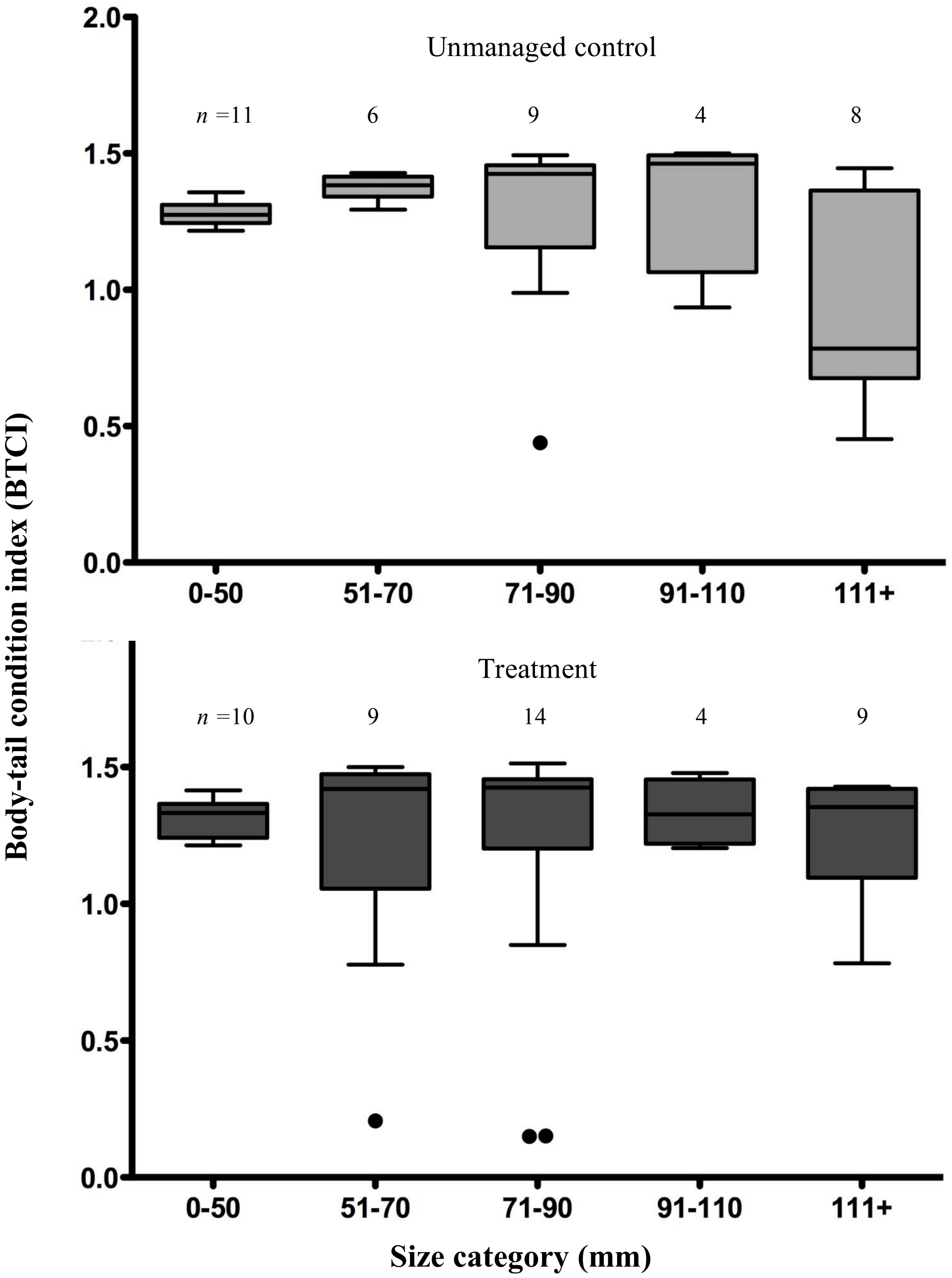

Figure 24. Box plots of the body-tail condition (BTC) index of chevron skinks in the unmanaged control (top) and treatment (bottom) sites, during trapping on Great Barrier Island between January and April 2008.

3.5 DISCUSSION

Small sample sizes are often problematic for the study of cryptic and/or endangered species, of which the chevron skink falls into both categories. However, failing to monitor, study and understand endangered animals can allow them to slip into extinction unnoticed (Grant et al. 2005). Accordingly conservation scientists can be forced to embark on research in which the outcomes cannot be guaranteed and/or the samples may be small. With small sample sizes, it is often difficult to get definitive results (Walters & Holling 1990) despite strong trends (Neilson et al. 2006). In interpreting the results of this study, it is more informative to view the respective components (population structure, skink condition, and sublethal injury) in concert by integrating the parts (Walters and Holling 2000), rather than considering them as stand-alone pieces of information.

The total captures of chevron skinks in this study represent an approximate 30% increase in the known records for this species. The survey technique described by Jamieson and Neilson (2007) was highly successful. The total captures in this single summer study utilising hand captures and G-minnow fish traps were equivalent to five summers study using traditional pitfall traps and hand captures (Neilson et al. 2006). Trapping also recorded the earliest neonate chevron skink capture (19/02/08). The previous earliest sighting of a neonate was March (Neilson et al. 2006).

3.5.1 Population structure

There were more chevron skinks caught in the treatment sites than in the unmanaged control sites per unit effort, however these numbers cannot be used to infer an impact of rats because there is no pre-treatment or historic data available for chevron skinks at three of the four sites, and no long-term data (>5 years) for any site. Accordingly there is no possibility to quantify and compare any change in the population characteristics (population structure, skink condition, skink catch rates) within sites as a response to rat control. Instead, this study examined relative proportions in the population structure and relative differences in condition between the treatment and control populations in light of the rat densities, which are substantially different between locations.

The population structure in this study showed erosion of juvenile (51-70mm) and sub-adult (71-90mm) size categories at the unmanaged control sites in comparison to the treatment sites. In light of the rat densities between the treatment and control catchments, these results suggest that the smaller size categories are more vulnerable to rats than adults, and that rats are suppressing recruitment in the unmanaged control sites. These results support the work of Hoare et al. (2007) who found a similar pattern of rats inhibiting recruitment of Duvaucel's geckos, although the loss of recruitment in the current study is not as severe. Hoare et al. (2007) observed zero recruitment in the population with rats, in contrast to this study where recruitment was merely eroded. Populations experiencing complete recruitment failure will only persist as long as older animals remain alive, since all offspring die and there are no new animals entering the breeding population (Janssen & Jude 2001). Reduced recruitment such as was observed in this study can lead to population declines and possibly extinction in the longer term (Cree et al. 1995; Hoare et al. 2007).

That some juveniles and sub-adult chevron skinks survive in the presence of abundant rats, where other lizard species do not may be partially explained by the respective life histories of chevron skinks and rats. Chevron skinks are diurnal and rats are nocturnal, therefore there is less chance of rats encountering a chevron skink than nocturnal species of lizard since their activity periods do not overlap. Whitaker (1978) and Towns and Daugherty (1994) stated that nocturnal lizards are more vulnerable than diurnal lizards due to this fact.

Accordingly, for the possibility of predation to occur in diurnal species such as chevron skinks, the nighttime refuge of the skink must be accessible to a rat. During the night when rats are foraging, adult chevron skinks are inactive and within refuges (Neilson et al. 2006). Although the nighttime refuge use of non-adult chevron skinks is presently unknown, it is suspected to be similar to adult retreat sites and microhabitats they are caught in during the day; mainly logs, trees, crevices, debris dams (Neilson et al. 2006) and fern crowns during flood (see chapter 4). The accessibility of these refuges to rats is difficult to quantify, therefore the percentage of 'safe refugia' is unknown. It is clear however, that chevron skinks would be vulnerable to rat predation when they are in silver fern crowns, leaf litter and herb cover. The chevron skinks in this study occupied these microhabitats only 16% of the time during the day (see chapter 4). Nighttime use of these microhabitats is probably even more infrequent as leaf litter and herb cover fixes were probably transit sites and not refuges commonly used at night. The majority of the time (84%) was spent in trees, logs, crevices, debris dams and in boulders, many of which would be inaccessible to rats.

The other possibility for rats and chevron skinks to encounter each other is through skinks inadvertently coming within the sense range of a rat during the day and being taken opportunistically. This is indeed plausible as during this study, a chevron skink was radio-tracked to an old rat nest (see chapter 4), although this is probably an uncommon occurrence.

In contrast to the differences in proportions of juvenile and sub-adult categories the difference in adult and neonate proportions between the treatment and control were less pronounced. While there were fewer neonates and adults caught per unit effort in the unmanaged control, the difference was not substantial. This is contrary to what might be expected given that juvenile and sub-adult size categories indicated reduced recruitment. This result may be a function of a number of factors. Firstly, it is possible that rodent control in the treatment had not been effective for long enough to observe a difference in the adult population as a response to reduced rat densities. Rat densities in the treatment catchments were considerably lower than the unmanaged control catchments as at August 2008 (Chapter 2). The methods of rodent control in the treatment area have remained the same since inception (Bouzaid's 2001, OCC 2002, entire peninsula 2004 – see Chapter 2, Figure 3), therefore it is reasonably safe to assume that rat densities have been stable at these low densities for at least five years. Historic rodent tracking rates undertaken since 2005 support this trend (Chapter 2,), although these tracking rates are considerably coarser than the absolute densities and tracking rates obtained in this study (Chapter 2) (Gillies and Williams, in press). Chevron skink growth rates indicate that the species reaches adulthood in 4-5 years, therefore real changes in the adult population as a benefit of rodent control would begin to be observed in the population structure within 4-5 years. As reliable rodent control has only been in place approximately this long, the benefits to adult chevron skinks observed in the population at the current time may therefore be slight. Secondly, as there are no pre-treatment data available for either area, it is also possible that the number of adults in the treatment area was initially lower than the unmanaged control area and the populations are now similar due to population recovery. Yet another possible explanation is that the chevron skink population is at carrying capacity in both areas, and despite reduced recruitment into the adult population in the unmanaged control area, there is enough recruitment to maintain the population.

The similar number of neonates is likely to be a function of the number of breeding adults in each area. Since the number of adults is similar between areas, it follows that the number of neonates captured should be similar. This is on the basis that adults are giving birth to similar numbers of neonates, however the time between birthing and monitoring was not sufficient to see the abundance of neonates decrease as a function of rat densities.

It is considered unlikely that migration into or from the study populations could have impacted on the population structure results. This study assumes there has been little or no movement of chevron skinks from unmanaged areas into the treatment area that would dilute the treatment effects. Current information about the movements of chevron skinks is limited to 13 recaptures (four from this study; six from Neilson et al. 2006; three by Halema Jamieson, DOC unpubl. data), and the radio-tracking of less than 20 individuals (nine from this study; eight from Neilson et al. 2006). Of the 13 recaptures, the largest movement between subsequent locations was over 100m. However, the majority (9 from 11) have been recaught less than 10m from their original capture location. No recaptured skinks have ever been found in different catchments. There are no records of radio-tracked skinks moving between catchments (Halema Jamieson pers. comm; pers. obs.). This information suggests that movement of skinks between catchments is limited and probably does not influence the results of this study greatly. Despite the lack of observed dispersal of skinks between catchments, dispersal would certainly occur as evidenced by the presence of skinks in bush that has historically been in pasture (Halema Jamieson pers. comm.).

3.5.2 Evidence of attempted rat predation – sublethal injuries

The eroded size categories observed in the population structure suggests that rats are impacting chevron skinks, particularly the smaller size categories. The two individuals observed in the unmanaged control area with sublethal injuries provide the first documented physical evidence of direct interactions between chevron skinks and rats.

3.5.2.1 Distinguishing between predators

Since the actual attacks causing the sublethal injuries observed on chevron skinks in this study were not witnessed, it can be problematic to categorically determine the animal that caused them. The potential predators of chevron skink on Great Barrier Island are kingfishers, morepork, banded rails, pigs, cats and rats. It is possible to implicate the suspected perpetrator of the injuries by observing the injury characteristics and associating these with the predators foraging strategy. Similarly, it is possible to rule out other possible predators to increase the confidence of the diagnosis.

There are many studies demonstrating that rats tend to eat their prey headfirst (Ivanco et al. 1996; Langley 1987; Timberlake & Washburne 1989). Ivanco (1996) showed that rats immobilise and manipulate their prey with their forelimbs so they can eat them headfirst. The reason for eating the prey headfirst is to reduce the possibility of the prey escaping during handling (Ivanco 1996) i.e. they die sooner. Both skinks in this study had sublethal head injuries, indicative of rat attack. Furthermore, the defined puncture holes noted on the head of one the injured chevron skinks were the exact dimensions of ship rat incisors caught in this study - 2mm at the tip of the teeth, and close to 3mm at the base of the teeth. The orientation of the puncture holes implies that the skink was attacked side on and from above, similar to how a rat would attack a skink. In addition, the width of the skinks head (and the distance between the injuries observed on either side of the skinks face) is precisely the known tooth-tip to tooth-tip gape width of ship rats, 20.7 ± 1.3mm (VanderWerf 2001), therefore it is likely the injuries to either side of the head resulted from the upper and lower incisors. Therefore the pattern of attack (concentrated on the head), plus the characteristics of the sublethal injuries on both chevron skinks in this study fits with the known feeding behaviour of rats.

In contrast, kingfishers spot their prey from an elevated position, then swoop down and catch their victim before returning to their perch, carrying the food crosswise in the bill (Heather & Robertson 1996). Smaller animals are killed in the impact, whereas larger animals may be battered against the perch until dead (Heather & Robertson 1996). Kingfishers are known to take skinks (van Winkel 2008) and geckos (Fitzgerald et al. 1986). van Winkel (2008) stated adult Duvaucel's geckos may be too large for kingfishers but juveniles may be vulnerable. The same would be true for adult chevron skinks, which are similar in length to adult Duvaucel's geckos. Furthermore, sublethal injuries from kingfishers are likely to be situated at the mid-body or shoulder, as opposed to being concentrated around the head region. Hitchmough (1979) found evidence of sublethal injury on green geckos (*Naultinus* spp.) presumed to be from kingfisher, which showed large beak shaped bruising around the body and nape, and these injuries were not observed on the chevron skinks in this study. Lastly, it is unlikely kingfishers could make the multiple small punctures observed on the sides of the faces of the skinks. Accordingly, the sublethal injuries observed were therefore not considered consistent with kingfisher predation.

Morepork are known to prey upon lizards as evidenced by the remains of nocturnal geckos found in morepork nests (Ramsay & Watt 1971). However, morepork are unlikely to encounter chevron skinks as they are inactive within refuges at night (Neilson et al. 2006) when morepork are feeding. In the case of a chance encounter with a morepork, the sublethal injuries to a chevron skink would include severe puncture wounds from the talons, and these injuries were not observed on the chevron skinks in this study.

In New Zealand, banded rail are generally only found in coastal areas including freshwater wetlands, saltmarshes and mangroves (Elliott 1987). During this study however, banded rail were observed and heard in forested habitats in areas where chevron skink were present (pers. obs.). The diet of banded rail is known to include lizards (Whitaker 1968), and the close relative, weka (*Gallirallus australis*), has been described as a 'voracious lizard predator' (Whitaker & Lyall 2004). The banded rail most likely feeds opportunistically on lizards, particularly as they share a similar foraging strategy with weka. The injuries to chevron skinks would however likely be similar to kingfisher predation, and again the injuries observed are considered inconsistent with this style of predation.

Other than rats, potential mammalian predators are pigs and cats. Pigs are known to feed on lizards in New Zealand (Thomson & Challies 1988), although the sizes of the injuries on the chevron skinks observed in this study are too small to be caused by pigs. Feral cats are also known to be efficient predators of lizard in New Zealand (Daugherty & Towns 1991; Fitzgerald 1990). Domestic cats have been known to capture chevron skinks on Great Barrier Island (Neilson et al. 2006), and many have bought them back to their owners alive (DOC, unpubl. data). The act of domestic cats returning alive skinks to their owners is considered a form of play (Biben 1979). The injuries sustained to chevron skinks during encounters with domestic cats are often fatal and always involve conspicuous punctures, often on the body and around the legs (DOC, unpubl. data). The sublethal injuries sustained by the chevron skinks in this study are not consistent with those inflicted by cats. Although puncture wounds were seen on the animals in this study, they were small and relative inconspicuous. Furthermore, Hall and Bradshaw (1998) stated that object play is rarely observed in wild species (despite it being common in domestic species) therefore it is even less likely that feral cats are responsible for the sublethal injures seen in this study. The assumed difference between feral and domestic feeding behaviour in cats would be related to hunger as feeding behaviour studies of cats have shown the probability and speed of kill increases with hunger, and small prey are always dispatched quickly with little or no play when cats are hungry (Biben 1979; Hall & Bradshaw 1998). Since chevron skinks are unlikely to survive encounters with feral cats and the pattern of injury is different from that observed in domestic cats, the sublethal injuries seen in this study are considered not from either domestic or feral cats.

