Diet overlap and potential competition between North Island brown kiwi chicks (*Apteryx mantelli*) and ship rats (*Rattus rattus*) for limited resources on Ponui Island, New Zealand.

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Lee Mark Shapiro

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Abstract

The introduction of mammals to New Zealand has devastated the native avifauna. Although not the most severely affected native bird species, all five species of kiwi (*Apteryx* Spp.) have sustained a severe loss of numbers and range. Kiwi have declined on the mainland from a failure to replace their numbers due to a high mortality rate of kiwi chicks. The main reason for this mortality is predation by introduced stoats (*Mustela erminea*). Many kiwi mainland populations have predator control enabling the recruitment of chicks. However a consequence of predator removal can be an explosion of rodent populations at control sites. Rodents do not directly prey on kiwi chicks but prey on invertebrates and these rodent population explosions may affect the number of invertebrates available to other forest dwelling animals such as kiwi. The potential exists for competition between rats and kiwi chicks as both feed on soil surface and leaf-litter invertebrates. Evidence from Kapiti Island where kiwi chick recruitment was high following rat eradication supports the competition hypothesis.

The aim of the current study was to investigate the diet overlap and thus establish whether there was potential for competition for food between rats and kiwi chicks on Ponui Island in Auckland's Hauraki Gulf. Ponui Island is an ideal location for this research because there is a rat population and a high density of North Island brown kiwi, but no stoats.

Kiwi chicks were measured and weighed weekly to determine growth rates, transmitters were changed every second week. Kiwi chick faecal samples were collected weekly from radio tagged individuals and the contents compared to those from ship rat stomachs, and the invertebrates available. Kiwi chicks and ship rats overlapped in the surface dwelling invertebrate component of their diets. Pitfall traps revealed no overall difference in the number and type of invertebrates found in bush and scrub habitat but weta and spiders were more abundant in scrub than bush, this was also the preferred kiwi chick habitat and was reflected in their diet.

The only rats caught in Ponui forest habitat were ship rats (*Rattus rattus*) and their diet was established from monthly kill trapping and by examining the contents of their stomachs. Ship rats ate mostly surface and litter dwelling invertebrates of the orders

Coleoptera, Orthoptera and of the class Chilopoda. The prey they consumed closely followed environmental abundance and availability of invertebrate species. The density of ship rats was estimated by carrying out a mark-recapture experiment over three months. Ship rat densities were found to be higher than most mainland ship rat density studies previously carried out in New Zealand. But the estimated density of ship rats on Ponui was similar to estimates undertaken for ship and Norway rats (*Rattus norvegicus*) on several New Zealand offshore islands including Campbell, Motutapere and Tawhitinui Island.

The environmental abundance of invertebrates was measured with the monthly collection of pitfall traps and soil core samples in bush, scrub and farmland habitat and leaf-litter samples in bush and scrub habitat where kiwi chicks and ship rats were monitored. There was no overall difference in the number and taxa of invertebrates found in scrub and bush habitat, however there were several individual taxa differences. There were significantly higher numbers of weta and spiders caught in pitfall traps in scrub compared to bush habitat over winter, spring and summer months. Recce plots were used to describe the vegetation composition in bush and scrub habitat across the study site and assess any impact this may have had on the make up and numbers of invertebrate taxa in those different habitats. Scrub and bush habitat differed in the plant species composition, average canopy height and percentage of leaf-litter ground cover. Although this did not have a significant effect on the overall invertebrate fauna of the two habitat types there were significant differences in the numbers of several key surface and soil dwelling invertebrate prey taxa.

Kiwi chicks on Ponui Island showed little growth over the four months they were monitored; the severity of their lack of sustained growth was illustrated when compared to the growth of chicks from the Warrenheip Operation Nest Egg crèche. Of the eight kiwi chicks that hatched from the monitored population on Ponui Island only one survived more than six months. There are several possible reasons for the lack of chick development; these include kiwi chick competition for invertebrate prey with ship rats, other kiwi chicks and adult kiwi and also low invertebrate prey availability and abundance.

Chapter Summaries

The overall aim of this thesis was to look at the potential for competition between North Island brown kiwi chicks and ship rats. The thesis is divided into the different aspects of kiwi and ship rat biology that are relevant to this aim. The thesis is composed of five chapters including:

- Chapter1 Kiwi chick diet and morphometrics
- Chapter 2 Ship rat diet and morphometrics
- Chapter 3 The density of ship rats with relevance to potential competition
- Chapter 4. The number and type of invertebrates available along with vegetation composition of different habitat types in the study site
- Chapter 5. The potential for dietary competition between kiwi chicks and ship rats. The diets of both species were compared to the environmental abundance of invertebrates, the density of both species and any potential differences in the vegetation composition of the different habitat types. Also included are recommendations and research outcomes.

As the main thesis question is broken down into its individual components there is some repetition in the text between individual chapters. The layout of this thesis enabled a detailed look at each of the components involved in potential competition on their own merits but still with reference to the original question.

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1

The diet, morphometrics and habitat use of North Island brown kiwi chicks (*Apteryx mantelli*) on Ponui Island, New Zealand.

Abstract The invertebrate diet of five North Island brown kiwi chicks on Ponui Island was examined over four months by comparing partial invertebrate remains from faecal samples to a reference collection of invertebrates from the same habitat. Soil dwelling larvae were found to be an important component of kiwi chick diet when available. Over the summer months these soil dwelling larvae emerged as adults and so their availability as prey decreased. In addition, the soil began to dry and probing was most likely restricted to softer areas. This is supported by the finding of an increase in the average number of several surface dwelling invertebrates per faecal sample from individual kiwi chicks. The weight and bill growth of chicks were recorded and compared to a group of kiwi chicks raised in a predator proof enclosure (Warrenheip) as part of Operation Nest Egg. The kiwi chicks on Ponui Island were found to consistently lose weight and as a result their overall growth was much slower than those in the Operation Nest Egg enclosure. The preferential use of scrub habitat by kiwi chicks for shelter and feeding was attributed to a higher number of several taxa of surface dwelling invertebrates found there compared to bush habitat. Kiwi chick diet was found to closely follow environmental abundance and availability of invertebrates.

1.1 Introduction

New Zealand's terrestrial avifauna is characterised by a high proportion of endemic and/or flightless species due to its evolution in the absence of land mammals (Bell, 1991). The introduction of numerous species of mammals especially humans has had a devastating effect on the numbers and distribution of many native birds, particularly the ground dwelling species. Although New Zealand's national icon, the Kiwi (*Apteryx* Spp.), has been affected to a lesser extent than species such as Kakapo (*Strigops habroptilus*), Takahe (*Porphyrio mantelli*) and Moa (Emeidae and Dinornithidae families), all five species of kiwi have experienced severe loss of numbers and/or range (McLennan *et al.*, 1996). Kiwi inhabit a very wide range of habitat types including mature forest, regenerating scrub lands, exotic *Pinus* plantations, swamps and farm pasture (Reid *et al.*, 1982; Colbourne & Kleinpaste, 1983; McLennan *et al.*, 1987; Miles, 1995; Miller & Pierce, 1995; Taborsky & Taborsky, 1995; Chan, 1999).

1.1.1 Numbers and survival

Due to the nocturnal nature of kiwi, counting the number of birds in a population is difficult but is the only reliable means of assessing the size and viability of different populations. Populations in these habitats are monitored by call count surveys (McLennan, 1992). The ability to reliably census an endangered animal is of great importance to establish rates of decline and to monitor large changes to population structure. Apart from a few small areas in Northland where the density of kiwi is thought to be 50-100 adults km^2 (Basse *et al.*, 1999), the present density of kiwi on the mainland is seldom thought to exceed four adults km^2 (McLennan & Potter, 1992, Miles, 1995). Similar densities to those of Northland are common from islands (such as Stewart, Kapiti and Little Barrier Island) where stoats are absent (McLennan & Potter, 1992).

The main cause of this low mainland density as shown by McLennan *et al.* (1996) is an inability of kiwi to replace their numbers due to predation of chicks by stoats (*Mustela erminea*), which were identified as their main predator. Adult kiwi (with exception of little spotted kiwi) are big enough (2-3 kg) to resist predation by mammalian predators like cats (*Felis catus*) and stoats. Their large egg size also limits potential predation

from rats (Basse *et al.*, 1999). However kiwi chicks forage independently of either parent at an early age and have no behaviours or defences that protect them against introduced mammals (McLennan *et al.*, 1996). Despite larger stoats possibly preying on large kiwi chicks, survival of kiwi chicks generally increases once chicks are >800g (McLennan *et al.*, 2004).

McLennan and Potter (1993) compared populations of little spotted kiwi (*Apteryx owenii*) on Kapiti Island (40°51'S, 174°55'E) to North Island brown kiwi (*Apteryx mantelli*) on the mainland in the Hawkes Bay and Northland regions. They found significantly more independent juvenile kiwi on Kapiti Island (41%) than the mainland (3%). They suggested that juvenile survival was poorer on the mainland because juvenile kiwi on Kapiti Island only had to contend with possible competition from Weka (*Gallirallus australis*), Norway rats (*Rattus norvegicus*) and Pacific rats (*Rattus exulans*), in contrast to those on the mainland which were at threat of predation from stoats, cats, dogs (*Canis familiaris*) and possums (*Trichosurus vulpecula*).

The present recruitment levels of North Island brown kiwi chicks on the mainland are 1-5%, which are well below the estimated 19% threshold theoretically needed to maintain kiwi populations (Basse *et al.*, 1999). To achieve this threshold level of recruitment Basse *et al.* (1999) suggested that stoat populations needed to be reduced by 80% in some years. They found this to be possible in small areas of forest (up to 1000 ha) but further work is needed to enable control in larger forests. The other option which has been employed for numerous endangered New Zealand species, including kiwi, is the translocation to predator controlled offshore and mainland 'islands'. Whilst this has been a success for certain kiwi populations (Kapiti Island, Tiritiri Matangi, Little Barrier Island and Karori Wildlife Sanctuary) there are a limited number of suitable offshore islands where kiwi can be translocated to, and mainland islands are expensive to create and maintain.

Intervention to increase the survival rate of kiwi chicks and reverse population declines came in 1991 in the form of the 'Kiwi Recovery Programme' (Robertson, 1998). Part of the recovery programme involves 'Operation Nest Egg' (ONE). This programme consists of taking eggs from wild Kiwi, incubating them in artificial incubators, and rearing the chicks in captivity (Colbourne, 1998). Chicks are then released back into the

source population once they are > 1 kg and can defend themselves against cats and stoats (Colbourne, 1998; Robertson & Colbourne, 2003). Naturally these conditions are 'artificial' in terms of what a kiwi chick would face in the wild with no intervention, but without ONE few kiwi would ever reach 1000g and survive to adulthood, and consequently mainland populations would continue to decline.

1.1.2 Kiwi diet and feeding

Several studies have investigated wild kiwi diet through the analysis of faecal samples (Gurr, 1952; Colbourne & Powlesland, 1988; Colbourne & Kleinpaste, 1990; Jolly, 1990; Miles, 1995) and gizzards (Gurr, 1952; Bull, 1959; Watt, 1971; Reid *et al.*, 1982; Chan, 1999). Reid *et al.* (1982) estimated the relative contributions of components to an 'average' kiwi diet from an analysis of 50 gizzards from North Island brown kiwi. They estimated that earthworms formed 40-45% of the diet, other invertebrates at 40-45% and plant material at 10-15%, with fruits being at least twice as important as greens. Any study of kiwi diet should reflect the foods that are available in a specified area given the bill morphology of the kiwi, this relates to underground and surface dwelling invertebrates. Reid *et al.* (1982) estimated earthworms to make up between 40-45% of adult North Island brown kiwi diet, but seasonal limits to earthworm availability may decrease this figure in adults and even more so in chicks due to their small bills. A study by Jolly (1990) looked at faecal samples from little spotted kiwi chicks on Kapiti Island and found they had been eating crane fly larvae, millipedes, earthworms, cave weta (Raphidophoridae) and caterpillars.

Important soil dwelling invertebrates in kiwi diet, like cicada nymphs and scarabaeid larvae emerge in summer and this creates a temporary decrease in the amount of food in the soil over summer (Colbourne & Kleinpaste, 1990). The emergence of these soil dwelling larvae as adults over the summer means these larvae come closer to the soil surface before emerging (Colbourne & Powlesland, 1988) and possibly shallow enough for kiwi chicks to utilise for a short period of time. These larvae may therefore be an important component in kiwi chick diet over the weeks before their emergence as adults when they spend time close to soil surface. Finally, the behaviour of some invertebrates in moving closer to the soil surface at night and after heavy rain may bring these key larvae even closer to the surface prior to their emergence.

Knowledge of wild kiwi chick diet is of increased importance due to the number of kiwi chicks reared in captivity with Operation Nest Egg. It is also important in order to assess both potential competition with pest species and the suitability of crèche sites. However, little is known about the diet of kiwi chicks. A yolk sac nourishes kiwi chicks for the first ten days, although they leave the nest to feed during this time (Robertson & Colbourne, 2003). Chicks fledge on average around three weeks after hatching (McLennan, 1990) and feed independently from either parent (McLennan *et al.*, 1996).

Kiwi chick foraging strategies are also of interest as there is the possibility of sex related differences in foraging strategies and since adult kiwi display sexual size-dimorphism it is possible that kiwi chick foraging patterns are related to sex.

The main aims of this chapter were to identify the invertebrate component of kiwi chick diet in comparison to invertebrate abundance and availability, compare this between individual chicks and see whether their diet changed over time. It was also to compare the growth rates of kiwi chicks on Ponui Island to chicks in a habitat (Warrenheip) with no predators and few potential competitors besides other kiwi chicks.

1.2 Methods

1.2.1 Study Site

The study site for this project was Ponui Island which is located in the Hauraki Gulf 30km east of Auckland (36°50'S, 175°10'E) (Plate 1.1). Ponui Island is 1770 hectares in size and just under a third of the island remains forested (Plate 1.2) after clearance for agriculture took place in the early 1900's (Brown, 1979). The main study site is within a large tract of broadleaf Kauri forest covering approximately 250 ha of the southern end of the island. The main study site consisted of four gullies adjacent to each other - Red Stony Hill Gully (RSHG), Pipe Gully (PG), Straight Gully (SG) and Hook Gully (HG) (Plate 1.3). The study population consisted of 35 adult North Island brown kiwi (21 males and 14 females) that were initially captured and fitted with transmitters in the last week of March 2004 and five kiwi chicks produced during the 2004 breeding season. This study focused on the diet and behaviour of chicks from breeding pairs within the study population.

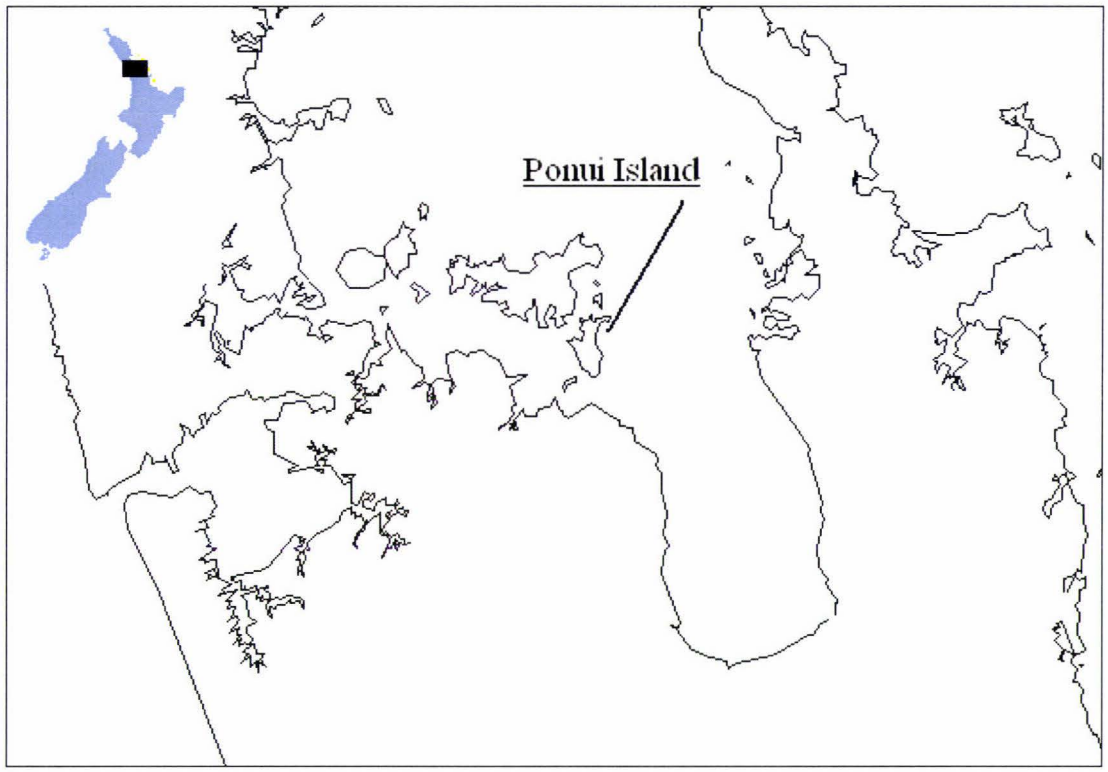


Plate 1.1 The location of Ponui Island in Auckland's Hauraki Gulf

1.2.2 Background

Call count surveys involve recording the number of kiwi calls over a two hour period after dark from several elevated vantage points surrounding the population in question over five continuous nights (McLennan, 1992). The time and direction of calls, measured by a compass bearing, are recorded and compared between listening sites to establish the number of calls in the area over the two hours. The relationship between call counts and the density of kiwi on the ground is not linear at either high or low densities (Miles, 1995); therefore it is difficult to accurately estimate population size from call rates and thus estimates made from call counts are often conservative. In total 14 North Island brown kiwi were introduced to Ponui Island in June 1964 by the New Zealand Wildlife Service following a request from the owners (Miles & Castro, 2000). Although exact densities of kiwi on Ponui Island are unknown the most recent survey carried out by the Department of Conservation in 1999 recorded an average call rate of 30.7 calls/hour on the island. By mapping the location of individual birds and assuming all male and female calls from a given area belonged to a single bird the population was estimated to be 120 adults (Miles & Castro, 2000). This estimate was thought to be conservative and is in contrast to mainland call counts of no more than 19.8 calls per hour in Northland areas which have up to 100 kiwi km^{-2} (Miles & Castro, 2000).

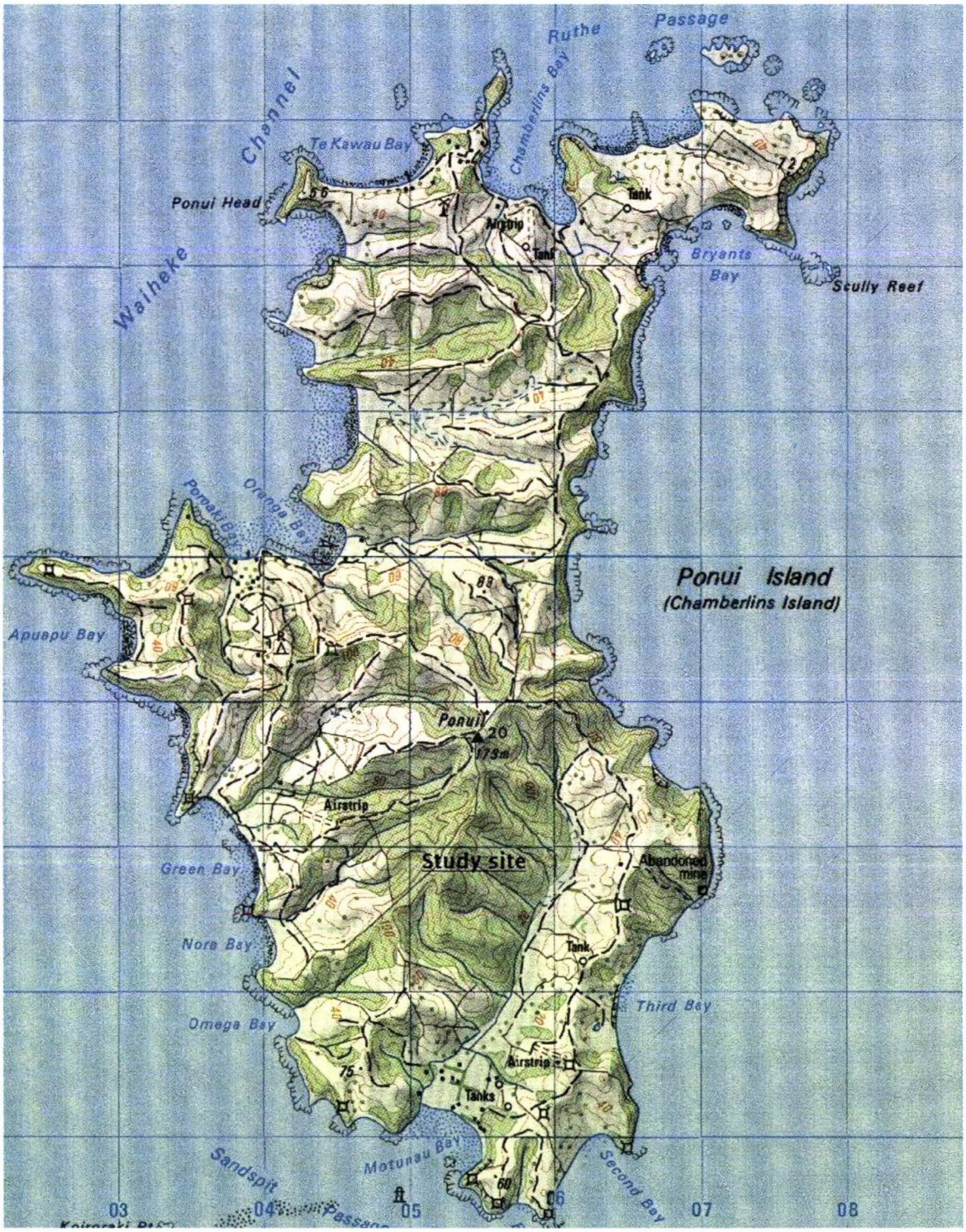


Plate 1.2 Map of Ponui Island and principal study site (Massey Image Webserver, 2003)

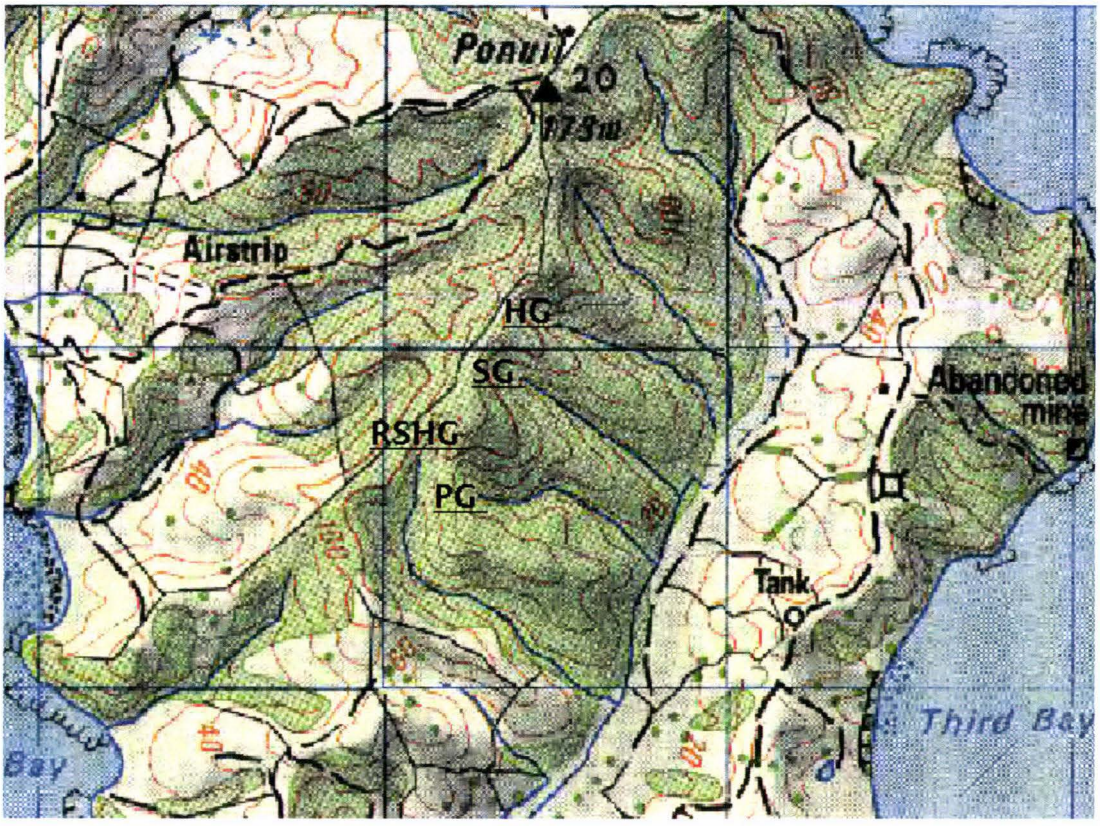


Plate 1.3 Detail of the area of the study site on the southern end of Ponui Island (Massey Image Webserver, 2003). The four gullies in the study site; Red stony hill gully (RSHG), Pipe gully (PG), Straight gully (SG) and Hook gully (HG).

1.2.3 Nests and chicks

Adult pairs were monitored by telemetry with a Telonics (TR4) receiver and a Yagi three element aerial to identify roosting and nesting behaviour. When nests were identified, candling of eggs according to Bassett (2004) was carried out approx every 15 days by a trained egg candler to establish embryo growth and an approximate hatching date. Nests were closely monitored leading up to the estimated hatching date. When a chick was observed to have hatched it was checked visually in the nest for the first five days. After five days, if the chick was seen to be mobile in and around the nest, a transmitter was attached with a hospital identification bracelet and insulation tape according to the method suggested by Miles & McLennan (1998) and Robertson & Colbourne (2003). Transmitters were movement enabled and when the chick moved it beat at 60 pulses per minute. After ten seconds of no movement it dropped to 30 pulses per minute. They were also mortality enabled and after 24 hours of no movement it

changed to 90 pulses per minute. The transmitters had an approximate two-month battery life and weighed 7-8 grams. All transmitters were produced by Kiwi Track Ltd and followed specifications of the Kiwi Best Practice Manual (Robertson & Colbourne, 2003).

1.2.4 Collection of faecal samples

Faecal samples from five kiwi chicks (Diego, Mauro, Niko Louise and Megan) were collected at their daytime shelters approximately every two days. These five chicks were monitored over the current study from November 2004 to February 2005 and form the basis for the diet and growth analyses. Chicks were located (but not handled or approached) at their daytime shelters on the ground using a Telonics receiver (TR4) and Yagi three element aerial. The shelters were marked for collection of faecal samples the following day or the next occasion when the chick was absent from that shelter site to avoid disturbing the chick daily. Chicks rarely used the same shelter site for more than one or two days consecutively, as faecal samples were collected every few days the location of the shelter site and the state of the faecal sample meant its date of excretion could be determined quite accurately; this helped to further identify the independence of samples. Faecal samples were collected in glass vials and refrigerated for later sorting. Samples were defrosted and washed through a gradation of different sized sieves - 500μm, 250μm and 125μm gauze. This enabled the collection of different sized fragments including tiny worm chaetae. The remaining material in each of the sieves was transferred to a Petri dish and examined under an Olympus sz40 microscope at 6.7x magnification. Insect material was removed and identified to either family or genus level from an invertebrate reference collection created from nine months of pitfall trapping in the three focal gullies in the main study site (Chapter 4). Invertebrate abundances were estimated following Colbourne & Powlesland (1988), where left and right mandibles of beetle larvae were counted and the larger value was used. Invertebrates were counted as the number of individuals per faecal sample. When more than one faecal sample per chick was collected in a day the invertebrate contents of those faecal samples were averaged to give one overall sample per day. This was done to increase independence of the samples.

1.2.5 Growth Data

After initially attaching the transmitter, each chick was located and caught weekly in its daytime shelter to take measurements, the transmitter was changed fortnightly. The three measurements taken were bill (cere to tip), tarsus and weight. The weight was recorded using 1kg Pesola™ scales (±1 g). The bill and tarsus were measured using Kincrome™ Vernier callipers (± 0.01cm) as suggested by Robertson & Colbourne (2003). The growth of Ponui chicks was compared to that of five chicks hatched at a similar time in captivity as part of the Operation Nest Egg management scheme; the eggs were taken from the nests of North Island brown kiwi in Tongariro National Park (J. Miles pers. comm.). These chicks were hatched under ideal conditions and fed *ad libitum* until released in a predator free crèche (Warrenheip) where there was no competition with rats. This comparison was undertaken to identify any differences in growth rates between two populations and the possible influence that competition from ship rats may have on growth rates.

