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**The ecology of ship rats (*Rattus rattus*) on Ponui
Island: implications for North Island brown kiwi
(*Apteryx mantelli*)**

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A thesis submitted in fulfilment of the requirements for the degree of
Master of Science in Biological Science

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2006



Drawing by Silver Bishop

The University of Auckland

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Abstract

This research investigated the population dynamics and habitat use of a ship rat population on Ponui Island, in the Hauraki Gulf. Ponui Island is also home to what is thought to be one of the highest densities of North Island brown kiwi (*Apteryx mantelli*) in New Zealand. A recent investigation discovered an overlap in the number and type of surface-dwelling invertebrates in the diet of kiwi chicks and ship rats. However, with the majority of the kiwi chick diet being formed of soil-dwelling invertebrates it was concluded that this competition may only be manifest in times of dry weather or poor soil condition. In times such as these, kiwi chicks, having shorter bills than adults, may have a reduced ability to probe the soil and so rely more upon surface-dwelling invertebrates to form the bulk of their diet. Potential competition will depend on the density and distribution of ship rats, kiwi chicks and invertebrates on Ponui Island. This research aimed to continue investigation into the ship rat population on Ponui Island with the overall outcomes of assessing the scale of potential competition in months subsequent to those in which observations were initially made, and adding to the body of knowledge on ship rat island populations.

This investigation had three individual aims. First, the population density of ship rats was estimated during the winter/spring of 2005, a period where previous density estimates were lacking. Comparison between estimates was then made. Second, home ranges of ship rats on Ponui Island were calculated after radio-tracking a sample of ship rats. In addition the extent to which the ship rats fully utilised the available three dimensional habitat was assessed. Third, the proportion of vegetation in the ship rat diet was accurately quantified to assess its importance in the diet relative to other food types, such as invertebrates that are also consumed by kiwi.

Population density of ship rats on Ponui Island was higher than estimates made in the same area seven months previously. This increase is believed to be due to recruitment after the recent breeding season. Ship rats on Ponui Island were found to occupy smaller home ranges than previously recorded for the species on the mainland, perhaps due to the high density estimated within the study area. Ship rats were highly arboreal in December, with this arboreality proposed to lessen during autumn and winter.

Vegetation was more important to the ship rat diet on Ponui Island than was previously thought; however it remained the minor constituent with the diet dominated by other material presumed to be invertebrate.

The predominance of what is assumed invertebrate material in the ship rat diet suggests a high reliance on this food type, and thus there is potential for overlap in ship rat and kiwi chick diet to occur during that time. The high population density estimated in this study means more ship rats are sharing habitat with kiwi than previously thought. This would imply increased intensity in potential competition at this time. However, the high degree of arboreality observed in ship rats is suggestive of reduced competition during this time due to differences in foraging style between kiwi chicks and ship rats. Although the adult forms of larval invertebrates that are important to kiwi chick diet will remain accessible to arboreal ship rats, thus it was concluded that differences in foraging style do not necessarily equate with decreased competition.

Findings of this study are discussed in relation to the design of future ship rat management strategies, and are also used to evaluate the scale of potential competition between ship rats and kiwi chicks.

It is recommended that similar investigation of the population of ship rats, combined with quantification of the invertebrate fauna biomass, be conducted on Ponui Island for twelve consecutive months to ascertain fluctuations in the scale of competition between ship rats and kiwi.

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1 General Introduction

1.1 Rodents in New Zealand

Only three mammalian species pre-date the arrival of humans in New Zealand. All three were species of bat, of which only two are extant. Many niches occupied by land mammals elsewhere in the world were, in New Zealand, exploited by flightless birds, large insects and other non-mammalian forms (Gibb & Flux 1973). Since the arrival of humans some 52 species of mammal have successfully established in New Zealand (Cochrane 1973). Within this total are four species of rodent, the house mouse (*Mus musculus*) the Polynesian rat or kiore (*Rattus exulans*), the Norway rat (*R. norvegicus*) and the ship rat or roof rat/black rat (*R. rattus*).

Polynesian people were probably the first strictly terrestrial mammal to arrive in New Zealand more than 1000 years ago, bringing with them the Polynesian rat and domestic dog (*Canis lupus familiaris*) (Gibb & Flux 1973). In the early nineteenth century European people began to settle New Zealand bringing domestic animals and stock, and with them rats (Norway and ship rats) and mice. Norway rats were the first to arrive having reached New Zealand by 1800 onboard European ships (Atkinson 1973). Ship rats arrived later, but they did not spread through the North Island until after 1860 and in the South Island after 1890 (Atkinson 1973). Kiore were formerly widespread on the mainland and offshore islands, but declined with the spread of Norway and ship rats (Gibb & Flux 1973). Today kiore are confined to some offshore islands and in a

handful of isolated locations in the south-west of the South Island (Ruscoe 2004). Atkinson (1973) attributes the almost complete disappearance of kiore on the mainland to the spread of the ship rat.

Norway rats and ship rats coexist in New Zealand in both towns and forest although there is some separation resulting from the particular part of the habitat that is utilised (Atkinson 1973). The ship rat is particularly agile, proficient at climbing and moving along branches and vine stems while the Norway rat is a burrowing animal that can climb, but is much less agile than *R. rattus* and will readily enter water (Atkinson 1973). In forests the ship rat utilises a three dimensional habitat by easily traversing the ground and the canopy, whereas the Norway rat tends to occupy the ground level and waterways (Atkinson 1973).

1.1.1 The ship rat in New Zealand

Since its introduction in the nineteenth century the ship rat has spread rapidly and is now pervasive throughout New Zealand. Wild ship rats are most abundant in mature, diverse, lowland podocarp-broadleaved forests, and are very scarce in pure beech (*Nothofagus*) forests except after a moderate to heavy seedfall (Innes 2005).

R. rattus has three colour morphs that interbreed freely (Innes 2005); frugivorous, with a grey-brown back (brown-tipped grey hairs with longer black guard hairs) and a creamy-white underside; alexandrinus, with a grey-brown back and a slate-grey belly; and rattus, with a black back and a slate-grey belly. The distribution of these colour morphs in New Zealand varies with location. The alexandrinus morph is rare or absent from the North Island except in Northland; the frugivorous morph rare or absent from the South Island and the rattus morph rare or absent from Stewart Island (Innes 2005). The reasons for this are unknown but could include founder effects (Innes 2005) or physiological characters associated with the coat colour genotype (Tomich 1968). Ship rats are nocturnal, often arboreal, shy and cautious animals. They are omnivorous generalists, but are capable of being selective, and eat a combination of plant and animal material in seasonally variable proportions (Best 1969; Daniel 1973; Innes 1979). Animal foods dominate the diet in the spring and summer and plant foods

dominate in the autumn and winter. Foods that are most important to the ship rat diet will be those that are most abundant in their habitat at the time (Best 1969). Invertebrates comprise the main animal component of the diet but rats will prey on other items such as birds, eggs up to 61 mm long and some reptiles; though usually in minor quantities (Innes 2005).

The spread of ship rats in New Zealand has been facilitated by their high fertility. Breeding is polyoestrus with a gestation period of 20-22 days, litter size averages five to eight (range 3-10), and the average interval between litters is 32 days (Innes 2005). Under tropical or sub-tropical conditions the ship rat can breed for 11-12 months of the year with the most intense breeding during the summer months (Best 1973). However, in New Zealand breeding cycles show a seasonal trend. Several studies have documented pregnant females in New Zealand during spring, summer and early autumn (Best 1973; Daniel 1972; Innes 1979; Innes 2001; Innes et al. 2001). Best (1973) found the annual fertility of the ship rat in New Zealand was higher than for rats with longer breeding seasons, being achieved through an increased number of litters born to each female per season. Best (1973) postulated that this increased fertility was an adaptation to the temperate zone that has enabled the rat to colonise New Zealand forests where seasonal changes occur.

1.1.2 Impacts of ship rats on native fauna and flora

“Ship rats and possums...are the most pervasive and devastating agents of change (in New Zealand)” (Brockie 1992).

Numerous studies have identified the ship rat as one of the major agents threatening New Zealand's native biota (Atkinson 1973; Dingwall et al. 1978; Innes et al. 2004; Moors 1983; Towns et al. In Press). The Big South Cape Islands rat irruption is perhaps the most famous account of the destruction the ship rat can wreak on native fauna when introduced to a novel ecosystem. Ship rats invaded these islands between 1962 and 1963 and within five years the greater short-tailed bat (*Mystacina robusta*), a flightless weevil and five species of bird endemic to New Zealand had disappeared and other animal and plant species were in decline (Bell 1978).

In a review of the literature on the effect of rats in New Zealand, Towns et al. (In Press) emphasise the role of the ship rat as a predator of flightless invertebrates, ground-dwelling reptiles, land birds and burrowing seabirds. These species may comprise the minor division of a ship rat's diet, but the omnipresence and high arboreality of *R. rattus* is such that this predation has a significant impact. Ship rats are responsible for frequent losses of eggs, chicks and sitting adult birds in non-beech New Zealand forests (Innes 2005).

As a consequence of this recognised destruction, eradication of ship rats has become a priority in many areas of New Zealand. New Zealand is a world leader in rat eradications, with the largest to date being that on 11400 ha Campbell Island. However, complete eradication of the species from the mainland is near impossible due to the size and cost of such a project. Control operations are thus used in the attempt to keep numbers low. Many offshore islands are now being used as havens for New Zealand's unique biodiversity, and eradication of introduced pests on these islands is high priority. Investigations into rat populations are of particular importance on offshore islands. The presence of rats on these islands renders them unsuitable for the establishment of endangered native fauna (Moors 1985). Today over 90 islands have been successfully cleared of introduced rodents (Towns & Broome 2003).

The density of ship rat populations can be irruptive, with fluctuations attributed to factors such as seasonal breeding, changes in food availability and predation (Blackwell et al. 2001; Daniel 1972; Daniel 1978; Innes et al. 2001). Ship rat population irruptions have been documented following heavy *Northofagus* beech seeding (Alterio et al. 1999; King & Moller 1997) and heavy rimu (*Dacrydium cupressinum*) mast seeding (Harper et al. 2005). Irruptions have the potential to hinder control programmes. Innes et al. (1995) stated that even when rat densities are decreased by 90% in control operations, they could recover in two to five months. The design of control operations is thus crucial to maximise potential benefits and minimise costs, and will be facilitated by accurate knowledge of the population dynamics of the pest species in question.

Rodent populations on islands are thought to be subject to differences in demography, reproduction, morphology and behaviour when compared to mainland populations, with this termed the island syndrome (Adler & Levins 1994). These differences include higher and more stable densities, better survival, increased body mass, and reduced reproductive output and dispersal (Adler & Levins 1994). However, some populations have been shown to exhibit some components of the island syndrome while not exhibiting others.

With the proposed differences in population dynamics between island and mainland rodent populations it is necessary to enhance knowledge of island populations, as efforts to eradicate rodents have been concentrated in these areas. Knowledge of behaviours such as home range areas and social organisation are essential prerequisites of any effective management strategy and may facilitate the design of more effective control operations (Hooker & Innes 1995). One of the two overall outcomes of this investigation is to contribute to the growing knowledge of ship rat populations through the examination of a population, including its dynamics, home ranges and habitat use, on a New Zealand island.

1.2 Ponui Island

The population of ship rats of interest in this study was that on Ponui Island, New Zealand. Ponui (36°55'S, 175°11'E) is a privately owned 1770 hectare island in the Hauraki Gulf (Figure 1.1). The island itself is split into three farms, South, Central and North Ponui. Pasture dominates the landscape, being used for beef and wool production with patches of mixed broadleaf-podocarp forest filling the remainder of the land.

In 1964 North Island brown kiwi (*Apteryx mantelli*) were introduced to Ponui Island by the New Zealand Wildlife Service at the owner's request. Six birds were introduced from Little Barrier Island and eight from Northland. Ponui Island is now thought to host one of the highest densities of North Island brown kiwi in New Zealand. Miles and Castro (2000) estimated 10 pairs/km². If kiwi were uniformly spread over the island this would mean a population nearing 350 adult birds (Colbourne 2005).

The island is free from a number of the mammalian species found on mainland New Zealand, including possums (*Trichosurus vulpecula*), rabbits (*Oryctolagus cuniculus*) and hares (*Lepus europaeus occidentalis*). However feral cats, working farm dogs and rodents (*Rattus rattus*, *Rattus norvegicus* and *Mus musculus*) inhabit the island. The status of stoats (*Mustela erminea*) and other mustelids on Ponui Island is unknown (D. Chamberlin pers. comm.). The Chamberlin family tell stories of stoats washing up on the beach and running into the forest, however confirmation of their presence has not been documented throughout the extensive research that has taken place on the island. With no stoats on the island feral cats, morepork (*Ninox novaeseelandiae*) and the occasional harrier (*Circus approximans*) are thought to be the main predators of the rodents. Feral cats and morepork have both been documented as predators of ship rats in New Zealand (Gillies 2001; Haw et al. 2001; Karl & Best 1982).

Due to the mixed genetic heritage of the kiwi population on the island, the Department of Conservation (DoC) has no plans to use these birds to enhance breeding populations elsewhere. The population thus provides a unique opportunity to study these endangered birds in detail that would not be possible in heavily managed populations. In the year 2000, with the collaboration of the Chamberlin family of the South Ponui Island farm, the Ponui Island Kiwi Research Programme was set up. A patch of mixed podocarp-broadleaf forest approximately 1.5 km² in size composed of four main gullies now contains 36 adult birds, and more recently 3 kiwi chicks, with transmitters attached that have been closely monitored since March 2004.

Investigations have recently been initiated to investigate the kiwi population on Ponui Island in detail to further knowledge of the interactions between this native species and introduced fauna. With the presumed lack of stoats on the island it is of interest to ascertain any effect the presence of rats and feral cats have upon the resident kiwi population.

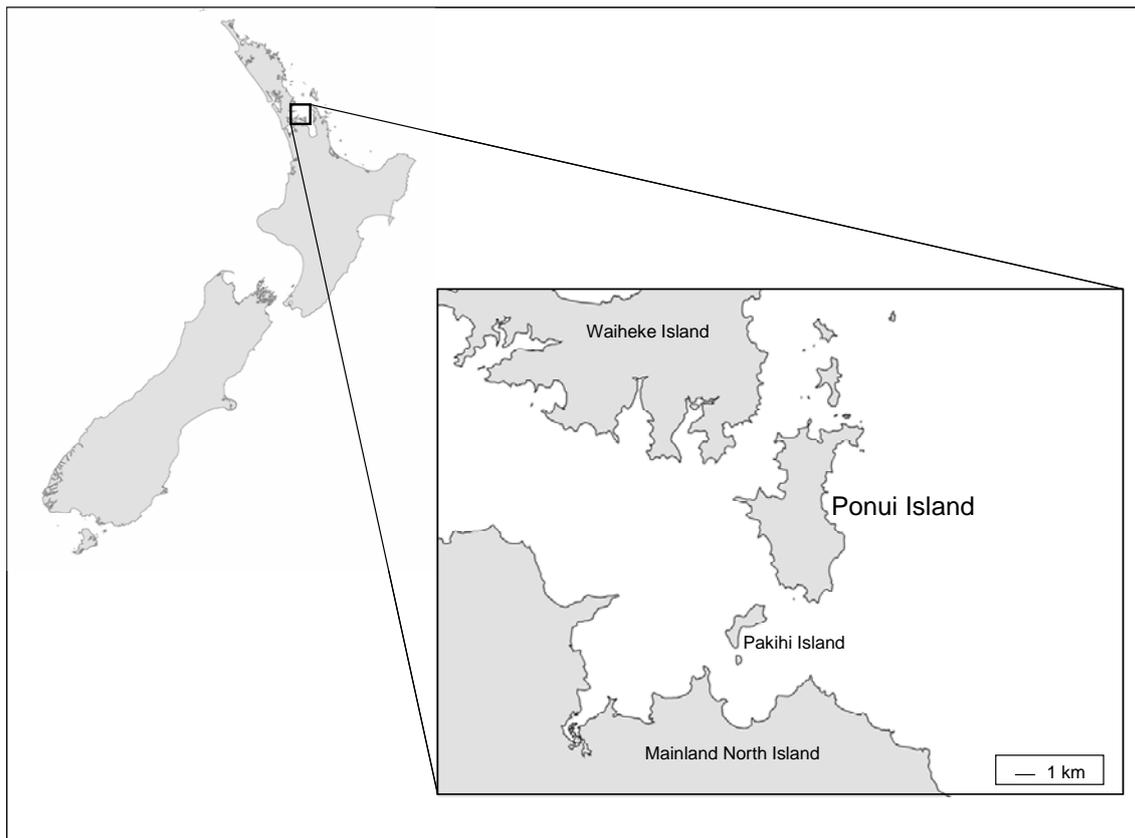


Figure 1.1 Location of study site, Ponui Island, in relation to mainland New Zealand and surrounding offshore islands.

1.3 The North Island brown kiwi

Kiwi (*Apteryx* Spp.) are the smallest of the ratites, a taxonomic group of flightless birds. Kiwi are endemic to New Zealand and are the country's unofficial emblem. As a taonga (treasure) species they have cultural significance for Maori (Robertson 2003). Today, five species of kiwi are recognised, the formerly brown kiwi is divided into three distinct species, Okarito brown kiwi/rowi (*A. mantelli* 'Okarito'), the North Island brown kiwi and the tokoeka. The tokoeka is divided into two varieties, Haast tokoeka (*A. australis* 'Haast') and southern tokoeka (*A. australis*). The other two species are the great spotted kiwi/roroa (*A. haastii*), little spotted kiwi (*A. owenii*). The North Island brown kiwi is found on the North Island and the little spotted kiwi is restricted to Kapiti Island and other offshore islands, with the remaining species all found on the South Island. All five kiwi species are threatened. Okarito brown kiwi/rowi and Haast

tokoeke are classified as Nationally Critical; North Island brown kiwi as Seriously Declining; great spotted kiwi/roroa and southern tokoeke as Gradually Declining; and little spotted kiwi as Range-Restricted (Robertson 2003).

Kiwi are large, nocturnal and flightless birds with vestigial wings and no tail (Robertson 2003). The birds rely mainly on olfaction for foraging with their nostrils placed near the end of their bill, with which they probe the soil and leaf litter for food (Kleinpaste 1990). Kiwi forage mainly upon earthworms and invertebrates with a relatively small intake of plant material (Reid et al. 1982). Soil-dwelling invertebrates form the bulk of the kiwi diet (Colbourne et al. 1990). The North Island brown kiwi is a seasonal breeder with a peak in egg laying in mid to late winter (Potter & Cockrem 1992). The kiwi egg is particularly sizeable with the North Island brown kiwi laying an egg that is approximately 400% above the allometrically expected value for a bird with an average body weight of 2.2 kg (Prinzinger & Dietz 2002). Eggs exceed 100 mm in length; the average dimensions of seven North Island brown kiwi eggs laid in Hawkes Bay were $129 \pm 2 \text{ mm} \times 78 \pm 1 \text{ mm}$ (McLennan 1988). Eggs contain more energy than any other of similar size and incubation takes 75-80 days, with chicks emerging in spring/early summer with feathers rather than down (McLennan 1988). Chicks receive no food from their parents, apart from a residual store of yolk absorbed from the egg just prior to hatching; chicks begin to make foraging trips independently within a week of hatching and fledge upon reaching 10-16% of adult weight (McLennan et al. 2004).