3.5.2.2 Reasons for survival

The sublethal injuries observed provide the first documented evidence of a direct predation interaction between rats and chevron skinks to date. They are also the first known example of any New Zealand lizards surviving a rat predation attempt. In the case of the chevron skinks, this survival is likely to be a function of size. Hall and Bradshaw (1998) stated that larger animals (relative to their predator) are less likely to be killed by predators. Handling time for a predator increases as the prey size approaches the predator gape size (Aljetlawi et al. 2004), and a 'killing bite' becomes harder to execute. The increased handling time for larger prey items also increases the time available for and chance of escape. The head body lengths of ship rats in this study had a mean of 160mm, while the kiore had a mean of 136mm. The SVL of chevron skinks in this study ranged from 36mm to 137mm. The head width of adult chevron skinks is similar to the maximum tooth-tip to tooth-tip gape width of ship rats and larger than that of kiore (VanderWerf 2001), while in younger animals the head width is significantly smaller than rat gape widths. It is therefore conceivable that adult chevron skinks are capable of escape from adult rats.

Hoare et al. (2007) demonstrated that larger individuals of Duvaucel's gecko apparently survived predation attempts by rats by comparing population structures between islands with and without kiore. Adult chevron skinks are similar in length to adult Duvaucel's geckos although they are lighter (Gill & Whitaker 1996). The physical evidence of failed predation in this study supports the deduction of Hoare et al. (2007) that larger Duvaucel's geckos were surviving kiore predation attempts.

From the observed injuries seen in this study it is probable that different size categories of skink have different vulnerabilities to rats, considering that smaller individuals are easier to handle and easier to dispatch. This is reflected in the eroded juvenile and sub-adult size categories observed in the unmanaged control sites.

3.5.3 Skink condition

In many studies of reptiles, condition is typically measured using body mass. This method is particularly useful when measuring impacts that are not related to direct predation; such as change in body condition due to antipredatory feeding behaviour (Martin & Lopez 1999; Perez-Tris et al. 2004), habitat deterioration (Amo et al. 2007), or parasite loads (Amo et al. 2004).

The impacts of direct predation on lizards are generally measured by quantifying sublethal injuries, most often using tail loss (Diego-Rasilla 2003; Fenner et al. 2008; Rand 1954; Vinegar 1975). There has been evidence to suggest that tail loss can be an unreliable indication of predation pressure (Jaksic & Greene 1984; Schall & Pianka 1980; Schoener 1979; Vitt et al. 1977) as it can indicate predator inefficiency. However a review by Bateman and Fleming (2009) suggests that tail loss can be linked to predator intensity with caution if supported by additional information on predator attempts and tactics. This study accepts that tail loss is a result of the inefficiencies of rats and has shown sublethal injuries resulting from interactions between adult chevron skinks and rats.

The comparisons of tail loss in this study were investigated using the body-tail condition (BTC) index. The frequencies of tail loss (which includes any individual with any degree of regenerated tail) were not considered appropriate to compare between the treatment and control areas since it is likely there were numerous skinks in the treatment area that were alive when rats were unmanaged (based on longevity data; Baling 2003). This study shows that chevron skinks regenerate their tails rapidly therefore the BTC index would not be greatly affected by past predation levels, unlike comparing frequency directly. Furthermore, tail loss frequency is a relatively coarse measure as it does not take into account skinks that may have suffered tail loss multiple times, which could occur in areas with high rat densities since adult chevron skinks appear to be able to survive rat predation.

The medians of the BTC index of individual size categories were not significantly different between the treatment and unmanaged control sites, although the largest category (111mm+) appeared degraded in the control. Although the difference between the treatment and control sites approached biological significance for this category it is likely that large variation and the small sample sizes negated a significant result. Variation of this index is expected as not all skinks lose their tails, and all skinks grow their tail back over time.

However, when comparing the BTC index of skinks between size categories within the treatment and the unmanaged control sites, a difference in the BTC index was observed which further supports an impact of rats. Given that skinks increase in length with age, this comparison showed that the BTC index of chevron skinks decreases markedly when skinks reach adulthood within the unmanaged area where rat densities are high. There is more than one possible reason why only the adult size category suffered a decrease in BTC index in the unmanaged area, while the other categories remained stable. Firstly, younger and smaller animals will suffer fewer injuries if the rate per time is constant (Schoener & Schoener 1980) i.e. the risk to each individual per unit time is the same and therefore the risk of injury increases with exposure time (age). This phenomenon is probably amplified in the results of this study as skinks could be in the largest category (SVL; 111mm+) for over 15 years based on longevity records from captive animals (Baling 2003). In contrast a chevron skink could mature from neonate to adult in just four years based on growth rates observed in this study (section 3.4.2), thereby passing through young size categories (SVL; 0-50, 51-70, 71-90, 91-110) quickly, with a reduced chance of encounter with a rat. Secondly, smaller animals occupy smaller refuges and are therefore less vulnerable to attack (Fenner et al. 2008). Therefore there would be fewer incidences of encounter with rats when skinks are small, and a concomitant increase as skinks grew and reached adulthood. Thirdly, small, young skinks are unlikely to survive a rat attack based on the injuries observed in adult skinks. Accordingly examples of rat-induced reductions of the BTC index in young skinks (neonates, juveniles and sub-adults) are purged from the data because the interaction usually results in death. This possibility would also explain why these size categories are eroded from the population structure.

In contrast, the BTC index of the skinks remained stable throughout all size categories in the treatment sites where rat densities were low, despite outliers. Since it is clear that rat densities are substantially different between the treatment and unmanaged control catchments (Chapter 2), the differences in the BTC index between areas is likely due to rats. The outliers observed in the treatment areas suggest either 1) there are low levels of rat predation attempts in the treatment that do not greatly effect the BTC index of the population overall or 2) there are other agents of autotomy that occur independently of rats and these are not frequent enough to cause a noticeable reduction in body condition between size categories; or they are not size specific enough to cause difference in condition between size categories.

Schoener and Schoener (1980) suggested that intraspecific aggression could lead to tail loss, although toe loss was probably more likely. No toe loss was seen in any chevron skink in this study, which suggests that intraspecific aggression was very uncommon. Furthermore, intraspecific aggression often results in semi-oblong bite mark scars (pers. obs.), and no such examples were seen in this study. Other triggers of tail loss that could be responsible for outliers are attempted bird predation (Fenner et al. 2008) or interspecific competition (Vinegar 1975). Chevron skinks would only be susceptible to interspecific competition for a short period of their life history as they quickly grow larger than all confamilials. It is known that tail loss can render animals more susceptible to subsequent attacks (Daniels 1985). This can be due to having no tail to distract predators, compromised locomotion (Formanowicz et al. 1990), or behaviour such as increased pausing (Lin & Ji 2005). Considering that skinks may be more vulnerable to predation after tail loss, the lack of outliers in the unmanaged control sites could be because these skinks are removed more quickly from the population compared to the treatment area, due to the greater pressure from rats.

The condition of the chevron skinks from this comparison suggest rat predation is causing reduced body condition in adult chevron skinks, and the variable index between size classes supports the suggestions from the population structure and physical evidence of failed rat predations that different size categories have different vulnerabilities to rats. That only two skinks with tail loss had other obvious injuries can be explained by the rapid healing observed in skink 2 (section 3.4.4; Figure 23) as all injuries apart from the eye damage and tail loss had become inconspicuous after less than seven months.

3.5.3.1 Costs of tail loss

Although tail loss allows lizards to survive potentially fatal encounters, it still exacts a cost on the affected animal since the tail is an important energy reserve (Andrews 1982). Therefore, the reduction in BTC index observed in this study has implications for the affected populations. A recent review by Bateman and Fleming (2009) summarised the impacts of tail loss on individuals. Tail loss has been shown to negatively affect sprint speed in lizards (Chapple et al. 2004; Goodman 2006) and endurance (Chapple & Swain 2002), which can lead to increase predation vulnerability (Bateman and Fleming 2009) and reduced survival (Fox & McCoy 2000; Willis et al. 1982; Wilson 1992). There are also costs of tail loss that can lead to reduced reproductive fitness including; loss of energy reserves (Dial & Fitzpatrick 1981; Vitt et al. 1977), reduction in resource allocation to offspring (Bernardo & Agosta 2005; McConnachie & Whiting 2003), reduction in mate searching time for males (McConnachie and Whiting 2003), and altered social status (Fox et al. 1990). In addition, tail loss in arboreal species may hinder climbing ability (Medger et al. 2008), and therefore cause problems for chevron skinks during their arboreal episodes.

3.5.3.2 Eye damage

Eye damage has been associated with a decrease in body condition in tuatara (Tyrrell et al. 2000). After the eye damage observed in this study, skink 2 lost 2.25g in less than three months and then a further 1.25g in seven months despite the SVL increasing and an additional 36mm of tail growth. It is unclear whether chevron skinks are predominantly visual predators or use chemosensory organs to detect their prey, however it seems apparent that the impacts of eye damage to chevron skinks results in a loss of condition, although this is only based on one animal.

3.6 SUMMARY AND CONCLUSIONS

At night when rats are foraging chevron skinks are inactive within refuges, and many of these refuges are not accessible to rats. This may explain why the results of this study indicate the impact of rats is subtle, and not as marked as is witnessed in lizards that overlap both spatially and temporally with rats. It is also possible that rat numbers in the treatment sites may not be low enough to guarantee the complete protection of chevron skinks or that rodent control may not have been in place long enough to see a full recovery of the chevron skink population.

Despite the reasons for these subtleties, the results of this study do indicate rats are capable of having a negative impact on chevron skinks, as there are differences in the population characteristics of chevron skinks between the treatment and the control sites. The population structure shows erosion of juvenile and sub-adult size categories in the unmanaged control sites where rat numbers were high, in comparison to the treatment sites where rat numbers were low. This observed pattern implies that rats are impacting the chevron skink population and that younger skinks are more vulnerable than adult skinks. Sublethal injuries observed in two adult chevron skinks in the unmanaged control areas provided physical evidence that rats are interacting with chevron skins and indicate that at least a proportion of adults are surviving these attacks, albeit with a cost. The costs of these attacks were impaired vision through eye damage, cuts and puncture holes, and probably tail loss. The probability of survival of such attacks on smaller individuals is expected to be minimal, which supports the findings from the population structure that juvenile and sub-adult skinks are more vulnerable to rats than adults. In addition rats also affect the condition of chevron skinks through tail loss expressed as the body-tail condition (BTC) index. Reduced levels of this condition index were only expressed in adult skinks greater than 111mm in the unmanaged sites, which infers that pressure from rats is greatest in this area. The fact that the BTC index was not reduced for smaller categories suggests that smaller individuals may not be surviving rat encounters, where it is clear encounters do occur. This further supports the findings of the population structure and the sublethal injuries, which suggest that adult skinks can survive rat attack, albeit at a cost.

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Chapter 4 Habitat preferences, home range and ranging behaviour of chevron skinks

4.1 ABSTRACT

A radio-tracking study was undertaken on Great Barrier Island to expand current knowledge of the habitat use and preferences of the nationally endangered chevron skink (*Oligosoma homalonotum*), and to investigate, for the first time, their home range and ranging behaviour. This study was undertaken in two large areas of native bush adjacent to Port Fitzroy in 2008. Refuge sites were investigated and habitat preferences were determined by comparing variables at actual chevron skink retreat sites with random sites using a logistic regression model. The use of crevices, trees and logs as refuge sites was high and refuge site fidelity of individuals was common. The logistic model indicated that chevron skinks used sites preferentially when trees, stream debris dams, and crevices were present, while using sites with soil and bare ground disproportionately less than they were was available. Home ranges were established using 95% minimum convex polygon (MCP) estimates. Home ranges of chevron skinks averaged 451m^2 and varied between 95m^2 and 1505m^2, although these were likely to be underestimates. There was some overlap between individuals and sharing of common refuges, although not simultaneously. Chevron skinks were shown to inhabit areas further away from streams than has been previously shown. An apparent arboreal response to flooding was also observed, and this was investigated by correlating rainfall with height above ground of arboreal retreats, and also by comparing these heights immediately before, during and after flooding events. Radio-tracked adult chevron skinks appeared to respond to flooding by climbing trees (in particular silver tree ferns; *Cyathea dealbata*), although ‘normal’ levels of rainfall did not appear to trigger this response. This assertion was supported by high hand capture rates of chevron skinks in silver fern crowns during flooding episodes and zero captures during dry periods. These findings significantly increase the knowledge of chevron skink ecology.

4.2 INTRODUCTION

Successful conservation management of endangered species relies on an understanding of the ecology of the animal concerned. Information on specific habitat preferences and requirements, general habits, and home ranges are invaluable for enhancing monitoring and survey efforts (Neilson et al. 2004). Furthermore, enhanced monitoring and knowledge of an animal's ecology also aids in identifying threats (Towns & McFadden 1993) and so helps guide conservation managers in making decisions that concern the species. The nationally endangered chevron skink (*Oligosoma homalonotum*) is one such species where there are still significant knowledge gaps regarding its general ecology. Early survey and monitoring of chevron skinks was hampered by a lack of understanding and the cryptic nature of the species (Baling 2003; Jamieson & Neilson 2007; Neilson et al. 2006; Towns & McFadden 1993; Towns et al. 2002). Subsequent research on chevron skink habitat preferences (Neilson et al. 2006) and improved trapping techniques (Jamieson & Neilson 2007) have greatly enhanced their capture rates, which has begun to lead to an understanding of the species. There is still much about the chevron skink that is not understood and real management gains for this species rely on increasing this knowledge.

4.2.1 Habitat preferences

The habitat use and preferences of reptiles are studied using a variety of methods. For example, Vitt and Avila-Pires (1998) used haphazard searching and Biazquez (1996) used transects to locate their study species, and both measured habitat use and microhabitat preferences from these focal points. Freeman (1997) used pitfall traps and compared the capture rates of two skink species between sampled macrohabitats to make comparisons between species. Methods such as these can have biases as habitats that are difficult to observe animals in, or are not included in the sampling regime are inadvertently excluded from the habitat preferences (Griffiths & Christian 1996; Weatherhead & Charland 1985). Advances in radio-telemetry have allowed researchers to determine habitat selection (Moore & Gillingham 2006) and refuge selection (Beck & Jennings 2003) without these biases (Burrow et al. 2001; Warrick et al. 1998). The use of ratio-tracking is however limited by the size of the study species as often only larger animals can be studied due to the size of transmitters.

On Great Barrier Island (GBI) the habitat preferences of chevron skinks have been previously determined using a combination of pitfall traps, comparisons of catchments with and without chevron skinks, and through radio-tracking eight adults in a single catchment (Neilson et al. 2006). The radio-tracking in the latter study was undertaken at a relatively modified site where houses were close to the stream in many parts. This study found that radio-tracked adult chevron skinks were more likely to be found at sites where crevices, debris dams and trees were present, than where they were not. This study also confirmed anecdotal suggestions that chevron skinks have an association with streams, in particular that they are more likely to be found in catchments with narrow, rocky streams, than in wide and/or silted streams. To date, the habitat preferences of chevron skinks have not been studied in relatively unmodified catchments.

Understanding the relationship between climatic conditions and habitat selection is also important in understanding the ecology of animals. Neilson (2002) identified that chevron skinks had high rates of evaporative water loss (EWL), and suggested that this physiological limitation leads chevron skinks, and in particular juveniles (Newman & Towns 1985) to preferentially select high humidity environments such as streamside locations. However, the rate of EWL is not related to humidity in isolation, but also to temperature (Procter & Studier 1970). Recent studies of reptiles have used the vapour pressure deficit (VPD) as a predictor of EWL (Beck & Jennings 2003), as it describes the relationship between relative humidity (RH%) and temperature (T°C) and is an indicator of the actual evaporative demands of air (Yoder et al. 2005).

The use of shelters (Clarke & Nicolson 1994) and burrows (Bulova 2002) have been shown to reduce EWL in reptiles. In New Zealand, high rates of EWL in *Cyclodina* spp. skinks such as robust, McGregor's and Whitaker's skinks appear to limit them to humid sites such as deep rock piles, burrows, crevices, and tight matted vegetation (Newman 1994; Towns 1999; Towns & Elliott 1996). Currently it is unclear how abiotic conditions such as temperature and humidity specifically affect the habitat choices of chevron skinks, and if refuge selection is based on these factors, as is suggested for *Cyclodina* spp. in New Zealand.