1.2.6 Shelter Types

The daytime shelter where chicks were found after fledging was classified as:

- Under reeds or a specific species of plant,
- Under pine needles,
- Under fallen trees/branches or
- On the surface if the chick had no vegetation hiding its body.

Shelter location was recorded in terms of habitat type, bush or scrub. In some cases chicks were moving during the day and were not stationary when located.

1.2.7 Statistical manipulations

Statistical analysis was performed using Primer v5.2.9 (Clark & Gorley, 2002). An ANOSIM (Analysis of similarities) test was used to analyse differences in diet between kiwi chicks. ANOSIM tests are described by Clark & Gorley (2001) as a rough analogue of the standard univariate 1- and 2-way ANOVA tests. The test used was a two-way nested ANOSIM and it allowed a statistical test (2-way layout) where two

levels of spatial replication are involved. Sites are grouped *a priori* to be representative of two treatment categories. The two levels analysed were the differences in individual chick diets and differences over the four months December 2004 to February 2005. The ANOSIM test gives a 'Global R' value and a significance level. The R statistic is a comparative measure of the degree of separation of sites. R values close to zero indicate that similarities between and within sites are on average the same, a value close to one indicates all replicates in a site are more similar to each other than those from other sites Clark & Gorley (2001). It is possible for significant R values to have little biological significance due to the high statistical sensitivity of the analysis resulting from very large numbers of replicates.

A non-metric multidimensional scale (nMDS) plot was also produced in Primer to illustrate any differences between the diets of the five individual kiwi chicks. nMDS represents non-metric relationships between multiple variables in two or three dimensions. The plot was created using the ten most frequent invertebrate food groups found in kiwi chick's faecal samples (including earthworms). As the plot was non-metric it contained no x or y axis. The nMDS plot also included a stress value which indicated the accuracy with which the plot represented the actual relationship of individual data points. Stress values for nMDS plots can range from 0.0 (perfect map) to 0.3 (low accuracy).

Univariate statistical tests were carried out in the software package SPSS (2001). The test used was a one-way analysis of variance (ANOVA). An ANOVA was carried out to compare the average monthly number of invertebrates in faecal samples for each individual kiwi chick. The analyses included comparing the average monthly numbers of scarabaeid larvae, tipulid larvae, spiders and weta (Stenopelmatidae and Rhaphidophoridae families) for individual chicks in months where their faecal samples were collected. Only results for Louise, Mauro, Diego and Niko are included for the ANOVA test as faecal samples for Megan were only collected from one month.

1.3 Results

1.3.1 Nests and chicks

The study involved monitoring a total of 12 North Island brown kiwi eggs in eight nests. Of these 12 eggs, eight chicks hatched and five of these lived beyond three days old. Only five of the chicks ever left the nest to feed and these were monitored over the current study. The fates of all 12 eggs monitored are listed in Table 1.1.

Table 1.1 The fate of the 12 North Island brown kiwi eggs monitored in the current study from July 2004 to December 2004 and the transmitter (Tx) frequency of the parents. Unknown parents with no transmitter are indicated by an X. The names of the chicks do not reflect their real sex, which is unknown at the time of publishing.

Nest	♂ Tx	♀ Tx	# Eggs	Hatch date	Chicks	Comments
1	30	78	1			-Egg died on 21/09/2004
2	63	12	1	5/10/2004		-Chick died on day six from septicaemia
3	51	24	1			-Nest abandoned on day three 7/10/2004
4	45	33	2	8/10/2004 18/10/2004	Niko Mauro	-Niko died after six months from an unknown cause. Mauro was alive on the 28/09/2005
5	57	X	2	1/11/2004	Louise	-Egg one died from an unknown cause. Louise's transmitter failed at week three.
6	01	11	2	3/11/2004 15/11/2004	Megan	-Megan died after three weeks from yolk sacculitis. Egg two died on hatching
7	84	20	2	29/11/2004 7/12/2004	Diego	-Diego died after six months from unknown causes. Chick two died after three days from yolk sacculitis
8	02	X	1			-Unknown fate, chick never seen

It's unclear whether the low number of eggs and late start to the breeding season experienced by the Ponui population was normal or if it fitted with the findings of other populations for 2004/2005. The breeding season of North Island brown kiwi was late in most areas in 2004/2005 and the numbers of eggs were lower than previous years at Tongariro National Park (L. Dew; J. Miles, pers. comm.) and in Northland (R. Colbourne, pers. comm.).

1.3.2 Diet

I analysed a total of 150 faecal samples from five kiwi chicks that hatched between October 2004 and December 2004 (Table 1.1). Samples were collected from November 2004 to February 2005 and on seven occasions more than one faecal sample was collected for an individual chick on one day and so an average of contents for these samples was used in the statistical analyses (Section 1.2.4). Thus 143 faecal samples were used for overall dietary analysis (Table 1.2). There was no significant difference in the overall diet of kiwi chicks across the four months faecal samples were collected (nested ANOSIM; Global R = 0.063; $P = 0.4$). As there was no overall effect of month on the diet of kiwi chicks, the diet of individual chicks was pooled across months, this also revealed considerable overlap in individual kiwi chick diets (Figure 1.1).

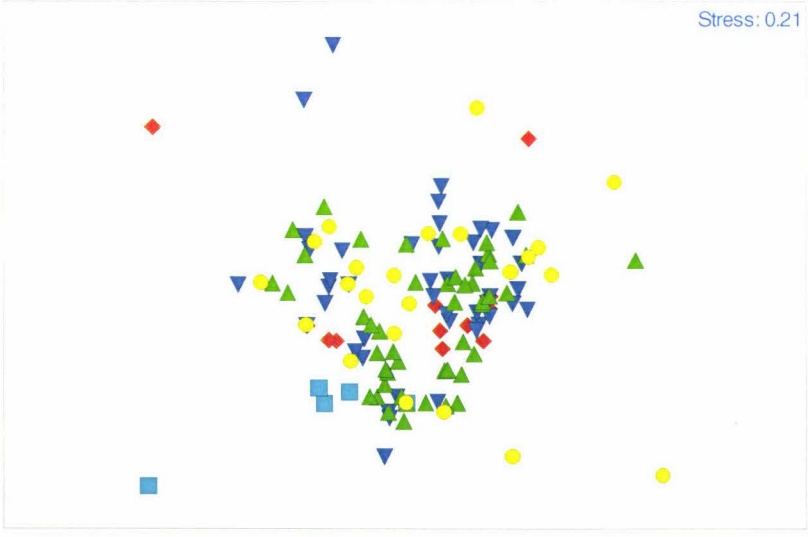


Figure 1.1 A dietary comparison of 143 faecal samples from five North Island brown kiwi chicks (● =Diego, ▲ = Niko, ▼ = Mauro, ■ = Megan, ◆ = Louise) on Ponui Island, using non-metric multidimensional scaling. Created from the nine most frequent invertebrate food groups found in chick faecal samples (Table 1.2) and included earthworms. Samples were collected from November 2004 to February 2005.

Table 1.2 The average monthly number of invertebrates per faecal sample for individual kiwi chicks from November 2004 to February 2005.
* In several cases more than one faecal sample was collected per chick per day, samples for that day were averaged to give one overall sample.

Month / Chick	# of faecal samples	Weta	Spiders	Centipedes	Cicada nymphs	Scarabaeid beetles	Scarabaeid larvae	Elaterid larvae	Tipulid larvae	Unknown
November										
Louise	9*	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.06 ± 0.17	0.00 ± 0.00	1.39 ± 1.59	0.17 ± 1.54	0.33 ± 1.70	0.00 ± 0.00
Mauro	16*	0.28 ± 0.45	0.28 ± 0.73	0.13 ± 0.34	0.00 ± 0.00	0.50 ± 0.89	5.63 ± 5.00	0.47 ± 0.49	1.69 ± 1.96	0.06 ± 0.25
Megan	7	0.00 ± 0.00	0.57 ± 0.53	0.00 ± 0.00	0.43 ± 0.79	0.00 ± 0.00	2.00 ± 1.15	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Niko	16*	0.28 ± 0.58	0.19 ± 0.54	0.06 ± 0.25	0.09 ± 0.27	0.44 ± 0.89	16.38 ± 9.68	0.47 ± 0.72	0.28 ± 0.58	0.06 ± 0.25
December										
Louise	9	0.22 ± 0.44	0.22 ± 0.44	0.11 ± 0.33	0.00 ± 0.00	0.33 ± 0.71	5.56 ± 3.54	0.11 ± 0.33	1.67 ± 1.80	0.00 ± 0.00
Mauro	16*	0.25 ± 0.45	0.19 ± 0.40	0.38 ± 0.50	0.00 ± 0.00	0.56 ± 0.89	7.13 ± 5.11	0.47 ± 0.80	6.00 ± 6.57	0.06 ± 0.25
Niko	14	0.36 ± 0.49	0.07 ± 0.27	0.57 ± 0.65	0.14 ± 0.36	0.50 ± 0.85	10.86 ± 6.27	0.86 ± 1.17	8.93 ± 9.00	0.07 ± 0.27
January										
Diego	14*	0.29 ± 0.47	0.14 ± 0.36	0.43 ± 0.65	0.04 ± 0.13	0.04 ± 0.13	2.18 ± 1.77	0.50 ± 0.65	1.68 ± 1.70	0.00 ± 0.00
Mauro	7	0.00 ± 0.00	0.14 ± 0.37	0.43 ± 0.78	0.14 ± 0.38	0.14 ± 0.38	1.00 ± 1.00	0.71 ± 0.76	0.29 ± 0.49	0.00 ± 0.00
Niko	14*	0.50 ± 0.65	0.14 ± 0.36	0.36 ± 0.74	0.00 ± 0.00	0.75 ± 1.05	6.86 ± 6.27	0.64 ± 0.93	3.54 ± 4.00	0.00 ± 0.00
February										
Diego	10	0.20 ± 0.42	0.60 ± 1.07	0.20 ± 0.42	0.00 ± 0.00	0.00 ± 0.00	1.80 ± 1.90	0.50 ± 0.71	0.00 ± 0.00	0.00 ± 0.00
Mauro	5	0.20 ± 0.45	1.20 ± 1.79	0.20 ± 0.45	0.00 ± 0.00	0.00 ± 0.00	3.20 ± 2.28	0.80 ± 1.30	2.40 ± 3.36	0.00 ± 0.00
Niko	6	0.83 ± 0.75	0.67 ± 1.03	0.33 ± 0.82	0.00 ± 0.00	0.67 ± 0.52	2.33 ± 2.25	1.33 ± 1.21	0.17 ± 0.41	0.00 ± 0.00

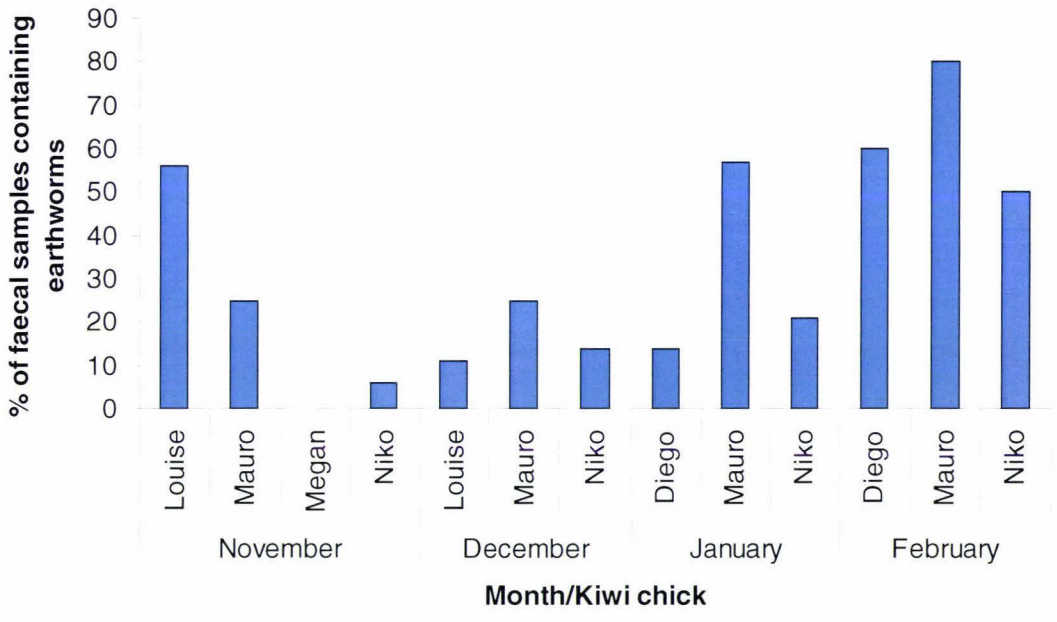
Of the three larval forms and one nymph found in the diet of kiwi chicks, the only adult form also found were scarabaeid beetles (Mumu chafer beetles; *Stethaspis longicornis*) (Table 1.2). The most common scarabaeid larvae found in chick faecal samples were Mumu chafer larvae. There were differences between individual chicks in the average number and the peak times for individual species of invertebrates in their faeces. The average number of scarabaeid larvae per faecal sample peaked for Niko in November and for Louise and Mauro in December (Table 1.2). For Niko the average number of scarabaeid larvae per faecal sample was significantly lower in January compared to the peak in November (one-way ANOVA; $F_{1, 28} = 9.88$; $P < 0.05$). Mauro experienced a significant decrease in the average number of scarabaeid larvae per faecal sample from December to January (one-way ANOVA; $F_{1, 21} = 9.65$; $P < 0.05$).

The average number of tipulid larvae found in chick faecal samples peaked for Louise, Mauro and Niko in December (Table 1.2). This peak in December was a significant increase in numbers of tipulid larvae per faecal sample from November for Mauro (one-way ANOVA; $F_{1, 30} = 6.33$; $P < 0.05$) and Niko (one-way ANOVA; $F_{1, 28} = 14.64$; $P < 0.05$) but not for Louise (one-way ANOVA; $F_{1, 17} = 3.77$; $P = 0.07$). No tipulid larvae were found in the faecal samples from Diego in February and so the average numbers of tipulid larvae per faecal sample in January were significantly higher (one-way ANOVA; $F_{1, 21} = 9.57$; $P < 0.05$).

The average number of spiders found in faecal samples for each of the chicks remained low over December and January with a slight peak in occurrence for the three chicks monitored in February (Table 1.2). Mauro had a significantly higher average number of spiders per faecal sample in February compared to December (one-way ANOVA; $F_{1, 19} = 4.87$; $P < 0.05$). For Niko the average number of weta per faecal sample was low over the four months but reached a slight, although not significant peak, in February compared to November (one-way ANOVA; $F_{1, 20} = 3.40$; $P = 0.08$) (Table 1.2).

Of the 143 faecal samples I analysed only four contained identifiable evidence of plant material. The three most numerous invertebrate groups I found in kiwi chick faecal samples were all soil dwelling larvae (Table 1.2). Although the exact numbers of earthworms in the diet of kiwi chicks were unknown, the percentage occurrence of earthworms in faecal samples shows they were an important part of kiwi chick diet over the four months (Figure 1.2a and 1.2b).

a)



b)

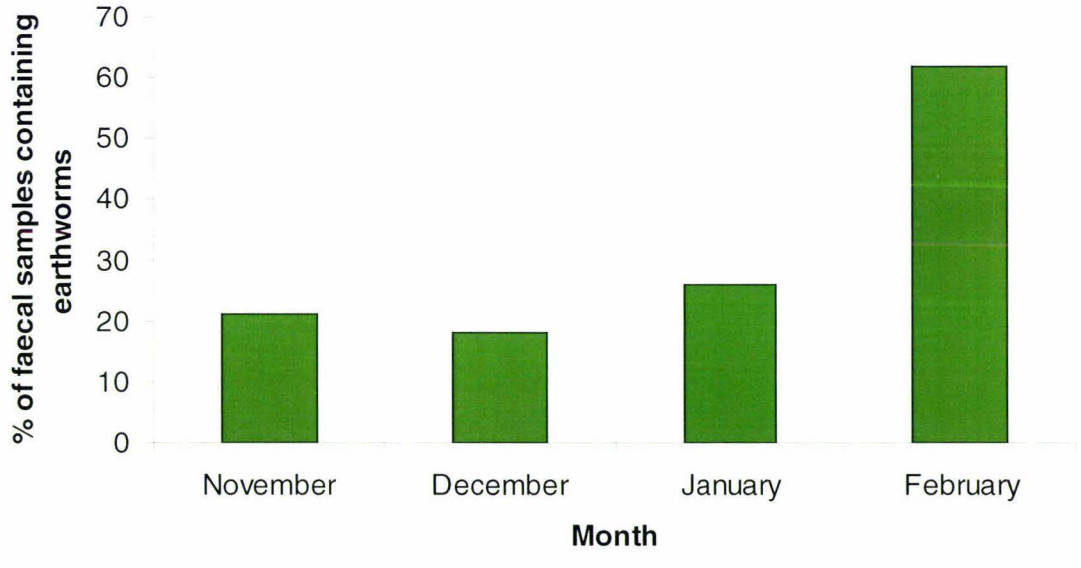


Figure 1.2 a) Monthly percentage of individual kiwi chick faecal samples that contained earthworm chaetae and **b)** the overall monthly percentage of kiwi chick faecal samples containing earthworms. Analysis included five kiwi chicks with faecal samples over four months from November 2004 to February 2005.

1.3.3 Kiwi chick growth

The weights for three chicks on Ponui Island which survived to the end of this project were found to be significantly (one-way ANOVA; $F_{1,7} = 101.05$; $P < 0.001$) smaller in April (when all chicks were over four months old) compared to those of the five chicks from Warrenheip (an Operation Nest Egg crèche). All three Ponui chicks appeared to plateau and/or lose weight from approximately 80 to 90 days of age (Figure 1.3).

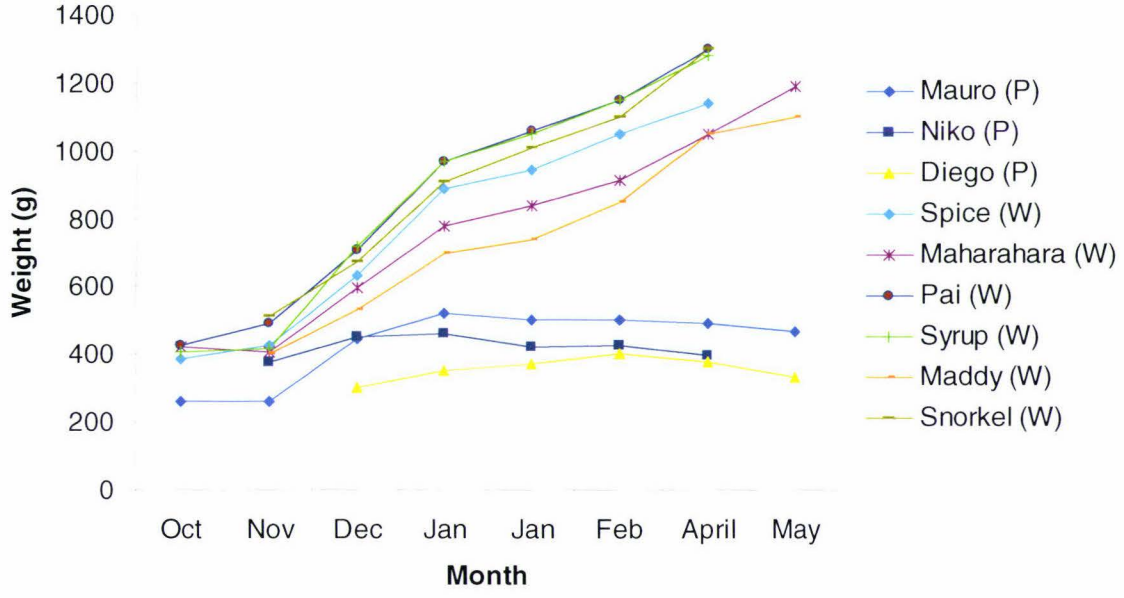


Figure 1.3 Weight curves of three kiwi chicks on Ponui Island (P) versus five chicks from Warrenheip (W) predator proof bush fragment (J. Miles pers. comm.), from October 2004 to May 2005 (with two points in January and excluding March).

The weight of the three chicks from Ponui Island appeared to plateau at around 400 g compared to the steady growth of all five chicks in the Warrenheip crèche (Figure 1.3). Chicks from both locations hatched over a three-week period at the end of September and start of October 2004, except Diego who hatched at the end of November 2004. No diet information is available on the chicks from Warrenheip so no dietary comparison can be made. The major difference is habitat (mainland versus island), the absence of adult kiwi and a lack of predators or potential competitors at Warrenheip. Kiwi on Ponui coexist with rats and cats whereas Warrenheip is surrounded by a predator proof fence that excludes rats. The three Ponui chicks have very similar weight curves (Figure 1.3) and this is consistent with the dietary data (Figure 1.1), which showed no overall significant differences in diet between the five chicks studied including the three here.

The difference in bill growth of the kiwi chicks on Ponui Island compared to the Warrenheip chicks was similar to the difference in weight. The three chicks from Ponui again were found to grow not only at a slower rate but their bill growth began to plateau around February (Figure 1.4). In April when all the chicks were over four months old the bill sizes of the three chicks on Ponui were found to be significantly smaller than those of the five birds from Warrenheip (one-way ANOVA; $F_{1,7} = 23.97$; $P < 0.05$).

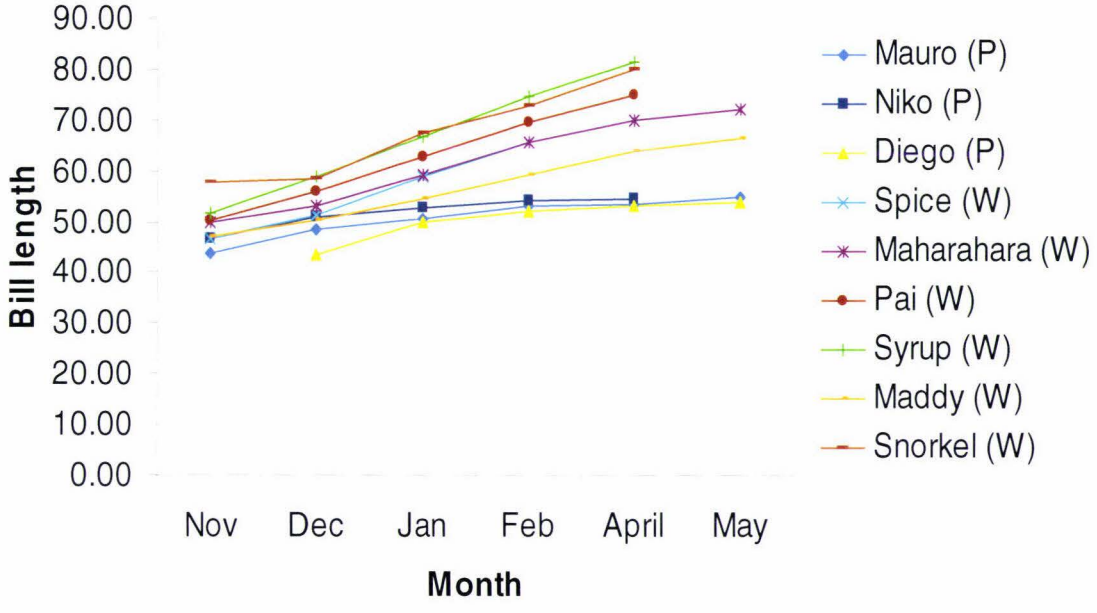


Figure 1.4 Bill length of three kiwi chicks on Ponui Island (P) versus five chicks from Warrenheip (W) predator proof bush fragment (J. Miles pers. comm.), from November 2004 to May 2005 (excluding March).

1.3.4 Shelter types

A total of 191 daytime shelter locations of five kiwi chicks were identified over the period from November 2004 to March 2005. Chicks were located in their respective nests on 82 days and the remaining 109 locations (Table 1.3) were of chicks once they had left the nest. Megan, who left the nest at night to feed, died in the nest 19 days after hatching. Chicks were found to spend the majority of time sheltering under reeds in scrub habitat. Chicks were found sheltering in scrub habitat for approximately 93% of all locations made. The differences in vegetation between scrub and bush habitat are described elsewhere (Chapter 4; Section 4.3.5).

Kiwi chicks were also observed feeding in scrub habitat at night and during the day (pers. obs.). Each of the five kiwi chicks monitored were found sheltering and feeding in areas no larger than eight hectares with overlap in ranges between neighbouring chicks. The combined area used by Diego, Niko and Mauro, who were found sheltering in similar areas and were monitored for several months, was approximately 15 hectares.

Table 1.3 Number of days spent in different shelter types by four kiwi chicks after fledging and sheltering independent of either parent, from November 2004 to March 2005. Shelter sites with * were in bush habitat and all other sites were in scrub habitat.

	Days located in different shelter types							
Chick	Reeds	Pine needles	Fallen Kanuka	Ponga branches	Astelia	Gorse	Moving	Surface
Mauro	20	2	1	0	1	3	4	1
Diego	15	4	3	2*	3	0	2*	3
Louise	7	0	0	2	0	0	2	1*
Niko	18	2	3	1*	1*	0	5	3

1.4 Discussion

There was significant overlap in the diet of the five North Island brown kiwi chicks over the four months of analysis. The overall monthly differences that occurred in the invertebrate diet of kiwi chicks followed environmental abundance quite closely (Chapter 4). The types of invertebrates found in faecal samples in the current study were similar to those found in faecal samples of little spotted kiwi in a diet study on Kapiti Island (Colbourne *et al.*, 1990). The weights and bill measurements of the three Ponui kiwi chicks were not only significantly lower than those of the five chicks from Warrenheip in April 2005, but the Ponui chicks weight fluctuated up and down compared to continuous growth of the Warrenheip chicks. Kiwi chicks were repeatedly found sheltering in scrub habitat, which is quite common (J. Miles; L. Dew pers. comm.) and consistent with the findings of Chan (1999).

1.4.1 Nests and chicks

Less than half of the males in the study population engaged in breeding, the males who did incubated a single clutch and fewer eggs than North Island brown male kiwi in other parts of their range (Miles pers. Comm.). It is important to note that even in the absence of any known predation of kiwi chicks on Ponui, chicks still had a high mortality rate due to bacterial infections before and after hatching.

1.4.2 Diet

I found no significant difference in the overall diet of the five kiwi chicks over the four months when faecal samples were collected. Despite the overall similarity of individual kiwi chick diet, soil invertebrates showed large peaks in occurrence in faecal samples and this may be due to the availability of those particular invertebrates in certain months due to their lifecycles and accessibility.

For each of the five kiwi chicks, scarabaeid larvae were the most common invertebrate over all four months with a peak in November and December. Scarabaeid beetles were first found in pitfall traps over summer in December (Chapter 4; Figure 4.2). By January the average number of scarabaeid larvae per faecal sample for Mauro dropped significantly compared to December. The decline in the number of scarabaeid larvae in kiwi chick diet from December to January and February is most likely a reflection of the beetle lifecycle. Scarabaeid larvae found in monthly core samples (Chapter 5; Figure 5.3b) were low overall and decreased from December to January, with none being found in February. Both sets of data fit with larvae migrating upward to shallow soil levels, emerging and taking flight as adults.

High average numbers of scarabaeid larvae per faecal sample were found in the months before these larvae emerged but were close to the soil surface. Colbourne & Kleinpaste (1990) also found that the high numbers of fully-grown cicada nymphs in the soil was reflected by high numbers in adult kiwi faecal samples. This occurred in November when Cicada nymphs migrate upwards to topsoil layers prior to their emergence as adults (Colbourne & Kleinpaste, 1990). Niko consistently had higher average numbers of scarabaeid larvae per faecal sample than the other four chicks monitored. Chicks

were found feeding in similar areas and so this difference may be due to Niko being the oldest chick of the five (Table 1.1). This may indicate that the ability to successfully locate and prey upon soil dwelling larvae may increase with age.

The low average monthly numbers of scarabaeid beetles in chick faecal samples may be due to their increased ability to elude capture compared with other invertebrates, this is due to their ability to fly and therefore spend less time in or on the ground. It may also be due to their numbers being low in areas where kiwi chicks were feeding and therefore be an effect of habitat type rather than diet.