Kiwi have evolved in the absence of mammalian predators, but co-exist today with as many as seven obligate or facultative carnivores introduced by Polynesians and Europeans (McLennan et al. 1996). Stoats and feral cats in particular have been singled out as important predators of kiwi with numerous publications elucidating this fact (McLennan et al. 2004; McLennan et al. 1996; Robertson 2003; Sales 2005). However, the degree of predation pressure on kiwi is dependent upon their growth stage (McLennan et al. 2004). Being 2-3 kg in weight adult kiwi are too large to be taken by cats and stoats, but the smaller young kiwi are subject to predation from these species (McLennan et al. 2004). In a study investigating the susceptibility of North Island brown kiwi to predation compared with developmental stage, it was found that at least

8% of chicks and 45% of juveniles were killed by predators (McLennan et al. 1996). Young kiwi suffer intense predation from stoats during their first four months of life or until reaching at least 800 g, when they become too large for stoats and cats to kill (Basse et al. 1999; McLennan et al. 2004). In North Island brown kiwi, growth rates have peaked by the point of hatching rather than later on in development as in other birds (McLennan et al. 2004). McLennan et al. (2004) concluded that a long evolutionary history in the absence of mammalian species has resulted in resource limitation dominating as an evolutionary driver rather than predation, thus accounting for the slow rates of development observed in kiwi.

In 1991 the Kiwi Recovery Programme was set up to raise awareness of the plight of the species to co-ordinate plans for rescue from its threatened status. Predation has been highlighted as the major factor responsible for the decline in kiwi numbers. To relieve birds of this pressure efforts have concentrated on managing kiwi in their natural range by reducing their exposure to predators (Robertson 2003).

1.4 Ship rats on Ponui Island: implications for kiwi

The role of predation by exotic species in the decline of kiwi has been clearly recognised; concurrently the role of ship rats as important predators of New Zealand's fauna has been firmly established. Within the literature, rats have not been cited as predators of young or adult kiwi. In addition, with kiwi eggs having a mean length of 129 mm they are too big to be punctured or removed by rats (Basse et al. 1999). Little investigation has been made, however, into the possibility of competition existing between ship rats and kiwi. Both species rely on invertebrates to form the bulk of their diet.

With their long bills adult kiwi are proficient at probing the soil for soil-dwelling invertebrates, the stratum that provides the bulk their diet (Colbourne et al. 1990). In contrast kiwi chicks have shorter bills which limit their depth of probing, especially as chicks generally hatch in warmer months (McLennan 1988) when the soil is drier and soil penetrability may decrease. In addition, most of the permanent soil-dwelling invertebrates such as worms migrate to lower, moister soil levels in summer where they

may be out of reach of kiwi, and other important soil-dwelling invertebrates to the diet such as cicadas (Hemiptera) and scarabaeidae will emerge from the soil to continue their life cycle as imagoes (Kleinpaste 1990). These limitations may result in kiwi chicks relying more heavily on surface-dwelling invertebrates in their diet at certain times of the year. This has promoted some thought into the possibility of competition between kiwi and other insectivores that forage upon the ground surface. Kleinpaste (1990) found a remarkable overlap in the surface invertebrates eaten by European hedgehogs (*Erinaceus europaeus*) and North Island brown kiwi in a North Island pine forest. However they questioned the degree of the competition, as hedgehogs hibernate over winter and are unable to extract food from the soil, the stratum that supplied the bulk of the kiwi food items. Similarly, Colbourne et al. (1990) suggested rats may compete with Little Spotted kiwi on Kapiti Island for surface dwelling invertebrates, but also noted that their foods are unlikely to overlap with the soil dwelling component of the kiwi diet.

Competition arises when individuals exploit the same limited resources. Ship rat diet is composed mainly of invertebrate animal material and, with the ship rat's inability to probe beneath the soil, many of these invertebrates will be surface-dwelling. If both ship rats and North Island brown kiwi chicks are utilizing the same food resources, these two species may be thought of as competitors. Kiwi are most vulnerable to predation in the first few months of life (McLennan et al. 2004). Therefore it is important that chicks have enough access to resources to survive to adulthood, when predation pressure is reduced. Investigation into the possibility of chicks having to compete for these valuable resources at this important juncture in their development is required. This theory formed the basis of work carried out by Shapiro (2005) on Ponui Island. Shapiro (2005) conducted an investigation into competition for surface-dwelling invertebrates between ship rats and the chicks of North Island brown kiwi. By analysing faecal samples, Shapiro (2005) found kiwi chicks on Ponui Island were feeding upon both soil and surface-dwelling invertebrates, although soil-dwelling invertebrates formed the majority of the diet. Shapiro (2005) established that the diet of ship rats and kiwi chicks on Ponui Island overlapped in the number of spiders

(Arachnida) weta (Orthoptera) and scarabaeid beetles (Coleoptera) eaten; all are surface litter dwellers. In addition, the percentage of ship rat stomachs and kiwi chick faeces containing earthworms was comparable. However, there was a significant difference between the diet of ship rats and kiwi chicks when total invertebrate diet was compared, due to the large number of soil-dwelling invertebrate larvae eaten by the chicks (Shapiro 2005). Shapiro (2005) concluded that the overlap in diet of surface-dwelling invertebrates may become more important when soil-dwelling larval forms are low in number or not available to kiwi chicks. This could occur during hotter months when soil penetrability decreases and soil-dwelling invertebrates move further down into moister soil areas, outside the probing depth of juvenile kiwi.

Shapiro (2005) found slow growth and low survival rates of chicks on Ponui Island; by the time of this study, only one kiwi chick out of five that were monitored in Shapiro's study remained alive. Shapiro (2005) assigned this low survival and growth rate to a combination of dry weather, fluctuating numbers of soil-dwelling invertebrate prey and possible competition from ship rats and other kiwi for surface-dwelling invertebrates.

With investigation made by Shapiro conducted in 2004/2005 this investigation will continue research into the population of ship rats to assess the scale of potential competition in the subsequent months of 2005.

The severity of competition between ship rats and kiwi would have implications for kiwi populations throughout New Zealand, especially in predator controlled populations. If cat and stoat populations are maintained without controlling rat numbers, there is potential for rats to increase in number in the absence of their main predators, and the competition between rats and kiwi could thus be more intense.

1.5 The need for further investigation

Shapiro (2005) assessed potential competition between ship rats and kiwi chicks by conducting investigations not only into the diet of each species, but also into the density of the ship rat population and into the invertebrate fauna on Ponui Island. Competition between species will be dependent upon the density and distribution of kiwi chicks, ship

rats and invertebrates on Ponui Island. Shapiro (2005) identified possible competition between ship rats and kiwi chicks during one study period encompassing June 2004 to February 2005. Thus continual investigation into possible competition should be carried out to determine the potential significance of competition during subsequent seasons and years. This research has three individual aims, the results of which will further knowledge of ship rat populations on islands and enhance understanding of the scale of potential competition between ship rats and kiwi chicks.

Shapiro (2005) calculated the density of ship rats on Ponui Island during the summer of 2004/2005. Ship rat populations have been observed to undergo seasonal fluctuations in their density (Alterio et al. 1999; Blackwell et al. 2001; Daniel 1972; Harper et al. 2005; King & Moller 1997), and so density estimates from subsequent seasons are necessary. However, the island syndrome hypothesises that rodent populations will be more stable on islands than on mainland areas (Adler & Levins 1994). The effects of this syndrome are thought to increase with increased island isolation and decreased island area (Adler & Levins 1994). Ponui Island is 1770 ha in size and in close proximity to the mainland and other islands, and so it is proposed here that it may behave more like a mainland area than an island in terms of the island syndrome in rodent populations. One aim of this study is to estimate the population density of ship rats in the subsequent winter/spring, after the estimate made by Shapiro (2005) in the same area, and to assess any fluctuations found.

To date no investigation has been made into the home ranges and behaviour of the ship rats on Ponui Island. By radio-tracking a sample of ship rats within the known habitat of radio-collared kiwi the aim is to assess ship rat use of habitat and any overlap with that of kiwi. With ship rats capable of utilising the three dimensional environment, it is crucial to gauge the degree to which this available habitat is used. Kiwi are restricted to the two dimensional habitat, and so habitat usage may only partly overlap that of the ship rat. The degree of arboreality of ship rats reflects the degree to which the two species are foraging in the same manner, as arboreal ship rats will be foraging in the canopy while kiwi are restricted to the ground.

While detailing the invertebrate diet of the ship rats on Ponui, Shapiro (2005) commented on the difficulty of identifying plant material and concluded that the importance of vegetation in the diet of ship rats on Ponui Island cannot be discounted. The final aim of this study is to accurately quantify the proportion of animal and plant material in the ship rat diet as this would have direct effect on the level of competition for invertebrate material between the ship rats and kiwi chicks.

The central outcomes of this investigation are two-fold, resulting from the three individual aims. First, by describing the population dynamics and habitat use of ship rats during a different season to Shapiro (2005), it may be determined whether the population undergoes fluctuations or if it is subject to more stability. The resulting knowledge is then available to aid control and eradication programmes throughout New Zealand. This information may also prove valuable should eradication or control of ship rats on Ponui Island ever be attempted. Second, the information amassed by the complementary investigations, this study and that of Shapiro (2005), will provide a more complete picture of the ship rat population on Ponui Island in terms of their dynamics, diet and habitat use. This information can be used to aid assessment of the degree of potential competition between ship rats and kiwi chicks.

1.6 Research aims

1. To describe the population structure and dynamics of ship rats on Ponui Island.

Using mark-recapture analysis the structure of the ship rat population will be described and the density estimated. By sampling the same population as Shapiro (2005) in a similar manner during subsequent months fluctuations in population density can be realised and reasons for this considered.

2. To describe the home range areas and behaviour of the ship rat on Ponui Island.

By radio-tracking ship rats their home ranges will be calculated and, by radio-tracking within known home ranges of radio-collared kiwi on Ponui Island, any overlap in habitat usage between the two species will be compared. In particular the degree to which the ship rat utilises its three dimensional habitat will be assessed to aid this comparison. Radio-tracking will also be used to observe behaviour, such as sociality and denning habits.

3. To quantify the degree of vegetation in ship rat diet on Ponui Island.

By accurately quantifying the importance of vegetation in ship rat diet on Ponui Island the degree of competition for animal material with chicks of North Island brown kiwi will be assessed. Observations on vegetation in the diet will be compared with those made by Shapiro (2005). Ship rat diet will be compared across three different habitat types in a forest on Ponui Island to assess any differences between.

Finally: to amalgamate the results and so build upon the two central themes of this research. First, by increasing knowledge on the ecology of ship rats on Ponui Island, the degree to which limited resources are in demand and thus the scale of competition between ship rats and kiwi chicks will be better understood. Second, by aiding our understanding of island ship rat population dynamics further information will be available for use when designing ship rat management strategies.

2

Population dynamics of ship rats (*Rattus rattus*) on Ponui Island

Abstract: The density of ship rats (*Rattus rattus*) was estimated within a section of podocarp-broadleaf forest on Ponui Island in winter and spring. Ship rats were live-trapped for six days each month for five consecutive months, July to November 2005, and individually identified. Mark-recapture data was analysed using the programmes DENSITY and MARK, with closed-capture models, to estimate population parameters and density for each month. Ship rat densities within the study site ranged from 6.73 ± 4.23 rats/ha to 22.43 ± 5.23 rats/ha between July and October 2005. Estimates for November failed to run due to a reduction in trapping success. Densities in this study were higher than those previously estimated in the same area for the previous summer. Densities estimated on Ponui lend support to the island syndrome hypothesis that rodent populations on islands are higher in density than those on mainland areas. However, the fluctuation in density observed between seasons contradicts one element of this theory, that rodent populations on islands are more stable. This is thought to be due to the relatively large size of Ponui Island and its proximity to the mainland. Difference in density between seasons is attributed to recruitment after the breeding season. The increase in ship rat density in this study implies potential competition between ship rats and the chicks of resident North Island brown kiwi (*Apteryx mantelli*) could be more intense on Ponui Island during this time.

2.1 Introduction

Population density is the parameter of greatest interest to biologists studying population dynamics (Efford 2004). However, absolute density of animal populations, and in this case ship rat populations, can be difficult and time consuming to measure, and so few estimates exist (Innes 2005). To date, studies suggest a pattern for higher densities of ship rats on New Zealand's offshore islands than on the mainland (Table 2.1). The density of ship rats on two islands, the Shiant Islands and Goat Island yielded quite different density estimates during different years of study (Craig 1977; Key et al. 1998; MacKay & Russell 2005; McDonald et al. 1997). Differences in the methods utilised or fluctuations in the population could account for this variation.

The density of ship rat populations can be irruptive, with fluctuations attributed to a range of environmental parameters. The combined effects of predation by feral cats (*Felis catus*) and changes in abundance of food supply are the two most important factors affecting the density of ship rats in the Orongorongo valley (Daniel 1972). Ship rat numbers increased after heavy seed-fall in *Northofagus* beech forests (Alterio et al. 1999; King & Moller 1997) and after heavy rimu (*Dacrydium cupressinum*) mast seeding on Stewart Island (Harper et al. 2005). Modelling ship rat population dynamics highlighted the importance of variation in food availability in determining the timing and amplitude of ship rat population irruptions (Blackwell et al. 2001). Modelling also indicated predators cannot prevent a prey-species irruption, due mainly to intrinsic differences in reproductive rate, but that predation can delay the onset of prey-population increase during irruption events (Blackwell et al. 2001).

Seasonal breeding of ship rats in New Zealand can account for fluctuations in the population density. Ship rats have a high fecundity with a short gestation period and a capacity for large litters (Innes 2005). However, in the Orongorongo valley Daniel (1972) found the average production of the population was roughly only 10.9 young per female per year. On Rangitoto Island Miller and Miller (1995) recorded ship rats with a mean of seven embryos and a mean number of 7.4 ± 1.2 uterine scars. The annual disappearance rate of ship rats in the Orongorongo valley exceeded 90% for both males

and females, with the maximum longevity recorded being 11 months for a male and 17 months for a female (Daniel 1972). Disappearance is the term used for marked individuals that cease to be re-caught in repeated live-trapping sessions; this could be due to death or emigration. Seasonal breeding, when linked with a pulse in recruitment, could result in corresponding seasonal fluctuations in density.

The importance of the influence of seasonal breeding, food availability and predation on a population is evident in the planning of current conservation strategies for endangered flora and fauna pursued by the New Zealand Department of Conservation (DoC). DoC has designated certain offshore islands as remote habitats within which the conservation of endangered flora and fauna can be encouraged by pest eradication operations. Innes et al. (1995) stated that even when rat densities are decreased by 90% in control operations, they could recover in two to five months. The design of operations has been crucial to maximise potential benefits and minimise costs, and is facilitated by accurate knowledge of the population dynamics of the pest species in question. With this knowledge control operations can be enhanced by influencing the placement and number of traps to maximise trap success, and by dictating the timing of trapping to avoid the breeding season when young can easily avoid detection by trapping efforts, or by coinciding with peaks in populations so as to maximise kill rates. With greater understanding of ship rat population dynamics the recovery of a population after control could be predicted and perhaps prevented. This study aims to add to the body of knowledge on ship rat populations in New Zealand, by describing the population dynamics of ship rats in native forest on an offshore island.

Table 2.1 Ship rat density estimates from previous studies on mainland New Zealand and its offshore islands. After MacKay and Russell 2005.

	Location	Season	Density (rats/ha)	Source
Mainland	Orongorongo valley	29 month mean	1.7	Daniel (1972)
	Puketi forest, Northland	Spring	2.9	Dowding and Murphy (1994)
	Rotoehu forest, Bay of Plenty	Summer	6.2	Hooker & Innes (1995)
	Kaharoa forest, Bay of Plenty	Summer (January)	4.8	Brown et al. (1996)
	Lake Waikaremoana	Winter (June)	8.22	Blackwell (2000)
Island	Haulashore Island	Not recorded	25-50	Taylor (unpubl.)
	Halfmoon bay, Stewart Island	Winter (August-September)	2-2.5	Hickson et al. (1986)
	Goat Island	Autumn (May)	12-20	Craig (1977)
	Goat Island	Autumn-Winter (April-June)	3.3	MacKay and Russell (2005)
	Motutapere Island, Coromandel	Autumn (April)	4.7	MacKay (2005)
	Tawhitinui Island, Marlborough Sounds	Autumn (May)	2.6	MacKay 2005
	Shiant Islands, Hebrides	Spring (May)	12	McDonald et al. (1997)
	Shiant Islands, Hebrides	Summer (July)	22-85	Key et al. (1998)

2.1.1 *The island syndrome in rodent populations*

Populations of rodents on islands often differ when compared to mainland populations in terms of demography, reproduction, behaviour and morphology (Adler & Levins 1994). Adler and Levins (1994) referred to this phenomena as the *island syndrome*, with the result being higher and more stable rodent population densities on islands. Initial density estimates for Goat Island (12-20 rats/ha) and Haulashore Island (25-50 rats/ha), 9.3 ha and 6 ha in size respectively (Craig 1977, Taylor unpubl.), reflect this phenomenon.

Population density is predicted to increase with increasing island isolation and decreasing island area (Adler & Levins 1994). Island isolation has a direct effect upon population density in that it limits dispersal, as increased isolation results in reduced dispersal sinks. Increased island isolation leads to a more sedentary lifestyle for the rodent population in question as immigration and emigration are reduced, thus social stability, neighbour familiarity and kin recognition is increased, and aggressive interactions are decreased. It is theorised that this in turn will lead to higher and more stable population densities (Adler & Levins 1994).

The effect of area on population density is less direct. Adler and Levins (1994) hypothesise that the low intensity or absence of density depressing factors, chiefly predation, is primarily responsible for the area effect, as islands are proposed to have less diverse assemblages of predators. Predators, especially mammals, maintain areas as effective dispersal sinks since they remove dispersing animals permanently from a population (Tamarin 1978). Thus, with a reduction in predation, animals dispersing into marginal habitats may later return to the main population since they were not permanently removed. As island area increases, predators, competitors and habitat structure increases in diversity, resulting in decreased density (Adler & Levins 1994).

It might be expected the ship rat population on Ponui Island display components of this island syndrome. However, Adler and Levins (1994) note that not all island

populations exhibit all elements of the island syndrome and that some populations show mixed traits. Ponui Island is a 1770 ha island approximately 3 km from the mainland and in close proximity to neighbouring Waiheke, Pakihi and Rotoroa Islands. Thus, any components of island syndrome exhibited by the ship rat population may not be as marked on Ponui Island due to its low degree of isolation and fairly large size. This chapter aims to estimate the density of ship rats on Ponui Island during winter and spring and compare that with estimates in the same area made in the previous summer. If the ship rat population conforms to the island syndrome hypothesis it might be expected that the population on Ponui Island is more stable and the fluctuations in density noted in ship rat populations may not apply.