4.2.2 Home ranges

The home range of an animal is considered to be the area in which it regularly traverses to attain its food, shelter and mate requirements (Burt 1943). Lizard home range size appears to be predominantly related to body size on the basis that larger animals have larger energy demands and therefore need a larger area to satisfy them (Turner et al. 1969). However ‘fine-tuning’ of home ranges is likely to depend on ecological and social interactions (Christian & Waldschmidt 1984). In their review of lizard home ranges, Perry and Garland (2002) stated that most studies of home ranges have focused on food resources (Trivers 1976) and mates. However, it is also essential that home ranges contain all the thermal requirements of an animal (Perry & Garland 2002) and sufficient quality of habitat (Moore & Gillingham 2006). Lizards have been shown to change their home range location and size due to climatic variables (Christian & Tracy 1984) and resource abundance (Simon 1975).

Home ranges of chevron skinks have not yet been investigated and therefore home range size and the occurrence of overlap between individuals is currently unknown. Also of interest is how home ranges relate to streams, since a clear association has been shown in previous research (Neilson et al. 2006). In addition, it is unclear if chevron skinks demonstrate refuge site fidelity within their home ranges in the wild, in the same way as has been demonstrated in captivity (Baling 2003).

4.3 RESEARCH OBJECTIVES

The current study was undertaken using radio-telemetry of adult chevron skinks. The research objectives were to add to the known habitat preferences of chevron skinks from Neilson et al. (2006) with information from relatively unmodified sites, and to augment this by quantifying the potential for evaporative water loss in chevron skink refuges via vapour pressure deficit measurements. In addition, ranging behaviours were investigated and baseline information on home ranges was established, including overlaps and site fidelity.

4.4 METHODS

4.4.1 Study area

This study was carried out at Port Fitzroy (36° 16′ S, 175° 36′) on Great Barrier Island (GBI; 27 760 ha) in the Hauraki Gulf, New Zealand (Chapter 2; Figure 2), located approximately 90km NE from Auckland city. Unlike mainland New Zealand, GBI is free from introduced mustelids, hedgehogs (*Erinaceus europaeus*), Norway rats (*Rattus norvegicus*) and brushtail possums (*Trichosurus vulpecula*) (Towns and McFadden 1993). Goats were eradicated in 2006. Pigs (*Sus scrofa*), cats (*Felis cattus*), and three rodent species (ship rat, *R. rattus*; kiore, *R. exulans*; and mice, *Mus musculus*) are all relatively common on the island (pers. obs.). The predominant vegetation cover on GBI is manuka (*Leptospermum scoparium*) and kanuka (*Kunzea ericoides*) forest, which has been regenerating since the 1940's (Ogden et al. 2006), although it contains pockets of lowland mixed coastal broadleaf and lower and upper montane forest (Ogden 2004).

4.4.2 Skink capture

Chevron skinks were caught in four stream catchments[3] on Kotuku peninsula and Great Barrier Conservation Forest Area (GBFCA) (Chapter 3; Figure 15). The primary method of capture was G-minnow fish traps (Part number MT 28. Aquatic Eco-Systems, Inc. 2395 Apopka Blvd. Apopka, FL 32703) placed in stream debris dams, and baited with either banana or artificial lure (raspberry, Jamieson and Neilson 2007; or aniseed). Skinks were also captured opportunistically if they were seen during the course of fieldwork. Some skinks were located by searching in suitable holes and crevices with a head torch. One skink was observed approximately 2m off the ground in a puriri (*Vitex lucens*) and was captured by placing a G-minnow fish trap baited with aniseed over the entrance of the hole (Chapter 3; Figure 18). Trapping was carried out between January and April 2008. Trapping periods were January 11 – 21, February 10

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[3] These catchments comprised two treatment catchments where rats were controlled and two catchments where rats were unmanaged. There were insufficient skinks radio-tracked to make comparisons between these areas, therefore skinks were grouped to describe general behaviours.

– 16, March 10 – 16, and April 18 – 24. Additional trapping was done in hairpin stream from January 24 -28, and in the shop stream from February 24 -28. The genders of chevron skinks were difficult to determine with certainty between January and March, therefore these data were not used in this study.

4.4.3 Radio-tracking

4.4.3.1 Transmitter attachment

The methods developed by Neilson et al. (2006) were used to attach transmitters to chevron skinks, with some modifications. In this study, a single strap of Leucopor® surgical tape (13mm wide, 2.5 to 3 rounds of the tail) was used to attach the transmitter to the base of the tail. The strap was approximately 3-4mm posterior to the vent so the skink could carry out its normal excretory and reproductive functions. The transmitters were positioned on the lateral side of the tail in the lee side of the rear legs (Figure 25). This attachment position reduced drag so the skinks were still capable of moving through tight environments, such as cracks, crevices and debris dams. The transmitters used were BD-2 (formerly BD-2A, Holohil Systems LTD, Canada). The pulse rate of the transmitter was reduced to 30 per minute to increase the battery life to 30 days. Individually the transmitters weighed approximately 0.62g. The average weight of each transmitter including tape (and small fragments of leaf debris) was 0.90g, with a maximum of 0.92g.

A prerequisite of radio-tracking is the transmitter should weigh less than 5-10% of the body mass of the individual being tracked (Beausoleil et al. 2004; Mellor et al. 2004). In this study, the transmitter weighed substantially less than 10% of the skink, ranging from 2.2% - 3.5% of the total body mass. As chevron skinks are a nationally endangered species (Hitchmough et al. 2007), a number of additional safety initiatives were introduced. The Leucopor® tape was camouflaged using a xylene free Stephens vivid black permanent waterproof marker, and rubbed with wet clay to mimic the chevron patterning of the skinks (Figure 25). This was undertaken to reduce the risk of the skinks being spotted by visual predators such as kingfishers (*Halycon sancta*). In addition to transmitters weighing less than 5-10% of the body mass of the animal, transmitters were only attached to animals that were in good condition. Data were obtained from chevron skinks captured in 2006/07 by Halema Jamieson (DOC, unpubl.

data) and the correlation between SVL and weight was calculated (Figure 26). If captured skinks were below the best fit for this relationship (i.e. they were relatively light for their length) transmitters were not attached. Gravid chevron skinks were not used for this radio-tracking study. In addition, a skink of suitable weight and length was not used as it appeared to have been recently attacked by a rat (Chapter 3; section 3.4.4; Figure 22), and the extra stress of a transmitter was considered excessive.

In some instances, skinks were refitted with transmitters when the battery life was almost complete. Refitting only occurred if the skinks weight remained the same or increased and the attachment was causing no apparent harm or irritation. Transmitters were removed if the skink had lost any weight irrespective of the magnitude, or the transmitter was causing obvious harm or irritation. Bryan Welch (Biodiversity programme manager, DOC), who managed the transmitter trials with captive skinks at Auckland Zoo, oversaw these health benchmarks.

Figure 25. The attachment location and camouflaging technique used for chevron skinks at Port Fitzroy, on Great Barrier Island in 2008. The top photo shows the placement of the transmitter laterally on the lee side of the rear legs posterior to the vent. The bottom photo shows how the white tape was camouflaged with black permanent marker and soil to make the transmitter relatively inconspicuous. Inset: shows transmitter strap prior to camouflage.

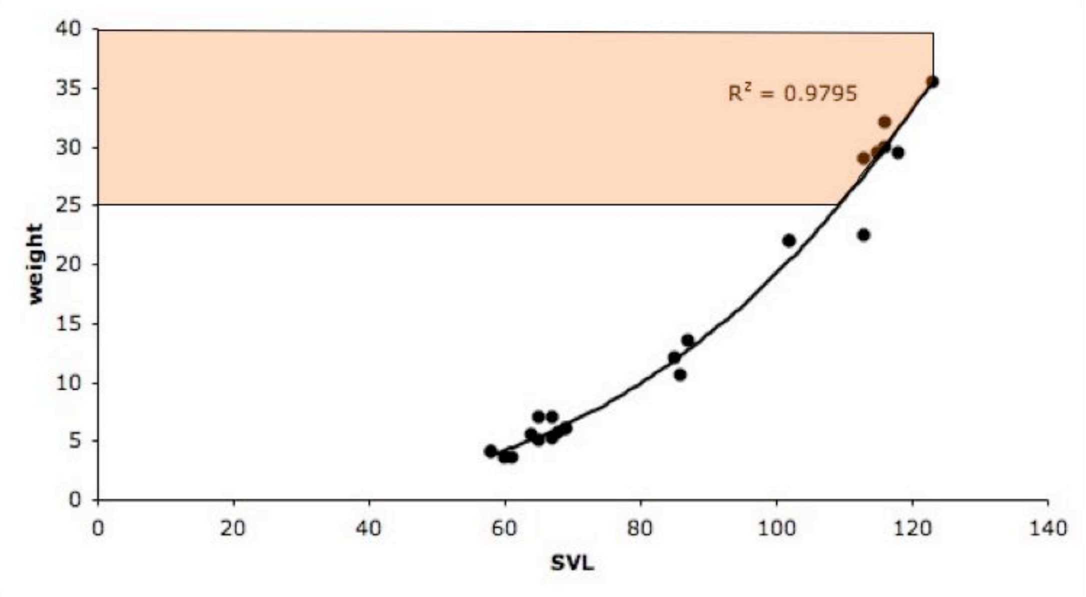

Figure 26. The relationship between snout-vent length (SVL) and weight of chevron skinks captured in 2006 and 2007 at Port Fitzroy, Great Barrier Island, calculated from data obtained from Halema Jamieson (DOC unpubl. data). Transmitters were only attached to chevron skinks whose weight and SVL were equal to or above this relationship, and above 25g (shaded area), unless they were gravid. To ensure wellbeing of chevron skinks, those animals outside this area were excluded from tracking because they were considered too small or not of suitable condition.

4.4.3.2 Telemetry equipment and location fixes

Following the attachment of transmitters, chevron skinks were relocated every day where possible until the transmitter fell off, or was removed (in one instance the battery ran out before it could be retrieved). Relocation of animals was undertaken using an R-1000 telemetry receiver (Communications Specialists Inc. Orange, CA, USA) equipped with a 3-element folding yagi antenna (Sirtrack Ltd. Havelock North, New Zealand). The precise locations of chevron skinks were confirmed by visual confirmation, or if skinks were inaccessible within a refuge, the aerial was removed from the receiver to ‘home in’ on the skink by obtaining the loudest signal from the receiver. Skinks were not disturbed if this could be avoided. Relocations were made between 1000hrs and 1400hrs, and also in the evening around 1900hrs where possible. Transmitters were removed for safety reasons if skinks were unable to be monitored for over two days, i.e. if researcher was forced to leave the monitoring site.

4.4.4 Habitat use

4.4.4.1 Refuge sites

At each relocation site, the specific refuge types that radio-tracked chevron skinks were located in were recorded to determine the percentage occurrence of each type (regardless of the surrounding habitat). Specific refuge types recorded were trees, crevices, logs, leaf litter, stream debris dams, herbage, and boulder.

4.4.4.2 Habitat preferences

The following variables were recorded from a 1m radius around each chevron skink relocation site following the methods of Neilson et al. (2006): distance from stream edge (m), substrate (% of soil, boulders >10cm, stones <10cm, solid rock, water, tree), microhabitat (% of stream debris dam, log, tree, leaf litter, herb cover, bare ground), presence or absence of crevices/clay holes. These variables were also taken at two random sites 5m to the true left and true right of each fix point perpendicular to the stream.

4.4.4.3 Vapour pressure deficit

The relative humidity (RH%) and temperature (T°C) were recorded inside each chevron skink refuge at all relocation sites, and 2cm outside the refuges (similar to Bulova 2002), and again simultaneously at random sites 5m to the true left and true right of each skink refuge site (similar to Moore and Gillingham 2006; Waldron et al. 2008). RH% and T°C readings were only taken for fixes between 1000hrs and 1400hrs to standardise for variations due to time of day. RH% and T°C readings were taken using a Thermo-Hygrometer probe (Model 321: Accuracy ± 0.5°C, ± 2.5%RH (10% to 90%)). The vapour pressure deficit (VPD) of these sites was calculated from the RH% and T°C using a formula described by Yoder et al. (2005). VPD values (and thus EWL rates) correlate negatively with temperature and positively with relative humidity.

Vapor pressure deficit (VPD) = saturation vapor pressure(e_s) – actual vapor pressure(e_a)

$e_s(T) = 0.6108 \exp (17.27T/T+237.3)$

$e_a \quad = RH/100(e_s)$

where e_s = saturation vapour pressure (kPa) at temperature = T (°C); e_a = actual vapour pressure (kPa); relative humidity = RH (%).

4.4.5 Ranging behaviour

4.4.5.1 Arboreal response to rain

The height above ground was recorded (to the nearest 0.5m) when chevron skinks were located in an arboreal retreat. The definition of arboreal was taken as skinks that were above ground in a standing or partially standing live plant, or a standing dead tree structure. Fallen and dead tree structures were considered as logs, and therefore skinks within them were not considered arboreal. As daily rainfall records were incomplete from Port Fitzroy, rainfall records were used from Okiwi station as collated by Joanna Sim (DOC, unpubl. data). Okiwi station is approximately 3km from the study sites.

The heights above ground of chevron skinks were also recorded before, during and after two separate flooding events: 24/2/08 and the 14-15/4/08. ‘Before’ flooding locations were taken as those immediately before rain commenced, ‘during’ flooding locations were those during heavy rain and when streams had risen notably (pers. obs.), and ‘after’ flooding locations were those taken immediately after rain ceased.

In addition, a total of 8 hours were spent conducting hand searches in silver tree fern crowns (*Cyathea dealbata*) during the two flooding events; 4 hours during the first flood and 4 hours during the second flood. Silver tree ferns were searched up to 10m away from the stream by lifting dead hanging fronds and examining around the fern scales in the crown assisted with a headtorch. As a comparison, 8 hours of searches were conducted in silver fern crowns using the same methods as above during dry weather in March and April.

4.4.6 Home Ranges

The capture location grid reference (New Zealand Grid – Geodetic datum '49) of each radio-tracked chevron skink was recorded using a Garmin GPSMAP® 60CSx. The bearings and distances to each successive relocation point were recorded so that each subsequent location could be converted to a grid reference.

4.4.7 Data analysis

4.4.7.1 Habitat use

Means and standard errors of percentage occurrence were considered to be the appropriate descriptive statistics for substrate and microhabitat variables at all chevron skink sites (actual relocation site and random site) due to sample sizes within the dataset being significantly greater than 50 and therefore approximating normalcy (Sokal & Rohlf 1973).

To determine habitat preferences, habitat variables at all relocation sites of radio-tracked skinks were compared with those at random sites using a logistic regression model with binary response (logit) and maximum likelihood method (PROC GENMOD; SAS institute v9.1, Cary, NC, USA). The variable response was set to 0 for radio-tracked sites and 1 for actual skink relocation sites. Microhabitat and substrate variables were converted to presence/absence data for the purpose of this analysis. The final model was obtained by removing non-significant variables from the full model using a backwards-stepwise approach.

To test for biases due to individual skink habitat preference and varying sample sizes per skink, a non-linear mixed model was run using individual skinks as a random factor for each habitat variable that were significant in the full logistic regression model above (PROC NLMIXED; SAS institute v9.1, Cary, NC, USA). Any significant models would indicate individual skink differences.

The VPD's outside chevron skink refuges were compared with the VPD's at random sites using a one-way ANOVA (Graphpad Prism 5.0 for Macintosh, Graphpad software, Sandiego, California, USA) to determine if, on a landscape scale, the environments adjacent to refuges were significant in determining refuge use. The use of burrows is considered to reduce the rates of EWL in some New Zealand reptiles (Towns 1999). The VPD was therefore compared inside and outside of chevron skink refuge sites using a one-tailed t-test (Graphpad Prism 5.0 for Macintosh, Graphpad software, Sandiego, California, USA) to determine if the potential for EWL was indeed lower inside refuges compared with the ambient environment immediately outside.

4.4.7.2 Ranging behaviour

The arboreal responses of chevron skinks to general rainfall and flooding events were tested separately. The responses to general rainfall were tested by correlating the heights above ground of chevron skink arboreal retreats with rainfall (Pearson's correlation in Microsoft excel). A Friedman's non-parametric ANOVA (Graphpad Prism 5.0 for Macintosh, Graphpad software, Sandiego, California, USA) was used to determine if chevron skinks responded to flooding events. Two flooding events occurred during this study and these were combined for this analysis, and the response of six independent skinks was measured. One skink was radio-tracked through both floods however the response of this skink was included in the analysis only once by averaging its response to ensure independence of the data.