The December peak in the average number of tipulid larvae per faecal sample for the three chicks monitored was possibly a reflection of the life cycle of tipulids in the first month of summer. The significant increase in numbers of adult diptera caught over summer compared to spring in pitfall traps may have provided numerous larval prey for kiwi chicks (Chapter 4 Figure 4.2). Larvae may have been close to the surface or more accessible to kiwi chicks directly prior to their emergence as adults. Significantly higher numbers of adult diptera, which consisted mainly of tipulids, were also caught over summer compared to other seasons in a study by Moeed & Meads (1987) of emerging insects in the Orongorongo valley (near Wellington). Tipulid larvae are often found in clumps (Colbourne & Kleinpaste, 1990) so that when kiwi do encounter them they are likely to have several of them on offer. Hence when close to the surface these gregarious larvae are likely to be a plentiful and possibly an easily obtainable meal for kiwi chicks.

Niko and Mauro showed a peak in the average number of elaterid (Wireworm) larvae per faecal sample in February. This followed environmental abundance, as the number of elaterid larvae found in soil core samples also peaked in February (Chapter 4; Figure 4.4). Although the other invertebrate groups found in faecal samples were not the most numerous in terms of average monthly number per faecal sample, their importance cannot be discounted.

There is also the problem of the number versus the weight of invertebrates preyed upon. A large number of an individual invertebrate prey in chick faecal samples does not automatically indicate a high importance in the diet of kiwi chicks, as large

invertebrates may only need to be taken in low numbers, compared to smaller prey, to achieve an equivalent biomass. The important difference between invertebrate prey taxa is that of size and what nutritional value each group has to a kiwi chick. Another problem is that of individual faecal samples, a larger faecal sample has the potential to contain more remains of invertebrate prey. Multiple faecal samples collected daily for individuals were averaged and this helped to avoid a bias from having numerous faecal samples and large numbers of invertebrates for individuals in a sampling period.

The presence of earthworm chaetae is an unreliable means of determining the number of earthworms eaten, as the number of chaetae per worm differs between species and between different sizes of worms (Wroot, 1985). Although the exact number of earthworms preyed upon by kiwi chicks was unknown, the high percentage of stomachs that contained them indicates they were a consistent part of kiwi chick diet. The overall monthly percentage of chick faecal samples containing earthworms increased over February. This is despite a decrease in the number of earthworms found in soil core samples in the same habitat over February.

At their peak occurrence tipulid larvae and scarabaeid larvae were found in the highest average numbers per faecal sample of any invertebrate group found in kiwi diet. Both larvae are soil dwelling and a decrease in numbers and occurrence may be due to life cycles, decreasing soil moisture and penetrability over drier summer months. Both types of larvae were found in very low numbers in soil core samples (Chapter 4; Figure 4.4). This is in contrast to the high numbers found in faecal samples. This would suggest that kiwi chicks were selectively hunting these larvae. Colbourne *et al.* (1990) suggested that little spotted kiwi on Kapiti Island were also actively selecting cranefly (tipulid) larvae and scarabaeid larvae.

While soil friability and soil dwelling invertebrates may vary with season, there is clearly an important role for soil dwelling invertebrates in the diet of kiwi chicks over the spring and summer months after they hatch and fledge. A possible reduction in the accessibility and availability of soil dwelling invertebrates over summer in New Zealand forests may lead to an increased number of other invertebrates being eaten. Surface, litter and shallow soil dwelling invertebrates may have been eaten more

frequently because of their availability and accessibility due to the probing constraints of kiwi chicks due to their small bill.

Another factor that may cause differences in the average monthly number of invertebrates per chick faecal sample is the growth requirements of kiwi chicks. Although the chicks on Ponui were not growing very fast or were even losing weight and no overall difference in diet was found between individuals over the four months, the average numbers of invertebrates per faecal sample may have been influenced by growth requirements possibly to a lesser extent than by abundance.

The current study shows that kiwi chicks were feeding on both surface and soil dwelling invertebrates. From the soil kiwi chicks were taking larvae, although it is unknown how deep these invertebrates were at and only low numbers were found in core samples (Chapter 4; Figure 4.4). The numbers of spiders, centipedes and other litter dwelling invertebrates eaten were consistent throughout, whereas larval prey showed obvious peaks that were probably related to abundance and soil penetrability. There is little evidence to support kiwi feeding preferentially on the surface. However, chicks can only probe much shallower depths than adults and even then adults may be probing at similar depths and competing with them. In a study on shorebirds, Barbosa & Moreno (1999) found a relationship between bill morphology and foraging strategies. Longer bills were found to be adaptively coupled to the use of a tactile foraging strategy, whereas shorter bills were found to be related to a visual strategy (Barbosa & Moreno, 1999). Over the summer months the dry/hard soil may restrict the depths at which kiwi can probe to hunt invertebrates and the shorter bills of kiwi chicks may be well suited to feeding on the soil surface using a visual foraging strategy.

1.4.3 Growth

There are various possible reasons for the difference in growth rates between the chicks on Ponui and Warrenheip. The location, vegetation, low soil penetrability over summer on Ponui and invertebrate differences between the sites as well as possible competition with ship rats and other kiwi due to the high density on Ponui may all be contributing factors.

The diet of chicks from Warrenheip was unknown, but unless disease was a contributing factor to the lower weights of the chicks on Ponui then food abundance, consumption and competition from other kiwi or competition with pests would have to be major factors in explaining the difference. The Warrenheip chicks were of course hatched in captivity as part of the ONE management program. Feeding before release may have given them an advantage in not having to forage for food for a period. Warrenheip contains no adult kiwi and no predators or rats, so these chicks grew without predation and any competition for food was restricted to that with other kiwi chicks and other birds within Warrenheip. Only one of the three chicks whose growth was recorded on Ponui survived, the other two that died were both too decomposed when found to establish cause of death. All five chicks in Warrenheip survived and were released to their natal territories in Tongariro National Park upon reaching 1000g. To make a more conclusive comparison invertebrate sampling and kiwi chick diet would need to be studied at both sites.

Another possible reason for the difference in weights may be to do with a difference in growth rates resulting from different foraging strategies of male and female kiwi chicks. Several studies on the foraging behaviour of various species of sea birds, that also display sexual size-dimorphism like adult kiwi, concluded that sex differences in the foraging behaviour of these birds was due to differences in body size rather than sex (Phillips *et al.*, 2004; Lewis *et al.*, 2005). In a study by McLennan *et al.* (2004) male and female North Island brown kiwi were found to grow at the same rate from hatching to adulthood but females continued to grow after males stopped. Since male and female kiwi chicks are thought to grow at the same rate then it seems unlikely that any sex related foraging strategy that occurred was the reason for the difference in weights of the Ponui and Warrenheip birds.

McLennan *et al.* (2004) found the bills of female juvenile kiwi between the age of 200 and 1400 days grew significantly faster than bills of male juveniles over the same period. The faster bill growth made no difference to the overall growth of females compared to males. The bill length comparisons made in the current study were of birds younger than 200 days so age is not thought to be a reason for the bill growth rate difference between Ponui and Warrenheip.

There was not only a difference in growth rates, but all four kiwi chicks (the fourth chick was lost due to transmitter failure) on Ponui which fledged lost weight well after absorbing their yolk sac. Growth rates taken from 41 North Island brown kiwi chicks from 1993 to 1998 at Lake Waikaremoana showed that chicks put on weight except for the first several weeks where they absorbed their yolk sac (Miles, 1998). Exceptions to this consistent weight gain have been observed - after heavy rain or bad weather chicks can lose weight from restricted feeding (R. Colbourne pers. comm.) but not consistently as was the case of the chicks on Ponui.

1.4.4 Shelter

Kiwi chicks in the current study spent the majority of time sheltering in scrub vegetation. Kiwi chicks have quite commonly been found inhabiting scrub and swamp habitat (J. Miles; L. Dew pers. comm.). Chan (1999) found that North Island brown kiwi chicks showed a clear preference for inhabiting scrub and regenerating bush over mixed podocarp/broadleaf and kauri dominant forest in Trounson Kauri Park. The exact reasons for chick preference for scrub habitat are unknown but shelter from aerial predators, food availability and the absence of adult kiwi have all been suggested (Chan, 1999). One common hypothesis put forward for the preferential use of scrub habitat by kiwi chicks is an increased number of shelter sites and shelter from aerial predators. Bush habitat in the current study site had a relatively open understorey resulting from browsing by stray cattle, seriously limiting the number of places to shelter apart from earth burrows and hollow logs. The ridges consisted mainly of regenerating scrub and provided dense cover and a multitude of shelter opportunities. But one reason for chicks sheltering in scrub habitat so often may be due to there possibly being more food there, this was indicated by the significantly higher number of weta and spiders caught in pitfall traps in scrub habitat compared to bush (Chapter 4; Section 4.3.1). Remains of both weta and spiders were regularly found in kiwi chick faeces and environmental abundance of these was high over summer months whereas the more common invertebrate prey, soil dwelling larvae, decreased in abundance over summer (Chapter 4; Figure 4.4). The preferential use of scrub habitat to shelter by kiwi chicks may therefore be a reflection of diet. There were higher numbers of surface dwelling invertebrate prey in scrub compared to bush at a time when soil dwelling larvae abundance was low in both habitat types.

The amount of overlap in ranges may be due to territory being of no concern to kiwi chicks or that these areas were possibly high quality habitat. It's also possible that the density of other kiwi chicks and adults was high enough that considerable overlap in range was necessary to obtain enough prey. The overlap in ranges may have affected the diet of individual chicks and potentially increased the possibility of intra-specific competition. Two of the three chicks that used similar areas and overlapped in their ranges were from the same nest and clutch, so it's possible that they used similar areas and overlapped due to their proximity to their parents nest.

1.4.5 Limitations of this study

The most obvious limitation to this study was the small sample size of kiwi chicks used to analyse diet, this was attributed to the low numbers of breeding pairs and numerous chick/egg deaths from bacterial infections. Working with an endangered animal does not always afford the luxury of large samples and the endangered nature of kiwi restricts the number of manipulations that can be carried out.

When kiwi are actively feeding a high food intake results in a quick passage through the gut - the interval between ingestion and defecation was found to be 70-85 minutes by Reid *et al.* (1982). Hence the faecal samples collected may only represent prey taken in the final stages of feeding from the previous night, before chicks found shelter. However if chicks returned to a shelter at different stages of the night to rest it may be a better representation than suggested, collecting faecal samples from a shelter was the most reliable method of retrieving a sample from a known bird.

Faecal samples may over-represent certain invertebrate groups. Chitonous parts namely mandibles last in the stomach longer than other body parts (Watt, 1971) and so the same over representation would occur in faecal material. Chaetae give an indication of the presence of earthworms in the diet of kiwi chicks but do not give an idea of the numbers eaten like chitonous body parts of other invertebrates.

1.4.6 Conclusion

The small sample size available to the current study limits the possible generalisation of the conclusions that can be drawn. However the diet of the five North Island brown kiwi chicks studied appeared to follow environmental abundance quite closely. Kiwi chicks appeared to be selectively taking certain prey, namely soil dwelling larvae as the number found in faecal samples far outweighed numbers found in core samples. Chicks showed a preference for sheltering in scrub habitat but it is unclear whether this was a choice or as a result of the close proximity of their nests to scrub habitat. The difference in growth rates between Ponui and Warrenheip was obvious, but again small sample size and differences in location means that further work in studying the growth rates and ecology of kiwi chicks on Ponui Island and comparing them with other sites is needed.

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2

Ship rat (*Rattus rattus*) diet and morphometrics on Ponui Island, New Zealand.

Abstract The diet of ship rats (*Rattus rattus*) living in forest on Ponui Island was analysed by examining stomach samples from 101 individuals caught on a kill trap line over nine months. Little evidence of plant material in ship rat diet was found and invertebrate prey dominated the diet. The overall diet of ship rats on Ponui Island followed environmental abundance and availability of invertebrates closely. There was a peak in the average number of weta (Stenopelmatidae and Rhaphidophoridae families) per ship rat stomach over summer months. Evidence of earthworms in ship rat stomach samples was found over the three seasons monitored, empty stomachs were only found over winter and spring months. There was a 97% infection rate of ship rat stomachs containing the parasitic nematodes *Physaloptera getula* and *Mastophorus muris*. The average number of nematodes per ship rat stomach peaked over summer months. Orthopterans, namely weta, have been suggested as possible intermediate hosts in the life cycle of the parasitic nematodes *P. getula* and *M. muris* and their occurrence and peak in abundance in the current study supported this hypothesis.

2.1 Introduction

2.1.1 Mammalian invasion of New Zealand

New Zealand's ecological history since the arrival of humans has been dominated by introductions of exotic species, none more damaging and invasive than the introduced mammals. The islands of New Zealand were free of all terrestrial mammals except bats until approximately 1000 years ago. The arrival of large numbers of introduced land mammals had traumatic effects on the native flora and fauna (King, 1990).
The terrestrial avifauna of the New Zealand Archipelago evolved not only in the absence of land mammals but in geographical isolation and is characterised by high levels of endemism at different taxonomic levels (Bell, 1991). One likely consequence of this isolation and absence of mammals is the evolution of sedentary life histories and flightlessness. The arrival of the first humans began major ecological impacts caused by human exploitation of natural resources and accelerated by the impacts of the human associated introductions of predatory and browsing mammals; the result being a loss of around 48% of the native avifauna and the endangerment of 50% of the remaining species (Towns & Ballantine, 1993).

Many of the surviving populations of native fauna are now restricted to isolated offshore islands that have few or none of the mammalian pests (King 1984). The first attempts at controlling these pests on offshore islands focused on the larger mammals including goats (*Capra hircus*), pigs (*Sus scrofa*), and cats (*Felix catus*). More recently attention has shifted to eradicating the smaller and logistically problematic species like mice (*Mus musculus and M. domesticus*), Norway (*Rattus norvegicus*), ship (*R. rattus*) and Pacific rats (*R. exulans*) (Towns & Ballantine, 1993).

The four species of rodents living in the wild in New Zealand are all members of the same family, the Muridae. All four were introduced – house mice, ship and Norway rats by the Europeans in the late 18th and early 19th century and Pacific rats by the Polynesians about 1000-1200 years ago (Atkinson, 1973; Innes, 2005). Along with possums (*Trichosurus vulpecula*), Brockie (1992) identified ship rats as being "the most pervasive and devastating agents of change".

Ship rats are characterised by three colour morphs (Innes, 2005); the black back grey belly of the "*rattus*" morph, the grey-brown back and slate-grey belly of the "*alexandrinus*" morph and the grey-brown back and white belly of the "*frugivorous*" morph. Despite interbreeding freely, most North Island ship rats are "*frugivorous*" while most of the "*alexandrinus*" morph are found in the South Island (Innes, 2005).

2.1.2 Ship rat diet in New Zealand

Most rodents have specialised diets of seeds or vegetation, but some are very adaptable omnivores (Innes, 2005). Ship rats living in New Zealand native forest eat both plant and animal foods all year round with proportions varying seasonally (Innes, 2005). The more common animal foods of ship rats in New Zealand forests have been identified as arthropods - mainly adult orthopterans, spiders, beetles, stick insects, cicadas and cockroaches (Gales, 1982; Miller & Miller, 1995; Blackwell, 2000). In New Zealand there is a seasonal predominance of arthropods in the diet of ship rats (Innes, 2005). This is apparently due to the relative scarcity of fruit in New Zealand forests in spring and summer (Leathwick, 1984).

Weta were found in 39-76% of ship rat stomachs in several New Zealand studies (Best, 1969; Daniel, 1973; Innes, 1979; Gales, 1982; King, 1990). The significance of weta in ship rat diet is illustrated by Daniel (1973) who found that 'animal food' comprised approximately 77% and 84% of food taken per stomach in spring and summer respectively with approximately a third being tree weta (*Hemideina thoracica*). Several species of parasitic nematodes have also been found in ship rat stomachs (Charleston & Innes, 1980; Miller & Miller, 1995; Blackwell, 2000) and it has been suggested that their occurrence is linked to the presence of weta in the diet of ship rats (Charleston & Innes, 1980).

Plant material has also been noted in the stomachs of trapped ship rats in New Zealand, some of which include Karaka (*Carynocarpus laevigatus*), Miro (*Prumnopitys ferruginea*), Supplejack (*Ripogonum scandens*), Nikau (*Rhopalostylis sapida*) and Karo (*Pittosporum crassifolium*) (Beveridge, 1964; Best, 1969; Daniel, 1973; Innes, 1979; King, 1990; Miller & Miller, 1995). Ship rats are also known predators of birds' eggs (up to at least 61mm long are taken) and chicks (Atkinson, 1978).

2.1.3 Ship rats as potential competitors

The role of rats as predators has been clearly established but it is unclear whether rats also play a role as competitors. Several studies have looked at the diet of ship rats in New Zealand's native forest (Gales, 1982; Miller & Miller, 1995; Blackwell, 2000), but few have compared this to the diet of a sympatricly occurring native species with similar feeding behaviour. A study by Cree *et al.* (1995) suggested that tuatara (*Sphenodon punctatus punctatus*) experience reduced density in the presence of Pacific rats. Even though circumstantial, evidence suggests that Pacific rats can cause extinction of tuatara through competition for food and/or predation of eggs. Although the cause of decline involves a possible combination of predation and competition it highlights the importance of further understanding the feeding ecology of rats and their role as potential competitors in New Zealand forests.

In many New Zealand forests total eradication of ship rats is not possible due to cost - both economic and in human effort - and therefore native fauna have to live in areas with either uncontrolled rodent densities or with low density rodent populations due to control operations. By further understanding the diet and general ecology of ship rats it may be possible to better direct existing trapping operations both of the rats themselves and of their predators. This may in turn enable better results in terms of insect prey survival and the success of native species using the same resources. Further understanding of rodent ecology should involve the recording of key rodent measurements including weight, head body length and tail length from populations to look at differences within sites and enable comparisons between different populations.

2.1.4 Current study

The current study has approached the gap in knowledge of possible rodent competition with native species by looking at rodent diet in an area where North Island brown kiwi (*Apteryx mantelli*) chicks were feeding, but more specifically by comparing rodent and kiwi chick diet over the first crucial months of a chick's life. This initial growth of chicks is of vital importance to their survival against mammalian predators. According to McLennan *et al.* (1996) the period of vulnerability of young kiwi to predation by stoats (*Mustela erminea*), their main predator, is relatively short - approximately nine

months or until the chick reaches 1kg. After passing this threshold, survival substantially increases. The main prey of stoats is rats and mice and thus a reduction of the stoats in an area may result in a population increase of rats and mice (Robertson *et al.*, 2003). Therefore, where stoats are controlled kiwi chicks may be hatching into areas where competition rather than predation has a significant influence on survival. Quantifying rodent diet is of key importance to assessing what, if any, competition occurs with native species and for determining any critical periods. By identifying these 'critical' times it may be possible to better direct trapping efforts. This chapter describes the diet of ship rats on Ponui Island (36°50'S, 175°10'E) from June 2004 to February 2005. In Chapter Five ship rat diet is compared to that of Northern Brown kiwi chicks on Ponui Island to analyse potential competition. The main aims of this chapter are to establish the diet of ship rats on Ponui Island and compare this diet to environmental abundance of prey, namely invertebrates. This chapter also aims to compare catch rates to other New Zealand ship rat populations.

2.2 Methods

2.2.1 Trap line

In June 2004 a trap line (40 Eziset supreme™ kill traps 20m apart) was set up in Hook Gully (HG) one of the four gullies in the main study site (Chapter 1; Plate 1.3) on Ponui Island (Chapter 1; Plate 1.1). The gully's vegetation was similar to that of the other gullies, starting at the base as scrub, bordering on swamp and merging into forest. The line was run every 30-35 days for three consecutive nights. Traps were (re)set at night in a period of 30 minutes either side of darkness and each trap was baited with peanut butter. Traps were checked and cleared the next morning between 0800 and 1000 NZST. Successful traps were recorded and captured rats were collected for dissection and all other traps were sprung at this time. Traps were removed at the end of each three-day trapping session.

Each trap had a rectangular wire mesh cover (31cm long x 18cm wide x 12cm high) with a small entrance (7cm wide x 7cm high) and a piece of impermeable plastic material (cort flute) covering the roof to avoid capture of non-target animals and

accidental triggering by rain. Traps were attached to the ground at each end with a single steel peg (30cm long) driven approximately 15cm into the soil.

The number of rats caught was calculated per 100 corrected trap-nights (CTN). Calculating corrected trap nights involves discarding any traps that were set off without a capture from the total number of traps. In the current study 40 traps were set for three consecutive nights each month - a total of 120 trap-nights per month and 1,080 over nine months. 23 traps were set off over the nine months with no capture, so the corrected trap nights were 1,057.

2.2.2 Trap line location

The trapline was located in Hook Gully (Chapter 1; Plate 1.3), a site representative of all gullies in the study area in terms of aspect, slope and vegetation. This gully was also chosen as it was not used for the kiwi chick feeding aspect of this study (Chapter 1) as rat removals may have altered chick diet. Hook gully was also chosen as it is far enough away from the live trapping site (> 500m) and would not impact on the ship rat mark recapture study in Pipe Gully (Chapter 3).

2.2.3 Measurements

After capture, rats were assigned to species, sexed and ship rats were classified into morphs. Male rats with scrotal testes and females with a perforated vagina were classed as mature (Cunningham & Moors, 1983). Each rat was weighed using 1 Kg Pesola™ scales (± 1g) and head-body length (HBL) and tail length were measured using Kincrome™ Vernier callipers (± 0.01cm).. The stomach and intestines were dissected out from the oesophagus to just above the opening of the anus with scissors. Each sample was weighed (1 Kg Pesola™ scales) and stored in a specimen jar with 70% Ethanol.

2.2.4 Stomach Analysis

Stomachs were cut along the greater curvature and the intestines were cut in half. Both were washed with water to remove contents into a gradation of sieves (500μm and

125µm). The stomach and intestine contents were then washed gently and sieved down. The material remaining in each of the sieves was transferred to a Petri dish and examined under an Olympus sz40 microscope at 6.7x magnification. Insect material was removed and identified (at 40x magnifications) using a reference collection of invertebrates created from nine months of pitfall data from the three gullies in the main study site (Chapter 4; Figure 4.2). Only invertebrates with bodies >8mm were used for analysis. This is similar to work done by Blackwell (2000) on ship rats and the methodology of Colbourne *et al.* (1990) with little spotted kiwi (*Apteryx-owenii*). Invertebrates could usually be identified to Family and in some cases to Genus.

In addition to identifying food items, all stomach nematodes were counted and collected for identification. This was carried out to enable a comparison of seasonal numbers and species of nematodes with those reported in several other ship rat diet studies in New Zealand (Charleston & Innes, 1980; Miller & Miller, 1995; Blackwell, 2000).

Invertebrate counts identified using the key were conservative. In cases where an invertebrate had more than one appendage or structure per individual - and several of these were present in a stomach - then the least number of individuals was recorded. For example, when two mandibles from the same invertebrate were of very similar size and from the left and right sides they were counted as one individual. The same method was applied to all other structures which occur multiple times on specific invertebrates. Invertebrates were recorded as numbers per stomach and frequency of occurrence calculated as the number of stomachs containing specific invertebrates as a percentage of total stomachs. Worm chaetae per stomach were counted but Wroot (1985) showed that chaetae are not a reliable indication of numbers of earthworms, so only presence or absence of chaetae and hence "earthworm presence" was recorded.

The number of invertebrates per stomach was also broken down into numbers per stomach in male or female ship rats and for those caught in different habitat types (bush and scrub). Ship rat diet samples were divided into three seasons; winter (June, July, August 2004), spring (September, October, November 2004) and summer (December 2004, January, February 2005).

2.2.5 *Statistical manipulations*

Analyses were preformed using Primer v5.2.9 (Clark & Gorley, 2002). A one-way ANOSIM (Analysis of similarities) test was used to analyse differences in diet due to season, habitat and sex. ANOSIM tests are described by Clark & Gorley (2001) as a rough analogue of the standard univariate one- and two-way ANOVA tests; the test used allows a statistical test (one-way layout) of the null hypothesis for which there are no assemblage differences between groups of samples specified *a priori*. The ANOSIM test gives a 'Global R' value and a significance level. The R statistic is a comparative measure of the degree of separation of sites. R values close to zero indicates similarities between and within sites are on average the same, a value close to one indicates all replicates in a site are more similar to each other than those from other sites Clark & Gorley (2001). It is possible for significant R values to have little biological significance due to the high statistical sensitivity of the analysis resulting from very large numbers of replicates.

Non-metric multidimensional scale (nMDS) plots were also produced in Primer to illustrate any difference in diet due to season, habitat and sex. nMDS represents non-metric relationships between multiple variables in two or three dimensions. As the plots were non-metric they contained no x or y axis. The nMDS plots also included a stress value which indicated the accuracy with which each plot represented the actual relationship of individual data points. Stress values for nMDS plots can range from 0.0 (perfect map) to 0.3 (low accuracy).

Univariate statistical tests were carried out in the software package SPSS (2001); these included a one-way analysis of variance (ANOVA) calculated to compare weight, head-body length (HBL) and tail length (TL) between male and female ship rats. A one-way ANOVA was used to assess any difference between ship rat stomach weights over the three seasons and also between the mean numbers of nematodes per stomach over the three seasons. With each of these, seasons were analysed for significance in pairs by running three separate one-way ANOVA tests. A Mann-Whitney U test was calculated to compare the numbers of scarabaeid beetles over summer and spring.

2.3 Results

Over the nine months of kill trapping from June 2004 to February 2005 101 ship rats were captured. A total of 1,057 corrected trap nights gave 9.56 rats trapped/100 corrected trap nights. Stomachs from all rats were analysed and 16 of the 101 stomachs were, excluding parasitic stomach nematodes, empty of invertebrates and seven of the 101 stomachs contained any plant material. Three of the 16 stomachs empty of invertebrates were full of plant material and only one of these 16 stomachs had no parasitic nematodes or plant material. Of the 101 ship rats captured 11 were classed as immature and 90 as mature. Rats from all three colour morphs were caught, 56 rats were the Frugivorous morph, 37 Alexandrinus and eight Rattus.

Over the nine months of trapping the numbers of rats caught per month were lowest in the last two months of spring and first two months of summer (Figure 2.1). A total of four pregnant females were trapped in the current study with the first caught in December, one in January and two in February.

2.3.1 Rat numbers and morphometrics

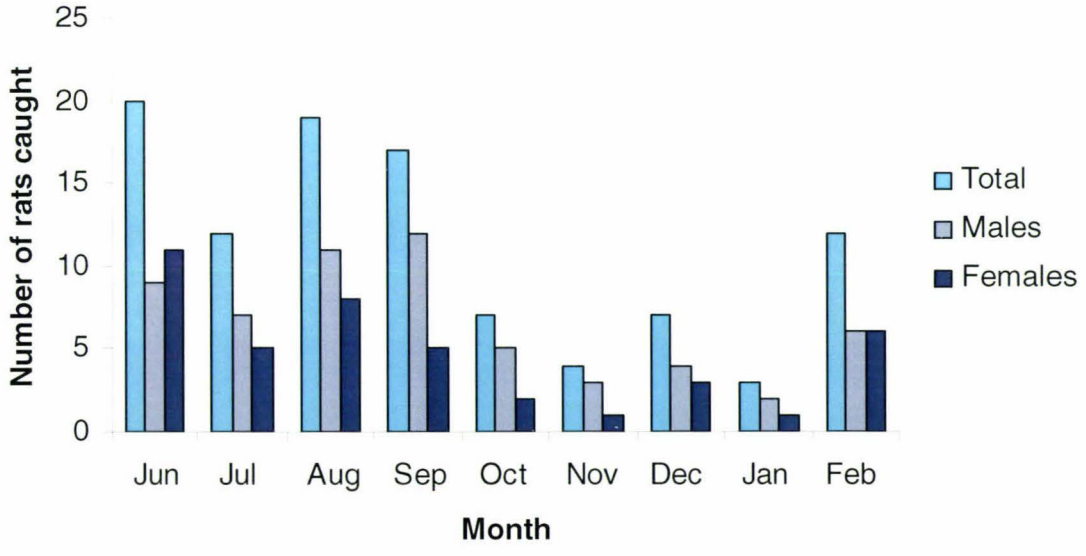


Figure 2.1 Monthly catch rate of ship rats on a trap line over nine months, from June 2004 to February 2005.

Males were significantly heavier (one-way ANOVA; $F_{1, 99} = 4.10$; $P < 0.05$) and had significantly larger head-body lengths than females (one-way ANOVA; $F_{1, 99} = 4.59$; $P < 0.05$) (Table 2.1).