2.1.2 *Ship rats on Ponui Island*

Shapiro (2005) conducted mark-recapture analysis from December 2004 to February 2005 on Ponui Island, giving monthly estimates of 10.20 rats/ha, 9.44 rats/ha and 6.04 rats/ha respectively. These densities are high when compared to those of mainland populations with only two density estimates of mainland populations falling within this bracket, 8.22 rats/ha estimated at Lake Waikaremoana (Blackwell 2000) and 6.2 rats/ha in Rotoehu Forest (Hooker & Innes 1995) (Table 2.1). The densities estimated by Shapiro (2005) support the island syndrome hypothesis that rodent densities are higher on offshore islands. With mark-recapture taking place only in the summer months it is necessary to conduct similar analysis of the ship rat population during subsequent months, to generate a more informative representation of the population dynamics of the ship rats. This is important to clarify whether the population on Ponui Island undergoes fluctuations in density similar to those reported by previous studies, or whether the population is more stable as hypothesised by the island syndrome.

2.1.3 *Implications for kiwi*

Shapiro (2005) identified overlap in the surface-dwelling invertebrate diet of North Island brown kiwi (*Apteryx mantelli*) and ship rats on Ponui Island, thus potential for competition between these two species exists. The degree of competition between kiwi chicks and ship rats on Ponui Island will be dependent on the population density of both

species. A higher density of rats leads to kiwi chicks sharing available feeding habitat and prey with higher numbers of potential competitors.

Shapiro (2005) estimated high densities of ship rats on Ponui Island from December 2004 to February 2005. The seasonal breeding of ship rats may cause corresponding changes in density, with numbers increasing following breeding. Numbers of ship rats may thus be low in spring and early summer reaching a peak in autumn (Innes 2005). Shapiro's estimates of density, while high, may underestimate the potential density ship rats can reach on Ponui Island. North Island brown kiwi chicks suffer intense predation for their first four months of life or until they exceed 800 g in weight (McLennan et al. 2004). With chicks hatching in summer months, they may not reach this 'safe weight' until at least mid-autumn or later, during a time that perhaps coincides with peak numbers in their potential competitor. A low growth and survival rate has been reported for kiwi chicks on Ponui Island (Shapiro 2005, I. Castro pers. comm.), thus this interference from ship rats may have greater impact upon kiwi chicks on Ponui Island.

This study aims to examine the ship rat population during months subsequent to those investigated in Shapiro's study to ascertain the degree of fluctuation in the population density. The degree to which the population is subject to the components hypothesised by the island syndrome will also be observed.

2.1.4 Chapter aims

The aim of this chapter is to quantify the density of ship rats on Ponui Island during five consecutive months from the end of winter through spring 2005, a period where data from Shapiro (2005) is absent. Density will be estimated using mark-recapture analysis of live animals in the same area and in a similar manner to that of Shapiro (2005) to enable comparison between results and any fluctuations in the population to be investigated. A more informative representation of the ship rat population dynamics on Ponui Island will then be achieved, and the degree to which the ship rat population complies with the hypothesised island syndrome will be assessed.

Results from these analyses will then be used to assess the degree of potential competition between ship rats and North Island brown kiwi chicks. Seasonal fluctuations in ship rat density may have corresponding effects upon the degree of potential competition existing between these two species.

2.2 Methodology

2.2.1 Study sites

The study site was located on Ponui Island in the Hauraki Gulf (36°55'S, 175°11'E), a privately owned island that is thought to have one of the highest densities of North Island brown kiwi in New Zealand (Miles & Castro 2000). A patch of mixed podocarp-broadleaf forest about 1.5 km² in size, composed of four main gullies, contains 36 adult kiwi and up to five kiwi chicks at one time, with transmitters attached that have been monitored by the Ponui Island Research Programme since March 2004.

Two main gullies within this area were used for this research, the first known as red stony hill gully (RSHG) and, immediately adjacent to that, pipe gully (PG) (Plate 2.1).

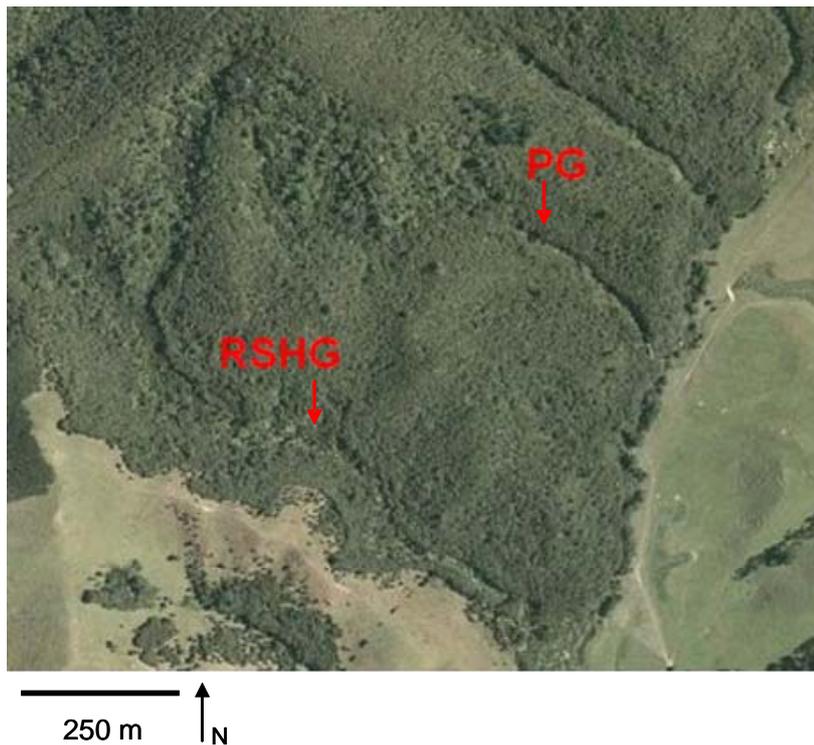


Plate 2.1 Aerial photograph of the two gullies used for live (PG) and kill (RSHG) trapping on Ponui Island. Image supplied by I. Castro.

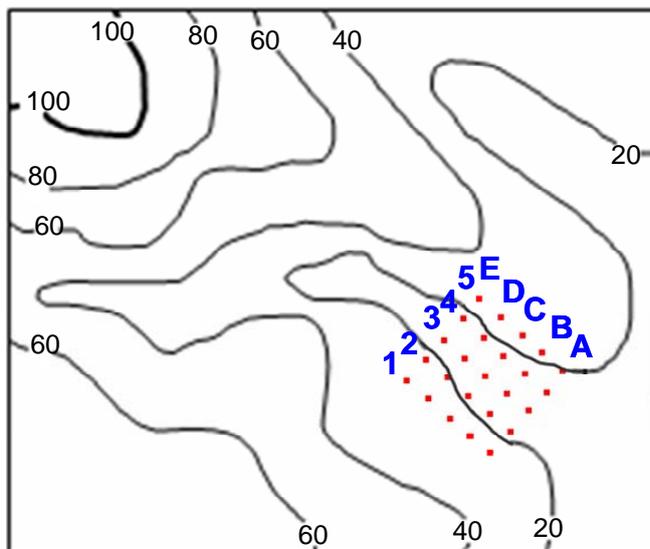
Three main habitats were identified within PG and RSHG. The first habitat was swamp, dominated by raupo (*Typha orientalis*) and located throughout the base of each gully. This bordered onto pasture with a kanuka (*Leptospermum ericoides*) canopy and *Coprosma arborea* with occasional lancewood (*Pseudopanax crassifolius*) subcanopy and an understorey of mingimingi (*Leucopogon fasciculatus* & *Cyathodes juniperina*). Moving up into each gully basin was the forest habitat. This habitat was mixed podocarp-broadleaf forest with a relatively sparse understorey, but dense sub-canopy and canopy. Species such as taraire (*Beilschmiedia tarairi*), pohutukawa (*Metrosideros excelsa*), puriri (*Vitex lucens*), and kanuka (*Leptospermum ericoides*) were found in this habitat type. Finally on the ridge of gully was scrub habitat, dominated by kauri with occasional *Coprosma arborea*, Mapou (*Myrsine australis*) and mingimingi (*Leucopogon fasciculatus* & *Cyathodes juniperina*). A full description of the vegetation in each habitat is given in Chapter 4.

The forest habitat of PG within the gully basin was chosen as the area of live trapping as it was the site used for the same purpose by Shapiro (2005). Thus the same area trapped by Shapiro (2005) during December 2004 to February 2005 was re-trapped in this study from July 2005 to August 2005, so enabling comparisons between results. Shapiro constructed a grid of 5 x 8 live traps with 25m spacing and was assisted with the checking of traps and handling of animals. In this study a grid of 5 x 5 traps with 25m spacing was constructed due to the limitations of one person covering all traps within a time frame that considers the welfare of trapped animals.

2.2.2 *Live-trapping*

A live-trapping grid was set up within the forest habitat of PG using Tanaka (Tanaka wire netting works Co. Ltd., China) brand live traps; dome-shaped wire cages with a spring loaded door triggered by a bait hook (Plate 2.2). A length of PVC piping was placed inside the traps to minimise the animals' exposure to the elements while contained. Twenty-five live traps were laid out in a grid, with five traps in a row and five rows in total, covering a one hectare area. Traps were spaced at 25 m intervals and set along fixed bearings to ensure equal spacing. Each trap in each row was labelled 1

to 5 with each row identified by a letter from A to E. Thus individual traps could be identified by x and y coordinates such as A1 and so on up to E5. The middle row of traps, row number 3, was placed along the gully floor with the rows either side (1 & 2, and 4 & 5) moving up the slopes of the gully towards more scrub-like vegetation (Plate 2.2).



(a)

(b)

Plate 2.2 (a) Map of the ship rat study site in PG with altitude contours indicating the layout of the grid in relation to the gully. Red squares depict the grid of 5 x 5 live traps spaced 25 m apart, with numbers and letters indicating their coordinates. (b) Tanaka brand live trap in position A3 within the trapping grid on the forest floor in PG. Photo by author.

Initially traps were left for two nights pre-baiting to acclimatise rats to the traps' presence. Traps were then baited with a mixture of peanut butter and rolled oats and left overnight. Traps were checked early the next morning and any rats caught underwent the procedure described below. Upon clearance, traps were then re-baited for the next night. Trapping was carried out for five consecutive monthly sessions between July 2005 and November 2005. Within each session all 25 traps were set for

six nights, so providing an equal trapping effort per month for five consecutive months, with 750 trapping nights in total.

During August a few rats died in cages due to particularly cold and wet weather, regardless of the presence of the PVC piping. Thus in September traps were covered with plastic sheeting to provide relief for caged animals.

2.2.2.1 *Rat handling procedure*

Traps containing rats were identified by their unique coordinates. Rats caught were run from the cage into a closed transparent plastic bag for the administration of an anaesthetic. Anaesthesia was delivered using a glass bottle, containing isoflurane, with two tubes leading out of it. One of these tubes was connected to a blood-pressure type hand-pump, while the other was fed into the sealed bag that held the rat. The hand pump was squeezed approximately six to ten times to generate gaseous bubbles in the liquid isoflurane, thus forcing anaesthetic down the second tube into the bag containing the rat (Plate 2.3). The rat was exposed to the isoflurane for approximately 30 seconds until it was deemed anaesthetised, by the cessation of struggling and/or closure of the eyes.

Rats were removed from the bag and immediately checked for respiration and pulse. Individual rats were then marked with ear tags (No.1 ear tags, Department of Conservation, Wellington). Tags were individually stamped with a prefix and a three digit number to allow for individual identification of each animal. Animals were then sexed, their colour morph noted, and non-surgically assessed for health (pelage condition, tail and ear condition and presence of ectoparasites). The maturity of the animal was then assessed after Cunningham and Moors (1993); a male rat with scrotal testes was deemed mature. Likewise a female with perforate vagina was considered mature. However external characteristics can be misleading when assessing maturity. For example male rats may actually be 'mature' without exhibiting scrotal testes (J. Innes pers. comm.) and a perforate vagina is not a reliable sign of maturity in females (Innes et al. 2001). Thus kill-trapping was also carried out to determine maturity through necropsy (see Section 2.2.3). Females were also judged for external signs of

pregnancy and/or lactation. Animals were subsequently placed in a small, transparent zip-lock bag and weighed using a 300 g Pesola scale (PESOLA AG, Switzerland), with the weight of the bag subtracted from the total to achieve the weight of the rat. It was noted at the time whether the animal was wet, moist or dry as this could affect the measured weight. Morphological measurements were then attained using a mounted head-body 30 cm metal ruler (Plate 2.3). The head-body length (HBL) and tail length (TL) was recorded for each rat. Upon completion of the assessment of each rat, the animal was placed back in the cage with some peanut butter/oat bait and monitored until deemed fit for release, having overcome the anaesthetic. Animals were released at the point of capture and watched until leaving line of sight.



Plate 2.3 Anaesthetising a ship rat with isofluorane and measuring the HBL of an anaesthetised ship rat. Photos by W. Hojem.

Rats that were quick to recover from the anaesthetic during each capture were sometimes placed back in the bag and anaesthetised for a second time, as was considered necessary for the completion of the handling procedure.

Upon consecutive recaptures of individual rats over the five months, the same procedure was carried out exactly so that any changes in the animal's condition could be tracked through successive measurements.

All handling of live animals was approved by the Animal Ethics Committee of the University of Auckland, protocol R385. Use of isofluorane was approved by the University of Auckland Animal Welfare Office, IDAO permit I385.

2.2.3 *Kill-trapping*

In addition to live-trapping, rats were also caught in kill traps to reveal their reproductive status through necropsy. Kill-trapping was conducted in RSHG, the gully adjacent to PG. Kill trapping was conducted in this gully to ensure exclusion of tagged animals used for mark-recapture in the live trapping area. Results from ship rat studies in both gullies were combined when discussing the ship rat population on Ponui Island, thus it was assumed that no differences exist between ship rats from the two gullies. Kill-trapping was carried out in the three identified habitats running through RSHG (Plate 2.4) for four months between August and November 2005. Seven traps were laid 25 m apart in a straight line directly adjacent to swamp at the bottom of the gully. A trap line of seven traps spaced 25 m apart was also laid along the gully basin in the forest, and the third trap line of seven traps spaced 25 m apart placed up on the ridge of the gully in scrub habitat. Trapping was carried out in these areas due to the need for stomach samples from each of the three distinct habitats (Chapter 4). Standard Victor snap-traps (Pest Management Services, Waikanae) were baited with a mixture of peanut butter and rolled oats for six consecutive nights per month or until at least five animals had been caught from each of the three habitats per month, as this was the sample size judged necessary for stomach analysis. Traps were covered by a rectangular wire mesh cage (31 cm long x 18 cm wide x 12 cm high) with a small square opening (7 cm x 7 cm) to reduce capture of non-target animals. Traps were tied to adjacent vegetation with string to prevent their removal by injured rats. Traps were checked the next morning after every trapping night.

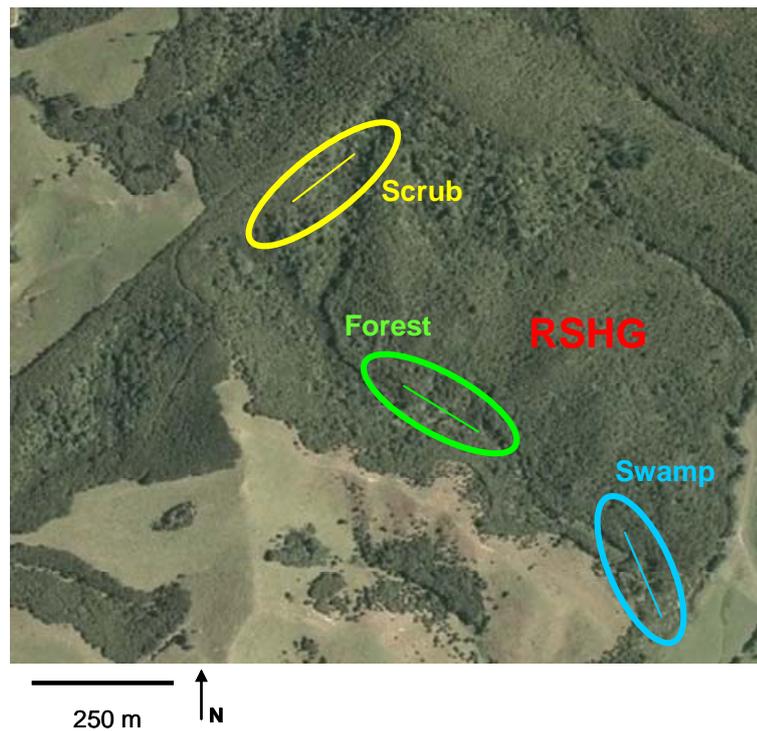


Plate 2.4 Aerial photograph of RSHG, identifying the three habitats where kill-trap lines were placed; swamp (blue), forest (green) and scrub (yellow). Image supplied by I. Castro.

Upon recovery, dead animals were sexed and their maturity and colour morph noted using the same procedure as for the live animals. Animals were then weighed and their HBL and TL measured as described above. Upon dissection male rats were inspected for scrotal testes, and as a more reliable form of indicating maturity, whether or not epididymal tubules in the testes were visible. The reproductive tract of female rats was removed and inspected for signs of maturity. The condition of the uterus was identified as being either quiescent with pale uterine horns or enlarged with thicker, pinker uterine horns that were noticeably infused with blood vessels. The ovaries were also inspected in the same way, whether or not they were red and infused with blood vessels. Quiescent uteri could either be mature or immature, but enlarged uteri associated with ovarian activity were classed mature (Innes et al. 2001). Finally, the uterine horns were checked for the presence of placental scars. These are visible to the naked eye as small black spots on the uterine wall that fade to a brown/grey colour with time. Females that

had bred at some time in their lives were defined by pregnancy, lactation or the presence of uterine scars (Innes et al. 2001).

2.2.4 *Statistical analysis*

Ship rat population density was calculated using the programme DENSITY 3.3 (Efford 2005). The software uses the method devised by Efford (2004) to estimate density from closed population capture-recapture data, using inverse prediction. The method fits a spatial model of animal trapping. The probability that an animal is caught in a trap at a given distance r from its home-range centre is assumed to follow a 2-parameter spatial detection function $g(r)$, half normal with parameters g_0 (detection probability when $r = 0$), and σ (the spatial scale of movements), when there is no competition from other animals. Range centres are assumed to follow a Poisson distribution with a density of D . The model then estimates D , g_0 and σ jointly from the trapping data. The locations of home range centres are unknown so trapping does not provide a sample of distances r . However, the mean distance between recaptures of marked individuals (d) does provide information on the scale of movements, σ , and information on D and g_0 is contained in conventional capture-recapture statistics (Efford et al. 2005). The relationship between the parameters and statistics from simulated samples is described by fitting a linear model. The model is then inverted and applied to statistics from the field sample, hence inverse prediction (Efford 2004). In this way population density may be inferred from closed population capture-recapture data without the need to estimate effective trapping area (ETA).

DENSITY analyses each session separately as closed populations and so five density estimates were calculated, one for each month of live trapping. Individual rats encountered within each session were regarded as initial captures regardless of any captures in previous sessions.

The main assumptions of DENSITY are that the population is closed, that is there are no births, deaths or dispersal events during a trapping session, and that capture does not affect the pattern of movement of an animal within a trapping session. DENSITY also assumes that an animal's home range does not alter during a trapping session. Losses

on capture (animals that die during a closed-population trapping session), are dropped from the analysis but the number of lost animals was added back to the final estimate as advised by Otis et al. (1978).