4.4.7.3 Home ranges

The 95% minimum convex polygon (MCP) home ranges were calculated in Ranges7 eXtra v1.7 (Anatrack Ltd.) using the grid references of individual skink locations. Home ranges were only calculated for animals with more than five fix points. An overlap analysis was run using Ranges7 eXtra v1.7 where chevron skink 95% MCP home ranges overlapped, to determine the extent of the overlap.

4.5 RESULTS

4.5.1 Transmitter attachment

The transmitter attachment method used in this study was highly successful and achieved satisfactory attachment times. Transmitters were voluntarily removed from six skinks, three skinks shed their transmitters during moulting, and one was not recovered as the battery expired before it could be retrieved (Table 5). Attachment times varied from 2 to 34 days (including refitting). Transmitters did not cause any obvious harm to the chevron skinks (Bryan Welch, pers. comm.). Four skinks gained weight while being radio-tracked (0.5-1.25g), two lost weight (0.25 and 1.25g) and one remained the same.

Table 5. Attachment dates and fate of the transmitters (TX) for radio-tracked chevron skinks at Port Fitzroy, Great Barrier Island in 2008

skink	TX on	TX off	Reason off	TX on	TX off	Reason off	Total days on
Tahi	26/1	2/2	Removed				8
Rua	19/1	26/2	Removed	11/4	21/4	sloughed	17
Toru	19/2	26/2	Removed				7
Wha	23/4	24/2	Removed				2
Rima	22/2	25/2	Sloughed				3
Ono	12/3	26/3	Refitted	26/3	15/4	Battery expired	34
Whitu	15/3	26/3	Removed				11
Waru	26/3	19/4	Removed				25
Iwa	6/4	14/4	Sloughed				8

4.5.2 Habitat use

4.5.2.1 Refuge sites

Nine chevron skinks were tracked and a total of 116 fixes were taken at 86 separate refuge sites. Chevron skinks were most often found in tree, crevice and log refuges (Figure 27). All skinks with more than five fix points (n = 7) were found in at least two of these refuge types and five of these were found to use all three of these refuge types. Other refuges utilised by chevron skinks were leaf litter, debris dams, herbage and boulders, although these refuges were used less frequently (Figure 27). One chevron skink was radio-tracked to an old rat burrow on the side of Aotea road as nesting material was still present. Another individual was located in a tunnel web spider (*Porrhothele antipodiana*) hole, with fresh web fragments suggesting the chevron skink ate the spider and remained in its hole.

4.5.2.2 Habitat preferences

Chevron skinks were not distributed randomly throughout the catchments at Port Fitzroy. Chevron skinks were most often found within 5m of the stream (almost 30% of the time), although they were found up to 58m away from the stream (Figure 28). When comparing actual skink locations with random sites, skinks used tree substrates proportionately more often than it was available, and used soil less often than it was available (Figure 29 . Chevron skinks used sites with trees, logs and stream debris dam microhabitats more often than they were available, and used sites with bare ground and leaf litter microhabitats less than they were available (Figure 30).

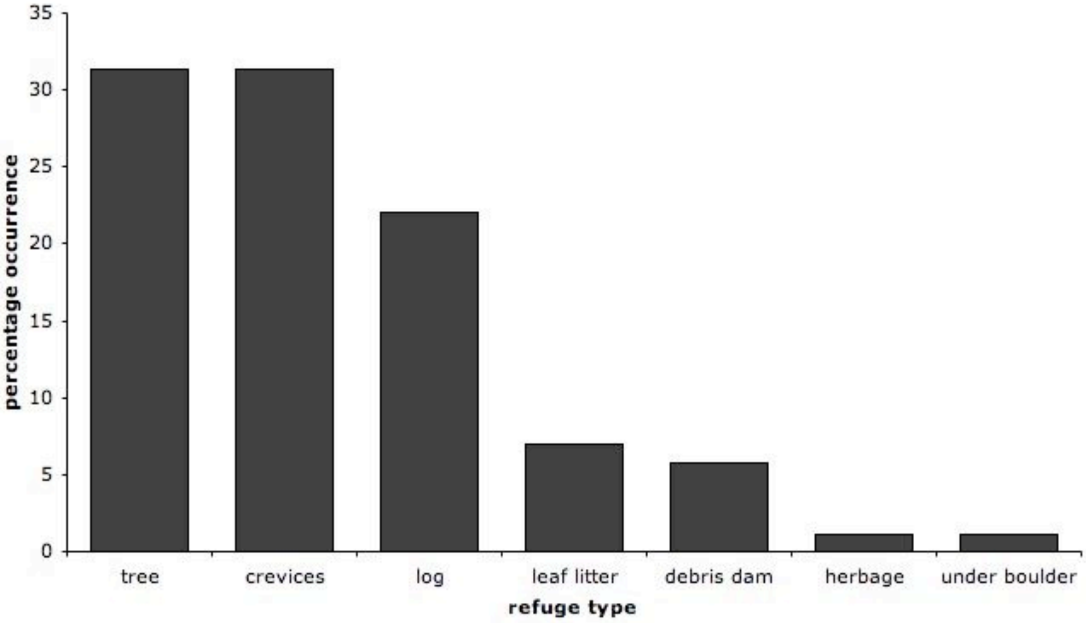

Figure 27. Percentage occurrence of unique refuge sites used by chevron skinks (n = 86) during radio-tracking at Port Fitzroy, Great Barrier Island in 2008.

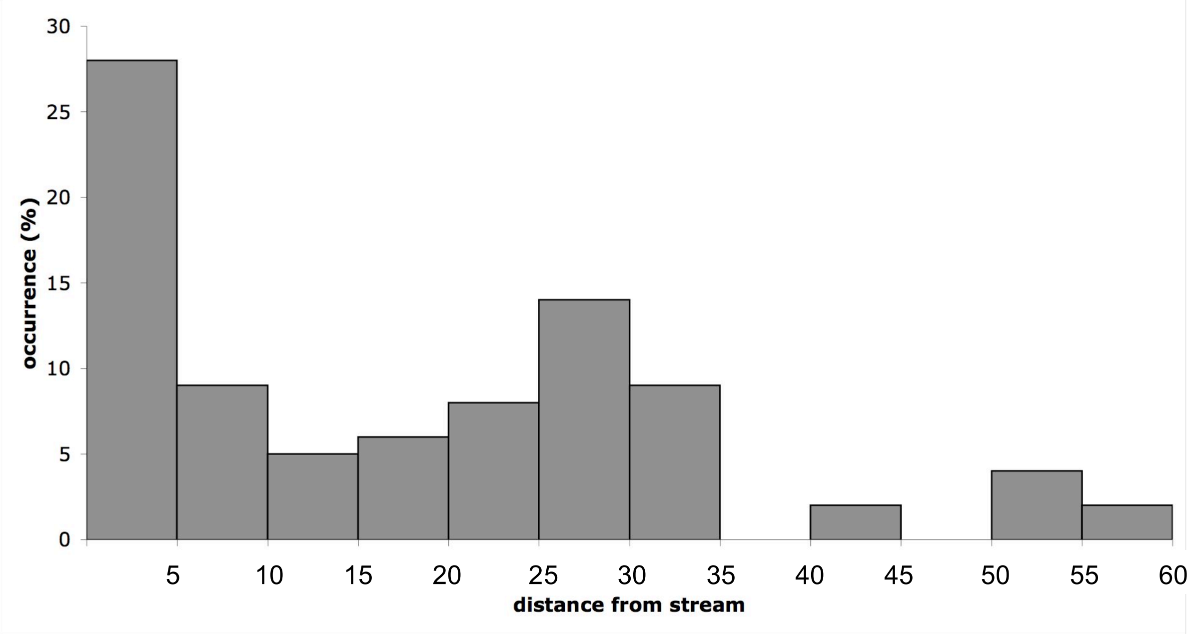

Figure 28. The percentage occurrence of chevron skink relocation sites (n = 86) as a function of distance from the stream edge at Port Fitzroy, Great Barrier Island in 2008.

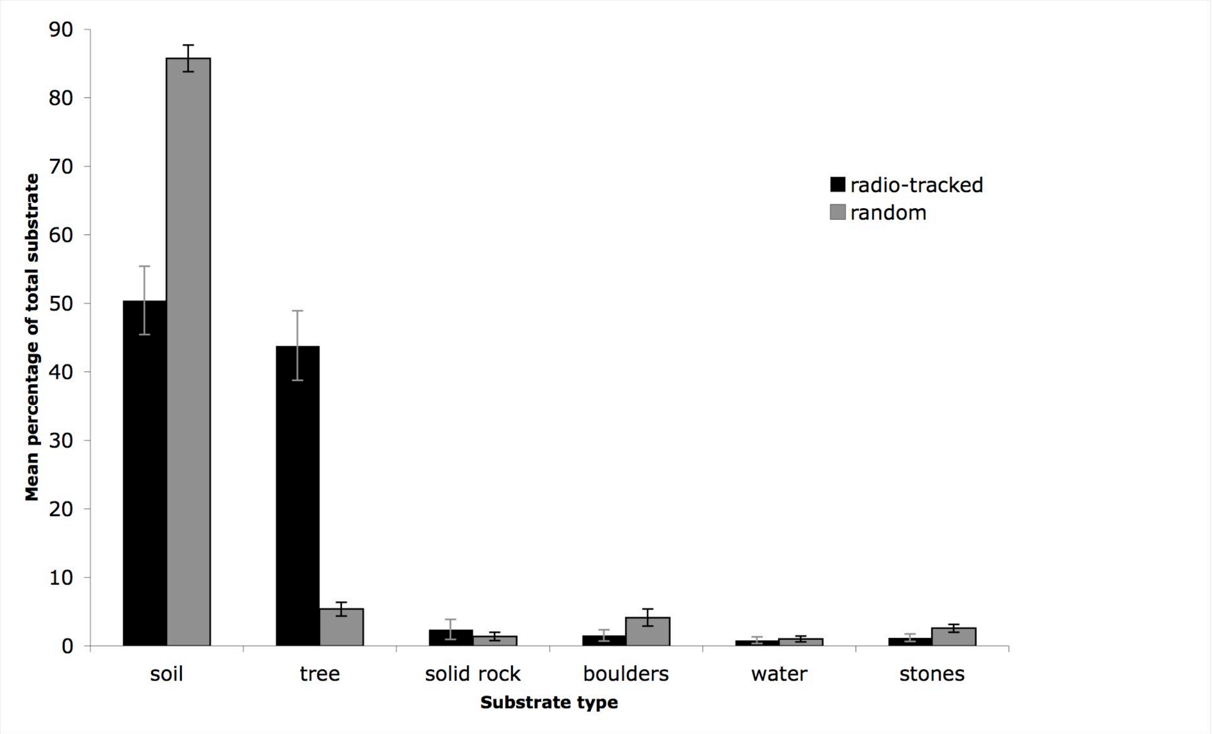

Figure 29. Mean percentage (± SE) of the occurrence of substrate types where chevron skinks were radio-tracked (*n* =86) and at random sites (*n* = 172) at Port Fitzroy, Great Barrier Island in 2008.

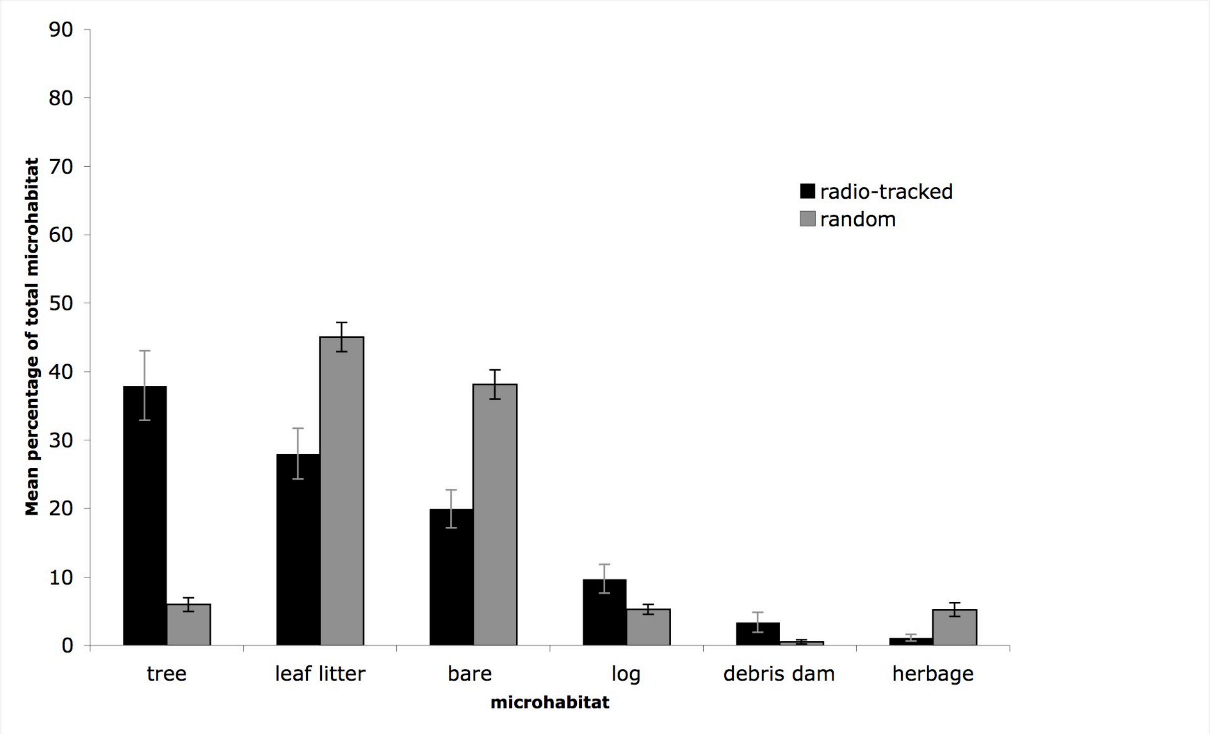

Figure 30. Mean percentage (± SE) of the occurrence of microhabitat types where chevron skinks were radio-tracked (*n* =86) and at random sites (*n* =172) at Port Fitzroy, Great Barrier Island in 2008.

The significant variables in determining the presence of chevron skinks from the maximum likelihood model were tree, debris dams, crevice, soil, and bare ground. The terms for debris dams, trees and crevices were positive, indicating that chevron skinks prefer these habitat variables. The terms for soil and bare ground were negative, suggesting that chevron skinks avoid sites with soil and bare ground (Table 6).

There was no significant variation between individual skinks in their ratios of presence and absence in each habitat variable used in the logistic regression: soil, debris dam, tree, bare ground, crevice (Table 7).

Table 6. Summary of estimated effects of habitat variables that predict chevron skink presence from a backwards-stepwise logistic regression model using maximum likelihood (PROC GENMOD; SAS institute v9.1, Cary, NC, USA) at Port Fitzroy, Great Barrier Island in 2008.

Variable	Parameter estimate	Standard error	χ^2	df	*P*
Tree	0.81	0.46	5.00	1	< 0.05
Debris dam	3.28	0.87	14.20	1	< 0.01
Crevice	2.65	0.44	35.67	1	< 0.01
Soil	-2.85	0.55	26.45	1	< 0.01
Bare	-1.60	0.46	11.86	1	< 0.01

Table 7. Summary of the non-linear mixed models (individual skinks as a random factor) for each microhabitat variable that were significant in the logistic regression model (Table 6) (PROC NLMIXED; SAS institute v9.1, Cary, NC, USA). Each variable was modeled separately and significant models would indicate difference between individual skinks.

Variable	Parameter estimate	Standard error	t	df	*P*
Tree	0.00	1.0	0	8	1.0
Debris dam	5.25	9.8	0.53	8	0.61
Crevice	-0.14	0.83	-0.18	8	0.86
Soil	0.25	0.38	0.68	8	0.52
Bare	0.24	0.37	0.66	8	0.53

4.5.2.3 *Vapour pressure deficit*

The VPD's outside actual chevron skink refuges and at random sites were not significantly different (F_2 = 0.025, P = 0.97) (Figure 31). However, the VPD was significantly lower inside chevron skink refuges when compared to outside the refuges (t_{34} = 2.022, P = 0.025) (Figure 31). Skinks were never relocated in refuges where the VPD was above 0.45kPa despite the ambient VPD outside refuges varying greatly (Figure 31).