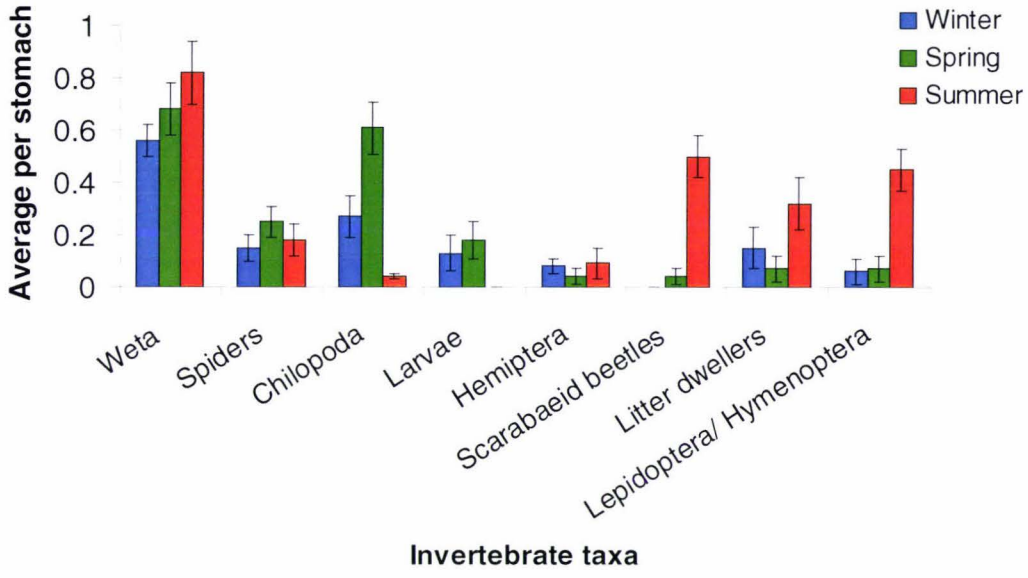
Table 2.1 Weight, head-body length (HBL) and tail length of male and female ship rats caught over nine months (June 2004 to February 2005).

Sex	N	Weight ± S.D. (g)	HBL ± S.D. (mm)	Tail length ± S.D. (mm)
Male	59	139.78 ± 33.59	157.21 ± 19.91	199.79 ± 31.64
Female	42	126.02 ± 33.71	148.84 ± 18.43	197.91 ± 28.17
Total	101	134.06 ± 34.16	153.72 ± 19.66	199.01 ± 30.12

2.3.2 Ship rat diet

There was no significant difference in the average number of invertebrates per ship rat stomach between any of the three seasons – summer-winter (one-way ANOVA; $F_{1, 72} = 3.04$; $P = 0.09$), summer-spring (one-way ANOVA; $F_{1, 50} = 0.17$; $P = 0.68$) and spring-winter (one-way ANOVA; $F_{1, 78} = 2.23$; $P = 0.14$). The average number of invertebrate prey per ship rat stomach was 1.75 ± 1.94 (S.D.) over winter, 2.39 ± 1.59 (S.D.) over spring and 2.59 ± 1.76 (S.D.) over summer. There were also no rats caught with empty stomachs over the summer months (Figure 2.2b). There was however a significant increase (Mann Whitney U Test; $Z = 3.78$; $P < 0.001$) in the average number of scarabaeid beetles (Mumu Chafers; *Stethaspis longicornis*) per ship rat stomach from spring to summer (Figure 2.2a).

a)



b)

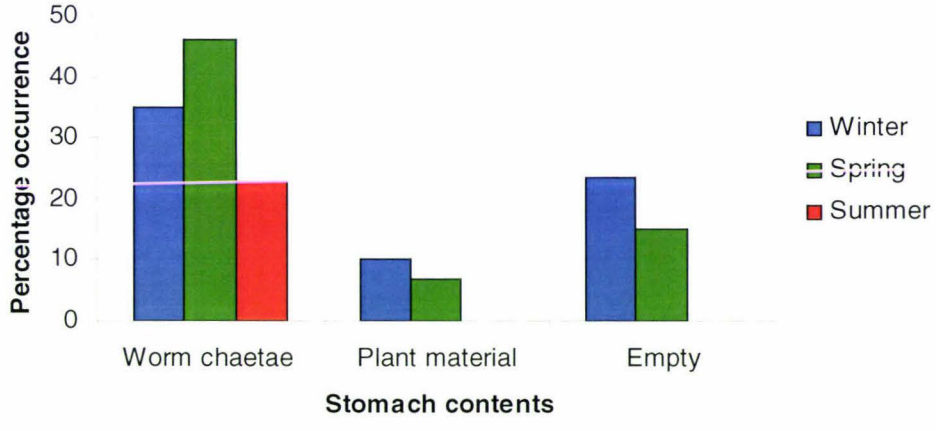


Figure 2.2 a) The average number of individual invertebrates (±Standard error bars) per ship rat stomach over three seasons from June 2004 to February 2005. Litter dwellers included bristletails, slaters, amphipods, carabidae beetles and cockroaches. Larvae included coleoptera and diptera **b)** The percentage of ship rat stomachs containing earthworm chaetae, plant material or that were empty of invertebrate prey over winter, spring and summer from June 2004 to February 2005.

An ANOSIM test was carried out on the rodent stomach contents for the three seasons. Although there was a significant difference between seasons in ship rat diet (one-way ANOSIM; Global R = 0.059; $P < 0.05$) the R value was very low indicating substantial overlap between seasons. It is possible for significant R values to have little biological significance due to the high statistical sensitivity of the analysis resulting from very large numbers of replicates.

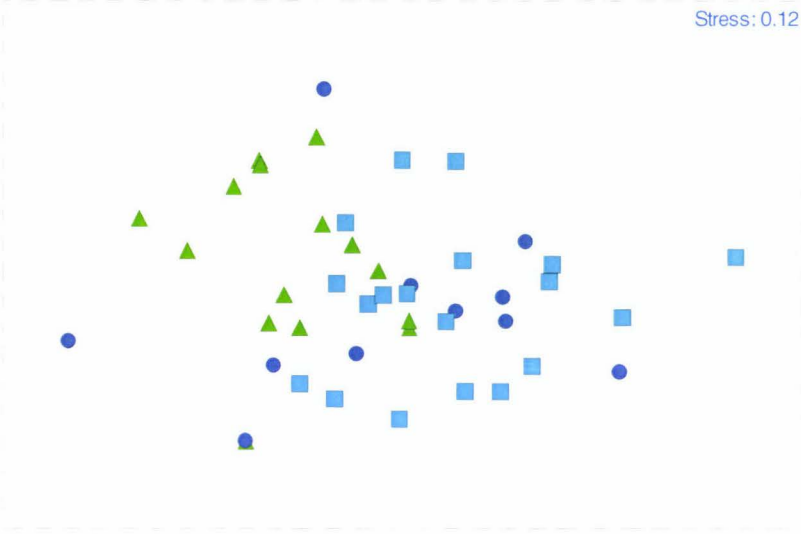


Figure 2.3 Non-metric multidimensional scaling of the effect of season on ship rat invertebrate diet from winter 2004 to summer 2004/2005, excluding all empty stomachs. ● = winter, ■ = spring, ▲= summer.

The mean stomach weight of rats caught over the spring months was significantly greater (one-way ANOVA; $F_{1, 76} = 9.65$; $P < 0.05$) than that of rats caught over the winter months (Table 2.2). The mean weight of stomachs from ship rats caught in spring was greater than those caught in summer, this is despite there being a higher mean number of invertebrate prey per stomach for ship rats caught over summer compared to spring.

Table 2.2 Mean stomach weights of ship rats caught over three seasons on Ponui Island, winter 2004 to summer 2004/2005.

Season	N	Mean weight of stomachs	±S.D.
Winter	51	22.53	8.13
Spring	27	28.19	6.64
Summer	23	22.96	11.81
Total	101	24.14	9.01

There was no significant difference in diet of ship rats caught in scrub and bush habitat over the length of the study (one–way ANOSIM; Global R value = 0.054; $P = 0.89$). There was no significant difference in diet between male and female ship rats over the nine month study (one-way ANOSIM; Global R value = 0.012; $P = 0.62$). The R value was very low in both instances indicating substantial overlap in diet between males and females and also between ship rats caught in scrub and bush habitat.

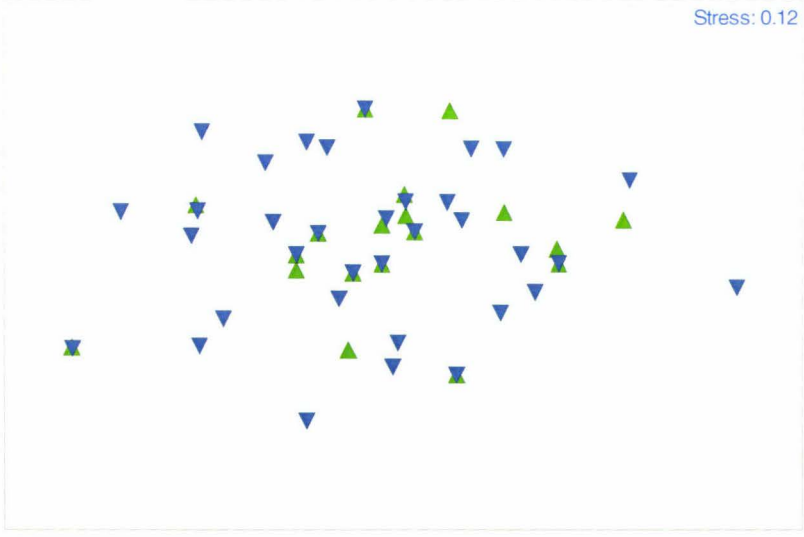


Figure 2.4 Non-metric multidimensional scaling of the effect of habitat on ship rat invertebrate diet from June 2004 to February 2005. ▲ = scrub; ▼ = bush.

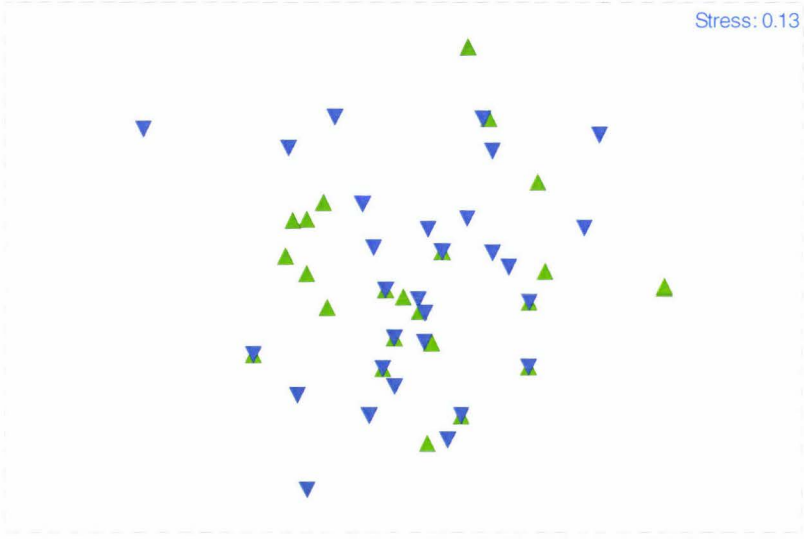


Figure 2.5 Non-metric multidimensional scaling of the effect of sex on ship rat invertebrate diet from June 2004 to February 2005. ▲ = Female; ▼ = Male.

2.3.3 Stomach Parasites

Of the 101 ship rats kill trapped only three had stomachs with no nematode parasites present and one of these was completely empty. The three stomachs devoid of parasites were all from rats caught over winter. The mean number of nematodes per stomach was significantly higher over summer than over winter (one-way ANOVA; $F_{1, 72} = 6.09$; $P < 0.05$). There was no significant difference in the number of nematodes per stomach over spring compared to summer (one-way ANOVA; $F_{1, 48} = 3.00$; $P = 0.09$; Table 2.3). The mean number of nematodes per stomach in spring was slightly higher than that in winter, but the difference was not significant (one-way ANOVA; $F_{1, 76} = 0.31$; $P = 0.58$; Table 2.3).

Table 2.3 The mean number of parasitic nematodes per ship rat stomach caught over three seasons (winter 2004 to summer 2004/2005).

Season	Stomachs (N)	Mean number of nematodes per stomach	±S.D.	Nematode species
Winter	51	13.13	11.57	*Physaloptera getula* *Mastophorus muris*
Spring	27	14.64	11.32	*Physaloptera getula* *Mastophorus muris*
Summer	23	21.05	14.81	*Physaloptera getula* *Mastophorus muris*
Total	101	15.25	12.54	*Physaloptera getula* *Mastophorus muris*

2.4 Discussion

In the current study, ship rat diet was dominated by invertebrate prey. A wide range of different invertebrates were eaten, with the percentage occurrence of some invertebrate prey differing seasonally. The occurrence of weta in the diet of ship rats was high throughout this study (Figure 2.2a). Their importance to ship rat diet follows the findings of several other ship rat diet studies in New Zealand (Daniel, 1973; Innes, 1979; Miller & Miller, 1995; Blackwell, 2000). The current study's peak in the number of weta in ship rat diet over summer was similar to that found by Innes (1979) and Miller & Miller (1995). Spiders occurred in ship rat diet throughout the current study and their frequency of occurrence was similar to that found by Blackwell (2000), although the study was in a mainland forest, so the comparison has to factor in possible differences in invertebrate numbers available. Leathwick (1984) suggested that the seasonal predominance of arthropods in ship rat diet may be because fruit is relatively scarce in New Zealand forests in spring and summer. I found little evidence for plant or fruit material in the diet of ship rats on Ponui Island with only seven out of 101

stomachs containing plant material. The low incidence of plant material found in this study supports the hypothesis of Leathwick (1984). However, one reason for the small amount of plant material found in rat stomachs may be its digestibility and the difficulty in identifying plant material even when examining cuticles. In addition, this study did not include autumn when fruits are thought to be most plentiful in North Island New Zealand forests (Leathwick, 1984). The importance of plant material to ship rat diet on Ponui therefore cannot be discounted.

2.4.1 Diet and environmental abundance

The overall ship rat invertebrate diet on Ponui Island followed 2004/2005 seasonal abundance quite closely; few New Zealand studies have compared ship rat diet to environmental abundance, and when it has been, no positive correlation was found (Blackwell 2000). The peak in the average number of weta per ship rat stomach in summer correlated with a significant increase in the number of weta caught over summer compared to spring in pitfall traps in similar habitat (Chapter 4; Figure 4.2). The summer peak of weta in ship rat diet appeared to be based on increased availability and provides evidence of diet following environmental abundance.

The increase in the average number of litter dwelling invertebrates per ship rat stomach (cockroaches and carabid beetles) over summer correlated with pitfall trap data over the same period in bush and scrub habitat (Chapter 4; Figure 4.2). The high number of scarabaeid beetles (Chafer beetles) per ship rat stomach over summer followed pitfall data, which first recorded scarabaeid beetles in forest and farmland habitat over the summer months with none caught over the spring and winter months (Chapter 4; Figure 4.2 and 4.3). The summer occurrence of chafer beetles in diet and pitfall data are further validated by Walker (2000) who describes the emergence of chafer beetles *en masse* (Mumu and Tangaruru) from the ground in early summer.

Another invertebrate group whose occurrence in ship rat diet followed its environmental abundance, determined from pitfall traps (Chapter 4; Figure 4.2), was that of the spiders. Both peaked in numbers over spring and decreased again over summer but to levels higher than winter. Ship rat consumption of spiders closely followed environmental abundance. The decrease in average numbers and percentage

occurrence of the soil dwelling food groups (larvae and earthworms) over summer in rat diet was consistent with the decline in soil moisture over the summer observed from the difficulty in digging soil core samples over those months (Chapter 4; Section 4.2.2).

There may be several reasons for ship rat diet reflecting seasonal invertebrate abundance on Ponui Island. Available food on Ponui Island may be very limited compared to the study site of Blackwell (2000) at Lake Waikaremoana. Ship rat diet may only be following fluctuations in what little prey is available. This hypothesis is supported by the lack of kiwi chick growth over the summer months (Chapter 1; Section 1.3.3). The difference between Blackwell (2000) and the current study may also be due to differences in study sites, simply the difference between the mainland and an island. Invertebrates on Ponui, an island, may have less chance of recovery from predators than they would on the mainland and only the most abundant invertebrates survive therefore limiting the prey choice.

Rats with empty stomachs were found over the winter and spring months with almost a quarter of rats caught in winter having empty stomachs. Ship rats on Rangitoto Island were also found to have higher numbers of empty stomachs over winter and it was suggested that food may have been limited at that time (Miller & Miller, 1995). Pitfall trap data on Ponui revealed that (apart from earthworms) of the invertebrates ship rats preyed upon (Figure 2.2a), the numbers trapped over summer were higher than winter (Chapter 4; Figure 4.2). Ship rat diet in the current study has already been shown to follow seasonal abundance quite closely, the lower number of available invertebrate prey and the occurrence of empty stomachs over winter and spring months adds further weight to the idea that food is very limited on Ponui Island year round, more so over winter and spring months. Despite this there is also the possibility that 2005 may have been an odd unrepresentative year which further highlights the need for long-term study on Ponui Island to establish yearly variation.

2.4.2 Catch rates and morphometrics

The nine months kill trapping yielded a catch rate of 9.56 rats/100 CTN. Catch rates per hundred trapping nights in mainland New Zealand forest vary widely being 1.7-35.8 in a Northland Kauri (*Agathis australis*) forest (Dowding & Murphy, 1994) and 1.8-5.6 in

a South Island Beech (*Nothofagus* Spp.) forest (Alterio *et al.*, 1999). The catch rates on offshore islands also vary from 9-82.4 rats/100CTN on Stewart Island (Hickson *et al.*, 1986) and 1.6 rats/100CTN on Rangitoto Island (Miller & Miller, 1995). The catch rate on Ponui followed seasonal fluctuations from other studies (Best, 1968; Innes, 1977) but the catch rates in previous studies vary so widely on island and mainland sites that any meaningful comparison is not possible.

The catch rates on the Ponui trap line dropped over the last two weeks of spring and first two weeks of summer. Several ship rat studies in New Zealand have found the same fluctuations (Best, 1968; Innes, 1977). The reason for this drop in catch rate may be due to an increase in available invertebrate food at the end of spring and the start of summer (as occurred in the current study). With more food available ship rats may be less inclined to go after trap baits. It was concluded by Best (1968) that if trapping was to be used to control ship rat numbers in New Zealand forests then winter and early spring would give the greatest return for trapping effort. Catch rates from the current study support this conclusion.

The significantly larger head-body length and average weight of male ship rats compared to females in the current study is consistent with various other New Zealand ship rat studies (Innes, 1977; Innes *et al.*, 2001; MacKay & Russell, 2005). The average weight, head-body length and tail length of both male and female ship rats in a study by Innes *et al.* (2001) in Pureora forest and a study by MacKay & Russell (2005) on Motutapere Island (36°47'S, 175°25'E) were all within one standard deviation of the same measurements in the current study. Despite similarities in all three measurements the different length, location and dates of each study make any comparisons difficult and these differences should be accounted for when drawing any conclusions.

2.4.3 Nematodes

There was a 97% occurrence of nematodes (*Physaloptera getula* and *Mastophorus muris*) in the stomachs of ship rats in the current study, this is high compared to several other New Zealand ship rat diet studies. The nematodes *P. getula* and *M. muris* were found in 65% of ship rat stomachs by Charleston & Innes (1980), 59% of stomachs by Miller & Miller (1995) and 51% of stomachs by Blackwell (2000). One possible reason

for the high number of ship rats infected on Ponui Island may be the predominantly invertebrate-based diet, with high numbers of weta eaten. It was suggested by Charleston & Innes (1980) that arthropods, namely weta, may be intermediate hosts in the life history of these nematodes.

Roberts *et al.* (1992) found that in a population of Kiore (*Rattus exulans*) on Tiritiri Matangi the prevalence of four species of nematode was influenced mostly by habitat but also by season and sex. They also found the most common nematode to be *M. muris* in nearly 100% of stomachs particularly in forest habitat. The idea of habitat effects on nematode incidence was also mentioned by Roberts *et al.* (1992), habitat was found to be the most important of four variables studied. Another of the habitat effects mentioned is density. Population density could be one of the contributing factors to the high number of infected rats and the number of nematodes per stomach in ship rats on Ponui Island. The ship rat density on Ponui was estimated (Chapter 3; Table 3.1) to be larger than those from several studies of ship rats in New Zealand mainland forests (Dowding & Murphy, 1994; Hooker & Innes, 1995).

It has been suggested that host food intake can be physically obstructed by large numbers of parasites (Crompton, 1984). The high infection rate of ship rats in the current study meant comparisons between the condition of infected and uninfected rats was not possible and this was also the same for looking at the effect of sex on infection rates.

2.4.4 Study limitations

The problem with most diet studies is obtaining information that is representative of true feeding patterns. The use of stomach samples to obtain diet information is considered to be more accurate than the use of faecal samples (Kronfeld & Dayan, 1998), but stomach samples have several possible limitations. One of the main limitations is that each stomach is just one sample from one individual and repeated sampling is not possible. The use of stomach samples by kill trapping removes animals from the population and the possible effects on the number of prey available to remaining animals is unknown, especially when the study population is small.

In the current study the capture location may affect what can be found in the diet. Ship rats had to be on the ground to be trapped therefore stomach contents may only represent prey obtained on the ground, as ship rats are agile climbers any food that was obtained while in a tree may already have been digested and/or excreted. If rats only spent part of the night on the ground feeding then this could potentially be a very limited sample of their diet, although ship rats were observed on the ground on many occasions in the study site (pers. obs.). Foraging is assumed to be unaffected by trapping and stomach samples representative of true diet structure but this may be untrue. The effect of bait on an animals foraging behaviour is unknown. The availability of nutritious bait, such as peanut butter, may influence the composition of meals (Clark, 1982). The ease at which trap baits can be obtained may cause the animal to cease regular foraging behaviour in favour of seeking trap baits.

2.4.5 Conclusion

Ship rats in the current study showed a wide choice of diet that was heavily dominated by invertebrate prey. Stomach samples revealed a diet of invertebrate taxa which closely followed environmental abundance and availability. This response in diet choice to abundance suggests that rats were able to respond to seasonal fluctuations in invertebrate prey. Ship rat catch rates per 100 nights trapping vary widely in New Zealand for both mainland forests and offshore islands. The Ponui catch rates fluctuated seasonally and were similar to seasonal changes in previous studies.

Stomach parasites were found in almost all rats captured, and the average number per rat was significantly larger over the summer months. The higher density of ship rats on Ponui relative to several mainland studies may be one factor affecting parasite load. The importance of arthropods in the diet and their possible link as intermediate hosts may also have influenced parasite loading.

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3

Density estimation of a ship rat (*Rattus rattus*) population using mark-recapture methods on Ponui Island, New Zealand.

Abstract The density of ship rats (*Rattus rattus*) was estimated for forest habitat on Ponui Island over three months. Mark-recapture methods were used with ear tagging to identify recaptured individuals. Ship rats were anaesthetised with a combination of Xylazine 3mg/kg and Ketamine 40mg/kg and this proved to be an effective means of reducing handling stress and enabled various manipulations to be carried out. A total of 135 captures of 49 individuals were made. Of the individuals that had the possibility of recapture 19 were never recaptured. Twelve of these were males, this gives support to the hypothesis that males increase their home range over the breeding season and this may reduce the possibility of recapture. Density and population estimates were made with the programmes DENSITY and MARK. Ship rat density over the three months ranged from 6.04 ± 1.73 to 10.20 ± 2.53 rats/ha on Ponui Island and was higher than previous density studies of ship rats carried out in mainland New Zealand forests. However, they were similar to densities estimated for ship rats and Norway rats (*Rattus norvegicus*) on several other New Zealand offshore islands.

3.1 Introduction

3.1.1 Background

A fundamental requirement for many research studies and management operations involving animals is the accurate assessment of a species' density in its natural habitat (Parmenter *et al.*, 2003). This is difficult when animals cannot simply be counted, as is the case with many nocturnal species. The two most common methods for estimating nocturnal small mammal populations are removal trapping and mark-recapture (Clark, 1980). Several New Zealand studies have investigated the density of rodents with reference to their diet of plant material or animal prey (Best, 1969; Daniel, 1973; Innes, 1979; Gales, 1982; Moors, 1983; Blackwell, 2000), but few (Whitaker, 1978; Cree *et al.*, 1995) New Zealand studies have considered rodent density to gauge its effects on the success of other animals which share a similar habitat and may potentially compete for limited resources. Competition has been explained as occurring when many individuals exploit the same limited resources - they are then competitors (Krebs & Davies, 1993). The point is that competition relies on the availability and demand for resources and importantly the numbers of individuals utilising the resources, so the inclusion of density estimation in cases of potential competition between species is important.

3.1.2 Ship rats and the value of density estimates

As with many island systems, conservation in New Zealand has involved the eradication of invasive species (Veitch & Bell, 1990). The current ability to solve previously difficult problems such as removing pest mammals from large islands has enabled a shift in philosophy and management from preservation to eradication (Towns & Atkinson, 1991). Such eradications were first pioneered on offshore island refuges and the latter applied on mainland sites (Towns & Atkinson, 1991). As a result of limited time and funds these eradications are often done without actually studying the ecology or effects of the relevant pest(s) before and after eradications.

Ship rats (*Rattus rattus*) are thought to have spread through New Zealand's North Island some time after 1860 (Atkinson, 1973) and are by far the most uniformly distributed of New Zealand's three rat species on the mainland (King, 1990). Ship rats

have historically been found on many of New Zealand's offshore islands. However many of these islands have been reclaimed through pest eradication and now provide pest free sanctuaries for endangered natives.

In contrast to offshore islands, total eradication of ship rats in mainland forests in New Zealand is not considered possible due to cost and rapid reinvasion (Innes & Skipworth, 1983). As a consequence native fauna must live in areas with either uncontrolled or low-density rodent populations. In these areas it is advantageous to have a good knowledge of the ecology/biology of the pest(s) involved. One way to achieve this is to accurately estimate the density of the pest species over different times of the year. This information can be applied in several ways. For instance, by reliably estimating density, trapping effort to control numbers can be adjusted to coincide with population peaks. More importantly, by identifying densities relative to the breeding and recruitment of many native species trapping effort can be more efficient. This would potentially minimise the numbers and effects of rodents on relevant native species at vulnerable times as well as saving conservation dollars.

3.1.3 Chapter aims

This chapter uses mark-recapture methods to estimate the density of an invasive pest species - the ship rat in a forest fragment on Ponui Island (36°50'S, 175°10'E). It combines two computer programs, both estimate population size, but one estimates density (DENSITY) and the other estimates several population parameters (MARK). The density estimate was part of a larger study looking at potential competition between ship rats and North Island brown kiwi chicks (*Apteryx mantelli*).

3.2 Methods

3.2.1 Trapping grid

A trapping grid was set up in the main study site in one of the four gullies - Pipe Gully (PG) (Chapter 1; Plate 1.3) on Ponui Island (Chapter 1; Plate 1.1). Forty Tomahawk™ live capture traps (Plate 3.1) were set out 25m apart in an eight by five grid, with five traps across and eight traps running up the gully. The grid covered 17,500m^2 (1.75ha^{-1}) and was run in three sessions - December 2004, January 2005 and February 2005, with four weeks between sessions and each session lasted five consecutive nights. At each session traps were baited with peanut butter and Nutella™. Traps were set between 2000 and 2100 and cleared at 0700 to 0800 NZST the following morning.

Plate 3.1 Weighing a ship rat in a Tomahawk live trap (Photo by C. Hojem).

3.2.2 Site choice

PG was the chosen site for the live trapping study based on several factors. Firstly, three of the four kiwi chicks that survived past three weeks of age hatched in PG. Although the three chicks moved into the scrub on the ridges, they were still close (<200m) to the live trap site and areas where the study ship rats were caught. PG is two gullies (500m) away from the kill trapping line in Hook Gully (HG). Hooker & Innes (1995) found the mean length of ship rat home range to be 194m in males and 103m in females. This is at least half the distance between the kill and live trapping sites and far enough away to negate possible interactions between the sites. A substantial increase in home range would have to occur to create any overlap between live and kill trapping. No ship rats ear tagged in the live trapping study were caught on the kill trap line (Chapter 2).

3.2.3 Treatment and manipulations

Cages were weighed before and after capture to determine individual ship rat weight and minimise handling. Each rat caught for the first time was anaesthetised with a combination of Xylazine 3mg/kg and Ketamine 40mg/kg injected intramuscularly as suggested by Plumb (1999). Rats were restrained within the cage by inserting a cloth covered plastic bag in the entrance to restrict the rat to the very end of the cage and reduce movement. Once the animal was anaesthetised, a fingerling tag was attached to the right ear using a pair of tagging pliers (Plate 3.2). A fingerling tag is a 'C' shaped metal tag with a sharp point at one end and a small hole at the other with a four digit identification code printed on the side. The sharp point of the tag punctures the ear and the point passes through the small hole, closing on itself. Once attached the tag measures 1cm long by 3mm wide and the identification code faces out.