The software requires a trap layout file and capture history file to calculate density. Trap layout and inter-trap distance is given in the form of x and y coordinates. The capture history file lists all capture events, with each individual rat's capture listed along with the session I.D., trap I.D. and day I.D. of capture. A buffer zone is then incorporated into the simulation which is the zone outside the trapping grid containing rats that are within range of being trapped.

Estimates for population parameters were then calculated using the programme MARK v4.2 (White 2001). Population size, inter-session survival probability, and capture and recapture probabilities were estimated. A robust design, closed captures model was used from which MARK estimates parameters from capture histories of all individuals, given in the form of a binary code sequence (e.g. 101 = capture, no capture, capture). Population size is the only parameter both MARK and DENSTY estimate. Although density is the main parameter of interest in this study, the probabilities of capture and recapture are of interest when analysing the trapping rates observed.

Each month of live-trapping is termed a session in DENSTY and MARK, with July the first session and November the fifth and final.

The statistical software package JMP 5.1 (2003) was used to carry out univariate analyses of variance (ANOVA) to examine differences in weights, head-body lengths and tail lengths between sex and colour morph of ship rats caught. Differences in ship rat catch rates according to trap placement were also analysed using univariate ANOVA in JMP 5.1 (2003). Chi square (χ^2) analyses were used to analyse the observed sex ratio and proportion of colour morphs found in the trapped sample.

2.3 Results

2.3.1 *Population demographics*

After six consecutive days of live trapping per month, over five consecutive months (750 trap nights), a total of 70 individual ship rats were caught in PG. Of these 70 individual ship rats, 43 (61%) were subsequently recaptured at least once. In total, when including initial catches and all subsequent recaptures, 183 capture events took place. Twenty-five rats were caught only once despite re-trapping efforts; this excludes one rat caught on the final night of the last session and one rat that died upon initial capture, and so were unavailable for recapture. Of the 70 rats caught 39 (56%) were male and 31 (44%) female giving a 1:1.26 ratio of males to females (with Yates' correction for continuity, $\chi_1^2 = 0.7, p > 0.05$). The 43 recaptured rats were composed of 25 male (58%) and 18 female (42%) (with Yates' correction for continuity $\chi_1^2 = 0.8, p > 0.05$). Of the 25 rats that evaded recapture, 13 (52%) were male and 12 (48%) female. Only two of the three colour morphs of ship rat found in New Zealand were caught in live traps, 44 (63%) of the total catch were frugivorus and 26 (37%) alexandrinus. This is a significantly higher number of frugivorus morph rats than alexandrinus ($\chi_1^2 = 4.12; p < 0.05$).

2.3.2 *Trapping success*

Trapping success was high during the first two trapping sessions with a peak of 15 rats caught in one night, but declined over the last three sessions to two or three rats being caught per night in November (Figure 2.1). Of the 70 individual rats caught over all trapping sessions, 79% were caught within the first two months; the number of new individuals caught was exceeded by the number of recaptures of marked individuals by the end of the first session in July, indicating that most of the population had been trapped by this time.

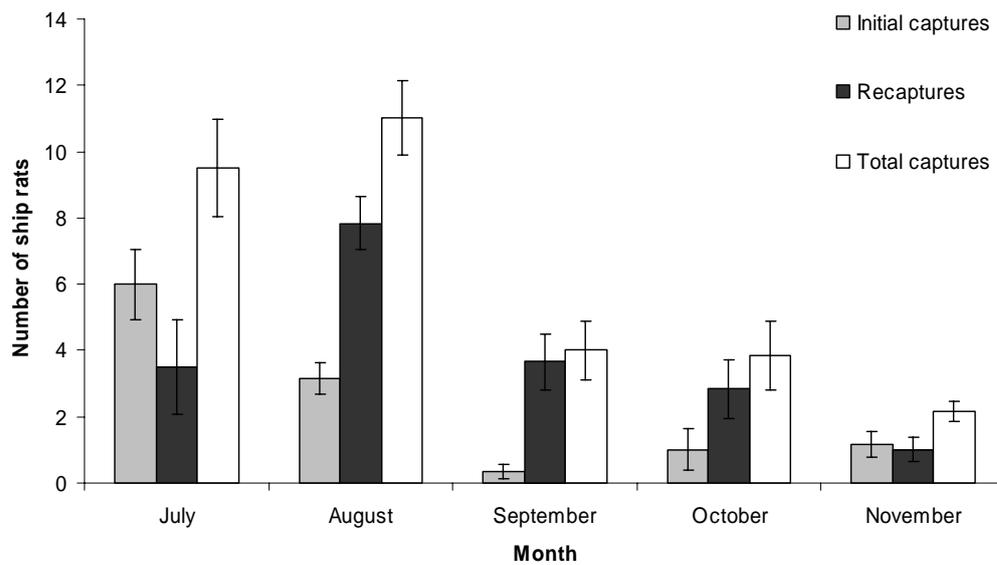


Figure 2.1 Average initial captures, recaptures and total captures of ship rats for six nights of trapping, during each of the five monthly trapping sessions (July to November 2005), including \pm one standard error. Each session is not treated independently here so that after initial capture any rat caught was considered a recapture thereafter, regardless of session.

The total number of rats caught over all trapping sessions varied according to trap placement. Trap line 3, running along the gully floor caught the least number of rats (Figure 2.2). The number of rats caught increased with traps placed adjacent to trap line 3, moving up the slope of the gully. That is, trap lines 1 and 5, running along the near-top of the slope either side of the gully floor caught the most ship rats over all trapping sessions. However, despite this trend, no significant difference was found in the number of rats caught according to trap placement ($F_{4,20} = 1.6614, p > 0.05$).

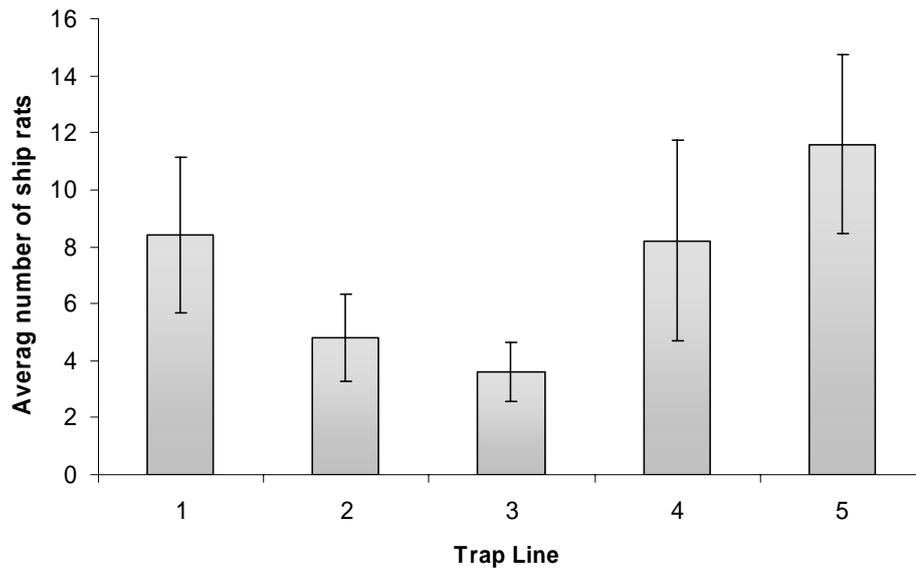


Figure 2.2 Average number of rats caught over all monthly sessions, \pm one standard deviation, according to trap placement. Trap line 3 ran along the floor of PG while adjacent lines ran up the slope either side with lines 1 and 5, the outside lines, running along the near-top of the slope in more scrub-like vegetation.

2.3.3 *Ship rat morphometrics*

The mean weight, head-body lengths and tail lengths of all rats caught in live traps from July to November 2005 fall within the ranges of ship rat morphometrics previously recorded elsewhere in New Zealand (Innes 2005) (Table 2.2).

Male ship rats were, on average, longer and heavier than females. However, no significant differences were found between the weights of males and females ($F_{1,66} = 1.70, p > 0.05$), likewise, head-body lengths ($F_{1,66} = 2.55, p > 0.05$) and tail lengths ($F_{1,66} = 0.12, p > 0.05$) were not significantly different between the sexes. However, frugivorous ship rats were significantly longer ($F_{1,66} = 4.93, p = 0.029$) and heavier ($F_{1,66} = 6.27, p = 0.0147$) than alexandrinus ship rats. No significant difference in tail length was found between colour morphs ($F_{1,66} = 2.14, p > 0.05$).

Table 2.2 Mean weights, head-body lengths (HBL) and tail lengths (TL), including ranges, of male and female ship rats live-trapped from July to November 2005. Numbers exclude two rats caught that escaped before measurements could be made.

Sex	N	Weight (g)		HBL (mm)		TL (mm)	
		Mean ± S.D.	Range	Mean ± S.D.	Range	Mean ± S.D.	Range
Male	38	145 ± 28	95-212	175 ± 15	145-206	202 ± 17	130-231
Female	30	136 ± 31	73-175	168 ± 19	124-202	205 ± 12	179-227
Total	68	140.80 ± 29.67	73-212	172.02 ± 16.97	124-206	203.24 ± 14.61	130-231

2.3.4 Density

Population density estimates calculated using DENSITY were similar within the first two sessions and the third and fourth sessions, with the latter two sessions being lower (Table 2.3). The model failed at estimating a density and other parameters for the fifth and final session, most likely due to the small number of recaptures in that month (M. Efford, pers. comm.).

Table 2.3 Estimated densities of ship rats within the study area for the four sessions, including population size of ship rats within effective area trapped (ha) as given in DENSITY.

Session	Month	Density \pm S.E (rats/ha)	Population size \pm S.E.	Effective area trapped (ha)
1	July	22.43 \pm 5.23	49.00 \pm 6.46	1.844
2	August	16.19 \pm 3.80	37.00 \pm 2.93	2.132
3	September	6.73 \pm 4.23	18.00 \pm 3.15	2.132
4	October	11.19 \pm 5.03	19.00 \pm 3.45	1.141

Population sizes for each session as calculated by MARK were similar to those calculated by DENSITY (Table 2.4). MARK does not give estimates for effective area trapped. The population size calculated by MARK is assumed to be the size in the effective area trapped as given in DENSITY (Table 2.4), as the same capture history was analysed by both programmes. Probability of initial capture was grouped together for all sessions in MARK so that only one estimate resulted. Probability of recapture was similar for the first two sessions, though decreased for the third and fourth sessions. Probability of recapture for the fifth and final session was very low. This pattern of reduced recapture probability can be explained by the decreasing trapping success and

consequent reduction in number of recaptures seen throughout subsequent sessions (Figure 2.3). Inter-session survival is similar between the first four sessions, but drops between the fourth and fifth session, both these effects are due to the marked reduction in trapping and number of recaptures in the final session.

Table 2.4 Population size of ship rats as estimated using MARK per session, including inter-session survival, capture (p) and recapture probability (c).

Session	Month	Population size \pm S.E.	Survival	Probability of initial capture (p)	Probability of recapture (c)
1	July	48.8 \pm 6.43	0.55 \pm 0.1	0.20 \pm 0.35	0.22 \pm 0.04
2	August	44.7 \pm 6.02	0.59 \pm 0.1	0.20 \pm 0.35	0.27 \pm 0.04
3	September	20.0 \pm 3.41	0.46 \pm 0.13	0.20 \pm 0.35	0.13 \pm 0.04
4	October	20.0 \pm 3.41	0.32 \pm 0.14	0.20 \pm 0.35	0.15 \pm 0.05
5	November	14.6 \pm 2.79		0.20 \pm 0.35	0.06 \pm 0.04

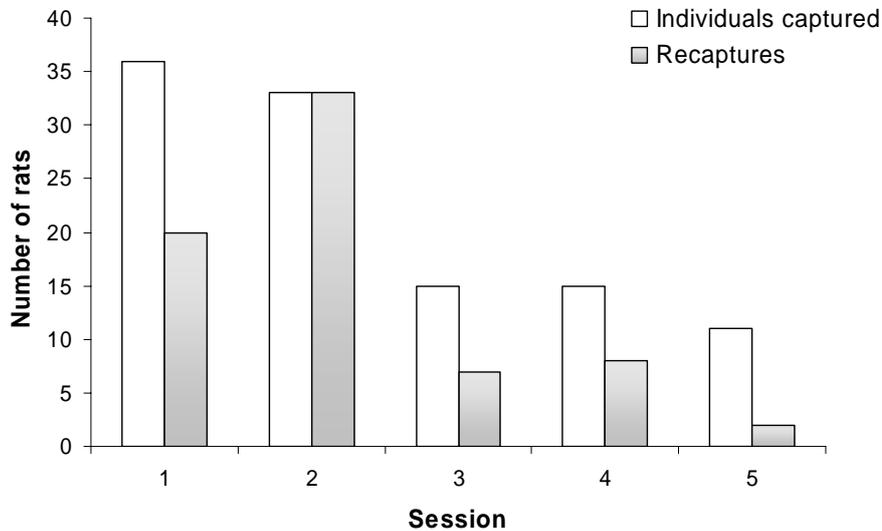


Figure 2.3 Number of individual rats caught in each monthly capture session (July to November 2005) and subsequent number of recaptures. Each session is independent so that a rat caught for the first time in a session is an individual regardless of capture history in previous sessions. Sessions were treated as independent in DENSITY and MARK analysis.

2.3.5 *Breeding season of population*

No pregnant or lactating females were caught in live or kill traps between July 2005 and November 2005. Thus trapping did not coincide with the breeding season of ship rats on Ponui Island. All but four rats caught over all sessions were classed as mature, two immature rats were trapped in July, one in August and the other in September. All were female. However, assessing maturity in live animals can be misleading (Innes et al. 2001) and thus only results from kill-trap animals were used to assess breeding condition.

In total 49 rats were caught in kill traps from July to August 2005. Of these 49 rats 33 were of the frugivorus morph, 15 alexandrinus, and one rattus morph was trapped.

There were significantly more frugivorous species in this sample than the other colour morphs, with rattus morph being in the minority ($\chi^2 = 31.6, p < 0.01$). Coupled with the distribution of colour morphs in the live-trapping sample, frugivorous morphs are most common on Ponui Island, followed by alexandrinus, with rattus morphs being quite rare. The total number caught in kill traps comprised 28 male rats and 21 females, giving a male to female ratio of 1:1.3 (with Yates' correction for continuity, $\chi^2_1 = 0.734, p > 0.05$).

The rate of kill-trapping success declined markedly from August to November (Figure 2.4). The quota of five rats each month from each habitat was chosen as this sample size was considered feasible to analyse for stomach content (Chapter 4) in the allocated time. However, despite trapping efforts being extended in October and November for four more nights, no rats were caught in the scrub habitat and in November only one rat was caught in the swamp and two rats in the forest. Kill-trapping was most successful in the forest with the most number of rats caught there each month.

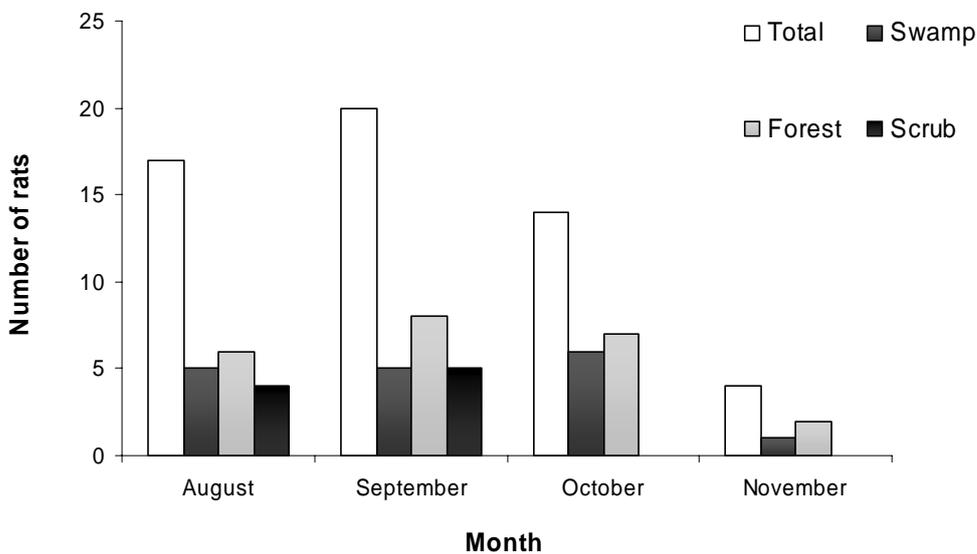


Figure 2.4 Total number of rats kill-trapped between August and November 2005 and numbers caught within each habitat type, swamp, forest and scrub.

All males were found to be mature, with visible epididymal tubules. Of the 21 females, four were excluded from uterine inspection due to the sample being accidentally discarded before analysis was made. Only four of the remaining 17 female rats exhibited uteri that were pale and quiescent with no uterine scars. These rats could be mature or immature. The remaining female rats (76%) possessed enlarged uteri associated with ovarian activity and were thus regarded as mature. Five of these 13 mature females (38%) possessed visible placental scars indicating breeding at some point in their lives (Table 2.5).

Table 2.5 Number of placental scars in each of the five female rats including date caught.

Female rat I.D.	Date caught	Number of placental scars
10	23.08.05	5
17	19.09.05	4
21	19.09.05	16
32	03.10.05	3
36	02.11.05	6

2.3.6 *Survival*

Shapiro (2005) conducted live-trapping within the same area of PG for three consecutive months from December 2004 to February 2005. During this time 49

individual ship rats were caught and marked. Shapiro conducted some kill-trapping in this area post live-trapping sessions, resulting in 40 of the original 49 marked ship rats remaining alive in the area at the end of the study (L. Shapiro pers. comm.). Between July and October 2005 eight ship rats individually marked by Shapiro were caught in live traps in PG. Thus 20% of the individuals marked by Shapiro were re-caught in this study, four months later. All eight rats were mature and over 100 g in weight when initially trapped. All, bar one, were found to have increased in weight and head-body length over autumn and the beginning of winter (between February 2005 and July/October 2005) (Table 2.6).

Table 2.6 Weight of ship rats individually marked by Shapiro while live trapping, between December 2004 and February 2005, and average weight when re-caught in this study between July 2005 and November 2005. One ship rat is excluded as the original weight measured by Shapiro was not available.

I.D. number	Weight (g) Shapiro study (2005)	Weight (g) this study	Weight difference (g)	Month last caught (Shapiro study: 2004/2005)	Month first caught (this study: 2005)
98	145	166	21	February	July
72	165	169	4	February	July
67	150	130	-20	February	July
69	160	185	25	January	July
32	110	157	47	December	July
28	150	175	25	January	August
33	170	173	3	February	August

Between July and November 2005, 18 of the 70 rats caught in this study died. This was due to either poor weather conditions or accidental deaths caused by trap doors collapsing onto the rats during live-trapping. These deaths were taken into account when analysing the data with DENSITY and MARK.