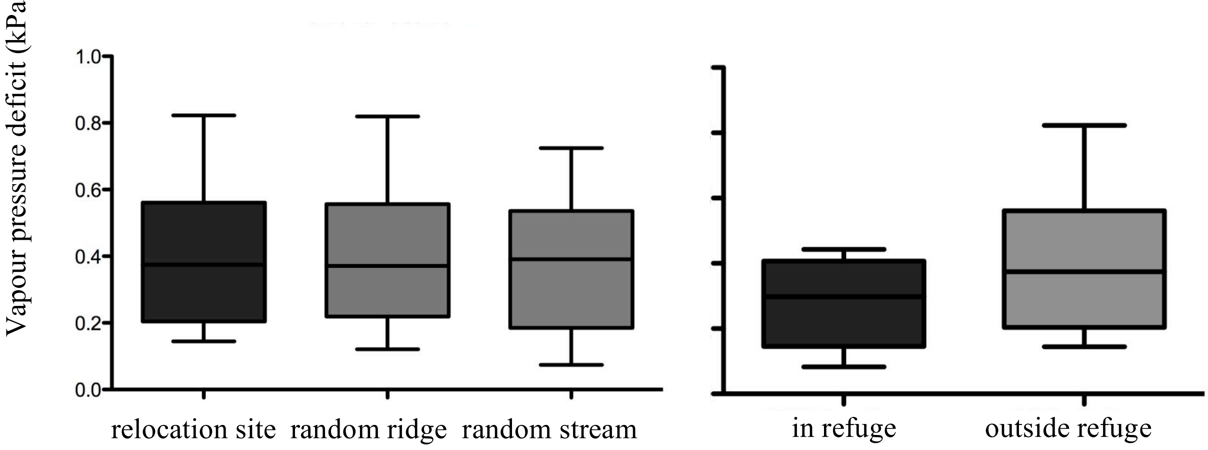

Figure 31. Left: the vapour pressure deficit (VPD) of the ambient air immediately outside a chevron skink relocation site, and at two associated random locations (5m perpendicular towards stream; 5m perpendicular towards ridge). Right: the vapour pressure deficit (VPD) of the ambient air inside chevron skink refuge site and immediately outside the refuge at Port Fitzroy, Great Barrier Island in 2008. A lower VPD corresponds to a lower rate of evaporative water loss (EWL).

4.5.3 Ranging behaviour

4.5.3.1 *Arboreal response to rain*

The height above ground of arboreal retreats for radio-tracked chevron skinks was only weakly correlated with general rainfall (r = 0.028, NS) (Figure 32).

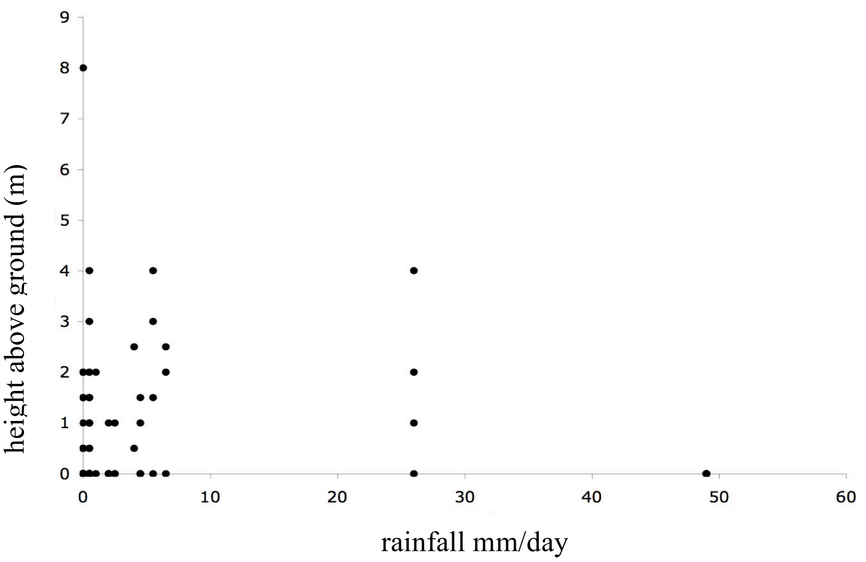

Figure 32. Correlation between height above ground of chevron skink arboreal retreats, and rainfall (r = 0.028) at Port Fitzroy, Great Barrier Island in 2008.

In contrast, during two heavy rain events that induced stream flooding (pers. obs.), four out of six radio-tracked chevron skinks either climbed trees after having been previously located on the ground or climbed further up the tree they were in, and one skink moved between trees. One of these skinks was tracked during both floods and responded on both occasions by refuging in a silver tree fern crown after having been previously located on the ground. During the first flood in February, three out of four radio-tracked chevron skinks climbed into silver fern crowns (between 1 and 4m tall). One of these skinks had been in a silver fern crown the day before the flood and moved to a new but shorter silver fern the day of the flood. The skink that stayed on the ground during the first flood was located around the headwaters of the stream it inhabited. During the second flood in April, one out of the three radio-tracked skinks climbed into a silver fern crown (2m), and the other two skinks moved further upwards on the fallen tree they were inhabiting; one moved into a thin hollow branch 4m off the ground, and the other into an epiphyte on top of the fallen tree.

The apparent trend before, during and after flooding events was for chevron skinks to move upwards during flood, and to retreat once the flood subsided (Figure 33). This trend approached biological significance, although it was not statistically significant ($F_2 = 7.143$, $P = 0.07$).

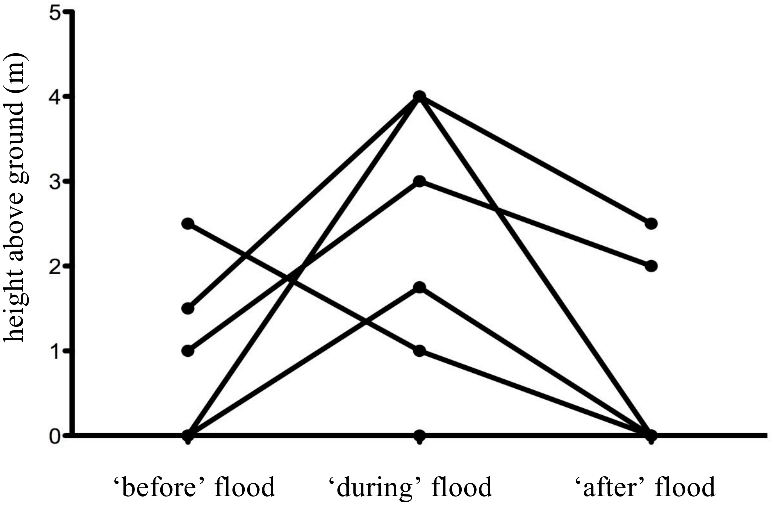

Figure 33. The height (m) above ground radio-tracked chevron skinks (*n* =6) were relocated 'before', 'during' and 'after' flooding events at Port Fitzroy, Great Barrier Island in 2008.

Active searches in silver tree fern crowns during the two flooding episodes revealed six chevron skinks (0.75skinks/hr) (Figure 34). Two of these were neonate skinks, one was juvenile and three were adults. Active searches in silver tree fern crowns during dry periods failed to detect any chevron skinks (0skinks/hr).

Figure 34. Photo of an adult chevron skink refuging *in situ* in a silver tree fern crown (*Cyathea dealbata*) amongst dead fern fronds at Port Fitzroy. Note the effectiveness of the camouflage amongst dead fern fronds. Photograph by author.

4.5.4 Home ranges

The MCP (95%) home ranges of radio-tracked chevron skinks varied from 95m^2 to 1505m^2 with a mean of 451m^2 ± 195.1m^2 (n =7) (Table 8). Overlap analysis revealed that two pairs of skinks (Waru and Ono; Tahi and Whitu) shared parts of their home range (Figure 35). Almost the entire home range of Waru (99%) was within the home range of Ono, while only 12% of Ono’s home range was shared with Waru (Table 9).

Waru and Ono inhabited the same fallen tree for 20 days (30 March – 19 April). They utilised the entire structure and were often refuging within 1m of the other, but never in the same refuge at the same time. The overlaps between Tahi and Whitu were modest being 11% and 30% (Table 9). Tahi and Whitu were not tracked simultaneously.

Chevron skinks showed some refuge site fidelity, with one skink using the same refuge on four occasions, one other skink using five refuges twice, and another skink using a single refuge twice. In both instances where chevron skink home ranges overlapped, skinks shared at least one common refuge, although never simultaneously.

Two chevron skinks had home ranges that crossed the major stream in the catchment, while all five other skinks had home ranges that utilised only one side of the stream (Appendix 2).

Table 8. The home ranges of chevron skinks at Port Fitzroy, Great Barrier Island in 2008. Only skinks with five or more locations were included.

Skink	Home range (m^2)	No. of fix locations
Tahi	458	9
Rua	95	7
Toru	118	7
Ono	693	25
Waru	156	16
Whitu	1505	10
Iwa	130	6
	mean = 451 ± 195.1	

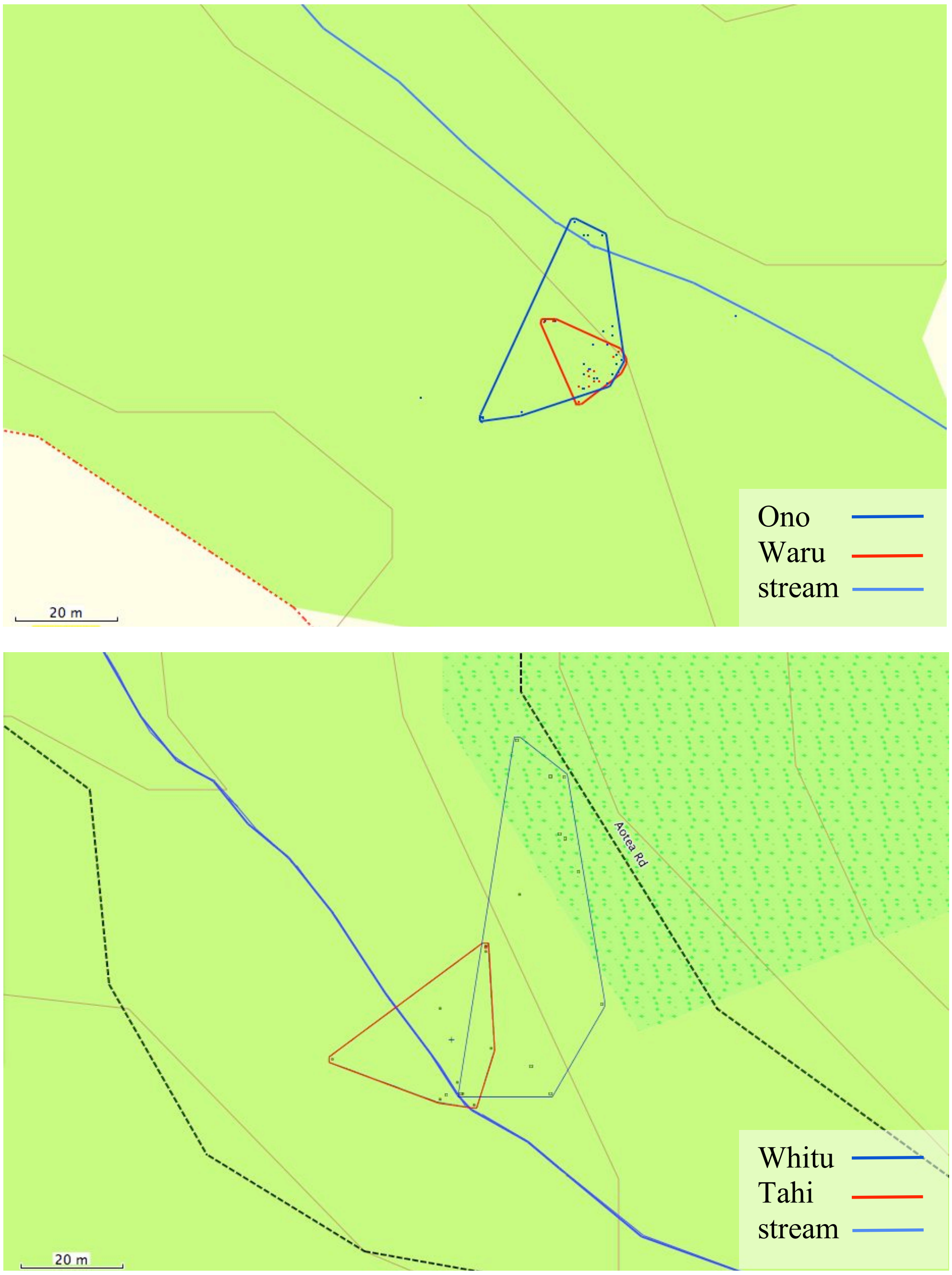

Figure 35. Overlapping home-ranges (95% MCP) and individual locations of chevron skinks at Port Fitzroy, Great Barrier Island in 2008.

Table 9. Estimated area of home range overlap (95% MCP) of two pairs of chevron skinks at Port Fitzroy, Great Barrier Island.

Skink ID		Estimated overlap	Percentage overlap	
skink a	skink b	area (m^2)	a on b	b on a
Tahi	Whitu	185	11%	30%
Ono	Waru	136	99%	12%

4.6 DISCUSSION

4.6.1 Transmitter attachment

The importance of avoiding research practices that may be detrimental to the study species is particularly pertinent for endangered species. While standard protocols for transmitter attachment dictate that transmitters should weigh less than 5% -10% of the animals body weight, this does not take into account the body condition of the animal. Large chevron skinks in poor condition may be less able to tolerate additional weight, despite being relatively heavy, and this may make them more susceptible to mortality (Halema Jamieson, pers. comm). The selective attachment of transmitters in this study took condition into account and achieved its target of 0% mortality. Camouflaging the transmitter attachment strap is also considered to be a useful safety initiative (Fair & Henke 1999). Considering many reptiles have cryptic camouflaging to avoid detection by visual predators (Cuadrado et al. 2001), manipulations to animals for research purposes should aim to minimise obvious visual anomalies such as transmitters. Transmitter attachment times in this study (2-34 days) were substantially longer than those achieved by Neilson et al. (2006) (3-8 days), due to improvements in flexibility of the transmitter aerials (Halema Jamieson pers. comm.) and the strap attachment system used. The transmitter attachment methods and safety initiatives used in this study were highly successful and are recommended for future use with similar large and cryptic skinks.

4.6.2 Habitat use

4.6.2.1 Refuge sites

The most commonly used refuge types of chevron skinks in this study were trees and crevices, followed by logs. The importance of crevices and trees as refugia for chevron skinks supports the work of Neilson et al. (2006), who found that these were the first and third most commonly used refuges respectively at the Tryphena study site on GBI. The current study also found that logs were a commonly used refuge in Port Fitzroy (22% of the time) while they were utilised less often in Tryphena (less than 10%; Neilson et al. 2006). Neilson et al. (2006) determined the second most important refuge site was debris dams, which were used approximately 25% of the time, and all skinks spent at least some time in them. Although six of the nine radio-tracked skinks were caught in debris dam traps in this study, only three skinks spent subsequent time in debris dams. In fact, debris dams were only used by skinks as refuges 4% of the time. It is not known whether capture in debris dams caused chevron skinks to subsequently avoid them, or whether there was a real difference in the use of debris dams between Tryphena and the current study site at Port Fitzroy.

4.6.2.2 Habitat preferences

The methods of obtaining random sites to compare habitat use with availability were slightly different between this study and a similar study by Neilson et al. (2006), as the objectives were slightly different. Neilson et al. (2006) took random sites from between 0-15m from the stream since their study skinks never went more than 13m from the stream. The current study endeavoured to test thermal preferences from VPD measurements as a further measure of skink preferences. VPD measurements at random sites needed to be taken more or less simultaneously, so logistically this needed to be close by. Accordingly, the random sites in this study are associated with the actual chevron skink relocation sites (similar to Moore and Gillingham 2006; Waldron et al. 2008).

Despite these methodological differences, the microhabitat and substrate preferences of chevron skinks were found to be similar. Both Neilson et al. (2006) and this study found that the most significant substrate variable in determining the presence of chevron skinks was trees. This emphasises the arboreal tendencies of chevron skinks and supports both Baling (2003) who noted this behaviour in captivity and Neilson et al. (2006) who first confirmed this behaviour in the wild. In this study, chevron skinks were often relocated within partially rotten and hollow puriri trees. It is possible that chevron skinks frequent such habitats as they contain numerous prey items such as cave weta (*Gymnoplectron* spp.; pers. obs.), which take refuge there during the day when chevron skinks are foraging. The capture of prey would be substantially easier in such contained environments as prey have less opportunities of escape. That two chevron skinks stayed within a single fallen puriri and maintained high activity for at least 20 days suggests that these habitats provide ample feeding opportunities.

The current study also found that chevron skinks were less likely to be found at sites with soil as a substrate, which was showed as a trend in Neilson et al. (2006). Although this result suggests chevron skinks avoid soil, this substrate is the most commonly available and was also present more often than any other substrate at chevron skink sites. It is likely that chevron skinks often choose sites where soil is absent (for example trees) rather than actually avoiding substrates with soil.