Species, sex, morph type, weight, tail length and head-body length (HBL) were recorded. Male rats with scrotal testes and females with a perforated vagina were classed as mature (Cunningham & Moors, 1983). Each rat was weighed using 1 Kg Pesola™ scales (±1 g) and HBL and tail length was measured using Kincrome™ Vernier callipers (± 0.01cm). Anaesthetised rats were dosed with Yohimbine 0.2 mg/kg, as suggested by Plumb (1999), to reverse the anaesthetic effects and then given 3-4ml

of fluid injected subcutaneously to reduce dehydration. Rats were then placed under a blanket to prevent hypothermia until sufficiently alert to be put back in their cage before becoming fully conscious and ready for release. Xylazine is a sedative/analgesic with muscle relaxant properties and it depresses thermoregulatory mechanisms. Either hypo/hyperthermia is possible depending on ambient temperatures. Adequate insulation or ventilation is recommended when dosing rodents with Xylazine (Plumb, 1999).

Recaptured rats were identified in cages by ear tags and released without any further manipulation. This procedure was done under Animal Ethics approval Number 04/153 from Massey University Animal Ethics Committee. The anaesthetic procedures were carried out by a certified veterinarian.

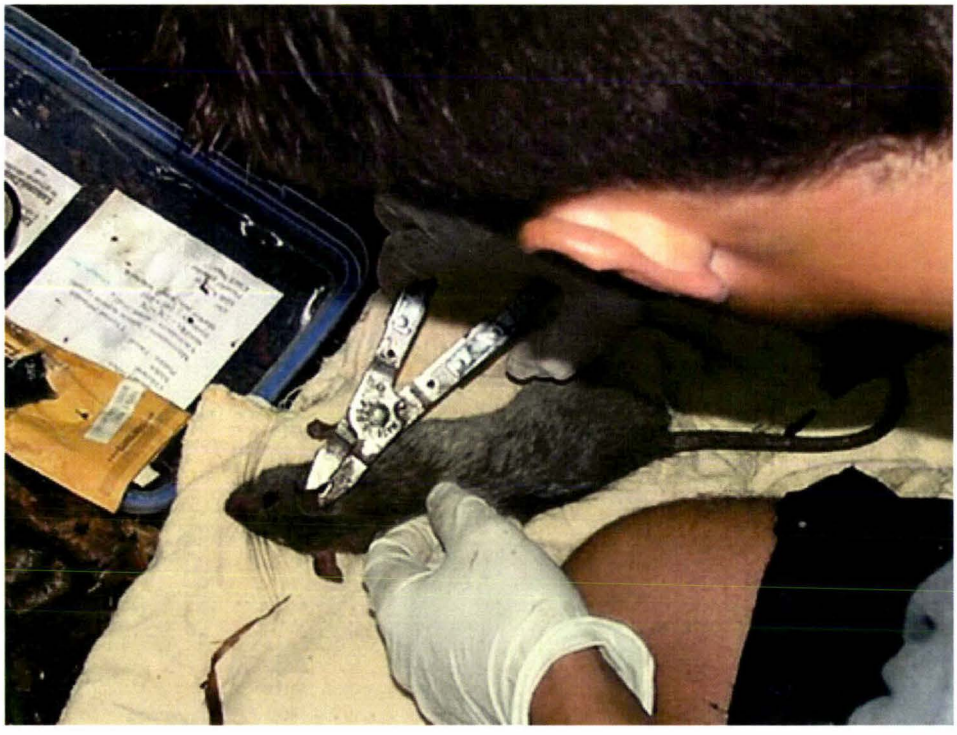

Plate 3.2 Attachment of a fingerling ear tag to a ship rat using tagging pliers (Photo by C. Hojem).

3.2.4 Statistical manipulations

The estimation of ship rat density was carried out using the software package DENSITY v3.3 designed by Efford (2005). This program uses mark-recapture data to estimate animal density. DENSITY implements the method of Efford (2004) for estimating absolute population density from closed-population samples. Each of the three months in the study was treated as a separate session and the five continuous nights of trapping in each as closed populations, so three densities were calculated. Initial captures and recaptures were only relevant to individual sessions and any rat caught for the first time in a session was treated as an initial capture regardless of any captures in previous sessions.

To obtain a density estimate, the program requires the trap layout and inter-trap distance in the form of x and y co-ordinates. The program also requires an input file listing all individual trapping events and separate sessions. Each of these must be accompanied by the tag number of each rat caught and the trap it was caught in, this is used to calculate inter-trap movements as an indication of home range size. This enables DENSITY to estimate a buffer zone to add to the trapping grid area, this is the furthest point from the grid where a rat could still include the trapping grid in its home range and potentially be captured.

DENSITY uses simulation and inverse prediction to fit a spatial detection model and estimate animal population density *D*. *D* is understood as the intensity parameter of a spatial point process for home-range centres (Efford, 2004). Unlike most density estimates DENSITY only requires the capture history and uses inverse prediction to estimate the effective trapping area. It combines this with a population estimate to give the density.

Animals are assumed to occupy home ranges that are fixed for the duration of trapping, and traps are set at known locations. The probability of an individual animal being caught in a particular trap declines with the distance between its home-range centre and the trap. The detection model is a function $g(d)$ where d is the distance between an

animal's home-range centre and a trap (Efford, 2004). The probability of capture when the trap is located exactly at the centre of the home range is g(0).

Estimates for population parameters including inter-session survival probability, population size, capture and recapture probability were calculated in MARK v4.2, a mark-recapture software package designed by White (2001). A robust design was used for the data type and a closed captures model was used to estimate parameters. MARK uses capture histories of all animals in the form of a binary code to estimate the parameters stated above.

The purpose of using two computer programs, MARK and DENSITY, was to allow the inclusion of a density estimate (DENSITY) and several population parameters (MARK) in the overall analysis. Population was the only parameter that both programs estimated. Although density was the main parameter of interest, an estimate of recapture probability was useful for comparing the possible effects of capture and anaesthetic techniques used, on the probability of recapture, to other ship rat mark-recapture studies.

The statistical software package SPSS (2001) was used to carry out a one-way analysis of variance (ANOVA), this was used to analyse differences in head-body length and tail length between mature male and female ship rats. SPSS was also used to carry out a CHI square (χ^2) test to check for any significant difference between the sex ratio of recaptured ship rats and the overall population sex ratio.

3.3 Results

Over the three live trapping sessions from December 2004 to January 2005 a total of 135 captures of 49 individual ship rats were made. Of the 49 individuals captured 26 were male (53%) and 23 were female (47%). This is a female to male ratio of 1:1.13 – with all but one female being classed as mature. From the total individuals caught, 28 (60%) of 47 were recaptured over the three month study. This excludes two individuals caught for the first time on the last night of the final session so they were not available to recapture. Of the rats never recaptured 12 of the 19 were males, giving a female to male ratio of 1:1.71 for rats not recaptured. This is higher than the overall female to male ratio but the difference is not significant ($\chi^2 = 1.32$; d.f. = 1; $P = 0.25$). Two of the three ship rat morphs (King, 1990) were caught in the current study, 32 (65%) were the Frugivorous morph while 17 (34.7%) were the Alexandrinus morph.

The number of recaptures outnumbered the initial captures at the end of the first session (Figure 3.1) suggesting that by this time a large percentage of the population had been captured at least once. The number of initial captures was closest to the number of total captures in December (Figure 3.1) and this suggests that most of the individuals (61%) were initially caught in the first session.

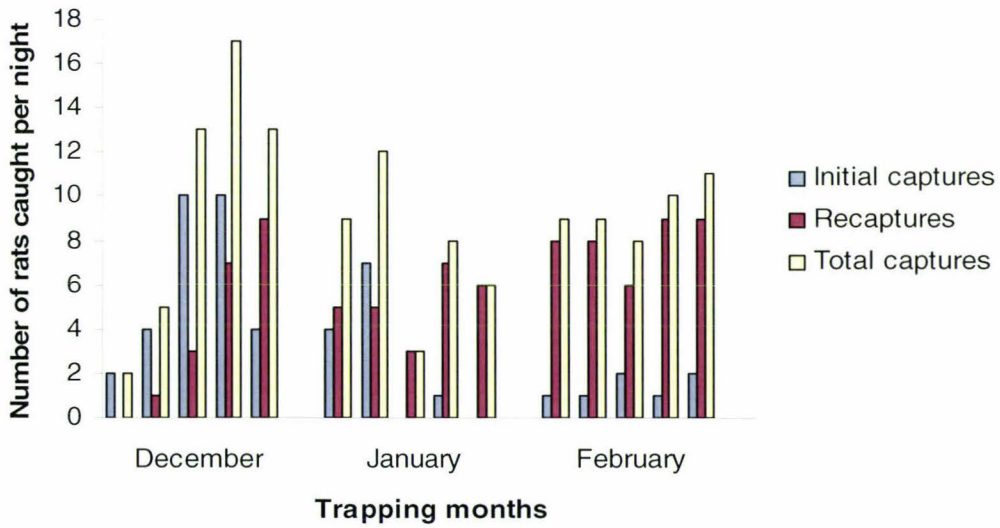

Figure 3.1 The number of ship rats initially captured, recaptured and total captures over three trapping sessions with five trapping nights in each session (December 2004 to February 2005). In this figure sessions were not treated as independent events. Any rat initially captured was treated as a recapture thereafter, regardless of session. This enabled an overall look at the population.

3.3.1 Density

Density for the first two trapping sessions was very similar. A lower density was estimated for the third session due to a smaller estimated population and larger effective trapping area (Table 3.1).

Table 3.1 Estimated density and population size of ship rats from live trapping over three months (December 2004 to February 2005). Also effective trapping area calculated from population and density estimates using the software package DENSITY.

Session	Density ± S.E. (ha^{-1})	Population ± S.E.	Effective Area Trapped (ha^{-1})
1	10.20 ± 2.53	38.00 ± 4.57	3.73
2	9.44 ± 3.32	38.00 ± 6.88	4.03
3	6.04 ± 1.73	27.00 ± 2.37	4.47

Initial capture probability was calculated in MARK by grouping the three sessions together so the probability calculated is constant for the three sessions (Table 3.2). The recapture probability was found to be the same for the first and third sessions but dropped considerably in the second session (Table 3.2). This is due to there being only 12 recaptures from a total of 26 individual rats caught in that session (Figure 3.2). The program DENSITY looks at each session as being independent so does not account for rats caught in previous sessions. It treats them as initial captures and are only classed as recaptures when within that session.

Table 3.2 Population and survival estimates with the probability of initial capture (P) and recapture (P) for each monthly session calculated using the software package MARK.

Session	Population ± S.E.	Survival ± S.E.	Capture (P) ± S.E.	Recapture (P) ± S.E.
1	40.32 ± 6.02		0.23 ± 0.05	0.40 ± 0.07
		0.57 ± 0.11		
2	34.88 ± 5.38		0.23 ± 0.05	0.14 ± 0.04
		0.75 ± 0.15		
3	30.79 ± 4.90		0.23 ± 0.05	0.40 ± 0.06

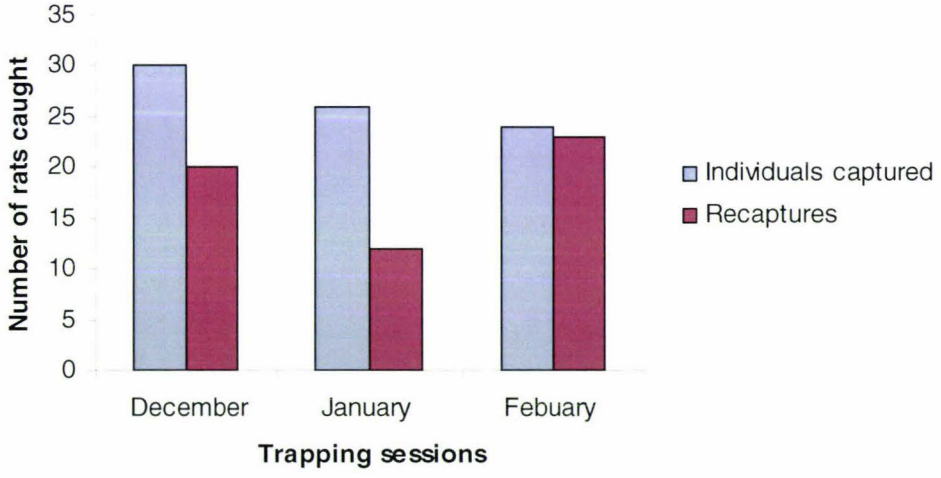

Figure 3.2 Number of individual ship rats captured and recaptured over three sessions (December 2004 to February 2005) treated as independent occasions, only counted as an initial capture and recapture when they occurred within the same session.

Male ship rats were found to have a significantly larger head-body length than females (one-way ANOVA; $F_{1, 47} = 8.01$; $P < 0.01$) (Table 3.3) and were also significantly heavier than female ship rats (one-way ANOVA; $F_{1, 47} = 5.00$; $P < 0.05$) (Table 3.3).

Table 3.3 Measurements of all ship rats when first captured over three months from live trapping December 2004 to February 2005.

Sex	N	Average weight ± S.D. (g)	Average head/body length ± S.D (mm)	Average tail length ± S.D. (mm)
Males	26	155.77 ± 19.22	179.41 ± 13.92	202.81 ± 17.89
Females	23	140.65 ± 27.77	167.18 ± 16.29	210.83 ± 19.10
Total	49	148.67 ± 24.57	173.66 ± 16.14	206.57 ± 18.71

3.4 Discussion

A total of 49 individual ship rats were live trapped on Ponui Island over three sessions giving an estimated monthly density ranging from 6.04 to 10.20 rats ha^{-1}. Very little mark-recapture or density estimation work has been done in New Zealand on ship rats on offshore islands and most studies are in conjunction with eradications. Work on Stewart Island by Hickson *et al.* (1986) primarily looked at the density of a population of ship rats prior to poisoning. The current study recorded a recapture rate percentage which was consistent with several previous mark-recapture studies on ship rats in New Zealand (Daniel, 1972; Hickson *et al.*, 1986). The density estimated was higher than most mainland studies (Daniel, 1972; Dowding & Murphy, 1994; Brown *et al.*, 1996), but it was similar to estimates from several other studies on Norway rats (Moller & Tilley, 1986; Taylor, 1996) and ship rats (MacKay & Russell, 2005; Russell & MacKay, 2005) on offshore islands.

3.4.1 DENSITY and MARK

Both MARK and DENSITY software programs gave similar estimates for the population of ship rats, the population estimated in DENSITY for each session fell within one standard deviation of those estimated in MARK.

Parameters were estimated for within each session, the survival estimate was the only parameter estimated for the interval between trapping sessions. The increase in the survival rate estimated by MARK between the first and second session interval compared to the second and third session interval was due to an increase in the percentage of ship rats captured in the second session that were recaptured in the third session.

The main assumptions of DENSITY are that the population is closed within each session, capture does not effect the movement of an animal within a trapping session and animals occupy home ranges that do not change within trapping sessions. As each session lasted five continuous nights its thought that these assumptions were met, however it's possible that any increase in male ship rat home range size over the breeding season would have violated the last of these assumptions. One of the main assumptions of the robust design model in MARK is also that the population is thought to be closed within each session; within this time it's assumed that there is no emigration or mortality. Again this assumption is thought to have been met due to the short period each session lasted.

The main difference between the two programs is that MARK deals with estimates of the probability of capture, recapture and survival. These estimates are based purely on the mark-recapture data, regardless of the movements or range of the animal being trapped. The density and effective area trapped estimated by DENSITY are based on the inter-trap movements made by individual animals between captures. These inter-trap movements rely on several assumptions listed above; the estimates made in DENSITY rely on more assumptions than MARK. Therefore DENSITY is possibly more susceptible to error, than MARK, from the violation of any one of its several assumptions.

3.4.2 Captures and Recaptures

Of the 49 individuals caught 30 were caught in the first month. This, combined with reasonable recapture rates over the three sessions, rules out trap shyness for the decline in initial captures and indicates that a high percentage of the resident population were

caught. The recapture rate of 60% on Ponui falls within recapture rates from two other mark recapture studies on ship rats in New Zealand. A lower recapture rate of 47% was recorded by Daniel (1972) in Orongorongo Valley (Wellington) and this was carried out monthly over a much longer period (March 1966 to July 1968). This longer study period may have experienced more fluctuation due to death, immigration and emigration. This is supported by an estimation done by Hickson *et al.* (1986) who carried out their trapping over the same months as the current study (December 1984 to February 1985) and recorded a 64.6% recapture rate on Stewart Island, which is a comparable value to the current study.

Rats caught in the first session had more opportunity to be recaptured than rats in the second and third sessions. Despite this, nine of the 19 rats never recaptured were from the first session. It appears that the number of opportunities to be captured did not influence recapture rates. The only noticeable difference between rats never recaptured and the remaining study population was the male skewed sex ratio.

Although the female to male ratio of rats never recaptured was not significantly different to the overall female to male ratio the higher number of males recaptured is of interest. One possible reason for a male skewed sex ratio of rats never recaptured may be that male ship rats were ranging further to increase their mating opportunities. Clark (1980) found a similar skewed sex ratio of captured ship rats; significantly fewer male ship rats than females were caught when breeding was taking place. Hooker & Innes (1995) found that the home range of male ship rats overlapped with one another and were larger than those of females. This study was carried out over December and January and several juvenile rats (<30g) were observed, indicating recent breeding. Dowding & Murphy (1994) suggested that males and females have similar sized ranges over winter, but that an increase in male range size coincides with the onset of the breeding season and probably the attempts of males to find and mate with as many females as possible.

In the kill trapping study pregnant females were first discovered in the last week of December 2004 (Chapter 2; Section 2.3) suggesting they had come into oestrous earlier that month, given that the gestation period of female ship rats is approximately 20-22 days (King, 1990). As the breeding season appears to have started in early December on

Ponui, the possible increase in male home range at this time as suggested by Dowding & Murphy (1994) possibly accounts for the low number of male recaptures.

Death and competition for traps is not incorporated into the DENSITY model so this may also be an important reason for non-recapture, although the fate of these non-recaptured rats is unknown.

As with any live trapping study the behaviour of the target species can widely affect the results and the current study is no exception. Out of the 49 individuals captured ten were recaptured five or more times, one individual (tag number 0022) was caught on 11 out of 15 possible occasions. The easily obtainable high-energy bait and minimal handling especially after the initial capture may have contributed to this "trap happy" behaviour. It has been suggested that the availability of nutritious bait, such as peanut butter, may influence foraging behaviour and meal structure of rodents (Clark, 1982). However, rats had to spend an entire night in the trap and if caught early in the night were restricted in the amount of time available to forage. It may be possible that trap baits were only taken at the end of the night but there is no evidence to support this.

3.4.3 Density

Rat density can reach much higher values on islands compared to the mainland, although data is sparse as populations removed by poisoning cannot be counted (Innes, 2005). Hickson *et al.* (1986) estimated pre-poison density of ship rats on Stewart Island as 2.0-2.5 rats ha^{-1}, which is lower than most estimates for density on islands. The density of Norway rats on Campbell Island before eradication was estimated at ten rats ha^{-1} (Taylor, 1986). An island study in the Bay of Islands also estimated a density of ten Norway rats ha^{-1} (Moller & Tilley, 1986). Several recent studies have also found high island densities of ship rats that are similar to the current study. A study on the density of ship rats on Motutapere Island (36°47'S, 175°25'E) estimated >5 rats ha^{-1} (MacKay & Russell, 2005) and a similar study on Tawhitinui Island (41°02'S, 173°48'E) also estimated ship rat density at >5 ship rats ha^{-1} (Russell & MacKay, 2005). Ship rat density can reach even higher levels on islands - on the six hectare Haulashore Island (25m off the coast of Nelson City) where food was abundant in 1991 the total

population at the time of the eradication was reckoned at between 150 and 300 rats, giving a density of 25-50 rats ha^{-1} (Innes, 2005).

As expected, the estimated density of ship rats per hectare in the study area over the three sessions was higher than most estimated densities in mainland New Zealand forests or bush fragments. Many mainland New Zealand studies have estimated lower rat densities than those on islands. A density of 2.9 ship rats ha^{-1} was estimated in spring in Puketi Forest (Northland) by Dowding & Murphy (1994). Daniel (1972) estimated the mean monthly density of ship rats in mixed forest in the Orongorongo Valley (Wellington) to be 1.7 rats ha^{-1} over 29 months. Extinction trapping in Kaharoa by Brown *et al.* (1996) - a forest remnant north of Rotorua - gave an estimated density of 4.8 ha^{-1} (Innes, 2005). The difference in estimated density between mainland sites and between mainland sites compared to Ponui Island may be partly due to a difference in latitude and forest type.

Most ship rat densities in New Zealand have been estimated by taking the number of rats caught in a study over an area described as the 'effective trapping area'. This is the area trapped plus a buffer strip to account for rats caught that may live just outside the trapping area. The buffer strip may be estimated to be half the average ship rat range diameter (Dowding & Murphy, 1994; Brown *et al.*, 1996) or half the mean distance moved between successive captures (Daniel, 1972). Home range area of male ship rats has been found to increase over months that coincide with breeding (Dowding & Murphy, 1994)) so unless the 'buffer strip' added to the trapping area is calculated monthly or seasonally, effective trapping area may be changing but not be accounted for. If density is calculated by dividing the estimated population by the effective trapping area, then density over summer may be overestimated. This is due to the 'buffer strip' being larger so the effective area will be larger. Male ship rats from outside the trapping area and buffer strip may end up being counted in the study population due to their increased movements during breeding. To adjust for this an increase in the 'buffer strip' is needed. DENSITY uses inverse prediction to estimate the 'buffer strip' from mean maximum distances moved between traps. It does this for each session so is able to account for any changes in distances moved.

Two mainland studies estimated ship rat densities similar to the current study. The first was Blackwell (2000) which estimated 8.22 rats ha^{-1} in tawa-podocarp forest at Lake Waikaremoana. The second was by Hooker & Innes (1995) and estimated the ship rat density in Rotoehu Forest (Bay of Plenty) to be 6.2 rats ha^{-1} over summer (December-January). Both estimates fall within the standard error of the density estimates from the current study. These two studies estimated higher densities of ship rats than numerous other mainland studies. There are many possible reasons for the high estimated densities. These may include the method used for estimating the density, the timing of the studies or even the density of predators at the sites.

The seasonal breeding of ship rats causes corresponding seasonal changes in density due to increased numbers from breeding, from low numbers in spring and early summer to a peak usually in autumn (Innes, 2005). It was suggested by Best (1969) that if snap trapping was to be used to control ship rat numbers in New Zealand forests then winter and early spring trapping would give the best return for trapping effort. The current study was carried out over summer. Density estimates may therefore be lower than will be reached later on in the year.

Density is also affected by predators; the absence of mammalian predators other than cats on Ponui may partly explain the higher densities estimated. There are thought to be no resident stoats on the island and in the absence of other common ship rat predators the density of ship rats is likely to be influenced mostly by feral cats (*Felis catus*). There are resident populations of morepork (*Ninox novaeseelandiae*) and harriers (*Circus approximans*) on the island that may also be responsible for some ship rat predation. However, cats have been identified as one of the major predators of rats in many New Zealand forests. A study by Karl & Best (1982) on Stewart Island found that rats were the staple diet of feral cats and were found in 93% of scats collected. Rat remains were found in 40-50% of cat scats over most seasons over a three-year study in the Orongorongo Valley near Wellington (Fitzgerald & Karl, 1979). Although feral cat diet was not examined on Ponui, rat kill traps were in an area where cats were frequently sighted (pers. obs.) and five scat groups collected in Red Stoney Hill Gully had abundant fur in them (I. Castro pers. comm.).

3.4.4 Morphometrics

In the current study the average weight and head-body length measurements of male ship rats were significantly larger than females (Table 3.3) and this is consistent with various other New Zealand ship rat studies (Innes, 1977; Innes *et al.*, 2001; MacKay & Russell, 2005). The measurements of ship rats on Motutapere Island (MacKay & Russell, 2005) were very similar to Ponui and they all fell within one standard error of the same measurements in the current study. Although trapping on Motutapere only lasted approximately two weeks and comparisons to other studies or locations are probably more useful when made at similar times of the year and take environmental differences into account.

3.4.5 Anaesthetics

Recapture rates from the current study (60%) were closer to those of Hickson *et al.* (1986) (64.6%) than those of Daniel (1972) (47%). Both the current study and that of Hickson *et al.* (1986) anaesthetised rats before measuring them. Rats were handled in a sleeve of wire and canvas without anaesthetic in the study by Daniel (1972). The use of anaesthetics may have a direct effect on the recapture of the rats due to rats associating capture with stress from manipulations performed without anaesthetic.

The combination of Xylazine 3mg/kg and Ketamine 40mg/kg injected intramuscularly provided an excellent level of anaesthesia to carry out various manipulations on ship rats in the current study. It appeared to minimise stress from handling. Ketamine is thought to induce both anaesthesia and amnesia by 'functionally disrupting the central nervous system by overstimulating it or inducing a cataleptic state' (Plumb, 1999). The possibility of inducing amnesia when carrying out live captures and mark recapture studies is a positive effect because it may help to alleviate sample bias due to trap shyness or trap happiness.

The use of injectable anaesthetics on ship rats in mark recapture studies may be safer and yield better recaptures than traditional gases (chloroform and isoflurane) delivered in an anaesthetic box or plastic bag. Five rats caught in the study by Hickson *et al.* (1986) died from an overdose of chloroform anaesthetic. No rats in the current study died from an overdose of anaesthetic. In the current study an injection of Yohimbine

allowed the anaesthetic used on ship rats to be reversed at any time. This avoided rats being anaesthetised for longer than necessary. The weight based dosing of injectable anaesthetics allows a precise dose to be delivered as opposed to general or even repeated dosing from gases. This also reduces the chance of rats regaining consciousness while being handled and further increasing handling stress.

3.4.6 Conclusion

The current study found the density of ship rats in a section of bush on Ponui Island to be similar to estimated densities of Norway and ship rats on offshore islands in several other New Zealand studies. The estimated density in the current study was higher than most densities in mainland forests and bush fragments. This may have been due to lower densities of predators such as cats on Ponui or even the time of year the study was carried out. The use of the injectable anaesthetics Ketamine and Xylazine provided an excellent level of anaesthesia that could be easily reversed and enabled various manipulations to be carried out with ease. Trap happy behaviour from several rats was one possible bias in the current study but the effect on population estimates appeared to be minimal as both software packages used looked at the capture history of individuals.

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4

Invertebrate fauna and vegetation of forest and farmland habitat on Ponui Island, New Zealand.

Abstract The invertebrate fauna of Ponui Island was examined over a nine month period using pitfall traps, soil core samples and leaf litter samples taken monthly across scrub, bush and farmland habitat. Pitfall traps revealed no overall difference in the number and taxa of invertebrates caught across bush and scrub habitat, although there were significantly more spiders and weta found in scrub habitat compared to bush habitat over winter, spring and summer months. Over this period, farmland pitfall traps showed considerably lower species diversity but greater abundances of surface invertebrates compared to scrub and bush habitats. There was also a significantly higher number of earthworms found in soil core samples in farmland habitat compared to both scrub and bush habitat. Little difference was found in the low numbers of invertebrates and taxa found in leaf litter samples from bush and scrub habitat, although there was a significantly higher percentage of ground covered in leaf litter in bush compared to scrub habitat. Vegetation sampling carried out in scrub and bush habitat based on species composition at various canopy heights showed a distinct difference between the two habitat types. Although the difference in plant species composition between the two habitats did not affect overall invertebrate species diversity and abundance, it did affect the abundance of several invertebrate taxa that were important in kiwi chick diet.

4.1 Introduction

4.1.1 Invertebrates

The decline of native insect species in New Zealand appears to stem from the influence of humans; these include loss of habitat and the introduction of exotic vertebrates and invertebrates which may be competitors, predators or parasites (Ramsay, 1988). Invertebrates are found at all trophic levels and are important in nutrient cycling and the decomposition of dead animals and plants; they're also important prey in the forest ecosystem (Moeed & Meads, 1987a). For many species of native birds in New Zealand, invertebrates make up a large percentage of their diet.

Most of the estimated 20,000 or more species of insects in New Zealand are found only in native bush habitats and as native bush habitats have diminished, so have the insects (Walker, 2000). In addition, the decrease in the number and types of invertebrates is also attributed to increases in the number of introduced animals that prey upon them (Craig *et al.*, 2000). The introduction of rats (*Rattus rattus, R. norvegicus* and *R. exulans*) and mice (*Mus musculus* and *M. familiaris*) is credited as a major factor in the decline of many native invertebrate species. Like many of New Zealand's native birds some species of native insects are extremely rare and are restricted to offshore island refuges (Walker, 2000); these islands are usually rodent free (Ramsay, 1988).