2.4 Discussion

The estimated ship rat density of 6.73 to 22.43 rats/ha is higher than most estimates for mainland ship rat populations, but in accordance with estimates calculated for other offshore island populations. Only one estimate of ship rat density recorded on the mainland falls within range of densities in this study; Blackwell (2000) estimated 8.22 rats/ha at Lake Waikaremoana. Thus this study supports the island syndrome hypothesis that rodent densities are higher on islands. The densities calculated on Ponui Island in this study are higher than most estimates of populations on islands. This includes the estimates made of the same population by Shapiro (2005) during the previous summer of 6.04 to 10.20 rats/ha. The maximum density of 10.20 rats/ha estimated by Shapiro in December is less than half the 22.43 rats/ha estimated by this study in July, seven months later.

2.4.1 *DENSITY and MARK*

Both *DENSITY* and *MARK* gave similar population size estimates for each session when standard error is included in the comparison. The main assumptions of *DENSITY* are that the population is closed within each session; there are no births, deaths or dispersal events, and that capture does not effect the movement of an animal or an animal's home range does not change within a session. These assumptions are believed to have been met in this study, due to the short duration of each capture session. The robust design, closed capture model used in *MARK* analysis also assumes that populations are closed within each session, and this assumption is also thought to have been met.

The densities estimated in this study varied quite markedly over the four consecutive monthly sessions. *DENSITY* estimates population density from the pattern of movements and the recapture of marked individuals in the trapping data (Efford 2004). Variation in the number of recaptures of individuals encountered in each session will therefore result in variation in the density estimated for those sessions. Consequently, it is the variation observed in the trapping success that warrants explanation, as this in

turn affects the densities estimated for the four sessions. The density of rats over all sessions may actually be relatively uniform, while it is the trapping success that fluctuates. This does explain the failure of DENSITY to estimate a population density for the fifth session in November. When sessions are treated independently, 11 individuals in the fifth session were counted, of which only two were recaptured. With such a low number of recaptures, the model failed to estimate parameters for this session. In the second session, in August, all individuals were re-caught and this suggests that complete enumeration of the population was almost achieved in this month. Thus, when compared with all sessions analysed, results from the August session probably give the most accurate account of the density of ship rats in this study area.

2.4.2 *Ship rat densities on Ponui Island*

2.4.2.1 *Ship rat densities in this study*

Of the 25 rats not recaptured, 11 were first caught in the first session, July. This is despite rats caught in the first session having more opportunities for recapture than those caught in the latter sessions. The number of opportunities for recapture thus did not seem to affect recapture rate. The high recapture rate over all sessions (61%) indicates a low degree of trap shyness exhibited by the rats.

The decline in trapping success coincided with the onset of spring. Trapping success rates may be affected by any changes in food abundance during this period. Best (1969) suggests a seasonal shift in the focus of feeding activity of ship rats. In a South Island population cave weta (*Raphidophoridae*) were most frequently eaten in the autumn and winter along with berries and seeds also from on the forest floor, while tree weta (*Stenopelmatidae*) had a summer peak in their frequency in the diet that was similar to other animal foods of canopy origin (Best 1969). Cave weta are available on the forest floor all year round while tree weta are available only in the canopy. To use each food group most efficiently, rats would have to shift from foraging among the humus, leaf litter and shrubs of the forest floor during the autumn to spring months, to the foliage of the forest canopy in spring and summer (Best 1969). During the winter months, while

foraging is focused upon the forest floor, the appeal of nutritious peanut butter bait within traps could explain the high trapping success and recapture rates seen in this study during this time. With the onset of spring during the last three trapping sessions, the rats may have switched their foraging to focus upon the forest canopy, so reducing contact with live traps set on the forest floor. These factors could then also explain the decline in kill-trapping success during the same period, as trap shyness cannot develop during kill-trapping sessions.

The period of trapping in this study did not correspond with the breeding season. While kill-trapping between June 2004 and February 2005, Shapiro (2005) documented the first sighting of a pregnant ship rat in the last week of December 2004. With a gestation of 20-22 days (Innes 2005) this suggests breeding on Ponui Island commenced in early December of that year. The home range areas of male ship rats have been found to increase with the onset of the breeding season (Dowding & Murphy 1994; Hooker & Innes 1995), with the acquisition of mates the causative factor. Assuming the breeding season recommenced in December 2005, the final trapping session in November could have coincided with an increase in male home range. An increase in male range could have contributed to the decrease in trapping success of particular individuals in the final session, with males moving further from the trapping grid. This also implies the opposite, new males from other areas increase their range and enter the trapping grid area, and so overall number of males available to capture may not alter. However, it is the rate of recapture that is of most importance when estimating density using DENSITY. Thus, the hypothesised loss of marked individuals due to increased ranging, regardless of the influx of new individuals, perhaps caused the failure of DENSITY to estimate a population density for the final session, in November.

Together these factors probably explain the reduction in recaptures of individuals over the five sessions and in turn account for the fluctuations in density estimated by DENSITY for each month.

2.4.2.2 *Comparing densities with previous estimates on Ponui Island*

When comparing the density estimates of this study to those of Shapiro (2005), it is clear that ship rat densities were higher between July and November 2005 than between December 2004 and February 2005. Methods used to estimate density in this study were based on those used by Shapiro (2005), and so variation observed should not be due to the methodology in use. The differences in density between this study and that of Shapiro (2005) may be due to changing dynamics within the population between sampling times. No pregnant females were caught while trapping on Ponui Island in this study, thus the breeding season does not include late winter and spring (July to November). Shapiro (2005) concluded that ship rat breeding began in the beginning of December 2004 on Ponui Island. With a gestation period of 20-22 days and an average litter size of five to eight (Innes 2005) the population had the potential to increase rapidly in the subsequent months. When assessing the maturity of the ship rats kill trapped, 13 of the 17 females caught were deemed mature. Five of these 17 rats showed placental scars in their uterus, giving an indication of previous litter size, with scars ranging from 3-16 in number. The sixteen placental scars found in one female most likely represent her previous two or more litters, as this number exceeds the expected litter size of ship rats (Innes et al. 2001). With five females with placental scars the sample is small, and scars do not exactly represent the litter size, as embryos may have reabsorbed during pregnancy (Conaway 1955). However, the range in the number of scars found indicates the possible litter sizes that can be expected from this population. The minimum weight recorded while live trapping was for one female rat with external signs of immaturity caught twice in July, with an average weight of 73 g. A further eight individual rats were recorded with average weights below 100 g throughout trapping. With the observation of breeding in December by Shapiro (2005), this suggests that the population trapped in this study from July-November included young adults recruited from the previous breeding season. Recruitment could explain the increased density in the area seen in the study. The capture of eight rats in this study that were initially caught in the summer during Shapiro's (2005) study, suggests a moderate survival rate of ship rats within the study area given the increase in weight

observed. Daniel (1972) estimated a ship rat lifespan of 11-17 months depending on sex. Given the presumed seasonal breeding in summer and the large weights of these ship rats upon initial capture by Shapiro in summer 2004/2005, it is estimated that these ship rats were from the 2003/2004 breeding season which suggests they are at least 17 months in age. The ship rat population perhaps has an increased survival rate than previously recorded for ship rat populations in New Zealand, and thus the potential to remain high in number.

With this study commencing seven months after the onset of the breeding season, it might be expected that densities during autumn were even higher than observed here. Immediately following breeding it can be expected that numbers would increase fairly dramatically. This would then be followed by a decrease as not all offspring may have been recruited into the population due to death or emigration.

The high density of ship rats on Ponui Island estimated by this study and that of Shapiro (2005) is in support of the island syndrome theory (Adler & Levins 1994), where rodent populations on islands are found at high densities. Stoats (*Mustela erminea*) are not believed to be present on Ponui Island (D. Chamberlin pers. comm.), however feral cats and morepork (*Ninox novaeseelandiae*) are present and both have been documented preying upon ship rats (Gillies 2001; Haw et al. 2001; Karl & Best 1982). With feral cats being the only mammalian predator in the forests on Ponui Island, reduced predator pressure could explain the high densities of ship rats observed as suggested by the island syndrome hypothesis (Adler & Levins 1994). However, the impact of predation by feral cats on Ponui Island must not be underestimated. During radio-tracking of ship rats in the study area (Chapter 3) one radio-collared rat was predated, most likely by a feral cat or morepork. Ship rats are a frequent diet item of feral cats (Gillies 2001; Karl & Best 1982), and numerous sightings of feral cats have been documented within the study sites by the author and fellow researchers on the island. Cat scats found on Ponui Island have also been observed to contain a lot of fur (pers. obs., I. Castro, pers. comm.). In addition, a feral cat was once sighted attempting to retrieve a rat from a live trap during the July session (pers. obs.).

Food availability on Ponui Island is likely to be the most important influence on ship rat carrying capacity. In Lake Waikaremoana mustelids were experimentally removed from a treatment block but no increase in rodent numbers (ship rats and mice) was observed when compared to a non-treatment block (Blackwell et al. 1998). It was suggested that rodent populations were more likely to be limited by food supply than predation, but the role of predation in a decline or low phase of population eruption needs further clarification and cannot be ruled out (Blackwell et al. 2003).

Variation in the density of ship rats observed between summer and winter/spring on Ponui Island is not in accordance with the theory of Adler and Levins (1994) that rodent populations on islands should be more stable than those on mainland areas. The theory implies that stability will increase with a reduction in island area and increase in isolation. Ponui Island is relatively large and in close proximity to the mainland and other islands. Although, it has not yet been determined what constitutes a large island area in terms of the effects of island syndrome, the size of Ponui Island lends itself to increased complexity in habitat structure which is thought to reduce the consequences of island syndrome (Adler & Levins 1994). While Ponui, as an island, may have a reduction in dispersal sinks and thus a more stable ship rat population at a higher density compared to the mainland, this reduction and hence stability may not be as acute when compared to smaller islands. Hence we see a combination of the effects of proposed island syndrome in rodent populations on Ponui Island, a high density subject to fluctuations.

2.4.3 *Ship rat morphometrics on Ponui Island*

Shapiro (2005) found male ship rats were significantly longer and heavier than females while sampling one year previously on Ponui Island. This is in agreement with the findings of Innes et al. (2001) in Pureora Forest Park. However, no significant difference between the morphometrics of male and female ship rats was found in this study. Interestingly, differences in body length and weight were found between the two colour morphs live-trapped, a finding that has not been recorded previously. Comparisons between morphometric data should be approached with caution however,

as measurements may not have been recorded in the same way and the age and sexual maturity of animals sampled at different times of year may cause variation in results (Innes 2005).

2.4.4 *Implications for kiwi*

The high density of ship rats on Ponui Island in this study means that North Island brown kiwi share the same habitat with higher numbers of rats than originally thought by Shapiro (2005). This, in turn, could influence the severity of competition between the two species. If kiwi chicks share their foraging behaviour and habitat with more rats, the competition between the two for limited resources will be more intense.

High densities of ship rats on Ponui Island could also increase the chance of establishment of stoats on the island, as ship rats are frequent prey items of stoats (King & Murphy 2005). Stoats are present on the neighbouring Waiheke Island (King & Murphy 2005) and have been sighted on nearby Pakihi island (J. MacKay pers. comm.). Stoats are known to be capable of swimming distances of 1.5 km (King & Murphy 2005), and so the possibility of them swimming across to Ponui Island is real. The Chamberlin family have recounted stories of stoat-like animals washing up on the beach and running into the forest in the past. Stoats have been identified as intense predators of young kiwi (McLennan et al. 2004), and their arrival on Ponui Island has the potential to devastate the kiwi population.

Kiwi are especially vulnerable to predation in their first four months of life, or until reaching at least 800 g in weight (McLennan et al. 2004). With a high number of ship rats potentially competing for food with kiwi chicks, chick growth rate may be slowed and this period of vulnerability extended, thus increasing predation pressure upon kiwi chicks.

The increased trapping success of ship rats further up slopes in more scrub-like habitat is significant when considering competition between kiwi chicks and ship rats. Shapiro (2005) observed kiwi chicks spending the majority of time feeding and sheltering on higher ground in the forests on Ponui Island, in scrub habitat. In addition, a clear and

significant habitat preference by young North Island brown kiwi for scrub and regenerating forest over mixed podocarp-broadleaf and kauri forest was noted by both Gibbs (2000) and Chan (1999). The increase in the capture rate of ship rats as the incline of the gully slope increased suggests a preference of the rats to frequent higher ground also. The steeper ground up the slopes either side of the gully would be associated with drier, harder soil, especially in summer months. In a study on North Island brown kiwi foraging behaviour on Ponui Island, Cunningham (2006) found probe-hole depth was significantly shallower in the scrub habitat than in gully and forest habitats, and soil penetrability in the scrub was lower than the other habitat types. Thus, in periods of drought when soil can become denser, the already limited probing depths of kiwi chicks may be reduced in this habitat type. In turn, kiwi chick foraging for surface-dwelling invertebrates may increase. If more rats are foraging within these areas of harder soil, where chicks are more common, the potential competition for surface-dwelling invertebrates between the two species could be more intense.

2.4.5 *Conclusions*

This chapter aimed to estimate the population density of ship rats during winter and spring on Ponui Island, during a period where no estimates were made by Shapiro (2005). The density of ship rats within the same area of forest was found to be higher in this study than when estimated in summer by Shapiro (2005). Ship rat densities on Ponui Island are higher than previous density recordings of ship rats made on the New Zealand mainland. This component of the island syndrome in rodent populations is thus supported. With the difference in densities estimated in summer and winter/spring, the ship rat population is believed to be subject to fluctuations in density, in contrast to the island syndrome theory where rodent populations on islands are thought to be more stable than those on mainland. However, the size of Ponui Island and its proximity to the mainland and other islands could explain why this component of the island syndrome is not manifest in this ship rat population.

This chapter also aimed to use observations from ship rat population dynamics on Ponui Island to assess the degree of potential competition between ship rats and the chicks of

North Island brown kiwi. The results of this study reveal that kiwi chicks are sharing habitat with increased numbers of potential competitors than initially considered. The observation of potential ship rat preference for scrub-like habitat is similar to that of kiwi chicks; competition in this habitat for surface-dwelling invertebrates between the two species is thought to be more intense due to soil condition. Results imply that ship rat population density will fluctuate on Ponui Island, and thus the competition may have corresponding degrees of severity during different times of year.

3

Home ranges and behaviour of ship rats (*Rattus rattus*) on Ponui Island

Abstract: The home range of ship rats (*Rattus rattus*) was investigated within an area of mixed podocarp-broadleaf forest on Ponui Island in the Hauraki Gulf. Behaviours such as degree of arboreality, denning habits and sociality were simultaneously observed. Radio-tracking proved problematic, but despite low tracking success home ranges were calculated to be between 0.11 and 0.51 ha, and were found to overlap both within and between sexes. Using a combination of radio-tracking and live-trapping location records, home ranges of ship rats on Ponui Island are believed to be smaller than those previously measured elsewhere in New Zealand. This is thought to be a consequence of the high density of ship rats calculated in the area at the time. Ship rats were found to be social and used the same den site or another nearby over consecutive days. Ship rats radio-tracked in December 2005 were highly arboreal, which was thought to reflect food sources being exploited at the time. The degree of arboreality is believed to increase the threat of predation upon tree-nesting birds in the forest study site, while simultaneously decreasing possible encounters with North Island brown kiwi chicks (*Apteryx mantelli*). As ship rats potentially compete with kiwi chicks for surface dwelling invertebrates, this arboreality suggests a decrease in such competition at this time. However, kiwi chicks forage upon soil dwelling larval invertebrates, the adult stages of which will remain an available food source to arboreal ship rats.

3.1 Introduction

3.1.1 Home ranges of ship rats in New Zealand

Burt (1943) defined home range as the area normally traversed by an individual during its activities of food-gathering, mating and caring for young. Various methods have previously been utilised when estimating ship rat home ranges, including radio-tracking (Dowding & Murphy 1994; Hooker & Innes 1995; Pryde et al. 2005), live-trapping (Daniel 1972; Innes & Skipworth 1983), smoked paper tracking (Innes & Skipworth 1983) and spool-and-line tracking (Cox et al. 2000; Key & Woods 1996). Estimates of ship rat home ranges in New Zealand range from 0.014 to 11.35 ha (Table 3.1), with variation most likely due to the different methods used to gather location records, although habitat and season will also have an effect. Previous estimates of ship rat home ranges derived by live-trapping are smaller than those estimated using radio-tracking, most likely due to the fact that home range area calculated using live-trapping is limited by the area that is trapped. By using a combination of both live-trapping and radio-tracking a more complete estimation of an animal's home range size can be realised (Ribble et al. 2002); where one method is problematic the other is advantageous. Live-trapping has certain shortcomings in that the capture of an animal prevents its further movement until it has been released, and may induce 'trap inhibition bias' which underestimates actual distances moved (Innes & Skipworth 1983). In addition, with only one location record being obtained per night for each animal, accumulation of live-trap records can be particularly time-consuming. More recently, with advancing technology, studies have used radio-tracking as a means to estimate home range of even very small animals. Many location recordings can be accumulated over successive nights with radio-tracking, behavioural data of the subject can be gathered simultaneously, and the utilisation by the ship rat of their three dimensional habitat can be fully appreciated. However, radio-tracking can be expensive, laborious and prone to failure, perhaps explaining why only three studies to date have radio-tracked ship rats in New Zealand (Dowding & Murphy 1994; Hooker & Innes 1995; Pryde et al. 2005).

Regardless of method used, most previous studies agree that male ship rat home range areas are generally larger than those of females. Hooker and Innes (1995) and Innes and Skipworth (1983) both concluded that home ranges of male ship rats were larger and overlap more than those of females. However, Dowding and Murphy (1994) and Daniel (1972) found that while home ranges of males were on average larger than those of females, the difference was not significant and there was also considerable overlap in home ranges of females. Conversely, Key and Woods (1996) found female ship rat home ranges were longer than males during a spool-and-line study on the Galapagos Islands. Pryde et al. (2005) recently conducted radio tracking of ship rats in a South Island beech (*Northofagus*) forest and found much larger home ranges for male ship rats than those recorded in North Island non-beech forests, although in this study only two males were radio-tracked.

3.1.1.1 Factors affecting home range

With the onset of the breeding season, previous studies have shown that home ranges of male ship rats will increase while those of females remain similar in size (Dowding & Murphy 1994). Hooker and Innes (1995) found that home ranges of females were small and overlapping, while home ranges of males were larger and some overlapped considerably during a four-week period in the breeding season. Each male's home range touched the home ranges of several females. Mate acquisition can explain the increase in a male's home range at the onset of, and during, the breeding season. Hooker and Innes (1995) concluded that ship rat social organisation can be explained as food-determined female dispersion, which in turn determines male dispersion.

Population density can also have an affect on an animal's home range area. Both Daniel (1972) and Innes & Skipworth (1983) suggested that home range sizes of ship rats were inversely related to population density. In a study on two species of mouse (*Peromyscus leucopus* and *Peromyscus maniculatus*), Wolff (1985) found that home range sizes were marginally negatively associated with population density. At low densities, individuals of the same sex maintained exclusive home ranges, whereas at high densities, home ranges would decrease until reaching a minimum. At this point,

levels of overlap would increase resulting in increased aggression and territory defence (Wolff 1985). At high densities during the breeding season, home ranges of field voles (*Microtus agrestis*) were half the size of those measured at low densities (Erlinge et al. 1990). Increased densities will in turn increase encounter rates between individuals, and thus a reduction in home range can be expected.