Crevices and stream debris dam habitats were found to be significant variables in determining chevron skink presence in this study, similar to Neilson et al. (2006). The use of crevices by reptiles reduces the threat of predation (Christian & Tracy 1981; Fenner et al. 2008) and lowers the potential for EWL (Bulova 2002; Clarke & Nicolson 1994). In addition, chevron skinks presumably also seek burrows/crevices as they often contain prey items such as tunnel web spiders (*Porrhothele antipodiana*) and other invertebrates. Pygmy blue-tongue lizards (*Tiliqua adelaidensis*) have also been shown to use the burrows of several species of ground dwelling spider (Milne et al. 2003). The use of debris dam microhabitats was significant in predicting chevron skink presence although it was used infrequently. This suggests that debris dams are a relatively uncommon microhabitat, but receive use disproportionate to their availability. As chevron skinks suffer from high rates of EWL (Neilson 2002), debris dams would offer respite from hot, dry conditions as they are generally very damp and humid. Such microhabitats could be particularly important for smaller chevron skinks as they would be more vulnerable to EWL due to their surface-area-to-body-size ratio (Nicholson et al. 2005). The high trapping rates of all size categories using G-minnows in debris dams supports the suggestion that debris dams are an important refuge for chevron skinks.

Debris dams may also be useful to chevron skinks as a shelter to make themselves less vulnerable to visual predators when crossing streams. The negative association with bare ground microhabitats supports this assertion. When chevron skinks are not in refuges they would be particularly vulnerable to their native visual avian predators, and so possibly evolved their cryptic colouration as a defence. The cryptic nature of chevron skinks implies that they rely on camouflage to avoid predation; therefore the use of open ground would increase their vulnerability (Gilbert & Boutin 1990). The fact that chevron skinks are often in ferns, and spend time in fern leaf litter and debris dams makes sense of the dorsal chevron patterning and colouration of chevron skinks. This patterning is almost identical to dead fern fronds under which it refuges in these locations. This apparent avoidance of bare ground of chevron skinks has implications for conservation management. Towns and McFadden (Towns & McFadden 1993) indicated that chevron skinks would benefit from the control of goats and pigs as these species severely degrade habitat, both ground cover and leaf litter. This study supports these suggestions on the basis chevron skinks would have greater cover opportunities in low disturbance areas particularly when moving about on the forest floor and would therefore be less vulnerable to predation.

The presence of logs was not a significant predictor of chevron skink presence, even though logs were an important refuge site for chevron skinks. This suggests that logs are utilised frequently by chevron skinks, although their use relative to their availability is not disproportionate. Logs are known to be important drivers of forest ecology (Harmon et al. 1986) and in New Zealand forests invertebrate species richness increases closer to logs, and they provide refuges for large invertebrate species (Evans et al. 2003). Furthermore, logs and other forms of coarse woody debris tend to accumulate at the bottom of slopes such as in stream beds and terraces (Harmon et al. 1986; Rubino & McCarthy 2003), which is an important area for chevron skinks. In young forests lacking abundant logs, refuging sites and foraging opportunities for chevron skinks would be fewer; therefore this study considers the importance of logs to chevron skinks should not be understated.

4.6.2.3 Vapour pressure deficit

The study of evaporative water loss (EWL) of chevron skinks by Neilson (2002) highlighted that chevron skinks have high rates of EWL and suggested this may physiologically restrict them to damp environments. The current study investigated how relative humidity (RH%) and temperature (T°C) interact to predict EWL through measuring the vapour pressure deficit (VPD). This study found that chevron skink refuges have lower potential for EWL than the ambient conditions outside refuges and this may indicate that chevron skinks are using retreat sites to maintain their water levels.

The use of refuges to lower the potential for EWL is well documented for reptiles, particularly desert species (Beck & Jennings 2003; Bulova 2002). In New Zealand reptiles, refuge use as a means to lower EWL is implied but untested (Towns 1999). This study confirmed that the VPD is favourable inside chevron skink refuges. However VPD cannot be confirmed as the sole determinant of refuge choice, since refuges are also useful as retreats from predation and for foraging opportunities. The apparent increase in activity of chevron skinks after rain, and on humid days (Halema Jamieson, pers. comm.) supports the suggestion that VPD/EWL is a limiting factor for chevron skinks in some climatic conditions, and also support the assertions of this study that refuges offer retreats from conditions of high EWL.

The VPD's outside of the refuge site were not different between actual and random sites although it is likely that the close proximity of random sites to actual sites affected these results. Chevron skinks have never been caught in ridge habitats (Neilson et al. 2006) and in this study radio-tracked skinks were never relocated on or near ridges. Neilson et al. (2006) have implied this is due to the dryness of these habitats. Ridges were never sampled as random sites in this study as skinks were never close enough to them for them to be sampled as defined by the methodology. If the VPD was tested on a broader habitat scale that included ridges, it is likely that differences would have arisen since ridges are generally drier and hotter than valleys.

In this study the VPD of chevron skink refuges stayed below a certain level (0.45kPa), despite the ambient conditions outside burrows fluctuating widely and attaining relatively high VPD measurements (up to 0.82kPa). There is likely to be VPD threshold, above which the environmental conditions constrain skink activity. During winter when conditions are cooler and wetter these constraints would be removed. This potentially explains why many sightings occur in non-forested areas during wetter cooler months (Neilson et al. 2006; DOC unpubl. data)

4.6.3 Ranging behaviour

4.6.3.1 Arboreal response to rain

This study showed no correlation between the height above ground at which chevron skink refuges were located and general rainfall. This indicates that in most cases arboreal behaviour of chevron skinks was not related to rainfall, but must be due to other cues such as foraging opportunities, escape from predators or thermal preferences.

Despite the non-correlation between general rainfall and the height above ground that chevron skink refuges were located, radio-tracking adult chevron skinks suggested they do respond to significant flooding events with arboreal behaviour. This finding approaches biological significance although it was not significant. The small sample was the main constraint hindering the statistical test, as nearly all skinks climbed in response to the flood. The only skink that appeared to respond contrary to this hypothesis was still located up in a silver fern during the flood, however it was lower than the one it was in prior to the flood. This *apparent* negative response also hindered the statistical significance. All considered, the arboreal response to floods of chevron skinks is considered to be real. This assertion was supported by the high capture rates during targeted searching in silver fern crowns during flood, and the lack of any captures during identical searches in dry conditions. The fact that all size categories were found in silver fern crowns indicates that this response is not limited to adults, although this should be tested further.

Since chevron skinks are associated with stream environments (Neilson et al. 2006; Newman & Towns 1985) it is logical that the purpose of this response is a safety mechanism to avoid being swept away in floodwaters (Baling 2003). There is no known evidence of this type of behavioural response being observed in reptiles before this study, although it has been shown in stream dwelling invertebrates (Lytle 1999; Lytle & Smith 2004; Lytle & White 2007). These studies indicated that some invertebrates anticipate flooding events using rainfall cues to avoid being washed away. The behaviour demonstrated by escaping invertebrates is always negatively geotactic – they always choose the steepest available route (Lytle & Smith 2004). This negatively geotactic behaviour appears to be the same response that chevron skinks demonstrated in this study, and future research should be undertaken to confirm this.

Cues for the arboreal response of chevron skinks to flooding remain unclear. Chevron skinks responded to flooding regardless of their proximity to the stream in this study (between 8 and 26m), so it is clear they were not responding directly to the floodwaters. Lytle (1999) indicated that rainfall duration was the main cue that invertebrates respond to, although acknowledged there could be auxiliary cues. In this study chevron skinks only responded to floods and not to ‘normal’ levels of rainfall. It is therefore possible that there is a rainfall intensity or duration threshold above which a response is initiated in skinks. It is also possible that chevron skinks use auxiliary cues. Lytle (1999) suggested that acoustic cues such as the sound of flooding could prompt a response, or climatic variables such as atmospheric pressure, lightning or cloud cover. There is anecdotal evidence that chevron skinks preempt rain in captivity and start climbing in their cages (Bryan Welch, pers. comm.). In the absence of rain and acoustic cues, such a response is likely due to atmospheric pressure, although this is untested. Anecdotal evidence from lizards in the Pacific suggest that normally terrestrial lizards display arboreal behaviour prior to cyclones, possibly in response barometric changes (Aaron Bauer pers. comm.).

4.6.4 Home ranges

The home range estimates in this study are the first for chevron skinks. The mean home range size (95% minimum convex polygon) of chevron skinks in this study were slightly lower than Otago skinks (*Oligosoma otagense*), a similar sized skink of the same genus in the South Island. The estimates were also lower than the 900m^2 to 1100m^2 that would be expected based on their body size (Christian & Waldschmidt 1984). It is possible that the home ranges presented in this study are an underestimate as home range size estimates increase indefinitely with the number of relocations and too few relocations result in an underestimate (Stone & Baird 2002).

The information presented in this study reveals that adult chevron skinks can overlap in their home ranges, and will share common refuges, although not simultaneously. Both overlaps appeared to be between males, although this is not certain due to difficulty in determining sex categorically. The overlaps presented are likely to be underestimates as not all chevron skinks in an area were radio-tracked. None of the skinks appeared to have any scars that are indicative of territoriality, such as oblong bite marks or missing toes. How chevron skinks respond to one another in the wild, and how this defines their home ranges remains unknown.

Chevron skinks displayed a degree of site fidelity in this study, and therefore it is possible they were familiar with their home ranges. This supports the research undertaken on captive chevron skinks (Baling 2003). The reasons for familiarity with home range and site fidelity could be to avoid diseases, predators and stress (Dubas & Bull 1992). Koenig et al. (2001) showed that blue-tongue lizards (*Tiliqua scincoides*) used key refuge sites multiple times and suggested these ‘safe’ refuges reduced the skinks’ vulnerability to predators and allowed them to persist in suburban environments. This phenomenon could also be true for chevron skinks in this study. Multiple use of refuge site indicates the site is probably ‘safe’ from predators. Skinks may build up preferences for certain sites where they were not disturbed and aversions to sites where they were. Spiny-tail iguanas select winter refuge sites because they are safe from predators and provide basking opportunities, and it appears they ‘recognise’ and reuse the site the following winter if it has proved to be favourable (Biazquez 2001). Such behavioural responses could assist chevron skinks in surviving in the presence of abundant predators.

Adult radio-tracked chevron skinks moved substantially further away from streams in this study than was previously reported in Neilson et al. (2006). This could be due to climatic conditions as lizards have been shown to shift their home ranges in response to changes in climate (Christian et al. 1983). This possibility is considered unlikely as this study and that of Neilson et al. (2006) were both conducted during the same season. It is possible that during particularly dry and hot summers chevron skinks will stay closer to streams, however as skinks were radio-tracked over three summers by Neilson et al. (2006), any such effect should have been negated in their study. Another possible reason for this difference is chevron skinks use the habitat differently in Tryphena, or the skinks in Neilson et al. (2006) were not radio-tracked long enough during any individual monitoring period to register movement away from the stream.

4.7 SUMMARY AND CONCLUSIONS

This study augmented current knowledge of habitat use and preferences, established new information on the ranging behaviour and baseline information on the home ranges of chevron skinks.

Chevron skinks used trees, crevices and logs most often as refuge sites. The significant habitat variables in determining the presence of chevron skinks were trees, crevices and debris dams, all of which were used more frequently than what they were available; and bare ground and soil, which were used less often than they were available. Chevron skinks also showed a tendency to prefer logs although this was not significant. These findings were similar to those during a similar study of chevron skinks by Neilson et al. (2006). Furthermore, the refuge sites of chevron skinks were shown to have lower potential for water loss when compared to the ambient outside conditions in this study. This indicates that refuge use could be important for chevron skinks to maintain acceptable levels of evaporative water loss. Refuge selection could also be important to reduce vulnerability to predators, and as foraging sites. The relative importance of each of these factors is not understood.

Chevron skinks appear to display a negatively geotactic response that is initiated by flooding events, and this response causes them to climb trees. As chevron skinks associate with streams, this is considered to be a safety mechanism that allows them to avoid being taken by floodwaters. The cues for this response are unknown, but could include duration and intensity of rain or atmospheric pressure changes. ‘Normal’ levels of rainfall do not appear to cause this arboreal response.

The home ranges of chevron skinks indicate that during the time of year of the research, adult chevron skinks can move further away from streams than has been previously suggested. The home ranges of chevron skinks also overlap in come cases, and in these instances common refuges are shared, although not simultaneously. In addition, chevron skinks demonstrated site fidelity, which indicates there is some familiarity and preference for certain sites within their home ranges. These sites may offer effective refuge from predation, favourable thermal qualities and foraging opportunites, and may be ‘remembered’ by skinks as ‘safe’ sites.

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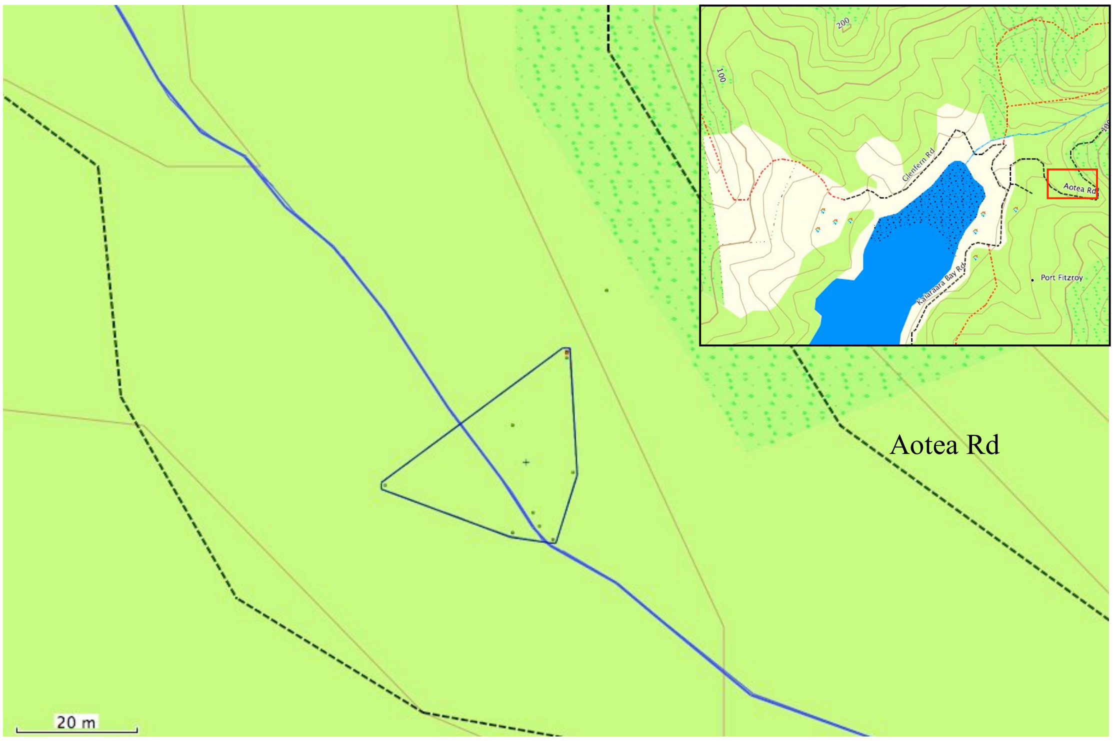
4.9 APPENDIX

Appendix 2. Home ranges (95% minimum convex polygons) and individual fix points of chevron skinks at Port Fitzroy, Great Barrier Island in 2008