The few large invertebrates that still survive on islands with rats may have modified behaviours which allow them to coexist with predators (Moeed & Meads, 1987b). For instance, on islands with no rats but mice, Moeed & Meads (1987b) found that ground weta (*Hemideina similis*) and tree weta (*H. crassidens*) moved about freely at night and were hardly alarmed by the presence of an observer. This was in contrast to islands where Pacific (*R. exulans*) and Norway rats (*R. norvegicus*) were present, here weta did not forage far from their burrows and took refuge when even slightly disturbed (Moeed & Meads, 1987b).

The presence of predators is not the only factor affecting presence and diversity of invertebrates in New Zealand. Habitat diversity was also found to be important in the

survival of larger invertebrates in the presence of mammalian predators (Moeed & Meads, 1987b). In addition, the seasonal fluctuations of invertebrates and their lifecycles are usually dependent on factors such as temperature, humidity and available food. Lower numbers of earthworms and amphipods were found in the forest litter and topsoil on Red Mercury Island (36°37'S, 175°55'E), when compared to Kapiti Island (40°51'S, 174°55'E) during similar sampling periods (Moeed & Meads, 1987c). The dry conditions on Red Mercury Island are thought to be one of several factors responsible for the differences in the invertebrate fauna between these two sites. In a study of pitfall trapped invertebrates in the Orongorongo Valley, Moeed & Meads (1985) found that the temporal distribution of several species was positively correlated with temperature.

4.1.2 Vegetation

The arrival of humans in New Zealand not only signalled the endangerment of many native birds and insects, but the clearing of land for agriculture and housing meant that many forest habitats were greatly modified or even destroyed (Craig *et al.*, 2000). The current study site, Ponui Island, is an example of a habitat that has had its flora modified from logging and farming. Areas surrounding the trig on the southern end of Ponui were logged for mature Kauri (*Agathis australis*) in the early 1900s although small stands of Kauri still remain. Ponui is 1770 hectares in size and just under a third of the island remains forested (Miles & Castro, 2000). Many of the ridges in the main stand of remaining bush on the southern end of the island were burnt off to graze cattle; as a result these ridges are made up of regenerating scrub. Grazed pastureland borders the large stand of remaining bush in the main study site (Plate 4.1); the absence of fencing has allowed cattle to access the bush for shade, water and to browse. Several effects of cattle movement and browsing in the Ponui bush are that the understorey is very open and soil has been compacted in areas (D. Chamberlin, pers. comm.). There has also possibly been a loss of palatable species of plants in the browse layer as has been the case in many other New Zealand forests (Wardle *et al.*, 2001).

The combined effects of cattle browsing and logging have meant that diversity of flora in the forested area on Ponui Island is limited. Brown (1979) described the diversity of

native flora of Ponui Island as small and unvaried and the diversity of flora of similar sized (Great Mercury Island and Kapiti Island) and even much smaller islands (Tiritiri Matangi) as being larger by up to 30%. The flora of Ponui appears to be highly modified with a low level of plant species diversity. This low level of diversity will possibly be compounded by the effects of rodents on the island in modifying the remaining invertebrate and plant life. The number and species composition of invertebrate fauna can be linked to the habitat type and specifically the vegetation type. The diversity and abundance of certain invertebrate taxa depends, to some extent, on the amount of litter on the forest floor (Moeed & Meads, 1987b).

4.1.3 Study aims

The primary aim of this chapter was to quantify surface, soil and leaf litter dwelling invertebrates in bush, scrub and farmland over different seasons on Ponui Island (36°50'S, 175°10'E). The presence of these invertebrates provided an indication of environmental abundance from which the diets of ship rats and kiwi chicks inhabiting the same habitat could be compared to. The other aims were to describe habitat type based on vegetation analysis and use these characteristics to examine any differences in invertebrate fauna.

4.2 Methods

The pitfall and leaf litter invertebrate sampling methodology used in the current study was similar to that carried out by Moeed & Meads (1985, 1986 and 1987a). The main difference in leaf litter sampling in the current study was that samples were sorted in a tray and invertebrates removed, this is in contrast to Moeed & Meads (1986) where Tullgren funnels were used to extract invertebrates from samples. Soil core sampling methodology was similar to that used in a study of the diet of little spotted kiwi on Kapiti Island (Colbourne *et al.*, 1990), the differences were that there were more cores taken and more areas sampled in the current study.

4.2.1 Pitfall traps

In the third week of June 2004, 125 pitfall traps were dug at 25 sites with five pitfall traps at each site. The 25 sites were set up across three different habitat types; scrub, bush and farmland pasture. The number of pitfall sites was determined based on available sampling time and the size of the study site. The proportion that each habitat type made up of the study site was determined using a high quality aerial map and confirmed on site by identifying individual trees, the numbers of pitfall trap sites were assigned accordingly. Ten pitfall sites were assigned to each of scrub and bush habitat and five sites to farmland pasture. Location of pitfall sites in each habitat type was decided by using randomly selected points on a grid map within the main study site (Plate 4.1). At each site five pitfall traps were placed in a square pattern with one pitfall trap at each corner and one in the middle; the corner traps were spaced 15m apart giving a total site area of 225m^2. The total area of the pitfall trap sites occupied approximately 0.5% of the total area of the study site (100 ha), this is taking into consideration that swamp habitat was not sampled. Ponui swamps are very deep and pitfall traps could not be established there.

Pitfall traps consisted of a 20cm deep circular hole with an approximately 8cm diameter. Each hole contained a 20cm pipe set flush with the ground surface. Each trap had a 200ml plastic cup containing 20ml of antifreeze (ethyl glycol) inside, the sides of the cup touched the inside of the pipe with no gap between them and the top of each cup was approximately 8cm below ground level. Traps were covered with a metal lid

(30cm x 30cm) 2-3cm above the ground to limit the amount of plant material and water entering the cup. Each trap was cleared and reset (antifreeze reused when possible) approximately every 30-35 days from June 2004 to February 2005. The contents of individual cups were sieved and placed into a specimen jar with 70% ethanol for storage and identification.

The pitfall trap contents were later sorted using an Olympus sz40 microscope at 6.7x magnification and invertebrates were identified to their Order and in many cases to Family using several invertebrate identification references (McColl, 1981; Grant, 1999 and Walker, 2000). Any invertebrates that I could not reliably identify were identified by Rogan Colbourne at the Department of Conservation, Wellington, New Zealand. Only invertebrates > 8 mm were considered as these were found to be the minimum size taken by little spotted kiwi (Colbourne *et al.*, 1990). Invertebrates were placed into small glass vials with 70% ethanol to create a reference collection for invertebrate identification from core and litter samples. Whole specimens were also used to create a reference collection to compare and identify partial remains of invertebrates from rodent stomach samples and kiwi faecal samples. For the analyses the invertebrates found in pitfall traps were grouped by months to represent seasons winter (June-August), spring (September-November) and summer (December-February).

4.2.2 Soil core samples

Two core samples were taken from soil in habitat adjacent to each of the 25 pitfall sites (Plate 4.1); this took place approximately every 30-35 days and the cores were taken between 30 minutes after dark and midnight. The collection of cores at night was necessary to sample invertebrates relevant to the diet of kiwi chicks and ship rats. Each core was taken with a steel corer 20cm x 20cm x 20cm. The corer was driven into the ground by foot and the soil immediately transferred to a bucket, the soil was broken up by hand and then sieved to find and identify invertebrates. Over summer months the soil was increasingly dry and on several occasions the steel corer only partially penetrated the soil and soil had to be extracted with a small spade. All invertebrates were identified, recorded and released; unknowns were put in glass vials containing 70% ethanol for identification using pitfall trap invertebrate identification references.

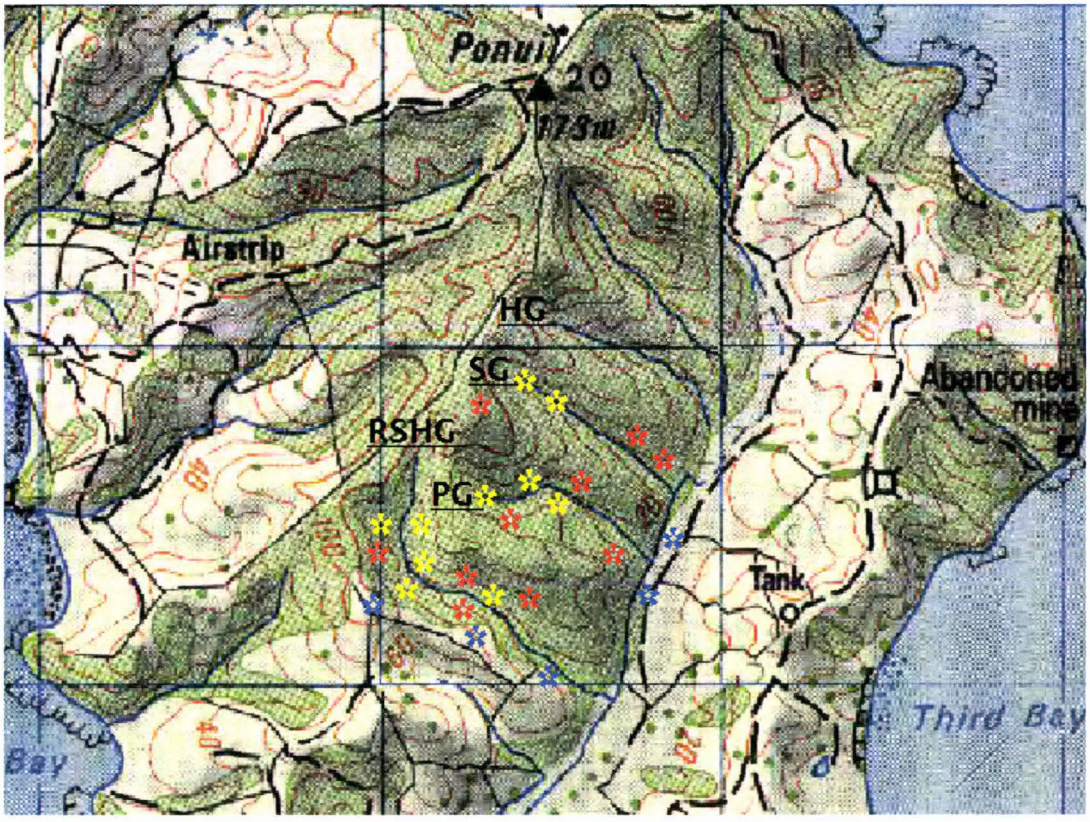

Plate 4.1 Map of the location of pitfall sites within the study site (Massey Image Webserver, 2003). * = scrub habitat, * = bush habitat, * = farmland habitat.

4.2.3 Leaf litter samples

One leaf litter sample was taken in habitat adjacent to each of the 20 pitfall sites in bush and scrub habitat (Plate 4.1) approximately every 30-35 days and was collected between 30 minutes after dark and midnight. Each sample was selected randomly by throwing a wooden square (30cm x 30cm) over my shoulder onto the ground and collecting the leaf litter from that spot. Leaf litter consisted of all material on the surface down to the soil level; each sample was collected using a small garden spade and placed in a zip lock plastic bag for sorting and identification. Contents were emptied in a sorting tray with an overhead lamp several hours later; individual invertebrates were collected and identified to Family level using the invertebrate key created from pitfall trapping. As litter samples were sorted several hours after collection there is the possibility that predatory invertebrates may have reduced the other invertebrates in the sample before they were sorted.

4.2.4 Vegetation analysis - Recce Plots

Vegetation analysis, in the form of Reconnaissance (Recce) plots, was carried out at the same ten bush and ten scrub sites used for pitfall trapping (Plate 4.1). Recce plots are used to describe vegetation in a set area and were a modified version of those set out by Allen (1992). Plots were carried out on 15m x 15m grids, analysis involved assessing five height categories for plants and recording the plant species in each category; <30cm, 30cm-2m, 2-5m, 5-12m, 12-25m and >25m. Analysis also involved estimating the percentage of ground cover within each grid; this included leaf litter, moss, bare ground, vascular vegetation and rock. The category of interest and the only one reported in the current study was the percentage of ground covered in leaf litter. The species composition of plants and the percentage of ground covered in leaf litter at each site allowed an overview of differences in vegetation, with relevance to invertebrate fauna, between sites.

4.2.5 Statistical manipulations

Multivariate statistical analysis was performed using Primer v5.2.9 (Clark & Gorley, 2002). An ANOSIM (Analysis of similarities) test was used to analyse differences in types of invertebrate taxa caught in pitfall traps over bush and scrub. ANOSIM tests are described by Clark & Gorley (2001) as a rough analogue of the standard univariate 1- and 2-way ANOVA tests; the test used allows a statistical test (1-way layout) of the null hypothesis for which there is no assemblage differences between groups of samples specified *a priori*. ANOSIM tests give a 'Global R' value and a significance level. The R statistic is a comparative measure of the degree of separation of sites. R values close to zero indicates similarities between and within sites are on average the same, a value close to one indicates all replicates in a site are more similar to each other than those from other sites Clark & Gorley (2001).

It is possible for significant R values to have little biological significance due to the high statistical sensitivity of the analysis resulting from very large numbers of replicates.

A non-metric multidimensional scale (nMDS) plot was produced in Primer to illustrate any differences in the types of invertebrate taxa between bush and scrub habitat. nMDS represents non-metric relationships between multiple variables in two or three dimensions. As the plot was non-metric it contained no x or y axis. The nMDS plot also included a stress value which indicated the accuracy with which the plot represented the actual relationship of individual data points. Stress values for nMDS plots can range from 0.0 (perfect map) to 0.3 (low accuracy). A cluster analysis was also produced in Primer and illustrated differences in plant species composition in bush and scrub habitat. This was done by recording the number of height tiers that each plant species was recorded in, within each sampling site, from the Recce plot vegetation analysis and then comparing habitat types.

Univariate statistical tests were carried out in the software package SPSS (2001); these included a one-way analysis of variance (ANOVA). Bush and scrub pitfalls were combined to give an overall view of forest pitfalls; this was due to there being no overall significant difference in invertebrate taxa between the two habitats in respect to numbers of invertebrates caught in pitfall traps.

Separate one-way ANOVA's were used to test whether numbers of weta, earthworms, spiders and amphipods differed between bush and scrub habitat over winter, spring and summer. One-way ANOVA's were carried out on forest pitfall data to test whether numbers of weta, cockroaches and diptera differed between summer and spring and whether numbers of earthworms and scarabaeid beetles differed between winter and spring. A one-way ANOVA was used to test any differences between numbers of earthworms found in soil core samples on farmland and forest habitat over winter, spring and summer. The percentage of ground covered in leaf litter in bush and scrub habitat was also compared using a one-way ANOVA.

4.3 Results

4.3.1 Pitfall traps in bush and scrub habitat

I found no overall difference between the number and type of invertebrates caught in pitfall traps in bush and scrub habitat (one-way ANOSIM; Global R = 0.088; $P < 0.001$).

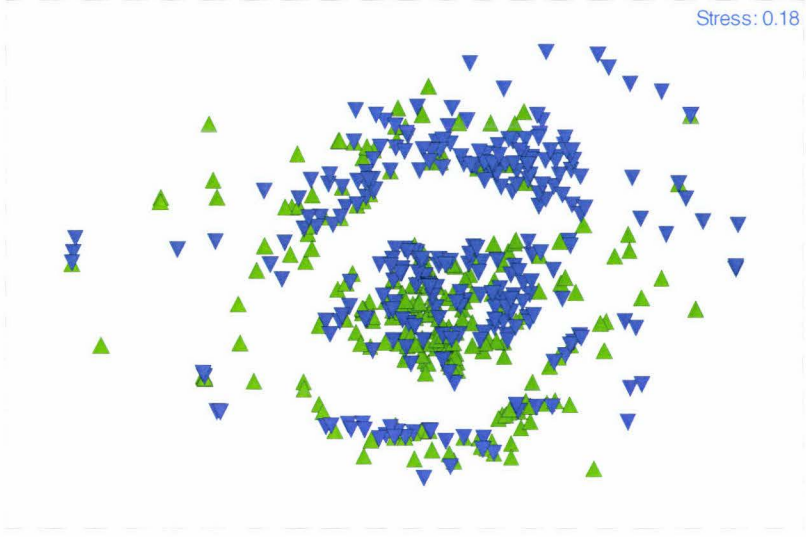

Figure 4.1 Non-metric multidimensional scaling of all invertebrates caught in pitfall traps from bush and scrub habitat; bush = ▲ , scrub = ▼ .

Although there was no difference in the overall number and type of invertebrate taxa caught in pitfall traps between bush and scrub habitat, there were significant differences in the numbers of several individual taxa. There were significantly more weta caught in pitfall traps in scrub habitat than in bush over winter (one-way ANOVA; $F_{1, 280} = 9.06$; $P < 0.05$), spring (one-way ANOVA; $F_{1, 295} = 40.10$; $P < 0.001$) and summer months (one-way ANOVA; $F_{1, 274} = 41.19$; $P < 0.001$) (Appendix 4.1). There were also significantly more spiders caught in scrub habitat than bush over winter (one-way ANOVA; $F_{1, 280} = 3.69$; $P < 0.05$), spring (one-way ANOVA; $F_{1, 295} = 10.72$; $P < 0.05$) and summer (one-way ANOVA; $F_{1, 274} = 7.49$; $P < 0.05$) (Appendix 4.1). Finally the number of amphipods in bush habitat was significantly higher than in scrub habitat over spring (one-way ANOVA; $F_{1, 295} = 10.55$; $P < 0.05$) and over summer months (one-way ANOVA; $F_{1, 274} = 21.60$; $P < 0.001$) (Appendix 4.1).

As there was no overall difference in the type and number of taxa found in pitfall traps between bush and scrub habitat both habitat types were combined to analyse the effect of season, the combined habitat types are referred to as *forest habitat*. Numbers of invertebrates in pitfall traps, soil core and leaf litter samples are given for scrub and bush habitat types (Appendix 4.1, 4.2 and 4.3) but graphed as combined forest habitat (Figure 4.2, 4.4 and 4.5).

Pitfall data for forest habitat revealed several invertebrate taxa that had a significant seasonal fluctuation in their numbers (Figure 4.2). One of the most noticeable changes in forest pitfall data was a significant increase in the number of weta from spring to summer months (one-way ANOVA; $F_{1,\ 571} = 31.20$; $P < 0.001$). There were significantly more diptera and cockroaches over summer than spring (one-way ANOVA; $F_{1,\ 571} = 25.81$; $P < 0.001$; one-way ANOVA; $F_{1,\ 571} = 26.70$; $P < 0.001$ respectively). There was a significant drop in the number of earthworms caught from winter to spring (one-way ANOVA; $F_{1,\ 577} = 10.55$; $P < 0.05$). No scarabaeid beetles were caught over the winter and spring months in forest pitfall traps and so the numbers caught in summer were significantly higher (one-way ANOVA; $F_{1,\ 571} = 58.08$; $P < 0.001$).

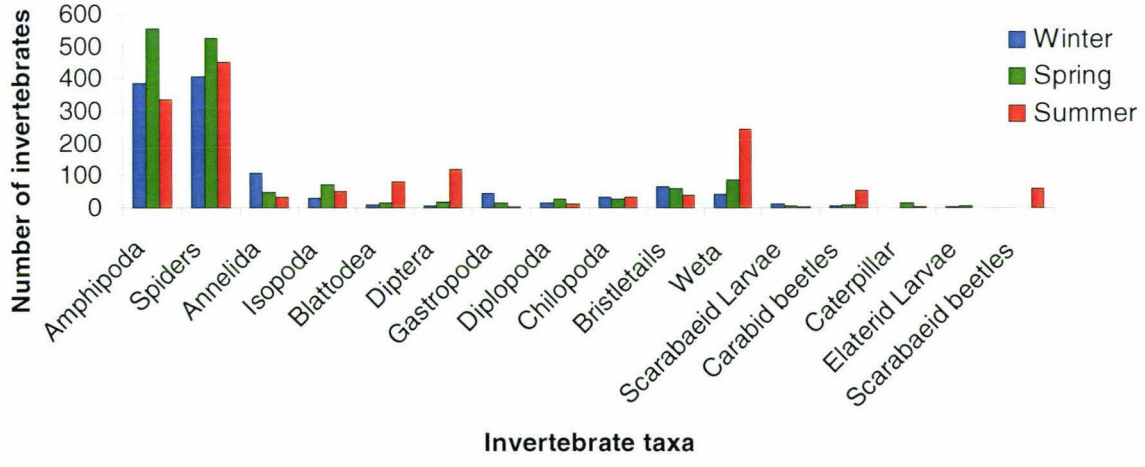

Figure 4.2 The number of invertebrates caught in pitfall traps in forest habitat on Ponui Island from winter 2004 to summer 2004/2005.

4.3.2 *Pitfall traps in farmland habitat*

There were nine different invertebrate taxa found in pitfall traps on farmland habitat on Ponui Island compared to 16 different taxa found in forest habitat (Appendix 4.1). There were significantly fewer earthworms caught in pitfall traps on farmland habitat over summer compared to spring months (one-way ANOVA; $F_{1, 147} = 83.07$; $P < 0.001$) (Figure 4.3).

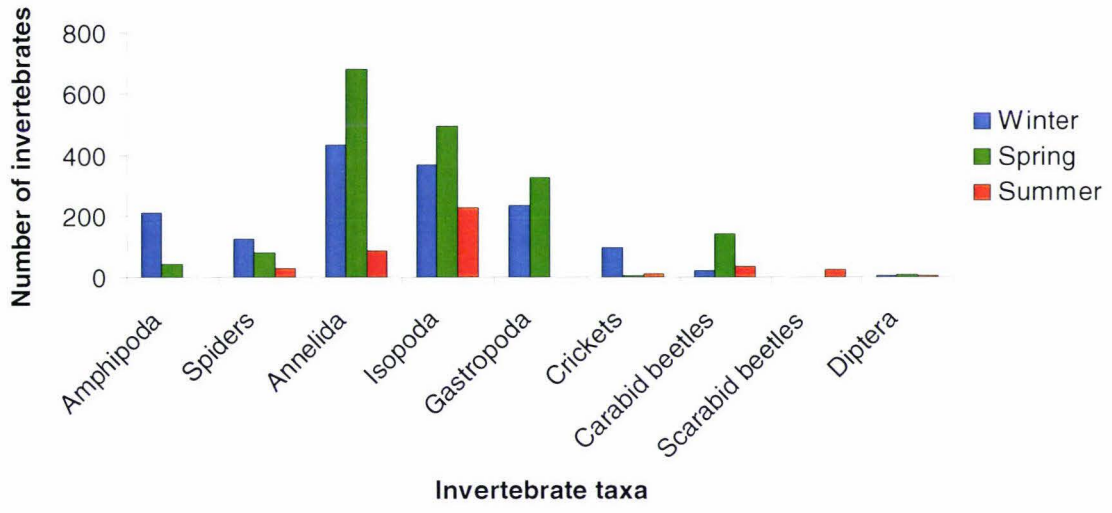

Figure 4.3 The number of invertebrates caught seasonally in pitfall traps collected over farmland habitat from winter 2004 to summer 2004/2005.

4.3.3 *Soil core samples from forest and farmland habitat*

The only invertebrate taxa consistently found in soil core samples from forest habitat sites were earthworms (Figure 4.4), there were significantly more earthworms in bush habitat than scrub habitat over summer (one-way ANOVA; $F_{1, 59} = 10.33$; $P < 0.05$). There was a progressive decline in the number of earthworms found in forest habitat from winter months to spring and summer months. Soil core samples taken from farmland habitat showed a large peak in the number of earthworms found in winter with a decrease in numbers over spring and significantly fewer earthworms found in summer compared to spring (one-way ANOVA; $F_{1, 25} = 17.75$; $P < 0.001$) (Appendix 4.2). There were significantly more earthworms found on farmland compared to forest habitat over winter (one-way ANOVA; $F_{1, 73} = 30.75$; $P < 0.001$), spring (one-way ANOVA; $F_{1, 73} =$

62.97; $P < 0.001$) and summer months (one-way ANOVA; $F_{1, 73} = 12.23$; $P < 0.05$). The only other invertebrates found in farmland core samples were elaterid larvae, amphipods, scarabaeid larvae and chilopods; although, these were found in less than one invertebrate per 30 core samples taken each season (Appendix 4.2).

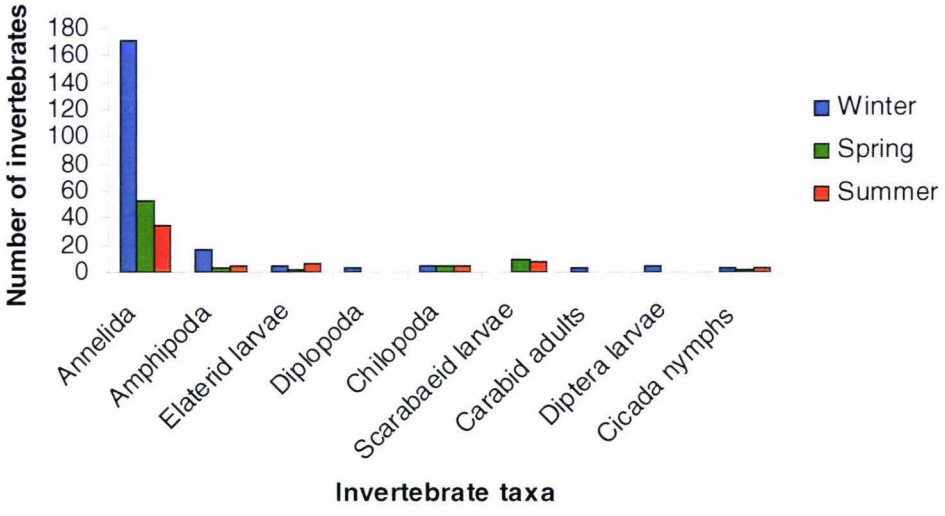

Figure 4.4 The number of invertebrates found seasonally in soil core samples in forest habitat on Ponui Island from winter 2004 to summer 2004/2005.

4.3.4 Leaf litter samples

The low numbers of invertebrates found in leaf litter samples from forest habitat (Figure 4.5) was a reflection of the low numbers found in both bush and scrub habitat (Appendix 4.3). The most noticeable difference in numbers of invertebrates found between scrub and bush habitat was the amphipods and spiders, which both had higher numbers in leaf litter samples from bush habitat. For spiders this is in contrast to the significantly higher numbers found in pitfall traps in scrub habitat compared to bush.

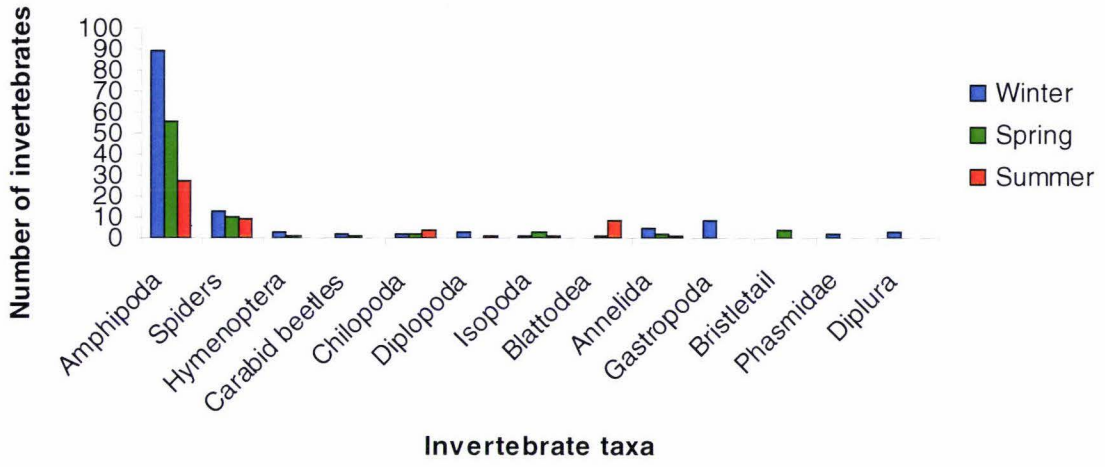

Figure 4.5 The number of invertebrates found in leaf litter samples in forest habitat on Ponui Island from winter 2004 to summer 2004/2005.

4.3.5 Vegetation

The four gullies in the study site had a similar topography, from swamp bordering on farmland and then to broadleaf forest in the gullies with scrub habitat on the surrounding ridges, with a small stream running along the base of each gully to the swamp at the bottom. As bush and scrub habitat sites were decided prior to the vegetation analysis it was necessary to compare habitat composition from vegetation analysis data to check the validity of this separation (Figure 4.6.)