3.1.2 *The value of radio-tracking ship rats*

Behavioural data of ship rats obtained by radio tracking (the amount of time spent in trees, the distances moved, the home range areas and social organisation) are essential prerequisites of any effective management strategy and may facilitate the design of more effective control operations (Hooker & Innes 1995). Information from radio-tracking studies can provide information on optimum spacing of traps in a control operation and thus increase the probability of their success. With the continued reliance on pest control operations in New Zealand to conserve native species, behavioural data such as that derived from radio-tracking studies of pest animals can greatly aid the design and execution of such procedures. With few previous radio-tracking investigations of ship rats in New Zealand, this study aims to enhance the knowledge of ship rat behaviour and habitat use by radio-tracking ship rats in a mixed podocarp-broadleaf forest in New Zealand, moreover on an island where there is added conservation value and usually higher rat densities (Chapter 2).

3.1.3 *Activity of ship rats, as revealed by radio-tracking*

Ship rats are capable of being highly arboreal, with Hooker and Innes (1995) recording 73% of fixes above 2 m in primary forest. In a kauri (*Agathis australis*) forest in Northland rats were moving on the ground for an average of 93.5% of records (Dowding & Murphy 1994). This difference may be due to the difference in physical structure of the habitat, with the kauri forest of Dowding and Murphy (1994) having a relatively sparse sub-canopy, or due to differences in food sources being exploited at the time. By radio-tracking rats during the day observations on denning behaviour can be attained. Ship rats generally den in trees and may frequently change dens or use the same one for consecutive days (Dowding & Murphy 1994; Pryde et al. 2005).

Table 3.1 Ship rat home range area, length estimates and the method of estimation from previous studies in New Zealand.
MCP = Minimum Convex Polygon. RP = Restricted Polygon.

Location	Season	Home Range Area (ha)		Home Range Length (m)		Method of Analysis	Source
		Males (n)	Females (n)	Males	Females		
Greenwood's Bush Nr Palmerston North	Winter-Summer (August-January)	0.101 (1)	0.025-0.044 (4)	53	32-44	Smoked Paper Tracking (minimum area method)	Innes & Skipworth (1983)
Greenwood' Bush Nr Palmerston North	Autumn-Summer (May-January)	0.022 (1)	0-0.014 (4)	35	0-20	Cage trapping (minimum area method)	Innes & Skipworth (1983)
Orongorongo Valley, Wellington	29 month study	0.17 (15)	0.08 (16)	-	-	Cage trapping (minimum area method)	Daniel (1972)
Puketi Forest, Northland	Spring	0.94 (5)	0.79 (7)	159	185.5	Radio tracking (MCPs)	Dowding & Murphy (1994)
Rotoehu, North Island	Summer	1.52 (5)	0.49 (4)	194	103	Radio tracking (MCPs)	Hooker & Innes (1995)
Rotoehu, North Island	Summer	1.08 (5)	0.30 (4)	-	-	Radio tracking (RPs)	Hooker & Innes (1995)
Eglington Valley, Fiordland	Autumn (March)	7.51-11.35 (2)	0.27 (1)	400-700	200	Radio tracking (MCPs)	Pryde et al. (2005)

3.1.4 *Home ranges and behaviour of ship rats: implications for kiwi*

Shapiro (2005) outlined potential competition between ship rats and North Island brown kiwi chicks (*Apteryx mantelli*) for surface dwelling invertebrates on Ponui Island. The home range sizes of ship rats and their use of habitat on Ponui Island will have influence upon the severity of this competition.

With ship rat densities estimated at between 6.73 and 22.43 rats/ha in Pipe Gully (PG) in winter and spring (Chapter 2), an individual kiwi's home range in PG is expected to overlap with a large number of ship rats. The density of kiwi on Ponui Island is also estimated to be high at 10 pairs per km² (Miles & Castro 2000), thus 20 individual kiwi could potentially be sharing habitat with over 2000 ship rats in a one hundred hectare area at particular times of the year. Overlap between the home ranges of the two species is inevitable; any variance in habitat use and thus potential for encounter between the two species is subsequently of interest, having possible impact upon the degree of potential competition existing between ship rats and North Island brown kiwi chicks.

3.1.5 *Chapter aims*

This chapter aims to calculate the home range of ship rats on Ponui Island by combining both radio-tracking and live-trapping data. Habitat use by ship rats and their degree of arboreality will be ascertained with behavioural data derived from radio-tracking. With tracking occurring over five consecutive months, any changes in home range areas and activity may be observed. Ship rats inhabiting known home areas of North Island brown kiwi will be radio-collared to use the behavioural data obtained to aid the assessment of the degree of competition occurring between these two species.

3.2 Methodology

3.2.1 Study site

The study site was located on Ponui Island in the Hauraki Gulf (36°55'S, 175°11'E), a privately owned island that is thought to have one of the highest densities of North Island brown kiwi in New Zealand (Miles & Castro 2000). A patch of mixed podocarp-broadleaf forest about 1.5 km² in size, composed of four main gullies, contains 36 adult kiwi and up to five kiwi chicks at one time, with transmitters on that have been monitored by the Ponui Island Research Programme since March 2004.

Ship rats were radio-tracked in Pipe Gully (PG), a mixed broadleaf forest with regenerating kauri on Ponui Island (Plate 3.1). This area is home to a number of known, radio-collared North Island brown kiwi. Live-trapping was being carried out in this site (Chapter 2) and so animals were readily available for radio-collaring. The gully basin area of PG was the area in which ship rats were live trapped (see Chapter 2) and subsequently tracked.

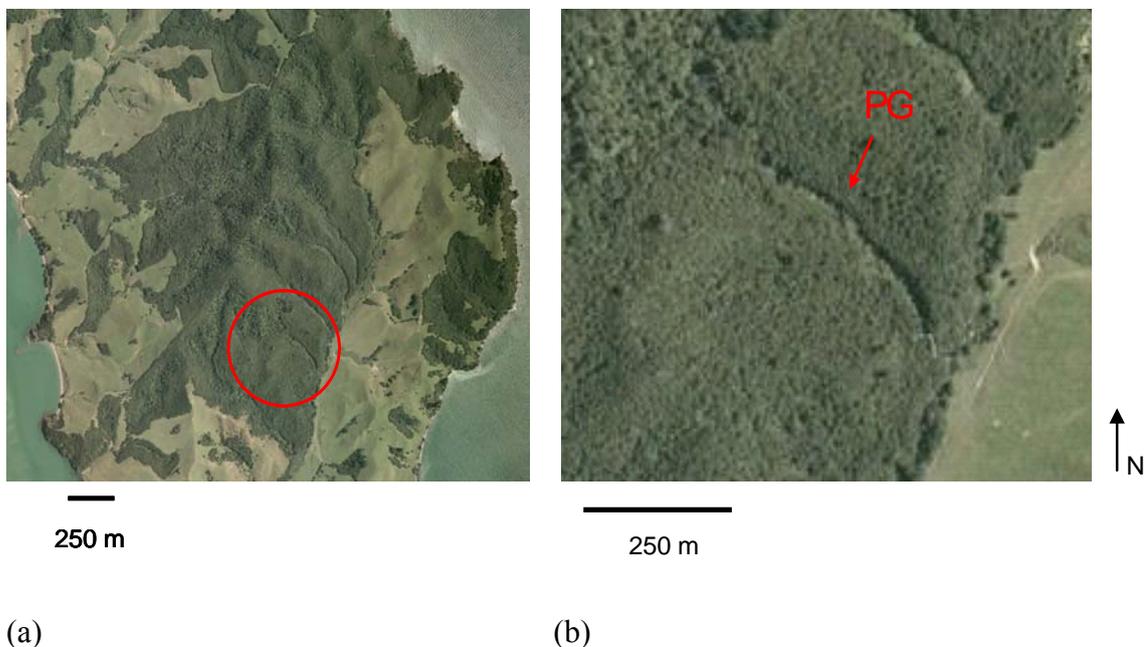


Plate 3.1 (a) Aerial photograph of the main patch of forest on Ponui Island within which kiwi are radio-collared, indicating the area of forest in which tracking of ship rats was carried out, in (b) pipe gully (PG). Image supplied by I. Castro.

3.2.2 *Transmitters*

The radio-tracked ship rats were trapped as part of the five month live-trapping study in PG between July and November 2005 (Chapter 2). In total, thirteen rats were radio-collared with small (< 5 g), single-stage radio-transmitters with an external whip aerial and attached with a plastic pull tie collar around the neck (LT1-303x2, Titley Electronics Pty. Ltd., Australia). Only animals weighing at least 150 g were collared, so that transmitters were no more than 4% of the animals total body weight. In addition, only animals exhibiting external signs of maturity were collared; males with scrotal testes, and females with a perforate vagina (Cunningham & Moors 1993). Rats were also assessed for health; only those with good pelage condition and body and tail condition were used in this study for tracking. The aim was to build a sample of radio-collared rats comprised of equal numbers of males and females. However, this was not possible as the need for subjects alone outweighed the need for an equal sex-ratio in the sample. The first rats available that were over the required weight, deemed mature and in good condition, were radio-collared.

Animals were anaesthetised using isoflurane as described in Chapter 2. While anaesthetised, collars were slipped around the animal's neck and secured. Animals were then released at the point of capture, after a period of recovery from the effects of the anaesthetic.

All handling of live animals was approved by the Animal Ethics Committee of the University of Auckland, protocol R385.

3.2.3 *Tracking*

Before tracking of radio-tagged animals took place, practice in pinpointing locations was carried out on transmitters hidden in unknown locations in an open field. Practice was conducted on transmitters hidden at ground level and transmitters that had been hoisted onto a tree branch. Tracking of ship rats commenced once techniques to narrow down the location, and estimate the height of transmitters, had been sufficiently rehearsed.

Animals were tracked at night using a TR4 receiver (Telonics, Arizona, U.S.A.) and a hand-held Yagi antenna (Sirtrack Electronics, Havelock North, New Zealand) between August and December 2005. Tracking took place over a maximum of four nights each month, with tracking commencing after dusk and each rat being located between three and five times a night. Single fix sampling was used, in that one fix was taken for each individual as quickly as possible and repeated every hour, an interval which confers reasonable independence between points (Hooker & Innes 1995). The closer in time two locations are taken, the less likely they are to be statistically independent (White & Garrott 1990). With hourly fixes it is reasonable to assume that sufficient time has elapsed for the animal to move from one end of its home range to the other. Using this sampling method on a series of individuals enabled their behaviour to be compared at similar times of the night and is also an economic way of building up range maps (Kenward 1987). To obtain a radio-collared animal's location, the peak signal was found and the gain turned down until at its lowest volume, the antenna was then swung slowly either side until the signal disappeared at the null points. The location of the animal was taken as the bearing that bisects the angle between the two directions in which the signal was lost (Kenward 1987). Each rat was located to within 5 m of its position. A Garmin eTrex[®] Legend C handheld navigation system (Garmin International Inc., Kansas, U.S.A.) was used to obtain Global Positioning Satellite (GPS) coordinates of the location. Due to the extensive cover provided by the forest GPS coordinates were subject to inaccuracy of up to 30 m, and so the location of the rat in relation to the live-trapping grid was also noted. Reflective tags were placed at each trap and the location of each fix was recorded by judging the distance and bearing from the nearest trap in the grid. Animals were then judged on their arboreality, being on the ground, 0-2 m above ground or above 2 m in the trees. This could be achieved by sweeping the Yagi antenna through the vertical plane; the signal reaching a maximum when the antenna boom is pointed exactly at the tag. By repetitive sweeping of the antenna across the vertical plane and the horizontal plane, the peak signal could be judged and the arboreality of the rat confidently assigned.

A fix of an animal's location was also taken once every day, following a night of tracking, between 1200 and 1600 NZST. Ship rats are nocturnal and so one location recording was sufficient during the day as animals were unlikely to move. Day fixes also provided information on the denning sites of ship rats in forests.

On each night of tracking a scan was conducted for radio-collared kiwi in the area. Kiwi were previously banded by the Ponui Island Kiwi Research Programme, with two stage adult transmitters (KiwiTrack Ltd., New Zealand) having a range of 2-3 kms in open space. All known kiwi transmitter frequencies of birds in PG were scanned to ascertain which were in the immediate area. Scanning was carried out between fixes for radio-collared ship rats. Whether a kiwi's transmitter signal could be picked up determined the presence or absence of the individual in the area. Due to the activity of the kiwi and the dense forest, accurate fixes of individuals during the night were not possible. The following day a location for each kiwi heard at night was recorded in respect to the live-trapping grid, and with a GPS location.

3.2.4 *Analysis of location data*

Home range areas were calculated with the Ranges6 v.1.217 programme (Kenward et al. 2003a). Location recordings were initially analysed with minimum convex polygons (MCPs). This is the oldest and most commonly used method for estimating home range, with simplicity, flexibility of shape and ease of calculation being its advantages (White & Garrott 1990). Home ranges are constructed using this method by drawing a line around the outermost locations recorded for an animal. However, this limits its utility since home range size is strongly influenced by peripheral fixes and the home range calculated gives no indication of how intensely an individual uses an area, and may even include areas that are never visited (Hooker & Innes 1995). The home range estimated with MCP is a function of the number of locations used to generate the estimate; the size of a home range continues to increase as the number of locations increases. Thus two estimates are not strictly comparable if one is based on many more location points, as that one would be expected to be somewhat larger (White & Garrott 1990). Despite this, the MCP method was chosen for this study since it is the most common method of estimating home range sizes of ship rats and is therefore useful for gross comparisons with other studies. In addition, the MCP method is more robust than other methods when the number of fixes is low (Harris et al. 1990).

The keyword in the definition of home range given by Burt (1943) is *normal*. The home range is not the *total* area traversed by an animal in its lifetime but the area normally used while carrying out its activities (White & Garrott 1990). Thus, excursions outside these areas should not be included in estimation of home ranges.

Outlier points should be eliminated so that the remaining area depicts the normal home range. One such method is to remove 5% of locations, based on ordering criteria, to infer a 95% MCP on the location recordings. To eliminate cores that exclude some locations it is necessary to choose a peel centre, with the furthest locations from the peel centre excluded first (Kenward et al. 2003b). In this study the peel centre chosen was the harmonic mean centre (HMC). The HMC is the location where the inverse reciprocal mean distance to all the other fixes is a minimum (Spencer & Barrett 1985). This provides a more robust estimator than the simple arithmetic mean which can be estimated in an area devoid of locations (Kenward et al. 2003b).

In addition to constructing MCPs to estimate home range, concave or restricted edge polygons (RPs), were also used for analysis in Ranges6. Restricted polygons eliminate large areas which are not visited. The outermost set of fixes for an animal are joined but the maximum length of a line between points is restricted by a proportion, in this case half of the maximum range width (Kenward et al. 2003b). This method is thought to be more robust than MCPs and was the preferred method of Hooker and Innes (1995).

Minimum home range estimates were also calculated from successive live captures of individual rats. In total 43 rats were caught more than once throughout the live trapping sessions, and of these 34 were omitted because they were re-trapped either at the same site consecutively or at sites on a straight line from which the minimum home range could not be estimated. The maximum number of recaptures for an individual was six, thus estimated home range will not reflect true home range areas. However, this information was analysed to supplement analysis of ship rat home ranges using radio-tracking on Ponui Island. Location fixes were analysed in Ranges6 v1.217 (2003a) using the 100% MCP method.

3.3 Results

3.3.1 Tracking success

Radio-tracking of ship rats on Ponui Island proved to be problematic, with a low success rate achieved (Table 3.2). During live trapping in July four rats were fitted with transmitters, three males (I.D. numbers 72, 476 and 69) and one female (I.D. number 68). Upon the commencement of tracking in early August, all samples had failed. Two transmitters, belonging to the female and one male, were found on the forest floor. The rats had shed their transmitter collars. One other male rat had died in a live-trap overnight during particularly bad weather. The final radio-collared male was transmitting a signal from a Puriri tree (*Vitex lucens*) continuously and it was concluded that the collar had been shed from the rat and lodged in the tree, or the rat had died in the tree.

In September efforts to collar more rats during the six days of live trapping provided a new sample of three radio-collared ship rats, two males (I.D. number 434 and 72) and one female (I.D. number 98). Tracking of these rats began in early October. The female rat (98) was tracked successfully for one night with three location fixes recorded, and one day-location fix taken the next day. However, the following night the transmitter was found on the forest floor and the rat was presumed to have shed its collar. One male rat, number 434 was successfully tracked for two nights with one day location also recorded. During the second night of tracking the rat was recorded moving above ground a maximum of only 3m in three hours. When scanning for a location the following day the transmitter was again found on the forest floor, with rat remains including fur, flesh and heart, found surrounding the transmitter (Plate 3.2). It was concluded that this rat had been predated upon by either a feral cat (*Felis catus*) or morepork (*Ninox novaeseelandiae*). Unfortunately the signal for the final male rat (I.D. number 72) could not be picked up even when a search was carried out by traversing the area of the live-trapping grid including a 50 m surrounding zone. This was the area deemed normally feasible for the rat to cover, given movements observed of radio-collared rats 434 and 98, and the inter-trap movements of rats observed during live-trapping sessions. It was assumed that the transmitter on this rat had failed.



Plate 3.2 Transmitter and remains of rat number 434 found on the forest floor following the second night of tracking. It was concluded that this rat had been predated upon. Photo by author.

During the next live-trapping session in October three more rats were fixed with radio-collars. This sample comprised two males (I.D. number 441 and 422) and one female (I.D. number 413). Efforts to track these rats began in November and were again unsuccessful. No signal could be picked up for any rat, regardless of increasing the search area. Live-traps were re-set in the hope of recapturing these animals. During four nights of trapping only one of the radio-collared rats was caught, number 422 was caught with a failed transmitter. The transmitter was found to have a damaged casing such that the battery and wires were exposed. From the damage to the casing it was clear that the transmitter had been gnawed. The position of transmitters on an animal's neck is such that it cannot itself reach the casing, and so it was concluded that other rats had chewed at the transmitter while on the rat's neck. With no recapture of the other two rats with collars, and no signal heard after this time, it was concluded that their transmitters had also failed, perhaps in a similar manner.

Four salvaged transmitters were then repaired in November for a final attempt at successfully tracking a sample of ship rats. Traps were re-set in December but due to the reduction in trapping success (Chapter 2) only three rats were caught, two males (I.D. number 440 and 424) and one female (I.D. number 463). These rats were successfully tracked for four continuous nights.

Table 3.2 Tracking outcomes for all ship rats collared between July and December 2005. N = night, D = day.