Tahi



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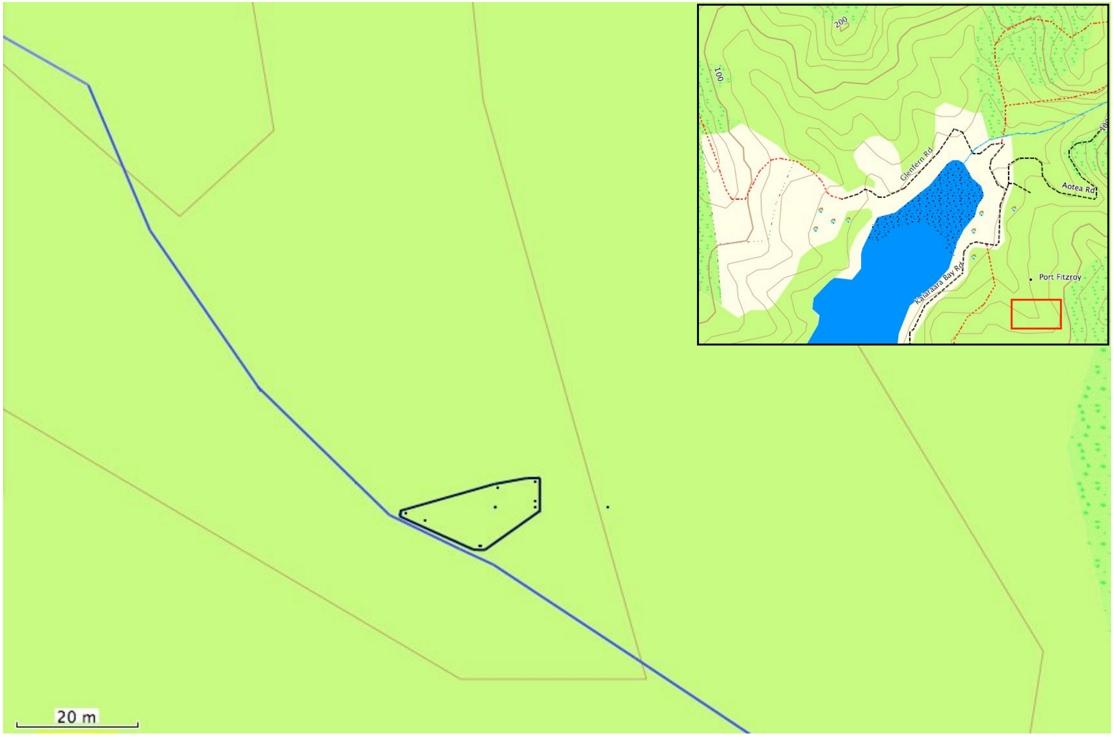
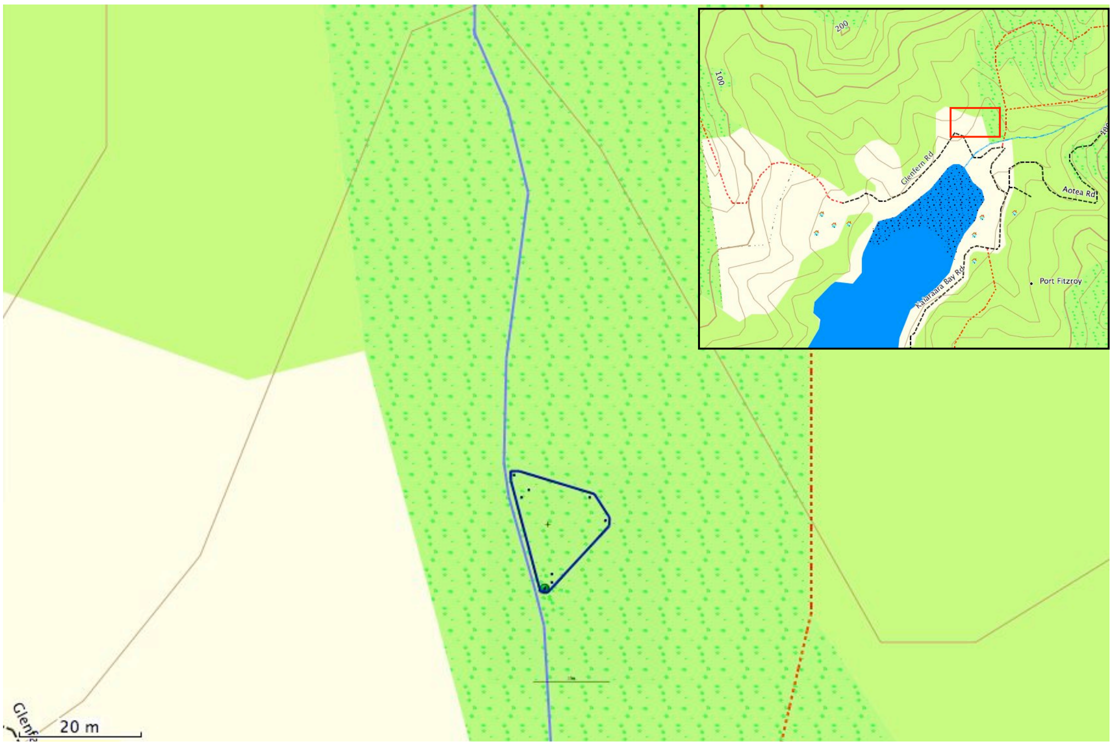


Toru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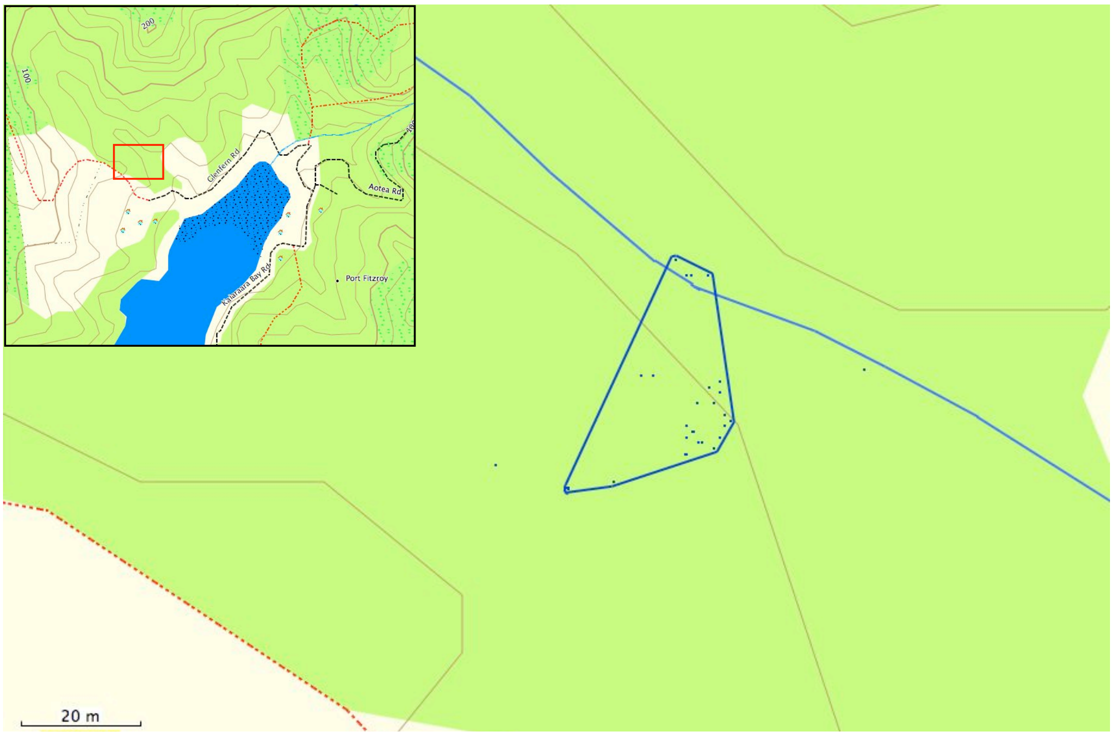
100
Glenfern Rd
Aotea Rd
Kaiaraara Bay Rd
Port Fitzroy
Glenf
20 m

Ono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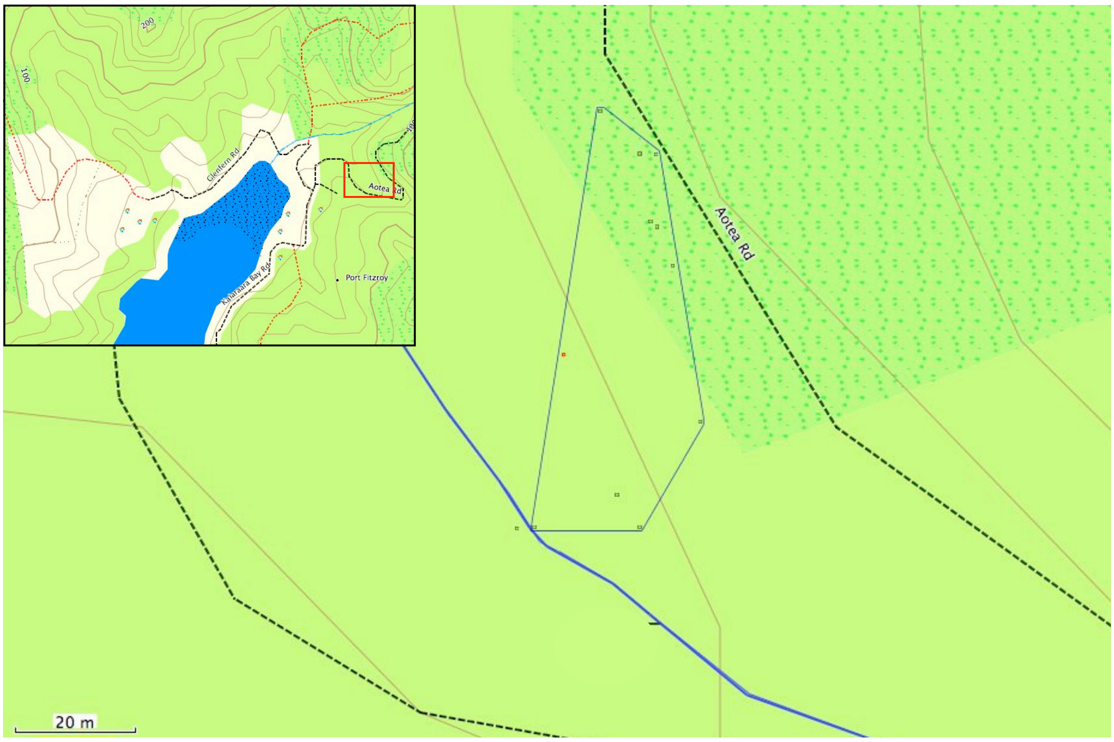
100
Glenfern Rd
Aotea Rd
Kaiaraara Bay Rd
Port Fitzroy
20 m

Whitu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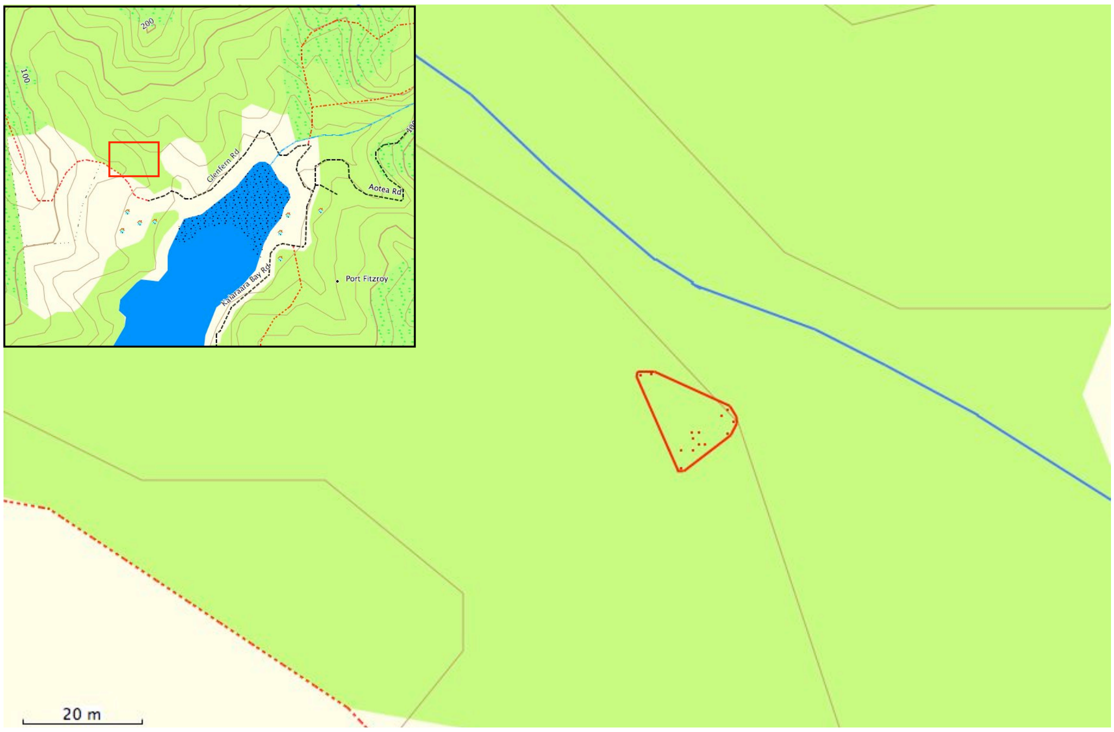
20 m
Glenfern Rd
Kaiaraara Bay Rd
Port Fitzroy
200
100

Waru


20 m
Glenfern Rd
Aotea Rd
Kaiaraara Bay Rd
Port Fitzroy
200
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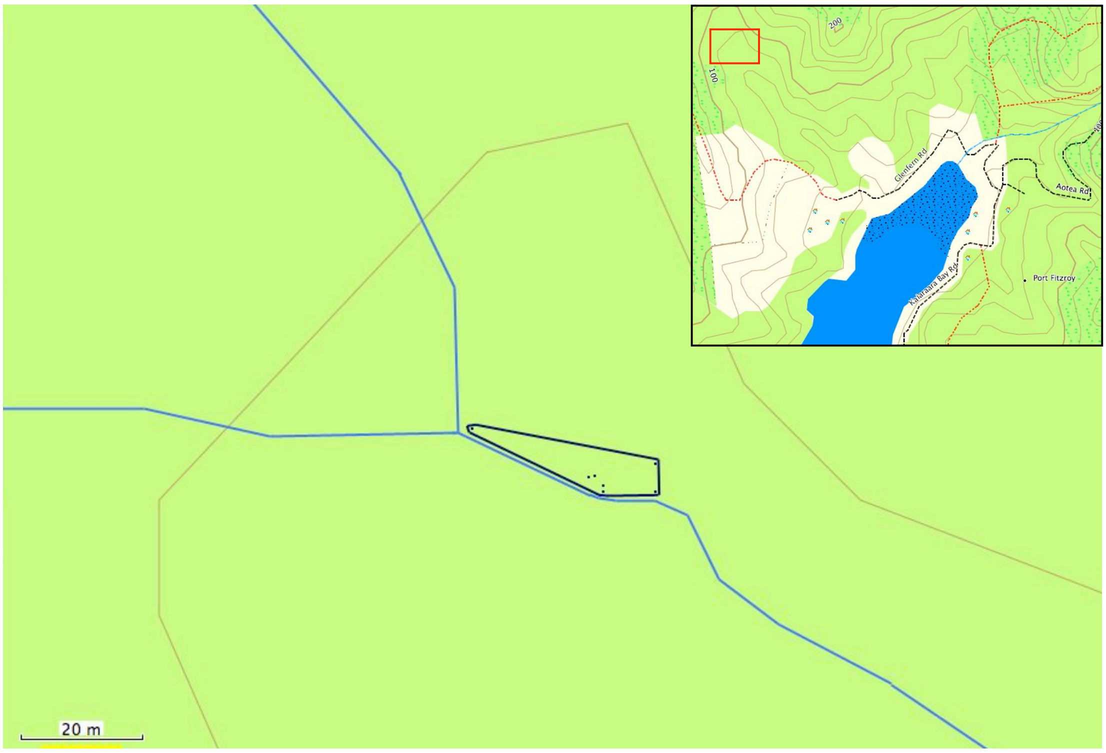
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Chapter 5 General summary and conclusions

5.1 INTRODUCTION

There were two main objectives of the research contained in this thesis. The first objective was to determine if rats have an impact on chevron skinks (*Oligosoma homalonotum*) and to determine the extent of their impact. This was achieved by first confirming that there were real differences in rat densities between the chosen treatment and control sites that would underpin comparisons. The rat densities obtained from this study then served as a platform to compare the population structure and condition of chevron skinks between sites. The second objective was to investigate for the first time, chevron skink home ranges and ranging behaviour, and to augment current knowledge of habitat use. This chapter discusses the outcomes of these objectives, the conservation implications of these findings and future research directions.

5.2 CONFIRMING THE EFFECTS OF EXTENSIVE RODENT CONTROL

The Zippin's removal method of rat estimation used in this study provided precise and robust estimates of ship rat densities. This confirmed that pest control conducted at the treatment site (Glenfern Sanctuary) was effective and the sites were appropriate to compare with the unmanaged control sites where rat densities were shown to be high. As absolute densities of rats have been infrequently calculated in New Zealand, the densities derived in this study add to the understanding of rat abundance in New Zealand forest. The rat density estimates from the unmanaged sites were lower than has been observed on mainland sites in other studies where absolute densities have been obtained. These differences may have been due to seasonal variation or differences in vegetation type. In the absence of mustelids, the densities from this study are also important as they provide an indication of rat densities when cats are the main predator regulating the population. Such information cannot be gained at mainland New Zealand sites as mustelids are the main predator there (Blackwell et al. 2003; Tompkins & Veltman 2006).