Bush habitat consisted mainly of broadleaf canopy species including Taraire (*Beilschmiedia tarairi*), Pohutukawa (*Metrosideros excelsa*), Kanuka (*Leptospermum ericoides),* Puriri (*Vitex lucens*) and Kauri (*Agathis australis*). The average canopy height was 23.00m ± 4.99m (S.D.) and included numerous epiphytes (*Collospermum hastatum*). There was on average higher plant species diversity in bush habitat compared to scrub habitat in the four top height tiers but not the lowest tier (30cm-2m) (Figure 4.7). There was a significantly higher percentage of ground covered in leaf litter in bush compared to scrub habitat (one-way ANOVA; $F_{1, 18} = 17.53$; $P < 0.05$) (Figure 4.8). This is mainly due to the numerous Taraire, Kauri and Puriri in bush habitat. Kauri were logged from the bush in the early 1900's (Brown, 1979) and the result was that the remaining canopy was made up of the smaller Kauri not taken during these operations

and several broadleaf species that were not targeted. Cattle have had access to the bush and the understorey is open and sparse from browsing and trampling (pers. obs.).

The scrub canopy height averaged 14.70m ± 3.50m (S.D.) and mainly consisted of Coprosma (*C. grandifolia, C. lucida, C. arborea*), Kanuka (*Leptospermum ericoides)*, and Lancewood (*Pseudopanax crassifolius*). Mingimingi (*Cyathodes fasciculata*) and Rewarewa (*Knightia excelsa*) were also abundant at lower levels. Scrub habitat was generally found on the sides and tops of ridges that were steep and contained lower plant species diversity compared to bush habitat (Figure 4.7). The ridge tops were burnt off in the early 1900's to graze cattle (P. Chamberlin, pers. comm.) and scrub is still regenerating, resulting in a low canopy and low species diversity compared to bush habitat in the top four height tiers. There were very few broadleaf plant species in scrub; this may have contributed to a significantly lower average percentage of ground covered in leaf litter (Figure 4.8).

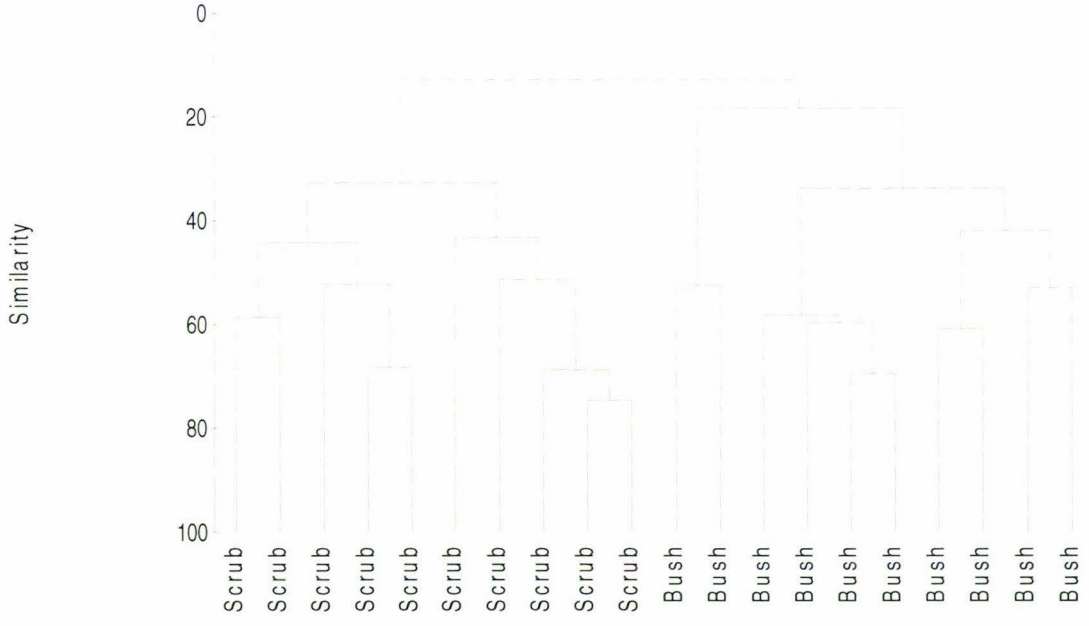

Figure 4.6 Cluster analysis of the number of height tiers each plant species was present at for scrub and bush habitat, with ten vegetation sampling sites for each habitat.

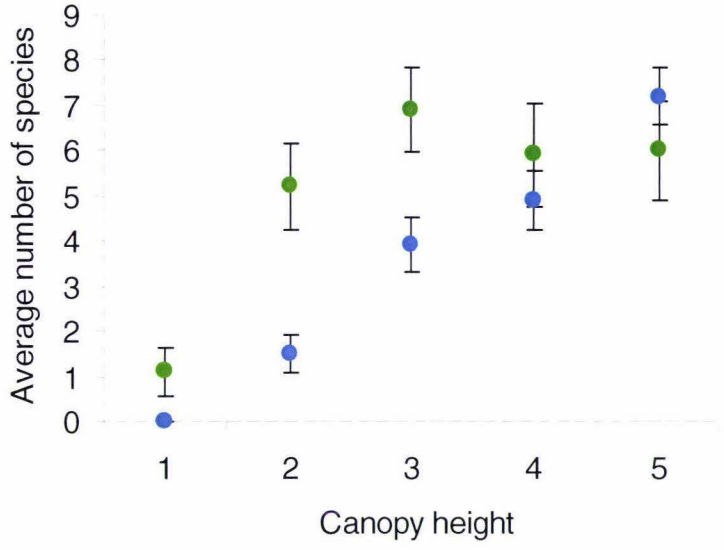

Figure 4.7 The average number (± S.E.) of plant species at five height tiers in ten bush and ten scrub habitat sites. Bush = ●, scrub = ● . Height tiers were; 1 = 25m+, 2 = 12-25m, 3 = 5-12m, 4 = 2-5m, 5 = 30cm-2m.

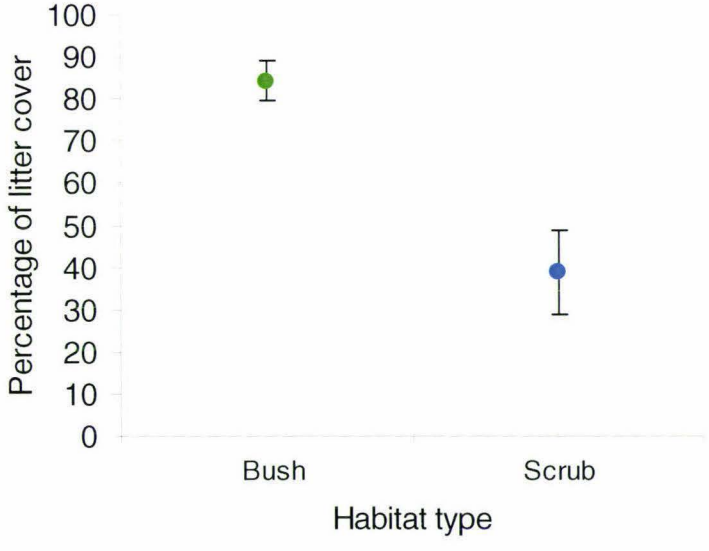

Figure 4.8 Average percentage (± S.E.) of ground covered in leaf litter as determined from the vegetation analysis (Recce plots) of ten bush and ten scrub habitat sites.

4.4 Discussion

Invertebrates on Ponui Island showed seasonal fluctuations in numbers across all three habitat types and for the three different sampling techniques used. Although there was no significant overall difference in the number and type of invertebrate taxa found in bush and scrub habitat, it is important to note that several taxa were found in significantly higher numbers in bush compared to scrub habitat and vice versa.

4.4.1 Pitfall traps

The peak in weta numbers in forest habitat over summer could have been due to breeding, increasing food availability or a decrease in predator numbers. A study by Moeed & Meads (1985) in the Orongorongo Valley, New Zealand, found that the number of weta caught in pitfall traps was higher over the summer and autumn than other months due to large numbers of juveniles. This supports the idea of breeding as being one possible reason for the increase in numbers of weta in forest habitat over summer on Ponui. Juveniles were found in the current study (pers. obs.), although their numbers were not recorded.

The two most numerous invertebrate taxa found in pitfall traps in forest habitat on Ponui were the amphipods and spiders. Amphipods are found in large numbers in damp forest humus and litter, especially under broadleaf species. They are thought to be preyed on by spiders, centipedes, beetles and some birds (McColl, 1981). The higher number of amphipods recovered from the bush pitfall traps were most probably the result of the higher percent of leaf litter cover.

In forest habitat the numbers of earthworms caught in pitfall traps was highest over winter. Winter rain may have forced earthworms to the soil surface at which point they could be caught in pitfall traps. The decline in numbers caught in spring and summer is probably due to a decrease in rain and soil moisture causing earthworms to retreat to lower soil levels.

The absence of scarabaeid beetles (Chafer beetles) from pitfall traps in spring and winter is probably a reflection of their life cycle. This is described by Walker (2000) as larvae living and feeding in the soil and then moving closer to the soil surface to emerge in summer and take flight. Walker (2000) describes the emergence of scarabaeid beetles *en masse* from the ground in New Zealand forests in early summer. Scarabaeid beetles usually become airborne at dusk, but return to the soil to lay eggs (Colbourne *et al.*, 1990). Higher catch rates of beetles were recorded by Moeed & Meads (1985) over warmer months. They suggested that the correlation is probably due to beetles breeding seasons coinciding with warmer temperature. On Ponui, low numbers of larvae were found in pitfall traps in all three seasons and these low numbers may be due to them only surfacing after periods of heavy rain.

4.4.2 Core samples

The only invertebrates found in substantial numbers in core samples in forest and farmland habitats were earthworms. The major decrease in the number of earthworms found in core samples in forest and farmland habitat from winter to spring and summer months was possibly due to a decrease in soil moisture over warmer spring and summer months. The findings of Colbourne & Kleinpaste (1983) support this idea; they found earthworms in Northland forests declined in soil core samples over the summer months due to their retreat to lower moister soil levels.

The low numbers of invertebrates found in soil core samples compared to kiwi chick faecal samples was probably due to the random nature of the sampling process I used, sampling was undertaken with no foresight as to where soil dwelling invertebrates were most numerous. Kiwi locate soil dwelling prey using scent, noise and vibrations (Wenzel 1968) so they are sampling soil invertebrates in a biased way compared to the method I used. So the random nature of core sampling may have caused the abundance of these invertebrates to be underestimated but only in comparison to kiwi sampling.

4.4.3 Leaf litter samples

The low number of invertebrates found in the leaf litter in forest habitat is similar to core samples taken from the same habitat. The higher number of amphipods and spiders in leaf litter samples from bush habitat over the three seasons compared to scrub habitat was possibly due to the significantly higher percentage of ground covered in leaf litter in bush habitat. The soil surface in scrub habitat was often bare and this limited the number of litter dwelling invertebrates that occurred and could possibly be collected. The collection of leaf litter at each site was only in a small area and it's possible that litter dwelling invertebrates were disturbed and moved away prior to collection. The numbers and types of invertebrate taxa caught in pitfall traps were a much more comprehensive representation of surface and litter dwelling invertebrates than leaf litter samples. Litter samples were merely a snap shot of invertebrates found in a small area compared to the monthly activity that pitfall traps monitored. Despite this, leaf litter samples provided an idea of what invertebrate taxa were present in forest habitat at a time relevant to kiwi chick feeding.

One possible bias to the method of collecting leaf litter dwelling invertebrates in the current study and a reason for the low number of invertebrates found, is the possibility that larger predatory invertebrates may have preyed upon smaller invertebrates before samples were sorted. Although there is no evidence of this occurring in the current study, any leaf litter sampling in future should be sorted immediately after collection to rule out this possible source of bias.

4.4.4 Vegetation

Despite no overall significant difference in numbers and types of invertebrate taxa between bush and scrub habitat, the various differences in vegetation composition and habitat characteristics made the two habitats easily distinguishable. The steep sides to the ridges and few broadleaf species of plants in the scrub habitat meant that the amount of leaf litter was very scarce and the soil very dry. This was illustrated by the difficulty experienced in extracting soil core samples over summer and the low number of

invertebrates found in core samples over summer months. The large broadleaf species present in the bush habitat were thought to contribute to the significantly higher percentage of leaf litter in bush compared to scrub. This was in turn thought to have contributed to the significantly higher number of litter dwelling amphipods in bush habitat compared to scrub over spring and summer months.

The differences in plant species composition, average canopy height and the average percentage of leaf litter cover between bush and scrub habitats, is thought to have contributed to a significant difference in the number of several taxa between the two habitats. Despite habitat having little effect on the overall number and type of invertebrate taxa found, the significant difference in the numbers of spiders and weta in regards to habitat type is important. Although this is only two taxa out of the 16 that were found in forest pitfall traps, the relevance of this study is to kiwi chick and ship rat diet. Both spiders and weta were found to be relatively common in kiwi chick (Chapter 1; Table 1.2) and ship rat (Chapter 2; Figure 2.2a) diet in the current study. So habitat did have an important effect on invertebrate numbers with relevance to kiwi chick and ship rat diet.

The higher average number of plant species, in the lowest height tier, in scrub compared to bush habitat was probably due to the effect of browsing by cattle in bush. Cattle were not restricted to bush habitat but most of the established tracks and year round sources of water were in bush habitat. It's also possible that the slightly higher plant species diversity at the lowest height tier in scrub compared to bush influenced the significantly higher number of weta found in scrub also. Scrub habitat may have provided a more diverse source of vegetation and potential refuges closer to the ground for weta to feed on and shelter under. The effects of farming and land clearance have influenced the habitat composition and in turn the invertebrate fauna of the scrub and bush habitat on the southern end of Ponui Island.

Although the separation of forested areas into bush and scrub habitat was done before vegetation sampling took place, it appears to have been justified by the cluster analysis and the differences in species diversity in the five height tiers.

4.4.5 Conclusion

The plant species diversity in scrub and bush habitat differed noticeably and the two habitats differed significantly in terms of the percentage of leaf litter cover. This did not affect the overall number and type of invertebrate taxa present in the two habitats. Despite this there were important differences between the two habitats in terms of the numbers of several invertebrate taxa. As both spiders and weta have been shown to be important components of kiwi chick diet then the significant difference in their abundance based on habitat type is of great importance. The significantly higher percentage of ground covered in leaf litter in bush habitat was also important in terms of the significantly higher number of litter dwelling amphipods found there.

4.5 References

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Appendix 4.1 Invertebrate taxa caught in pitfall traps in bush, scrub and farmland habitat. Winter = June, July and August; Spring = September, October and November; Summer = December, January and February.

	Winter			Spring			Summer		
	Bush	Scrub	Farm	Bush	Scrub	Farm	Bush	Scrub	Farm
Amphipoda	219	166	211	335	221	42	225	112	0
Spiders	173	234	125	203	322	80	178	274	29
Annelida	28	78	433	27	22	681	23	9	86
Isopoda	5	26	369	11	60	495	26	24	226
Cockroach	2	6	0	10	6	0	28	51	0
Diptera	2	5	4	11	6	8	86	32	2
Gastropoda	31	15	235	9	6	327	3	1	0
Diplopoda	7	8	0	6	21	0	1	12	0
Chilopoda	21	11	0	5	21	0	9	23	0
Bristletail	5	34	0	8	72	0	35	188	0
Weta	5	36	95	8	79	5	38	207	12
Scarabaeid larvae	9	4	0	1	6	0	1	1	0
Scarabaeid beetles	0	0	20	0	0	140	23	36	34
Carabid beetles	5	1	0	2	7	0	41	11	23
Caterpillar	1	0	0	15	1	0	3	1	0
Elaterid larvae	1	2	0	2	3	0	1	0	0

Appendix 4.2 Invertebrate taxa found in soil core samples taken from bush, scrub and farmland habitat. Winter = June, July and August; Spring = September, October and November; Summer = December, January and February.

	Winter			Spring			Summer		
	Bush	Scrub	Farm	Bush	Scrub	Farm	Bush	Scrub	Farm
Annelida	64	107	189	36	17	157	27	7	31
Amphipoda	12	4	1	3	0	0	5	0	1
Elaterid larvae	0	5	1	2	0	1	5	1	0
Diplopoda	3	0	0	0	0	0	0	0	0
Chilopoda	3	2	1	4	0	1	2	2	0
Scarabaeid larvae	0	0	0	9	0	0	5	2	1
Carabid beetles	3	0	0	0	0	0	0	0	0
Diptera larvae	2	2	0	0	0	0	0	0	0
Cicada nymphs	1	2	0	0	1	0	3	0	0

Appendix 4.3 Invertebrate taxa found in leaf litter samples in bush and scrub habitat. Winter = June, July and August; Spring = September, October and November; Summer = December, January and February.

	Winter		Spring		Summer	
	Bush	Scrub	Bush	Scrub	Bush	Scrub
Amphipoda	57	32	37	18	20	7
Spiders	7	6	10	0	8	1
Hymenoptera	2	1	1	0	0	0
Annelida	0	5	1	1	1	0
Isopoda	1	0	0	3	1	0
Blattodea	0	0	1	0	3	5
Gastropoda	6	2	0	0	0	0
Diplopoda	2	1	0	0	1	0
Chilopoda	2	0	1	1	1	3
Bristletail	0	0	2	2	0	0
Carabid beetles	0	2	1	0	0	0
Phasmidae	0	2	0	0	0	0
Diplura	2	1	0	0	0	0

5

Potential competition between North Island brown kiwi chicks (*Apteryx mantelli*) and ship rats (*Rattus rattus*).

Abstract The potential for competition between North Island brown kiwi chicks and ship rats was investigated by comparing diets of the two sympatric species. Diet was assessed from kiwi chick faecal samples and ship rat stomach samples over four months on Ponui Island. Kiwi chicks were found to have a large soil dwelling larvae component to their diet, which was absent from the diet of ship rats. Both species did however prey upon surface dwelling invertebrates including weta, spiders and scarabaeid beetles. The diet of both species closely followed environmental abundance and availability of invertebrates as measured by pitfall trapping, soil core and leaf litter samples. Competition for surface dwelling invertebrates became more likely when the number of soil dwelling larvae found in kiwi chick diet declined due to a decrease in their availability and accessibility as a result of increased soil density over summer months. Several recommendations are made regarding directions for further research and for choices of crèche sites for Operation Nest Egg.

5.1 Introduction

New Zealand's recent ecological history is dominated by the introduction of terrestrial mammals for purposes as diverse as establishing a fur trade (Possums, *Trichosurus vulpecula*) to biological control of other introduced mammals (stoats *Mustela erminea* to control rabbits *Oryctolagus cuniculus cuniculus*) (King, 1990). New Zealand's native terrestrial biota evolved in the absence of mammalian predators, many species of native birds are flightless or lack the appropriate behavioural defences to deal with the rapid expansion of mammalian species that accompanied the arrival and establishment of humans in New Zealand.

Many of the introductions were of domesticated mammals that escaped and established feral populations. In contrast, some mammals arrived in New Zealand accidentally. Rodents are notorious for following man to new and previously rodent free islands and habitats and New Zealand was no exception. The introduction of four species from the family Muridae included mice (*Mus musculus* and *M. domesticus*), ship (*R. rattus*) and Norway rats (*Rattus norvegicus*) by the Europeans in the late 18th and early 19th century and Pacific rats (*R. exulans*) by the Polynesians about 1000-1200 years ago (Atkinson, 1973; King, 1990). Ship rats quickly established and are now among the most widespread mammals on the New Zealand mainland, especially in forests (Innes, 2005).

Towns & Atkinson (1991) found in recent studies of cave deposits in New Zealand evidence indicating that of about 90 species of endemic land birds found nowhere else, 43 have become extinct since humans arrived 1000 years ago, nine of them since the arrival of Europeans. The causes of decline include hunting, collecting for specimens, habitat loss or degradation and competition and predation by introduced mammals (Clout & Craig, 1994). Predation remains the major threat to surviving avian species.

5.1.1 Kiwi

One native bird group severely affected by introduced mammals is the kiwi (*Apteryx* spp.), all five species of which have experienced significant population declines and range reductions (McLennan *et al.*, 1996). Several studies have looked at the predatory effect of mustelids, cats (*Felis catus*) and dogs (*Canis familiaris*) on kiwi (Miles, 1995; Miller & Pierce, 1995; McLennan *et al.*, 1996; Miles, 1998; Basse *et al.*, 1999; McLennan *et al.*, 2004) and predation by introduced mammals on young kiwi is stated as the single most important factor contributing to the demise of mainland populations (McLennan *et al.*, 1996; McLennan *et al.*, 2004). Mortality data on kiwi showed that stoats were responsible for ten (77%) of the 13 confirmed predations on kiwi chicks and juveniles in a study carried out by McLennan *et al.* (1996). Thus accordingly many mainland kiwi populations have trapping operations aimed at reducing the number of predators (Robertson & Colbourne, 2003). When stoat numbers are reduced their prey, rats and mice, which prey on invertebrates, may experience population increases (Robertson & Colbourne, 2003). Blackwell *et al.* (2003) found evidence of increased numbers of rodents in several areas of forest with synchronous southern beech (*Nothofagus* Spp.) seeding (38°47'S, 177°05'E) in New Zealand, where stoats were removed by trapping. The possible increase in rodent numbers may create potential for competition with other animals that also utilise invertebrate prey.

A few studies have looked at the diet of kiwi in the presence of mammalian predators (Colbourne & Kleinpaste, 1983; Colbourne & Powlesland, 1988; Colbourne *et al.*, 1990; Miles, 1995), but little is known about the effect of non-predatory mammals as competitors. Several studies have approached this gap with initial examinations of the diet of potential mammalian competitors with kiwi. For instance a study of North Island brown kiwi diet in an exotic forest by Colbourne & Kleinpaste (1990) looked at several hedgehog (*Erinaceus europaeus*) droppings. They showed 'remarkable' dietary overlap with surface and litter dwelling invertebrates in kiwi diet. Likewise Colbourne *et al.* (1990) suggested that rats may have competed with kiwi for surface dwelling invertebrates on Kapiti Island (40°51'S, 174°55'E). Rodents are not thought to directly prey on kiwi chicks and little is known about the threat they may pose to chicks as potential competitors. This is because stoats, which have a far more detrimental effect on kiwi chicks, also inhabit most areas where kiwi and rats co-exist.

5.1.2 Potential for competition

Ship rats will take certain insects when available, but in New Zealand a seasonal predominance (spring and summer) of arthropods occurs in their diet (King, 1990). Arthropods are also documented as being an important component of kiwi diet (Colbourne & Kleinpaste, 1983; Colbourne *et al.*, 1990; Miles, 1995). As suggested by Colbourne *et al.* (1990) rats may compete with kiwi for surface dwelling invertebrates but are unlikely to overlap in the soil component of kiwi diet. There is potential for overlap in forest where the litter layer is deeper, thus restricting kiwi to feeding on the top soil level (Colbourne *et al.*, 1990). Any potential competition that may exist will depend on the numbers, density and distribution of kiwi, rodents and invertebrates. At low densities of kiwi and ship rats competition may not occur or may not have any significant effects. One example that may add support to the hypothesis of competition between rats and kiwi for invertebrate food was seen on Kapiti Island. Here a population of approximately 1000 little spotted kiwi (*Apteryx owenii*) remained stable for 15 years. In the last nine years the population has increased to approximately 1200 birds. One possible reason for the increase was the eradication of rats in 1996, possibly improving the carrying capacity of the island with the reduction of food competition (R. Colbourne pers. comm.). The population estimates are based on the densities of birds monitored in the two main kiwi study areas (Te Kahu and Te Rere) that have been monitored over the last 20 years.

The period of vulnerability of young kiwi to predation by stoats (*Mustela erminea*), their main predator, is approximately nine months or until the chick reaches 1 kg and after passing this 'bottleneck' chances of further survival increase drastically (McLennan, 1997). If competition for limited resources with rodents causes the growth rates of kiwi chicks to slow or even plateau then the time taken to reach this crucial threshold size increases and as a result could possibly increase the likelihood of predation because the chick is exposed to the predator for longer. Therefore the effects of potential competition with rodents may have no tangible effects on adult kiwi but may add to the already extreme mortality rate of kiwi chicks. This will be more likely to happen as populations of kiwi increase as a result of management and may become the next limiting factor to kiwi populations in mainland situations where rats are found in high densities.

Any significant time spent feeding on the surface and in leaf litter, by kiwi chicks, may increase the potential for competition with other animals feeding at the same level, namely rodents. The increased growth requirements of chicks coupled with their feeding restrictions means that any competition is likely to be more intense than for adult kiwi. In addition to competing with rats, if the soil is hard, the adults may also be restricted to the same probing depths as chicks and thus compete with them too, adding to the problem. In a high-density population this could be a very important factor affecting chick survival.

This study examined the diet of kiwi chicks (Chapter 1) and the diet of rats (Chapter 2) to allow a comparison between them. In addition rat density in the area where kiwi chicks fed was calculated (Chapter 3) as well as the relative abundance of the invertebrate prey they consumed (Chapter 4). This chapter brings the information from the previous chapters together to evaluate the potential impacts of the overlap in diet between kiwi chicks and rats on the growth and survival of chicks on Ponui and to discuss the possible impacts of competition in other kiwi populations.

5.2 Methods

5.2.1 Overview

The study site for this project is located on Ponui Island (Latitude 36°50'S, Longitude 175°10'E). The main study site (100 ha) lies within a larger (250ha) tract of broadleaf/Kauri forest on the southern end of the island and consisted of three gullies next to each other - Red Stony Hill Gully (RSHG), Pipe Gully (PG) and Straight Gully (SG) (Chapter 1; Plate 1.3). The study population consisted of 35 adult North Island brown kiwi (21 adult males; 14 adult females) initially captured and fitted with transmitters in the last week of March 2004 and their offspring (eight kiwi chicks). This chapter uses the following information from previous chapters: kiwi chick diet and shelter sites (Chapter 1), ship rat diet (Chapter 2) and density (Chapter 3), invertebrate numbers and habitat distribution and information on vegetation in each habitat type (Chapter 4).

5.2.2 Diet

A total of 143 Faecal samples were collected from five North Island brown kiwi chicks from November 2004 to February 2005 (Chapter 1), analysed for invertebrate prey (Chapter 1; Table 1.2) and compared to the dietary analysis obtained from 25 ship rat stomach samples (Chapter 2; Figure 2.2a and 2.2b). The comparison of diet between ship rats and kiwi chicks to assess potential for competition involved only invertebrate prey. Some plant material was also found in the diet, but not used in this comparison. The average numbers of individual invertebrates per stomach or faecal sample were calculated; invertebrates were also recorded as the percentage of stomachs or faecal samples they were found in. The environmental abundance of invertebrates was measured in pitfall traps, soil core samples and litter samples (Chapter 4; Section 4.3)

5.2.3 Habitat use

The study site was divided into 'bush' and 'scrub' habitat and a description of the vegetation composition of these habitat types is presented in Chapter 4; Section 4.3. Kiwi chicks hatched in two separate gullies - PG and RSHG - and rats were kill trapped in HG and live trapped in PG. Both ship rats and kiwi chicks were caught and observed in scrub and bush habitat.

5.2.4 Density of ship rats and kiwi

The density of ship rats in PG was estimated by a mark-recapture study carried out from December 2004 to January 2005. The methods that were used for mark-recapture and estimating density are explained in Chapter 3; Section 3.2. Five kiwi chicks were included in the collection of faecal samples although the total number of chicks in the area is unknown as only the 35 adult birds had transmitters. On three separate occasions a chick without a transmitter was sighted, this was over the length of the study in the same area used by the kiwi chicks I was observing.

5.2.5 Statistical manipulations

Statistical analysis was preformed using v5.2.9 (Clark & Gorley, 2002). An ANOSIM (Analysis of similarities) test was used to compare diet between kiwi chicks and ship rats. ANOSIM tests are described by Clark & Gorley (2001) as a rough analogue of the standard univariate 1- and 2-way ANOVA tests; the test used allows a statistical test (1-way layout) of the null hypothesis for which there are no assemblage differences between groups of samples specified *a priori*. ANOSIM test are accompanied by a 'Global R' value and a significance level.

The R statistic is a comparative measure of the degree of separation of sites. R values close to zero indicate similarities between and within sites are on average the same. A value close to one indicates all replicates in a site are more similar to each other than those from other sites Clark & Gorley (2001). It is possible for significant R values to have little biological significance due to the high statistical sensitivity of the analysis resulting from very large numbers of replicates.

A non-metric multidimensional scale (nMDS) plot was also produced in Primer to illustrate any differences between kiwi chick and ship rat diet for nine key invertebrate taxa. nMDS represents non-metric relationships between multiple variables in two or three dimensions. As the plot was non-metric it contained no x or y axis. The nMDS plot also included a stress value which indicated the accuracy with which the plot represented the actual relationship of individual data points. Stress values for nMDS plots can range from 0.0 (perfect map) to 0.3 (low accuracy).