Rat I.D.	Sex	Date collared	Tracking outcome	Comments
68	Female	23.07.05	Failure	Shed collar
476	Male	21.07.05	Failure	Shed collar
473	Male	21.07.05	Failure	Died
69	Male	22.07.05	Failure	Probably shed
98	Female	21.09.05	1 N ; 1 D	Shed collar
434	Male	22.09.05	2 N ; 1 D	Predated
72	Male	19.09.05	Failure	No signal (damaged?)
422	Male	20.10.05	Failure	Damaged casing
441	Male	20.10.05	Failure	No signal (damaged?)
413	Female	20.10.05	Failure	No Signal (damaged?)
440	Male	11.12.05	4 N ; 4 D	Success
424	Male	12.12.05	4 N ; 4 D	Success
463	Female	11.12.05	4 N ; 4 D	Success

3.3.2 *Home ranges of ship rats on Ponui Island*

3.3.2.1 *Tracking determined*

The three ship rats radio-collared in December (I.D. 463, 440 & 424) were tracked for the same four consecutive nights, resulting in a total of 20 location recordings for each animal. Home range estimates for these three rats are thus comparable. The two male ship rats occupied home ranges 0.51 ha and 0.26 ha in size, larger than the home range calculated for the female at 0.11 ha (Table 3.3). The two ship rats tracked in October (I.D. 98 & 434) have few locations associated with them and so the home ranges calculated are not thought to be near the actual. In addition to four locations recorded by radio-tracking, the female (I.D. 98) was caught in live traps five times between July and September. Locations recorded by both methods were combined to calculate home range for this female. The male ship rat (I.D. 434) was tracked for two nights, but on the second night moved no more than 3m, hence the small home range of 0.03 ha calculated. The inclusion of these two ship rats in the analysis was for the purpose of investigating home range overlap between all the ship rats radio-collared in PG. Each of the three methods used, 100% MCPs, 95% MCPs and RPs, calculated very similar home range areas for all but one ship rat, indicating outlier points were not far removed from the mean centre of locations for these animals. The home range of female 98 tracked in October was very similar in size to that of male 424 tracked in December, when comparing estimates calculated with MCPs. However, when the restricted polygon method is used in lieu of MCPs, the female home range was reduced from 0.26 to 0.14 ha, while the home range of male 424 remained stable at 0.26 ha.

Home range lengths of ship rats in PG ranged from 40 m to 123 m. Males generally had longer home ranges than females, when excluding that calculated for male number 434 which almost certainly underestimates its true home range.

Table 3.3 Home range length (m) and area (ha) of ship rats radio-collared in PG. Home ranges were calculated using the three methods described: 100% minimum convex polygons (MCPs), 95% MCPs and restricted polygons (RPs).

Rat I.D.	Sex	Number of records	Home range length (m)	Home range area (ha) 100% MCP	Home range area (ha) 95% MCP	Home range area (ha) RP
463	Female	20	51	0.15	0.14	0.11
440	Male	20	123	0.56	0.52	0.51
424	Male	20	86	0.27	0.24	0.26
98	Female	9	94	0.26	0.26	0.14
434	Male	7	40	0.03	0.03	0.03

The home ranges of all five ship rats successfully radio-tracked in PG overlapped (Figure 3.1). Both within and between sexes home ranges were found to overlap considerably. Home ranges of males overlap extensively those of other males and, to a lesser extent, those of the two females. The home ranges of two females collared overlapped with each other, with the majority of the home range calculated for female 463 within that of female 98. Male rat number 424 had a home range that overlaps with all four of the other ship rats radio-collared. The male ship rat number 440 tracked in December had the largest home range area, overlapping those of three other rats including one female, at 0.51 ha (restricted polygon method).

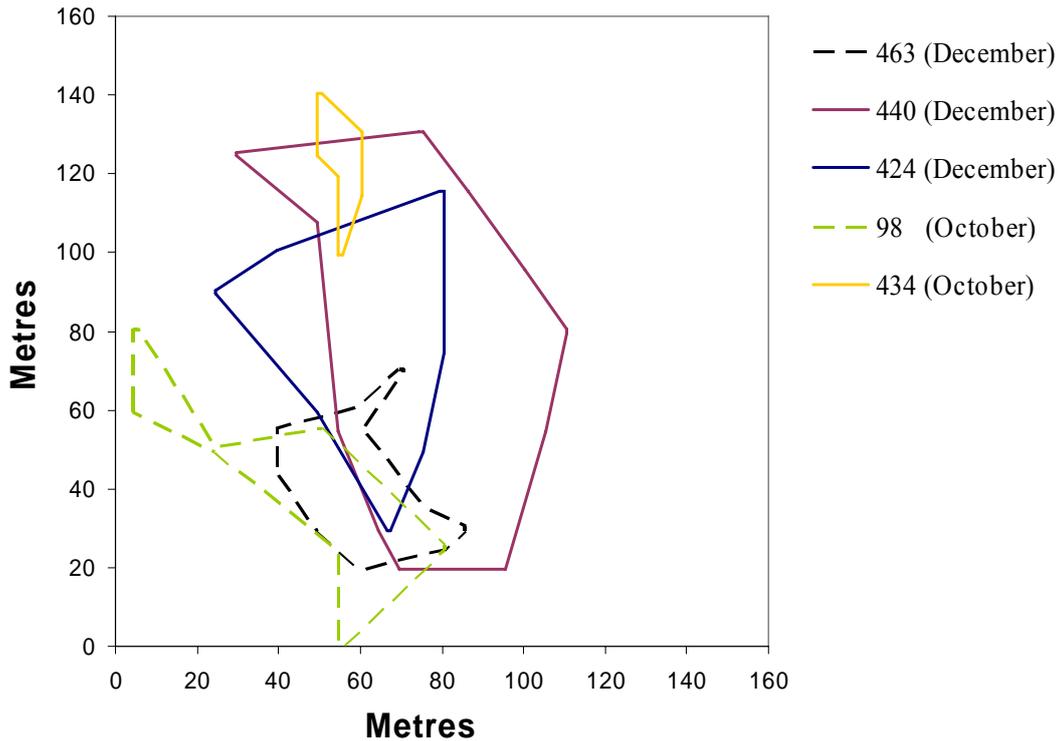


Figure 3.1 Home ranges (restricted polygon method) of radio-collared ship rats in PG. Dotted lines depict female ship rats while solid lines represent male ship rats.

3.3.2.2 *Trap determined*

Trap-determined home ranges of nine ship rats in PG varied from 0.04 ha to 0.14 ha in size. Of the nine ship rats that revealed trap-determined home ranges, two were female. The home range area of both females was within size range of those calculated for males. Trap-determined home range estimates are much smaller than those determined by tracking. The trapping grid was composed of five rows with five live traps, spaced 25 m apart. In the majority of cases rats were caught continuously in the same traps neighbouring the original point of capture, illustrated by the small home range lengths observed and the small home range areas calculated. One male rat, number 492, was caught in two neighbouring traps 25 m apart nine consecutive times throughout trapping in July, August and October but was then caught in a trap 75m away from the original point of capture in November.

Table 3.4 Home range length and area of ship rats in PG, as determined by live-trapping, calculated using 100% minimum convex polygons.

Rat I.D.	Sex	Number of records	Home range length (m)	Home range area (ha)
481	Female	6	50	0.07
479	Female	4	35	0.04
477	Male	3	50	0.07
483	Male	5	35	0.04
486	Male	5	35	0.04
72	Male	5	50	0.07
488	Male	6	70	0.14
458	Male	6	79	0.10
441	Male	3	35	0.04

3.3.3 Denning behaviour

All rats radio-collared were recorded as being up trees (>2 m above the ground) during the day. Only one day location was recorded for rat numbers 98 and 434 in October before radio-tracking failed. However, four consecutive day locations were recorded for the three rats radio-tracked in December. Female I.D. 463 was recorded in epiphytes (*Collospermums hastatum*) in the same kohekohe (*Dysoxylum spectabile*) tree for two consecutive days, and then moved to epiphytes in a rewarewa (*Knightia excelsa*) tree 5 m away on the third day, where it was again found on the fourth day. Male number 440 used the same den for three of the four days, among epiphytes in a pohutukawa (*Metrosideros excelsa*) tree. On the second day it was located within epiphytes in another pohutukawa tree 10 m away. The other male rat, I.D. 424, was found among epiphytes in the same pohutukawa tree for three consecutive days but on the fourth and final day was located at least 50 m away among epiphytes in a rewarewa tree. This location was outside the area of previous tracking locations, both day and night, made for this male. Radio-collared rats were never found in the same den site

together; however rats could have shared sites with other rats that did not have transmitters.

3.3.4 *Habitat use*

All but one fix for all rats radio-tracked throughout each night were in trees (99%). All of these were at least 2 m high in trees, except for rat number 424 which was located 1.5-2 m above ground once during the final night of tracking. Only once was a radio-collared rat recorded on the ground. Number 463 was located underground in a tunnel on the first night of tracking. Five un-collared rats were also encountered while tracking, three of these recorded on the ground. Upon approach each rat climbed up the nearest tree. However, it was not thought that tracking by foot to the location of each rat influenced their arboreality. The initial fix each night for each rat was always above 2 m in trees and so it is believed that human presence did not force the rats into the canopy.

Radio-tracked rats were observed directly a few times running along branches of trees, their agility being displayed when switching tree branches with ease. Once, female rat number 463 was observed with another un-collared rat that was slightly smaller in size. Both rats were traversing the same tree branch and crossed paths more than once.

3.3.5 *Radio-collared kiwi in Pipe Gully*

While radio-tracking rats between October and December transmitter signals of six radio-collared adult kiwi, four males and two females, were heard in the area during the night. While tracking in November for ship rats, two additional unknown kiwi (without transmitters) were encountered in PG within the live-trapping grid. In December, the same six radio-collared kiwi signals were picked up within the vicinity during the night. Day-time locations for all birds were recorded in October and December. Repeated day locations for the same birds were within 100 m of each other. All kiwi day-time locations were either among the area of live-trapping or within 100 m of the trapping grid (Figure 3.2). Over the course of live trapping between July and November 2005, a total of 70 individual rats were caught in this grid, and the density of ship rats was calculated from 6.73 to 22.43 rats/ha in this area (Chapter 2).

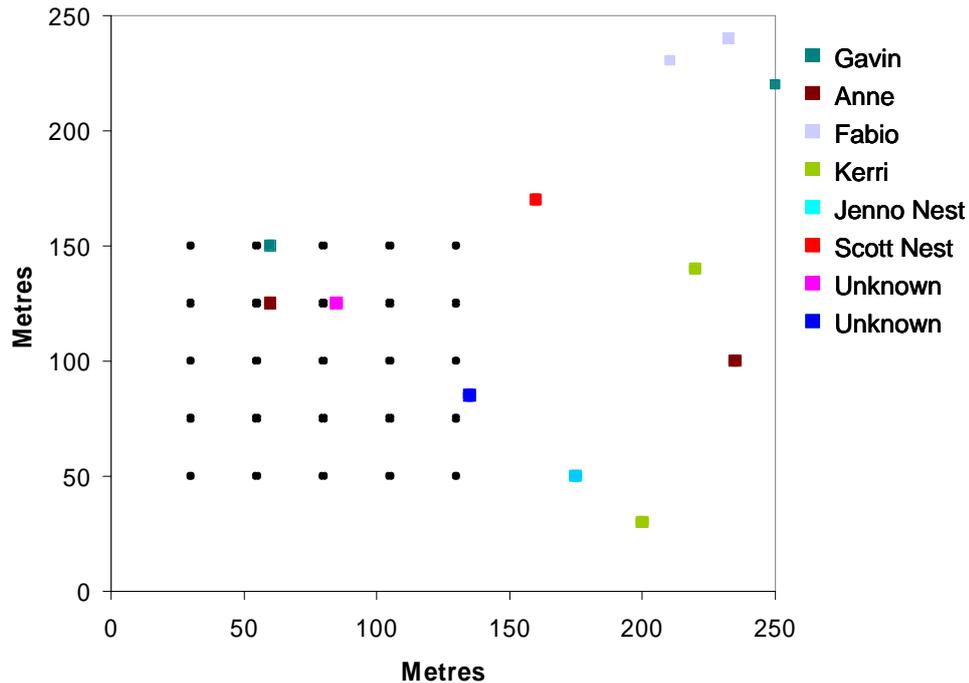


Figure 3.2 Locations of kiwi within PG between October and December 2005. Black circles represent the rat live-trapping grid.

Two males, Scott and Jenno, were recorded on nests in the day throughout tracking in October, November and December 2005. One nest, that of Jenno, was within the recorded home range of radio-tracked rat 424 (Figure 3.3). Both nests were no more than 40 m away from the recorded home ranges of all rats radio-tracked. Both males were incubating eggs during this time, and Scott's egg hatched around late November and Jenno's egg mid December (S. Cunningham pers. comm.). Only one other recorded kiwi location falls within the home range of radio-collared rats, that of an unknown kiwi without a transmitter that was encountered during one night of radio-tracking in November. All other kiwi day-time locations were, however, within 100 m of the calculated home range areas for radio-tracked ship rats.

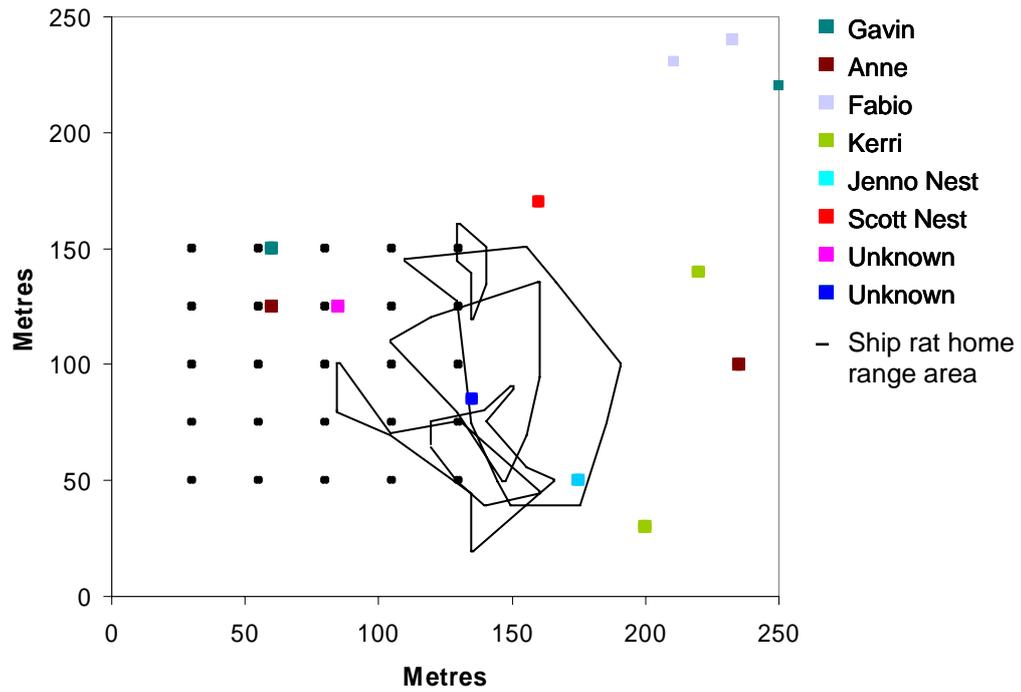


Figure 3.3 Calculated home ranges (RP method) for all five ship rats radio-collared in PG with kiwi locations recorded between October and December 2005. Black circles represent the rat live-trapping grid.

3.4 Discussion

3.4.1 *Home ranges of ship rats on Ponui Island*

Home ranges calculated for five ship rats on Ponui Island were generally smaller than previous home range estimates derived by radio-tracking for ship rats in New Zealand, regardless of the method of calculation used. When estimating the home range of an animal by radio-tracking, the accumulation of location recordings correlates with increased representation of the actual home range area for that animal. Very few location recordings were achieved for two of the five ship rats tracked in this study in October. Thus the home ranges calculated for three rats tracked in December for four continuous nights are thought to better represent home ranges of ship rats on Ponui Island. Two males had home range areas 0.27 ha and 0.56 ha in size, and one female 0.15 ha when calculated with 100% minimum convex polygons. These home range areas are smaller than those previously recorded for ship rats in New Zealand, which ranged from 0.94-11.35 ha for males and 0.27-0.79 ha for females, calculated using 100% MCPs (Dowding & Murphy 1994; Hooker & Innes 1995; Pryde et al. 2005). Home range areas as revealed by live-trapping in this study were particularly small, ranging from 0.04 to 0.14 ha in size. The difference between ranges estimated by radio-tracking and live-trapping are not surprising given the factors limiting home range estimation by live-trapping. The live-trapping recordings do, however, aid understanding of ship rat movements on Ponui Island. While live-trapping, 34 of the 43 ship rats recaptured were caught in the same trap or one neighbouring that trap. This fact alone implies ship rats in the study site have small home range areas.

The number of records for each radio-collared rat is particularly small at 20. Hooker and Innes (1995) found that only 80% of an animal's home range had been described upon the 200th location recorded, when radio-tracking ship rats in Rotoehu forest. Thus it can be assumed that the ranges calculated in this study underestimate the true home range size for each animal. Maximum home range length recorded for a ship rat in this study was 123 m, whereas the maximum home range length recorded by previous radio-tracking studies was 700 m, and the minimum 103 m. Unfortunately, this study is limited by the number of successful radio-tracking nights, and the movements of rats observed almost certainly underestimate actual home ranges. However, the

combination of evidence revealed by live-trapping and radio-tracking is suggestive of this ship rat population having smaller home range areas than recorded previously for populations elsewhere in the country.

Home ranges calculated for the two male ship rats tracked in December were larger than that of the female. With only one animal in this sample representing female ship rats in PG this difference may not be true for all, but is in support of previous findings that male ship rats generally occupy larger home ranges than females (Daniel 1972; Dowding & Murphy 1994; Hooker & Innes 1995; Innes & Skipworth 1983). Home ranges of all five ship rats radio-collared and tracked in PG were overlapping regardless of sex. The home ranges of the two males tracked in December overlap considerably, while the home range of the third male, I.D. 434, overlapped with these males to a lesser extent. However, the home range of this male tracked in October is almost certainly underestimated and thus the extent of overlap may have been greater. The home ranges of the two females tracked were found to overlap, with the majority of female 463's home range area within that of female 98. However the home range for number 98 was calculated from records obtained in October and that for number 463 in December, and so this overlap may not have existed if records were obtained during the same period. Previous studies of ship rats have resulted in varying conclusions about the degree of overlap between the sexes. Both Innes & Skipworth (1983) and Hooker & Innes (1995) found male ship rat home ranges overlapped to a higher degree than females, whereas Daniel (1972) and Dowding & Murphy (1994) found extensive overlap in home ranges of females. These contradicting results could be due to the different times of year in which rats were sampled or due to variability in the physical structure of the study site habitat.

3.4.2 *Factors affecting the home range of ship rats on Ponui Island*

Estimates of ship rat density within the study site between July and November 2005 were generally higher than those found on the mainland (Brown et al. 1996; Daniel 1972; Dowding & Murphy 1994; Hooker & Innes 1995) and exceed most previous density estimates of ship rat populations on islands (Craig 1977; Hickson et al. 1986; MacKay 2005; MacKay & Russell 2005). This high density most likely constrains the home range that an individual ship rat can occupy in the area. By decreasing home range size in an area of high density, interference between individuals will be reduced.

Dowding & Murphy (1994) and Hooker & Innes (1995) radio-tracked ship rats within two mainland populations, for which the density had been concurrently estimated at 2.9 rats/ha and 6.2 rats/ha respectively. When compared with Ponui Island, these two studies estimate appreciably lower densities of ship rats within their mainland sites while calculating noticeably larger home range areas.

Through necropsy of kill-trapped animals it was determined that the breeding season of ship rats in the study site did not coincide with the trapping period, July to November 2005 (Chapter 2). However, Shapiro (2005) first caught pregnant females at the end of December 2004, suggesting the breeding season commenced earlier that month. Assuming the breeding season re-commenced in December 2005, it can perhaps be expected that home ranges of males are larger than normal in this study due to their need to acquire mates. Male ship rats have been found to increase their home range at the onset of the breeding season (Dowding & Murphy 1994; Hooker & Innes 1995), presumably reflecting the attempts of males to find and mate with as many females as possible. This could then explain the final day-time location recording for male 424 which was found in a den site far removed from the area in which the rat was usually found. The male rat, I.D. 492, was repeatedly caught in adjacent live traps but trapped in November 50 m away from these traps. This movement may also have been in preparation for the ensuing breeding season.