Rat tracking rates were used as a relative measure of rat density in this study and the results correlated extremely well with absolute densities. These results suggest that at the densities presented, tracking rates will give an easy, cheap and reliable index of rat density. With caution it could be possible to infer rat densities at these sites from tracking rates alone, if they were collected in the same grid layout as used in this study at the same time of year. However, using two measures of rat density is recommended as it gives greater confidence in the observed trends (Blackwell et al. 2002). An unanticipated benefit of calculating absolute densities, which has not been noted before is their effectiveness when communicating results to laypeople. Rat tracking rates are an abstract idea and require a point of reference or prior experience in order for their relevance to be deciphered. In contrast, densities expressed as rats per hectare are immediately understood, which is important for communicating conservation concepts to the general public. Local landowners were particularly interested in these density estimates, as they sparked their curiosity.

This experiment also provided the first empirical evidence of interference competition of ship rat towards kiore. Interference competition between ship rats and kiore has often been implied and has been deduced indirectly (Atkinson & Moller 1990; Russell & Clout 2004; Yom-Tov et al. 1999). This study demonstrated this empirically by showing a behavioural response of kiore to ship rat removal in one of the experimental removal grids: catch rates of kiore increased as ship rats were progressively removed. The second unmanaged grid had a higher density of ship rats and proportionally less kiore, so the behavioural response could not be measured. This suggests kiore density may be a function of ship rat density and there may be a ship rat density threshold above which interference competition may be too great for kiore. Future research on Great Barrier Island where ship rats are at different densities could clarify this. Great Barrier is one of the few places where kiore and ship rat coexist, so this removal experiment should be repeated at a number of sites to confirm both these findings.

The behavioural response of kiore in this study meant they could not be included in density estimates, as the assumptions of Zippin's removal method require a constant catch probability. Accordingly, the density estimates in this study for ship rats are in fact underestimates of the total rat population. This highlights that caution needs to be taken when inferring the impacts of rats on fauna in multi-species rodent assemblages, particularly if correlating the impact with rat densities on a fine scale. As this study was making broad comparisons between an area with extensive rodent control and an unmanaged area, the method was appropriate to confirm there was a meaningful difference, which could be used to infer impacts on the chevron skink population.

5.3 THE IMPACTS OF RATS ON CHEVRON SKINKS

Rats appear capable of having a negative impact on chevron skinks, which could lead to declines and possibly localised extinctions on Great Barrier Island. The population structure appeared to show erosion of juvenile and sub-adult size categories in the unmanaged control sites where rat densities were high. This suggests the impact of rat predation is somewhat specific to these smaller size categories, most likely because they are more vulnerable than adults or neonates. This reduction in small size categories is similar to observations in other large New Zealand lizards (Hoare et al. 2007) and would likely result in reduced recruitment.

Sublethal injuries were also observed in this study and these were consistent with attempted rat predation. Injuries on the head appeared to be from rat incisors and cuts, small punctures, tail loss and eye damage were also present. This physical evidence confirms that there are interactions between rats and chevron skinks, and also confirms that adults are able to survive rat predation (albeit with a cost). These observations were the first known documented cases of New Zealand lizards surviving rat predation, and provide evidence that larger individuals of large reptile species have the capacity to persist in the presence of rats, as suggested by other studies (Cree et al. 1995; Hoare et al. 2007). Given the scale and severity of the injuries observed on the adult skinks, it is unlikely that neonate, juvenile and sub-adult size categories could survive such encounters, which reinforces the suggestion from the population structure that juvenile and sub-adults are more vulnerable than other size classes and therefore are eroded from the population structure. The probable reason why neonates do not appear eroded from the population structure is that monitoring coincided with their appearance, and there was not sufficient time for a decline to be observed as a function of rat density.

Based on observations, sublethal injuries from rats appeared to be accompanied by tail loss. Most of the sublethal injuries observed in adult chevron skinks appeared to be superficial as they healed quickly; only tail loss and the eye damage were notable after less than 10 months as demonstrated by recapture of an injured individual. Accordingly the extent of tail loss was considered to be indicative of rat predation on a wider scale, even in the absence of conspicuous ‘rat like’ injuries. A novel method was used to quantify the extent of tail loss as opposed using tail loss frequency, which was the ratio between snout-vent length and total tail length termed the body-tail condition (BTC) index. The differences in BTC index were not statistically significant when comparing size categories directly between treatment and control sites probably due to sample size. However, when comparing the index within unmanaged control sites the adult size category was significantly reduced, suggesting that rats were affecting skink condition and predation attempts were widespread in this skink population as a consequence of rat density. There were no reductions of the BTC index across small size categories, even in the presence of high rat numbers. Since interactions are known to occur, this suggests that interactions between rats and skinks in small size categories result in death and not tail loss; therefore they are not represented in the data. This idea is supported by the sublethal injuries, which are likely too severe to allow survival in small skinks, and the population structure that shows erosion of smaller size categories. Future studies in New Zealand could benefit from comparing frequency of tail loss or the BTC index to imply the impact of rats, as long as there are no confounding triggers of tail loss (Tyrrell et al. 2000).

Evidence from condition (BTC index) and population structure in this study both indicate that the impacts of rats on chevron skinks are subtle, particularly compared to studies of other lizard species that overlap spatially and temporally with rats where population structure differences between ‘rat’ and ‘non-rat’ areas have been more marked (Hoare et al. 2007). The reason for this subtlety is likely because the activity periods of chevron skinks and rats does not overlap. During the night when rats are foraging chevron skinks are inactive within refuges (Neilson et al. 2006), and many of the refuges observed in this study were not accessible to rats. By fortune of their habits, chevron skinks are potentially not as vulnerable to rats as large nocturnal skinks at least on Great Barrier Island. This explains why recruitment is reduced and not halted in the unmanaged sites, and why the BTC index is not reduced in all adults from the unmanaged population.

However, it is also possible that the subtlety of results may be due to rat numbers in the treatment sites not being consistently low enough to guarantee the complete protection of chevron skinks or that rodent control may not have been in place long enough to see a full recovery of the chevron skink population. The growth rates of chevron skinks observed in this study indicate that improved recruitment from rodent control should begin to be observed in the adult population after 5 years, which coincides with the timeframe of this study. A repetition of this study in 3-4 years is recommended to determine if the population structure differences are more marked after a longer time period, and if the catch rates (per unit effort) of chevron skinks increases relative to the unmanaged control sites. At Glenfern Sanctuary a predator proof fence was constructed to encompass the entire Kotuku peninsula in June 2008 and the eradication of all exotic mammalian predators is planned for winter 2009. The treatment sites used in this study are contained within the predator proof fence, except the lower half of the Fenceline stream. It is likely that rat numbers will be reduced to even lower levels, or eradicated within the current treatment site, meaning that any difference due to rats will be more marked in future studies. However, comparisons of data will potentially be confounded by the removal of cats and pigs that were considered to be equivalent between treatment and control areas in this study as they were not part of the routine control programme. While the predator fence may confound a simple repeat of the current study, the data gathered in this thesis does provide a platform from which to measure the response of chevron skinks to a total mammal eradication attempt. Many potential research projects could arise; the most important is how chevron skink catch rates, population structure and condition respond to complete eradication of all mammalian pests or different assemblages of mammalian pests if certain mammals cannot be eradicated, for example mice.

Chevron skinks have been recaptured in debris dam G-minnow traps, however it is possible they develop ‘trap shyness’ (Neilson et al. 2006). Although debris dams are dynamic structures, intensive monitoring using the dams is invasive and subtly changes the dam structure. For these reasons, monitoring undertaken to investigate the above objectives should be done at three to four year intervals, to minimise stream disturbance, and to reduce the likelihood of ‘trap shyness’. As catch rates can vary between years, and even between days within a monitoring period, it is essential that comparisons are made with a known control site from simultaneous monitoring periods.

It is recommended that two to three, 10-day trapping periods be undertaken during summer to monitor any response of chevron skinks. The stream catchment directly to the west of fenceline stream should be used as a substitute for the lower half of fenceline stream as this stream is known to contain chevron skinks (Tony Bouzaid, pers. comm.).

Given that rats are likely impacting on chevron skink populations, rat control measures should benefit chevron skink populations. Although results suggest that impacts on chevron skinks appear to be subtle at current rat densities, it is possible that at sites where cats are controlled on Great Barrier Island, rats may undergo a 'mesopredator release', which could have more substantial impacts to chevron skinks. Intuitively it may seem that removing a known predator would be beneficial to chevron skinks, however the removal of a 'superpredator' can have a net negative effect on some species in insular populations due to the predator release effect (Soule et al. 1988).

5.4 HABITAT PREFERENCES, HOME RANGE AND RANGING BEHAVIOUR

Radio-tracking proved to be a functional and successful method for determining chevron skink habitat preferences, home range areas and ranging behaviour. The safety and welfare initiatives implemented in this study are recommended for future studies of lizards in New Zealand, in particular disguising the attachment strap, and selective transmitter attachment based on *a priori* body condition thresholds. These measures should assist in reducing unnecessary mortality of the study species, and potentially reduce predation or predation attempts from visual predators.

In general, the habitat preferences of this study supported previous research on the chevron skink by Neilson et al. (2006), although there were a few differences. The main refuge sites used by chevron skinks in this study in order of most frequent use were trees and crevices followed by logs, while in Neilson et al. (2006) they were crevice, debris dams and trees. In both studies, significant habitat variables in predicting the presence of chevron skinks were crevices, debris dams and trees. Although debris dams are used disproportionate to their availability in this study, their percentage use was low compared to other refuges, and compared to chevron skink use in Neilson et al. (2006). In contrast, the use of logs was not disproportionate to their availability in this study, despite being important refuge sites. Because of their importance as a refuge site, the significance of logs to chevron skinks should not be understated. Chevron skinks also appeared to avoid bare ground microhabitat possibly as it would increase their vulnerability to predation. In light of all results it would appear that large complex structures such as logs and old rotting trees as well as crevices in the soil are particularly important to chevron skinks, as they were either used as specific refuge sites or associated with these sites as important habitat qualities. Accordingly, old mature forest with large trees, and large quantities of coarse woody debris probably provide ample sites for thermal retreat, foraging and refuge from predators. However, in areas with high proportions of bare ground, moving between refuge sites could be problematic for skinks. Pigs and cattle reduce the amount of leaf litter and ground cover and also create erosion, which would reduce the number of soil crevices. Accordingly, chevron skinks may be particular vulnerable to predation in areas where pigs and cattle are abundant regardless of forest age or the presence of refuge sites. Ungulate exclusion fences could be erected in Te Paparahi where cattle and pigs are present to quantify how these animals affect the amount of ground litter and whether chevron skinks respond positively to their removal.

The use of the VPD provided a sound way of amalgamating relative humidity (RH%) and temperature (T°C) as an indicator of water loss, a method that is often overlooked. The vapour pressure deficit (VPD) inside chevron skink refuges was shown to be significantly lower than immediately outside refuge sites, which indicates that refuges provide a potential retreat from evaporative water loss (EWL) and provide a stable thermal climate for chevron skinks. Refuges are also known to provide shelter from predators (Downes & Shine 1998) and probably provide foraging opportunities for chevron skink. It is likely there is interplay between these factors, which define refuge decision-making choices in chevron skinks, however the importance of each factor is unclear. Captive studies could manipulate these factors to determine the relative importance of each factor for refuge site choice in chevron skinks. The ambient VPD outside chevron skinks did not appear to be significantly different from randoms sites in this study, although this could have been due to sampling bias. Future research comparing VPD of refuge sites with availability should aim to test VPD differences on a landscape scale.

In response to flooding events, chevron skinks demonstrated an arboreal response, although this was not observed for normal levels of rainfall. This type of response has been observed in stream dwelling invertebrates, but no documented reports are known for reptiles. This response is likely to be a safety mechanism that allows skinks to avoid being washed away in stream torrents, and supports all previous assertions that chevron skinks are associated with streams. Neonate, juvenile and adult size classes were all observed demonstrating this behaviour, through comparisons of hand search efforts in silver fern crowns during both flooding and dry conditions. Distance from the stream did not seem influence the response therefore it is not likely to be a direct response to the actual floodwaters; rather it must be triggered by some other factor or combination of factors. A range of environmental cues could be responsible for this behaviour such as duration of rainfall, intensity of rainfall, acoustic cues of rainfall and flood, changes in barometric pressure, or cloud cover. These factors could be manipulated in a captive setting (Lytle 1999) to determine which cue or combination of cues triggers the response. The hand capture rates were particularly high during hand searches conducted in silver fern crowns during flood, therefore this method could be particularly useful as a survey method in areas where chevron skinks are difficult to find, such as on Little Barrier Island. The method could be standardised and used as a monitoring tool. For example areas could be compared simultaneously during flood by searching all silver fern crowns within 15m of the steam on 100m transects, and recording the number of ferns searched, those that were too high to be searched and the number of skinks located.

The estimates of chevron skink home range in this study were the first for this species. The 95% minimum convex polygon (MCP) home ranges of chevron skinks were shown to be large in some cases and overlap was shown to occur between some individuals. However, the mean home ranges in this study were smaller than expected based on their size (Christian & Waldschmidt 1984). It is likely that the home range estimates from this study are underestimates as home range calculations tend to expand with ever increasing numbers of relocations (Christian & Waldschmidt 1984). Future research should endeavour to reattach transmitters where possible to increase the duration of tracking and the number of relocations, to obtain more accurate home range estimates. It is possible that home range sizes may alter if chevron skink densites increased in Glenfern Sanctuary as a result of pest eradication. Home range size changes as a function of skink density could be investigated in the future. As with measuring the response to pest eradication, such a study should be undertaken on 3-4 yearly intervals to minimise trap shyness and habitat disturbance.

Radio-tracking also revealed that chevron skinks showed refuge site fidelity, often returning to the same locations on more than one occasion, and when skinks overlapped in their home range they shared at least one common refuge. Although preliminary, these results indicate that certain refuges are preferred by skinks and are not necessarily selected randomly. Similar to Koenig et al. (2001) it is possible that chevron skinks have strong familiarity with their home ranges and have a suite of ‘safe’ refuge sites. Captive manipulations coupled with radio-tracking for longer durations would help to clarify this. Chevron skinks were shown to use areas relatively distant to the stream edge in this study when compared to Neilson et al. (2006). The reasons for these differences could be due to climatic differences between years that could cause chevron skinks to shift their home ranges, or that chevron skinks use habitat differently between both areas, or chevron skinks were not radio-tracked not long enough by Neilson et al. (2006) during any individual monitoring period to register movement away from the stream. Future studies could investigate home range at different locations on Great Barrier Island to determine if there is variation in due to geographic location, forest type and altitude.

5.5 CONCLUSIONS

The research presented in this thesis demonstrated that rats are interacting with chevron skinks, and while at least a proportion of adults can survive these attacks, smaller sized skinks appear to be more vulnerable. Physical evidence was shown of probable failed rat predations, and population structures and skink condition in terms of tail loss all indicated an impact of rats. Accordingly, the impacts of rats on chevron skinks are likely to be reduced recruitment and reduced fitness due to sublethal injuries in adults. In the longer term, these impacts will likely lead to declines for this species. The diurnal habits of chevron skink may reduce their vulnerability to rats at the observed rat densities, and therefore the impacts are probably chronic and not acute, which will cause slow population declines. Further work needs to be undertaken to confirm how chevron skink populations respond to rodent control over longer time periods, and how chevron skinks are affected by greater rat densities, if and where they occur on Great Barrier Island.

This study significantly expanded current knowledge of habitat use of chevron skinks and added new knowledge about the home range and ranging behaviour of this species. Similar to a previous study on habitat use of chevron skinks, trees, crevices, debris dams and logs appear to be particularly important for chevron skinks, while they tend to avoid bare ground. Home ranges of chevron skinks can be large, and there can be overlap between individuals, including the sharing of common refuges, although not simultaneously. Individual skinks show a certain level of refuge site fidelity by using sites multiple times, and it is possible this represents refuge site preference. Although chevron skinks appear to associate with streams, home range data presented in this study show that in summer adults move further away from streams than previously anticipated. However chevron skinks were shown to exhibit an apparently unique arboreal response among reptiles to flooding events, which is strong evidence of their association with streams.

Given the highly restricted range and apparent declines of the chevron skink, this thesis provides valuable information regarding one of the suggested threats to this species, rats. Furthermore, the ecological information provided supports current knowledge and offers new insights into this fascinating and unique species, including new possibilities for survey and monitoring. Continued research and management will improve the likelihood that this unique species will remain a part of New Zealand's native forest ecosystem.

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