Univariate statistical tests were carried out in the software package SPSS (2001); these included a one-way analysis of variance (ANOVA) for differences between the average number of spiders, scarabaeid beetles, weta and the presence of earthworm chaetae in the stomachs of ship rats and faecal samples of kiwi chicks.

5.3 Results

5.3.1 Kiwi chick and ship rat diet

The three main invertebrate taxa taken as prey by kiwi chicks based on percentage occurrence in faecal samples were scarabaeid larvae (93%), tipulid larvae (54%) and elaterid larvae (39%), all soil dwelling. scarabaeid larvae peaked in their average number per faecal sample for individual chicks over November and December while the tipulid larvae peaked over December and elaterid larvae peaked in February (Chapter 1; Table 1.2). The subsequent decline in numbers of scarabaeid and tipulid larvae per chick faecal sample in January and February was followed by an increase in numbers of spiders per faecal sample from January to February (Chapter 1; Table 1.2). These three larvae were either absent or found in very low numbers in rat stomachs (Table 5.1).

Table 5.1 Comparison of the percentage occurrence of invertebrates in 143 North Island brown kiwi chick faecal samples and 25 ship rat stomach samples. All samples were collected from November 2004 to February 2005.

	% Occurrence in kiwi chick faecal samples	% Occurrence in ship rat stomach samples
Number of samples	143	25
Annelida: Chaetae	27	24
Arthropoda		
Chilopoda: centipede	22	4
Arachnida: spider	20	24
Insecta		
Orthoptera: weta	25.9	60
Hemiptera: cicada	6	8
Coleoptera		
Elaterid - larvae	39	4
Scarabaeid -beetle	24	40
- larvae	93	0
Diptera		
Tipulid - larvae	54	0
Plant material	3	4
Unknown	3	8

The three invertebrate taxa (Spiders, weta and scarabaeid beetles) preyed upon in the highest numbers by both kiwi chicks and ship rats were all surface dwelling invertebrates (Figure 5.1). Earthworm chaetae were also present in a similar percentage of chick faeces and ship rat stomachs (Table 5.1). There was no significant difference in the average number of spiders (one-way ANOVA; $F_{1, 166} = 0.02$; $P = 0.88$) or scarabaeid beetles (one-way ANOVA; $F_{1, 166} = 0.12$; $P = 0.73$) per kiwi chick faecal sample compared to the average number per ship rat stomach sample (Figure 5.1). There was a significantly higher average number of weta per ship rat stomach than per kiwi chick faecal sample (one-way ANOVA; $F_{1, 166} = 22.28$; $P < 0.001$) (Figure 5.1). The actual number of earthworms eaten was unknown, but there was no significant difference between the average number of ship rat stomachs and kiwi chick faeces that contained earthworm chaetae (one-way ANOVA; $F_{1, 166} = 0.28$; $P = 0.60$).

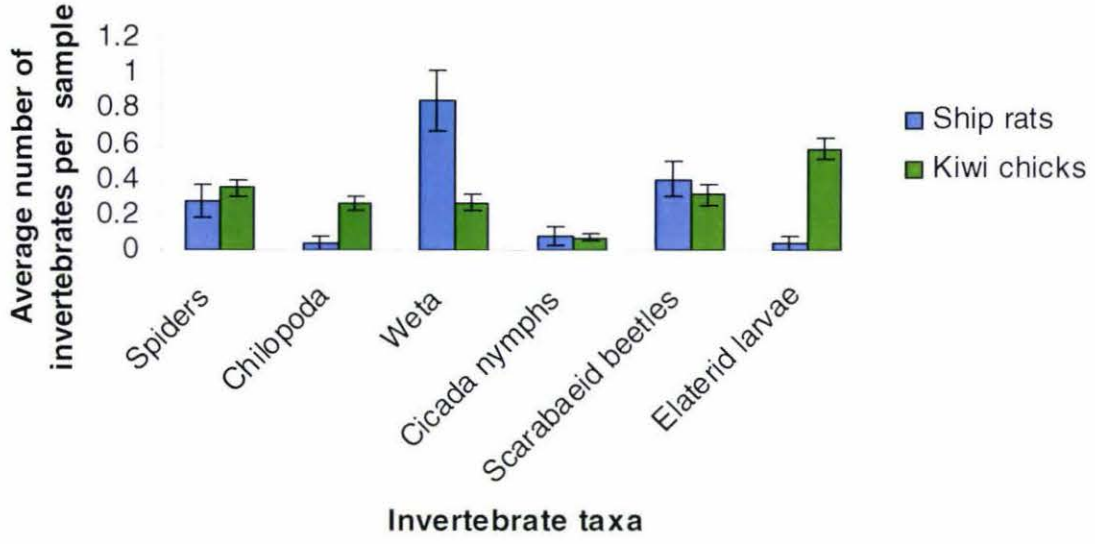

Figure 5.1 The average number of invertebrates (±standard error bars) per kiwi chick faecal sample and ship rat stomach sample. In total 143 kiwi chick faecal samples and 25 ship rat stomachs were collected from November 2004 to February 2005. Only invertebrate taxa eaten by both kiwi chicks and ship rats were included.

The main similarity in invertebrate diet between ship rats and North Island brown kiwi chicks was in the number and type of surface dwelling invertebrates eaten and the percentage of stomach and faecal samples containing earthworms. There was a significant difference in the diet of kiwi chicks and ship rats when considering the nine

invertebrate taxa present in both diets (one-way ANOSIM; Global R = 0.813; $P < 0.05$). This difference is due to the large number of soil dwelling larvae eaten by kiwi chicks.

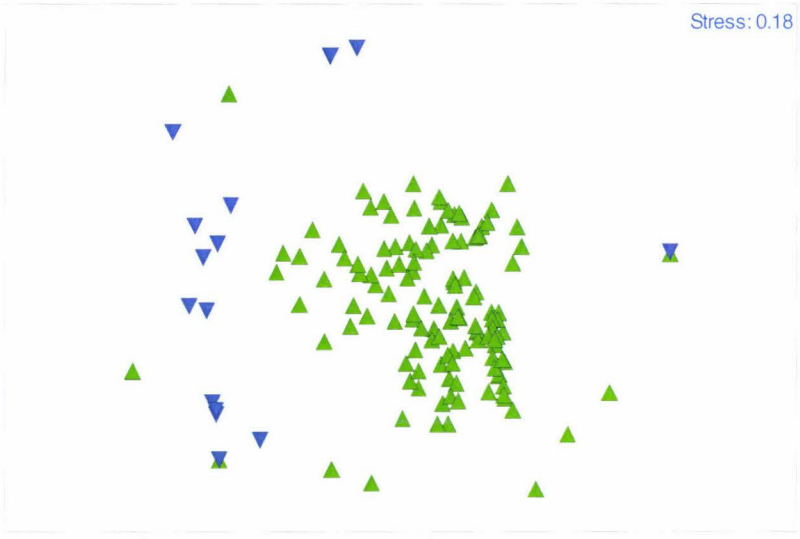

Figure 5.2 Comparison of dietary overlap of nine invertebrate taxa (Table 5.1) in kiwi chick faecal samples and ship rat stomach samples using non-metric multidimensional scaling. Samples collected from November 2004 to February 2005. ▲ = kiwi chicks ; ▼ = ship rats.

5.3.2 Environmental abundance of invertebrates

Ship rats ate similar types of invertebrates over the nine months stomachs were analysed, but there was an increase over summer in the number of weta and scarabaeid beetles eaten (Chapter 2; Figure 2.2a). This increase corresponds to an increase in environmental abundance of both taxa recorded in pitfall data over the same period (Chapter 4; Figure 4.2). For kiwi chicks soil dwelling larvae were the most common prey over the four months they were monitored and only low numbers of these larvae were found in soil core samples (Chapter 4; Figure 4.4). However the decrease in the number of scarabaeid larvae in kiwi chick faecal samples in January and February and the peak in elaterid larvae in February (Chapter 1; Table 1.2) corresponded to similar trends in the number of these larvae found in soil core samples over the same period (Figure 5.3b). Both kiwi chick and ship rat diets were found to follow the environmental abundance and availability of invertebrates.

Although both kiwi chick and ship rat diet appeared to follow environmental abundance quite closely, the number of several invertebrates preyed upon by both chicks and rats contrasted with their environmental abundance. There was a higher average number of spiders per faecal sample for individual kiwi chicks in February compared to the previous three months (Chapter 1; Table 1.2), this is despite a decrease in the number of spiders caught in pitfall traps over forest habitat for the same period (Figure 5.3a). The decrease in numbers of annelids in core samples from December 2004 to February 2005 (Figure 5.3b) mirrors that found in pitfall data over the same period (Figure 5.3a). But the percentage of chick faecal samples and ship rat stomachs containing earthworms over the same period was high considering the low environmental abundance in pitfall and core samples (Table 5.1). Numbers of invertebrates found in leaf litter samples were low over all four months (Figure 5.3c) and the abundance of surface dwelling invertebrates is better illustrated by pitfall data.

5.3.3 Habitat and density of ship rats and kiwi chicks

Kiwi chicks spent the majority of time sheltering in scrub habitat. They were also observed feeding in scrub habitat at night and during the day (pers. obs.). Individual kiwi chicks were found sheltering and feeding in areas no larger than eight hectares and these ranges overlapped between kiwi chicks. For the three kiwi chicks (Mauro, Niko and Diego) followed over several months, the combined area they used was approximately 15 hectares (Chapter 1).

Ship rats were caught in both bush and scrub habitat and there was no significant difference in the diet of rats caught in the two habitats (Chapter 2; Figure 2.4). Ship rat density was estimated at between 6.04 ± 1.73 and 10.20 ± 2.53 ship rats per hectare in the same area where kiwi chicks were sheltering and feeding (Chapter 3; Table 3.1). Based on the estimate of ship rat density, in the area that the three kiwi chicks were found to be sheltering and feeding (15 hectares) it is estimated that there would be between 90.60 ± 25.95 and 153.00 ± 37.95 ship rats. Individual kiwi chicks were found in an area no bigger than eight hectares and would have to share that area with between an estimated 48.32 ± 13.84 and 81.60 ± 20.24 ship rats.

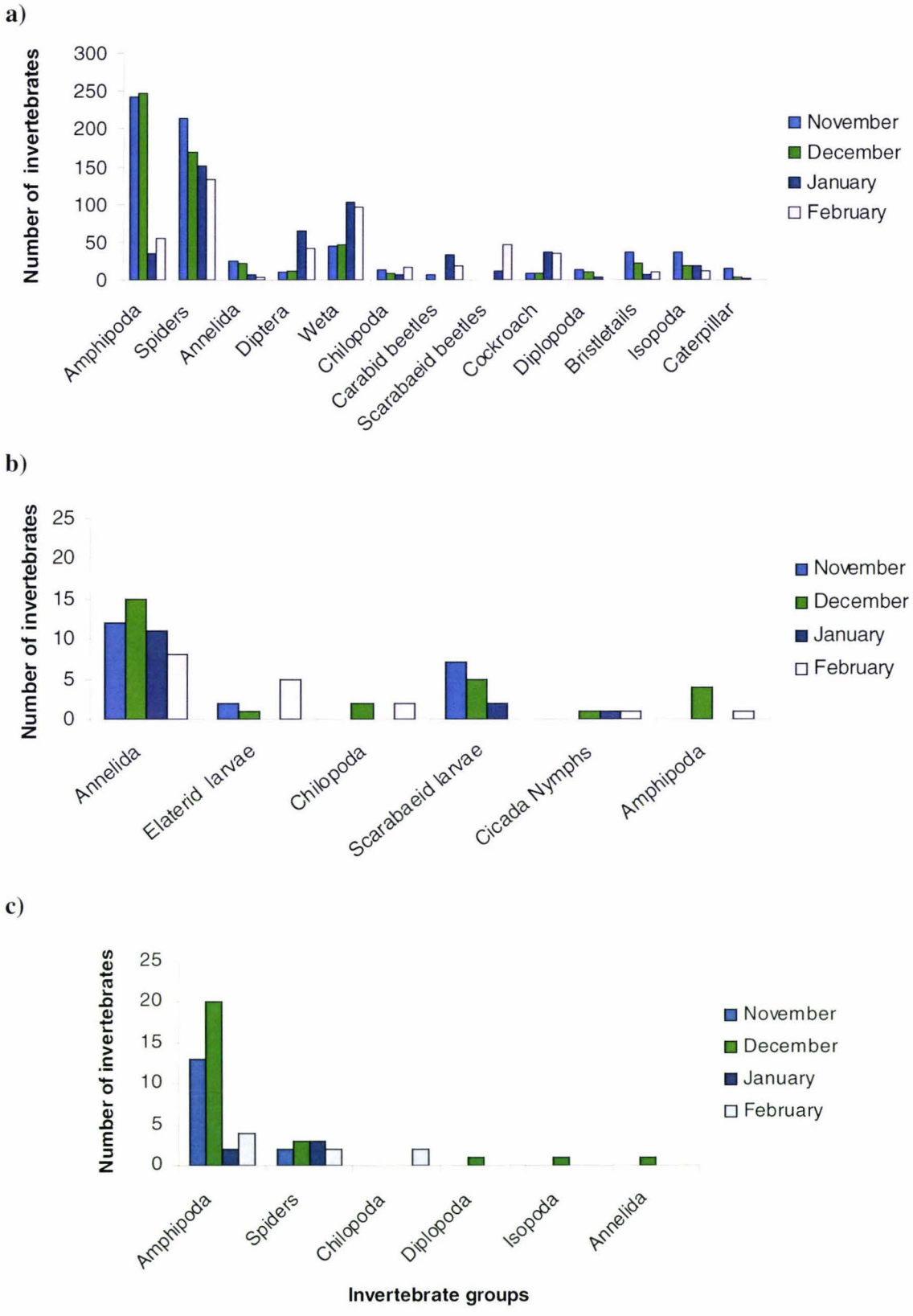

Figure 5.3 Monthly number of invertebrates caught in **a)** pitfall traps, **b)** soil core samples and **c)** leaf litter samples in forest habitat from November 2004 to February 2005. Forest habitat is scrub and bush habitat combined.

5.4 Discussion

From the dietary comparison between ship rats and North Island brown kiwi chicks the main similarity in invertebrate diet was in the number and type of surface dwelling invertebrates eaten and the percentage of stomach and faecal samples containing earthworms. There was a significant difference between the diet of kiwi chicks and ship rats when total invertebrate diet was compared. This was due to the large number of soil dwelling larvae eaten by kiwi chicks. The similarity in surface dwelling invertebrate diet may be important when larval forms are only available in low numbers or not at all to kiwi chicks. When this occurs surface dwelling invertebrates may become more important and possibly be preyed upon by kiwi chicks in higher numbers in following months to compensate.

The diet information from the current study was based on a small sample size of individual kiwi and any inferences toward other populations are made with complete recognition of their limits, a larger sample size and longer study period would further enhance the ability to make recommendations to other areas. The current study suggests that in areas where soil dwelling larvae are scarce or where soil density increases considerably over summer the potential for competition between kiwi chicks and ship rats could be important, particularly at high densities of ship rats. This would also be true for high densities of kiwi, adults and chicks, where intraspecific competition may add to any potential competition with rats and further compound the effects. When Norway rats (*Rattus norvegicus*) and Pacific rats (*Rattus exulans*) were eradicated from Kapiti Island in 1995 the recruitment of little spotted kiwi chicks (*Apteryx owenii*) increased (R. Colbourne pers. comm.) adding support to the hypothesis that they compete for food.

In the current study it was thought that the slow growth rates and low survival rate of chicks on Ponui Island compared to the Warrenheip site was due to a combination of dry weather, fluctuating numbers of soil dwelling invertebrate prey and possibly competition for surface dwelling invertebrates from ship rats and other kiwi on Ponui. There may be weight differences between the Ponui Island kiwi and those from Warrenheip based on genetics. Adult kiwi from Ponui have been suggested as being smaller on average compared to mainland populations (R. Colbourne pers. comm.). It is

not thought that genetic effects are an explanation for the constant weight loss and subsequent death of several chicks on Ponui. But this hypothesis could be simply tested by releasing several Warrenheip chicks on Ponui or vice versa.

Although kiwi use their bill to reach and extract soil dwelling prey they also spend time feeding in leaf litter and on the soil surface (Chan, 1999; pers. obs.). Chan (1999) also observed chicks probing under and around large objects such as roots and dead wood. North Island brown kiwi chicks in the current study hatched with bills ranging from 37.40mm to 43.5mm long and after three months the chick with the longest bill (Niko) was still only 54.2mm (Chapter 1; Figure 1.4). This considerably restricted the depth of soil they could probe to and the soil dwelling invertebrates that were available to them. For example Colbourne *et al.* (1990) found that most cicada nymphs on Kapiti Island were located at a depth of 5-15cm in the soil, a depth that would make them unavailable to kiwi chicks until their bills reached at least 50mm.

Another limit to probing depth is soil penetrability particularly in areas where the soil dries and compacts considerably. North Island brown kiwi chicks usually hatch from August to February and so over their first several months of feeding the soil may be dry and potentially restrict probing to upper soil levels, the soil surface and leaf litter. When a breeding pair has two clutches of eggs the second clutch may be restricted more than the first, as they will hatch at the height of summer when the soil may be at its driest.

5.4.1 Invertebrate prey

The major difference in the invertebrate diet of ship rats and kiwi chicks was the soil dwelling larvae, they were a large component of kiwi chick diet and almost absent from the diet of ship rats. These larvae fluctuated in their average number per faecal sample and in their environmental abundance and availability as established from core and pitfall samples. The seasonal fluctuations of these larvae in terms of environmental abundance were most likely due to their life cycle. This generally involves larvae moving closer to the soil or substrate surface before emerging as adults, taking flight, mating and then the females returning to lay their eggs in the soil or other substrate. Walker (2000) describes the emergence of scarabaeid beetles (Chafer beetles) *en masse* from the ground in New Zealand forests in early summer. Scarabaeid beetles usually become airborne at dusk, but return to the soil to lay eggs (Colbourne *et al.*, 1990).

These larvae appear to be found in core samples in most months but peak in occurrence in kiwi diet over November and December, whereas surface dwelling invertebrates like spiders and weta were preyed upon by kiwi chicks in similar numbers over the four months. These larvae may be an important food source for the short time when they peak in numbers and availability but the constant availability and larger size of weta and spiders may be of greater importance at other times.

Ship rats and kiwi chicks were both found to prey on spiders, weta, scarabaeid beetles and earthworms frequently. When soil dwelling larvae are not available, or are found in lower numbers due to larvae having already emerged, or dense soil restricts probing, there appears to be potential for competition. Its possible effects and implications would rely on seasonal conditions, invertebrate abundance and densities of kiwi chicks and ship rats. Soil dwelling larvae were only ever found in small numbers in soil core samples in the same habitat. The high numbers of these larvae taken by kiwi chicks suggests that they were actively selected for. If these larvae were actively selected for then it is uncertain whether this was due to the ease at which they could be obtained, their nutritional value as a food source, a combination of the two or other reasons.

Despite the dry conditions on Ponui Island over summer, kiwi chicks and ship rats still managed to locate and prey upon earthworms. Colbourne & Kleinpaste (1983) found earthworms in Northland forests were harder to come by over the summer months due to their retreat to lower moister soil levels. The soil on Ponui Island dried considerably over January 2005 to March 2005 (pers. obs.) and it became difficult to take core samples of soil with a stainless steel corer. Probing was likely also to have been restricted. Earthworm chaetae were found in a similar percent of ship rat stomachs and kiwi faeces and it is possible that these were preyed upon by both after spells of rain where earthworms may have come close to or onto the soil surface, or were possibly obtained from moist soil adjacent to streams and swamps.

5.4.2 Ship rats

Ship rats living in New Zealand native forest are thought to eat both plant and animal foods all year round, with proportions varying seasonally (Innes, 2005). Very little plant material was found in ship rat stomachs over nine months trapping in the current study

(Chapter 2; Figure 2.2b). This may be due to the fact that plant material is not as easily identifiable as invertebrate remains, even when studying the cuticles under a microscope. This detection factor needs to be taken into consideration when talking about overall ship rat diet and the presence of plant material in ship rat diet cannot be dismissed. Ship rat diet appeared to be dominated by invertebrate prey - weta were the most common prey in ship rat stomachs percentage occurrence wise (Table 5.1) and in the average number per stomach (Figure 5.1). Apart from amphipods which were not found in kiwi chick faeces or ship rat stomach samples, spiders were the most common invertebrate caught in pitfall traps (Figure 5.3a). The high number of weta eaten may be due to ship rats specifically preying on weta over the more common spiders due to their nutritional value, accessibility or simply that numbers of weta caught in pitfall traps did not represent their true abundance. Weta were also part of kiwi chick diet and their average number per faecal sample for individual chicks was quite consistent over the four months, while the average number of scarabaeid beetles per month was inconsistent. Although the increase in average numbers of weta per faecal sample in February was small it may be a reflection of the size of weta. It is possible that a small number of these were enough to compensate for decreasing numbers of scarabaeid larvae.

Both ship rat and kiwi chick diet followed environmental abundance and availability of invertebrates quite closely over the four months chicks were monitored. The number of weta, scarabaeid beetles and spiders eaten by ship rats over summer relative to winter and spring followed the same trends of abundance as those revealed by pitfall trap data.

The mean number of invertebrate prey per ship rat stomach over summer was higher than both winter and spring (Chapter 2; Section 2.3.2), this is possibly due to a combination of high numbers of invertebrates available over summer and higher numbers eaten due to the onset of breeding.

5.4.3 Potential competition

The average number of spiders, weta and scarabaeid beetles per ship rat stomach were similar to, and for the latter two, higher than overall average numbers found in kiwi chick faeces over the four months they were followed. The major source of error in this

comparison is what constitutes a 'meal' or feeding bout. Stomach content of ship rats probably only provides information on invertebrate prey taken in a short period before capture. Chick faecal samples may be a mixture of 'meals' and may contain food from different times based on digestibility. The methodology of averaging the invertebrate content of faecal samples when more than one sample was found per chick per day improved the independence of the samples. This helped to minimise error from the possibility of the contents of 'meals' being mixed and also helped to alleviate pseudo-replication.

If stomachs and faecal samples are assumed to be a similar or equivalent indication of diet type and amounts consumed then, a straight forward comparison between kiwi chicks and rats can be made.

With faecal samples differential digestion of whole parts of insects could bias the results; soft-bodied insects may be partly or wholly digested and rendered unidentifiable (Kunz & Whitaker, 1983). Chitonous parts namely mandibles last in the stomach longer than other body parts (Watt, 1971) and so the same over representation would occur in faecal material. But short of flushing the crop of kiwi chicks, which could affect growth and cause unnecessary stress, or only using dead birds, faecal analysis seems to be the most viable long term source of dietary information. Stomach samples only give one sample per subject as opposed to repeated data from kiwi chick faecal samples. Despite this the number of ship rats caught gave a good overview of diet and seasonal changes, whereas a small sample size of kiwi chicks gave a lot of data about few individuals. However the problem of independence of samples meant that in some cases multiple samples were averaged (Chapter 1; Table 1.2) and the overall sample size was reduced.

All three chicks monitored long enough to record growth curves on Ponui experienced weight loss over January and February. The average monthly number of scarabaeid larvae per faecal sample for individual chicks was at its lowest point in January and February compared to the two previous months (Chapter 1; Table 1.2). Colbourne *et al.* (1990) also found few scarabaeid larvae present in soil samples in February whereas most adults were present in summer and autumn. In the current study, despite an increase in the number of weta and spiders eaten by chicks in February they still lost

weight. This may have been due to the decrease in available soil dwelling larvae, restricted probing from an increase in soil density, or possibly increased competition for surface dwelling invertebrates with ship rats and other kiwi. The chicks appear to have lost weight as a result of a lack of food, since ship rats were taking the same invertebrate prey, then competition was a possible factor.

5.4.4 Density

The density of ship rats estimated on Ponui Island from December 2004 to February 2005 was higher than most estimated densities for ship rats in mainland New Zealand forests. Although the estimated density of ship rats on Ponui Island is high, further work is needed to establish whether this is higher than most years or even possibly lower than other years. The diet of ship rats and kiwi chicks was found to overlap in the surface dwelling invertebrate component. Therefore the high density of ship rats estimated on Ponui Island means that individual kiwi chicks were sharing areas and invertebrate prey with high numbers of ship rats. The potential for competition is illustrated by the similarity in numbers and types of invertebrate taxa preyed upon by both kiwi chicks and ship rats, combined with the high number of rats feeding in the same area as chicks. Potential competition should include other kiwi chicks and adult kiwi in that area that may also compete for prey.

The first pregnant female ship rat was found in December 2004 on Ponui Island, the first month of the density estimate. With an average ship rat gestation period of 20 to 22 days and with young being weaned after approximately 21 to 28 days (Innes, 2005) the first juvenile ship rats would be expected to be found around the end of January. An increase in the number of ship rats would be expected in the following months and the density of ship rats would also be expected to increase. If any competition was occurring between kiwi chicks and ship rats then it would possibly increase over the following months due to the number of juvenile ship rats entering the population. The estimated density of ship rats on Ponui Island from December 2004 to February 2005 is high compared to mainland forests but may be lower than subsequent months when juvenile ship rats will enter the population.

5.4.5 Recommendations

The current management practice used in Operation Nest Egg involves the use of fenced predator proof patches of bush that act as a crèche for kiwi chicks that are hatched in captivity (Colbourne, 1998). Future selection of these crèche sites should take into consideration several factors. Firstly an initial analysis of the site should involve looking at the changes in soil density over each season with an emphasis on summer when chicks will be present and soil is likely to be at its driest, possibly restricting probing. Areas where minimal changes in soil density occur seasonally, at least over summer, would be best suited as crèche sites or sites where large numbers of surface dwelling invertebrates are present to provide invertebrate prey regardless of soil density. Another factor that should influence site choice is the invertebrate taxa. Areas should have a diverse number of invertebrate species with numerous individuals. Potential sites should be monitored for invertebrates with pitfall, core and leaf litter samples to establish the prey value of the resident invertebrate fauna.

Similar recommendations were made by Jolly & Colbourne (1991) as criteria for selecting islands as potential sites for translocations of kiwi. Jolly & Colbourne (1991) stated that these islands should include 'forested habitat with good soil depth which is both sufficiently moist and developed to support their invertebrate food and include abundant ground invertebrate fauna'.

Due to the small sample size and length of this study further work is needed to show whether the potential for competition that exists results in actual competition between ship rats and kiwi chicks on Ponui Island. Further work is needed to gauge the effects from different years. Several factors need to be explored, for instance how the distribution of ship rats compares across scrub and bush habitat. Also what effect soil density has and in years where soil is easily penetrated over summer months do kiwi chicks still include weta and spiders in their diet. One area of particular interest is what effect an absence of ship rats would have on numbers of invertebrates. An eradication of ship rats from Ponui Island could be carried out to sample invertebrate numbers before and after to get an idea of the impact ship rats are having on invertebrates.

Kiwi are long lived birds and only need several young to survive and breed to replace their numbers. In the past kiwi may have experienced competition for surface dwelling

invertebrates from other native birds like robins and saddlebacks. The question is whether the competition from ship rats is equivalent to or more than that possibly experienced from other native birds. If rodents were to be removed from Ponui Island an ideal experiment would be to monitor kiwi chick success before and after eradication for several years either side of the eradication.

5.4.6 Future work

An important area that requires further work is the biomass of invertebrates that are preyed upon by both ship rats and kiwi chicks. Numbers alone only give an indication of what is eaten to a certain degree without the overall importance of individual invertebrates to diet. Although the estimated density of ship rats was high on Ponui there is no indication whether the number of invertebrates preyed upon is high compared to their abundance, or how numbers of invertebrates compare to other years. The estimated density of ship rats on Ponui Island is only relevant for the three months the study was undertaken. Long term studies are needed to look at the yearly and seasonal fluctuations in ship rat numbers. As kiwi appear to have flourished on Ponui Island since their introduction in the 1960s more work is needed to identify whether the fluctuating weight of kiwi chicks and their similarity in diet with ship rats, found in the current study, is common or whether this was just a rare occurrence.

5.4.7 Conclusion

When predation is not the major influence on kiwi chick numbers then competition between ship rats and kiwi chicks (and between kiwi chicks) may be an important factor in determining the growth rates of chicks. Potential competition between kiwi chicks and rats and it's effects on kiwi chick growth rates depends on factors such as food availability, the diet and numbers of both rodents and kiwi chicks in the area and their interactions. Ponui Island has a high density population of North Island brown kiwi and the estimated density of ship rats was higher than that found in most mainland forests. The high densities of both kiwi and ship rats and the similarity of surface dwelling invertebrate prey types taken may easily explain the loss of weight chicks experienced. This implies competition with ship rats for limited resources, further increased by a high density of both species.

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