The time at which tracking was carried out may thus coincide with extreme movements of male ship rats, resulting in a larger estimation of male home range size than may exist during other months of the year. However, home range areas estimated in this study most likely underestimate actual home ranges due to the small number of location recordings obtained, and so the true extent of increasing male home range may not have been observed.

3.4.3 *Behaviour of ship rats on Ponui Island*

3.4.3.1 *Denning & Sociality*

The three ship rats radio-tracked in December were always found among epiphytes more than 2 m up in trees during the day. The rats used the same den site more than once, and when they switched, two of the ship rats moved to sites a maximum of ten metres from the previous one while the other ship rat moved to a tree at least 50 m

away. This distance moved may be a consequence of the supposed commencement of the breeding season, with males thought to range further in the search for mates.

Radio-collared rats were never found in the same den location together; however rats could have been sharing dens with others not carrying transmitters. Evidence of social behaviour was exhibited by radio-collared female number 463 who was seen active with another un-collared rat. The transmitter failure of ship rat number 422 also indicates sociality between ship rat individuals, with the casing having been chewed by another rat.

In Puketi forest, Northland, radio-tracked ship rats denned together, foraged in close proximity and had considerable overlap in home ranges within and between sexes (Dowding & Murphy 1994). Radio-tracking observations on Ponui Island reinforce the suggestion of sociality in ship rat populations.

3.4.3.2 *Habitat use*

Location recordings for ship rats tracked in the night are indicative of a very high degree of arboreality, which is known for this species (Innes 2005). Two radio-collared rats were viewed directly during tracking in December, one while moving among epiphytes at least 3 m up in a tree and the other moving quickly, in the presence of another rat, along a tree branch. The total number of location records for radio-collared ship rats are few, but coupled with direct observation of rats in trees while tracking indicates how accessible the three-dimensional habitat is to these animals. In some cases human presence may have altered normal behaviour of individuals, but it is not believed to be responsible for the high degree of arboreality seen. Initial encounters with radio-collared ship rats were always in trees, so it is not thought that rats were forced into the canopy by human disturbance.

Radio-tracking was not successful during earlier months and so it cannot be concluded that ship rats continually exhibit this high degree of arboreality year-round. The decline in trapping success observed while live-trapping between July and November perhaps mirrors the degree of arboreality exhibited by the ship rats. Trapping success was high during July and August but declined steeply afterwards, with only two or three rats caught per night in November (Chapter 2). Ship rats eat both plant and animal material in seasonally variable proportions (Best 1969; Daniel 1973; Innes 1979), and this

decline in trapping success is thought to be due to changing feeding focus as winter develops into spring. Best (1969) proposed that ship rats shift their feeding focus according to food availability; the humus and leaf litter providing food items through autumn, winter and into spring with the forest canopy providing the dominant diet items with the onset of summer. The degree of arboreality would thus shift according to season. Trapping success in the winter months suggests ship rats spent more time on the ground during this time, while the decreasing success observed as trapping continued into November is suggestive of rats becoming more arboreal with the onset of spring and summer. Few fixes for ship rats were obtained while tracking in October, with the majority being recorded in December. These December fixes do indicate the high arboreality proposed in late spring and summer, and so it is presumed that had tracking been successful during previous months the shift in foraging focus would have been observed, with a lesser degree of arboreality. Food availability is thus thought to have great impact upon the home range use of ship rats.

The physical structure of PG would also influence the year round degree of arboreality in the ship rat population. Dowding and Murphy (1994) recorded ship rats above ground for an average of 6.5% of records in Puketi forest whereas Hooker and Innes (1995) recorded ship rats at least 2 m off the ground in trees for 73% of fixes in Rotoehu forest. Being a kauri forest the subcanopy in Puketi forest is relatively sparse, whereas the mixed broadleaf forest of Rotoehu provides a suitable frame for arboreal ship rats. The understorey of PG basin is relatively sparse, but the sub-canopy and canopy is dense with mature puriri (*Vitex lucens*), pohutukawa, rewarewa, taraire (*Beilschmiedia tarairi*), miro (*Prumnopitys ferruginea*) trees, and other such vegetation associated with mixed broadleaf forest in New Zealand. The structure of the study site then lends itself to the agility of the ship rat, allowing the rat to exploit the three dimensional habitat to fully utilise food sources. The use of the canopy would also alter the risk of predation on the ship rat. Ship rats are likely to be an important food source for the feral cats on Ponui Island, and so by minimising time spent on the ground the ship rats also reduce potential contact with these predators. However, the fairly common presence of morepork (pers. obs.) in the study site reduces the safety aspect of arboreality, as noted by the predation of male rat 434 that was continually recorded as being high in the trees when located prior to being predated.

The degree of arboreality demonstrated by the ship rats in PG has consequences for bird species on Ponui Island, which include kereru (*Hemiphaga novaeseelandiae*), fantails (*Rhipidura fuliginosa*) and tomtits (*Petroica macrocephala*) (*pers. obs*). Ship rats have been identified as significant predators of eggs, chicks and sitting adults birds, including the afore-mentioned species, in non-beech New Zealand forests (Dingwall et al. 1978; Innes et al. 2004; Innes 2005; Towns et al. In Press). Birds in New Zealand have a broad peak of egg-laying occurring from September to December (Cockrem 1995), which coincides with the proposed increase in the degree of arboreality of ship rats in non-beech forests. Thus tree-nesting birds in the forests of Ponui Island are particularly susceptible to predation by the ship rat population.

3.4.4 *Ship rat sharing habitat with North Island brown kiwi on Ponui Island*

North Island brown kiwi home ranges are larger than those of ship rats with estimates ranging from 5.5 to 91.8 ha (McLennan et al. 1987; Taborsky & Taborsky 1992, 1995). The home ranges of kiwi on Ponui Island are unknown, but can be expected, given these estimates, to be significantly larger than those of the resident ship rats. Given these kiwi home range estimates and the high ship rat density in the area (Chapter 2), it can be presumed from the burrow locations of kiwi in PG that the home range of each bird, when active at night, will overlap with those of the ship rats in the area.

The proximity of the ship rats radio-tracked to the nest of one male kiwi throughout tracking is of importance. The egg of this male is known to have hatched successfully in mid December (S. Cunningham *pers. comm.*). Juvenile kiwi are known to travel large distances while dispersing from the natal area, presumably searching for a suitable settlement area (Chan 1999; Gibbs 2000). However, while the yolk sac nourishes newly hatched kiwi chicks, they will leave the nest within a week of hatching to forage (McLennan et al. 2004), remaining close to their natal site during this time (Gibbs & Clout 2003). Thus the newly hatched chick of this nest will have foraged within the home range of at least one potentially competing ship rat, whose home range was found to overlap the nest location.

The high degree of arboreality observed while tracking the ship rats in December suggests of a low rate of encounter between the kiwi and the ship rats. With ship rats utilising the canopy of the forest more than the ground, possible encounters between the

two species may be infrequent during this time. Shapiro (2005) established that the diet of ship rats and kiwi chicks on Ponui Island overlapped in the number of spiders (Arachnida), weta (Orthoptera) and scarabaeid beetles (Coleoptera) eaten, all surface litter dwellers. The high arboreality suggests reduced foraging of these surface dwelling invertebrates by the ship rats at this time of year, with the majority of diet items being found in the forest canopy. This alone implies the degree of competition between the two species would be low at this time of year. Degree of arboreality is thought to be seasonal, with a peak in summer months, and so any effect it has upon the degree of competition between ship rats and kiwi chicks will also follow a seasonal pattern.

Shapiro (2005) found that three invertebrate taxa, scarabaeid larvae (Coleoptera), tipulid larvae (Coleoptera) and elaterid larvae (Diptera) formed the main component of the diet of kiwi chicks on Ponui Island. These three larval forms were found to be either infrequent components or absent from ship rat diet on Ponui Island due to their being found within the soil where ship rats do not forage (Shapiro 2005). However, all three taxa have winged adult forms (Miller 1971; Tillyard 1926) that would then be available to the ship rats as prey during this stage of their life-cycle. Thus even with arboreal ship rats and kiwi chicks having different foraging styles during certain times of the year, the diet of the two may still overlap with ship rats preying upon adult forms of larvae that are frequently consumed by kiwi chicks.

3.4.5 *Conclusions*

This chapter aimed to calculate home range of ship rats on Ponui Island, and despite low success in radio-tracking this was achieved. Home ranges of ship rats on Ponui Island are thought to be smaller than those of populations studied elsewhere in New Zealand. This is believed to be due to the high density of ship rats reported in the area, increasing encounters between individuals and thus forcing a reduction in size of home range. This chapter also aimed to obtain behavioural observation of ship rats while radio-tracking. Ship rats in PG were social and used either the same den site for consecutive days or another in close proximity. Ship rats radio-tracked in the mixed-broadleaf forest of Ponui Island were highly arboreal in December, perhaps reflecting food sources being utilised at the time. This arboreality may not persist throughout the year, with arboreality proposed to decrease over the autumn and winter months due to

seasonal changes in food sources. The high arboreality of ship rats in December may result in the predation of any tree-nesting birds in PG during this time, while simultaneously reducing the encounter rate between ship rats and North Island brown kiwi chicks. The high degree of arboreality exhibited suggests a reduction in the foraging of ground surface invertebrates by the ship rats, thus reducing any competition with kiwi chicks foraging on the ground. However, though arboreal, ship rats will still have access to adult invertebrates, the larval forms of which are predominant in the kiwi chick diet.

4

The importance of vegetation in ship rat (*Rattus rattus*) diet on Ponui Island

Abstract: The proportion of vegetation in the diet of ship rats (*Rattus rattus*) on Ponui Island was calculated using the line intercept method. This method is believed to be more accurate when gauging the relative importance of different food types to a diet than visual estimation, as used by the majority of previous studies on the diet of ship rats. Ship rats were trapped in three different habitats in a forest on Ponui Island; swamp, forest and scrub, between August and November 2005. Plant material was evident in the diet of all ship rats analysed, contrary to the findings of a previous study made one year earlier in the same habitat. Differences in results are attributed to increased accuracy in methodology rather than changes in the dietary habits of ship rats on Ponui Island. Despite increased importance of vegetation to the diet of ship rats on Ponui Island than previously identified, plant material remained a minor dietary constituent. No significant difference in the proportion of vegetation in the diet of ship rats was found between habitat types and month of capture. However results were suggestive of ship rats in scrub habitat consuming more invertebrate material than in the other habitat types. This may be significant considering greater potential for overlap in the foraging of surface invertebrates by ship rats and chicks of North Island brown kiwi (*Apteryx mantelli*) due to soil conditions in this habitat type. This study period did not coincide with abundant fruiting in the study site when it might be proposed that vegetation will have higher prevalence in the ship rat diet. Seasonal abundance of food type availability will have seasonal effects on the degree of competition for surface invertebrates between kiwi chicks and ship rats.

4.1 Introduction

4.1.1 *Ship rat diet in New Zealand*

Ship rats are omnivorous generalists, foraging upon material that is most abundant in the habitat at the time (Innes 2005). Two North Island native forest studies identified seasonality in the diet of ship rats, with animal foods dominating in the spring and summer and plant foods dominating in the autumn and winter (Daniel 1973; Innes 1979). Best (1969) also found that the relative volumes of plant matter to animal matter in the diet of ship rats showed the same marked seasonal variation in a South Island population. This seasonal variation in the diet was related to the seasonal abundance of each food type in the habitat (Best 1969; Daniel 1973). Miller and Miller (1995) found invertebrates dominated plant material in the diet of ship rats regardless of season on Rangitoto Island, with little plant material being eaten in autumn, winter and spring and none in summer. In a *Pinus radiata* plantation the winter diet of ship rats was dominated by invertebrates (Clout 1980), the lack of fruits and seeds contrasting with the winter diet of ship rats previously recorded in native forests (Best 1969; Daniel 1973; Innes 1979). This difference is probably due to the lack of available fruits and seeds over winter in a pine forest (Clout 1980). Best (1969) suggests that the rat is not a selective feeder but that foods that are most important to the diet will be those that are most abundant in the habitat at that time.

The main animal foods eaten by ship rats are arthropods, with weta (Orthoptera) frequently taken but also beetles (Coleoptera), spiders (Arachnida), cicadas (Hemiptera), stick insects (Phasmatodea) and cockroaches (Blattodea) (Best 1969; Clout 1980; Daniel 1973; Gales 1982; Innes 1979; Miller & Miller 1995). Both tree weta (*Stenopelmatidae*) and cave weta (*Raphidophoridae*) have frequently been identified in the diet of ship rats in New Zealand (Best 1969; Clout 1980; Daniel 1973; Innes 1979; Miller & Miller 1995). Best (1969) found a seasonal variation in the numbers of cave weta and tree weta eaten. Cave weta were most frequently eaten in the autumn and winter along with berries and seeds available on the forest floor, and tree weta had a summer peak in their frequency in the diet that was similar to other animal foods of canopy origin (Best 1969). Cave weta are available on the forest floor all year round while tree weta are available only in the canopy, leading Best (1969) to propose a

seasonal shift in the focus of foraging activity by the ship rats, from the leaf litter and humus of the forest floor in autumn and winter to the forest canopy in the summer. Results from radio-tracking (Chapter 3) agree with this theory, with 99% of fixes of radio-collared ship rats taken in December 2005 being recorded above ground.

Plant material found in the diet of ship rats is composed mainly of fruits and seeds, including those of *Coprosma* spp., karaka (*Corynocarpus laevigatus*), hinau (*Elaeocarpus dentatus*), miro (*Prumnopitys ferruginea*), kiekie (*Freycinetia baueriana*) and nikau (*Rhopalostylis sapida*) (Best 1969; Daniel 1973; Innes 1979; Innes 2005; Miller & Miller 1995).

Ship rats are also known to consume other prey items, such as native snails (*Wainuia urnula*) (Daniel 1973) and slugs (*Gastropoda*) (Best 1969). Ship rats have frequently been documented as predators of native birds (Atkinson 1973; Brown et al. 1998; Dingwall et al. 1978; Innes et al. 2004; Towns et al. In Press) with chicks, sitting adults, and eggs up to 61 mm long being taken (Atkinson 1978). However, birds comprise only a small proportion of the diet of ship rats, with the frequency of egg shells and feathers found in stomachs low (Best 1969; Clout 1980; Daniel 1973; Gales 1982; Innes 1979).

4.1.2 *Diet of kiwi*

Kiwi (*Apteryx* Sp.) forage mostly by probing the soil and the leaf litter for food with their long bill (Kleinpaste 1990). In an analysis of the gizzard contents of 50 North Island brown kiwi (*Apteryx mantelli*) the estimated relative contributions to an average diet was 40-45% earthworms, 40-45% other invertebrates and 10-15% plant material, with seeds and fruits being perhaps twice as important as greens (Reid et al. 1982). The importance of plant material in the diet of kiwi is undetermined, with previous investigations focused upon the invertebrate portion. Among the invertebrates eaten by kiwi, cicada nymphs, Scarabidae larvae, Cicindelidae larvae, Tipulidae larvae, Lepidoptera larvae, Arachnida and Orthoptera have been identified (Colbourne et al. 1990; Colbourne & Powlesland 1988; Jolly 1990; Kleinpaste 1990). Soil-dwelling invertebrates are believed to form the bulk of the diet of kiwi (Colbourne et al. 1990), with invertebrates in the soil strata contributing to 78% of the diet of kiwi in Waitangi State Forest, and vegetation only 5.2% (Kleinpaste 1990). Reid et al. (1982) found

vegetable matter in 40 of 43 gizzards, with the quantity and nature of most vegetation (fibrous leaves and bark material) indicative of incidental ingestion, while the number and variety of seeds in 24 gizzards suggested some berries and fruits were actively selected. Reid et al. (1982) discovered seed intake was inversely related to grit ingestion, leading to the suggestion that fruits and seeds played a part in the grinding of food.

Little Spotted kiwi (*Apteryx owenii*) are thought to be selective feeders choosing large, slow moving insects from the upper layers of the soil (Colbourne & Powlesland 1988). In contrast Reid et al. (1982) suggests North Island brown kiwi are non-selective feeders, with the numbers of prey taken reflecting their abundance in the environment.

4.1.3 *Ship rats as potential competitors with kiwi*

With invertebrates seemingly forming a large component of the diet of both kiwi and ship rats, the possibility of competition between the two for this food type arises. Colbourne et al. (1990) suggested rats may compete with Little Spotted kiwi on Kapiti Island for surface-dwelling invertebrates, but noted that overlap in diet of soil-dwelling invertebrates is unlikely. With soil-dwelling food forming the bulk of food items taken by kiwi, this competition may not be so intense (Colbourne et al. 1990). However, in summer months soil penetrability can decrease and hence access to food for kiwi decreases. In addition, most of the permanent soil-dwelling invertebrates such as worms migrate to lower, moister soil levels in summer where they may be out of reach of kiwi, and other important soil-dwelling invertebrates such as cicadas and scarabaeidae will emerge from the soil to continue their life cycle as imagoes (Kleinpaste 1990). Thus foraging on the soil surface by kiwi may be increased during this time, intensifying any competition existing between themselves and ship rats. This is particularly true for young kiwi. With their shorter bills their depth of probing is reduced and foraging for surface invertebrates may be more common. Juvenile kiwi are under intense predation pressure from stoats (*Mustela erminea*) until reaching at least 800 g in weight (McLennan et al. 2004). If competition from rats delays the time taken to reach this critical weight, pressure upon juveniles will be heightened.

This theory formed the basis for the work carried out by Shapiro (2005), who investigated any overlap in diet between chicks of North Island brown kiwi and ship

rats on Ponui Island. Shapiro (2005) found kiwi chicks on Ponui Island were feeding upon both soil-dwelling and surface invertebrates, although soil-dwelling invertebrates dominated. Shapiro (2005) established both kiwi chicks and ship rats consume the same type of surface-dwelling invertebrates in similar numbers, and the percentage of ship rat stomachs and kiwi chick faeces containing earthworms was comparable. However there was a significant difference between the diet of ship rats and kiwi chicks when total invertebrate diet was compared (Shapiro 2005). This was due to the large number of soil-dwelling invertebrate larvae eaten by the chicks. Shapiro (2005) concluded the overlap in diet of surface-dwelling invertebrates may become more important when soil-dwelling larval forms are low in number or not available to kiwi chicks. This could occur during hotter months when soil penetrability decreases and soil-dwelling invertebrates move further down into moister soil areas, outside the probing depth of juvenile kiwi.

4.1.4 *The need for further investigation*

A frequent method used to divide the proportion of animal versus plant material in the diet of ship rats has been to visually estimate, to the nearest 10%, the percentage of each food type in their stomach (Best 1969; Copson 1986; Daniel 1973; Drummond 1960; Innes 1979; Miller & Miller 1995; Moors 1985). However, visual estimates are prone to observer bias, scarce food items can be over-estimated while abundant ones can be underestimated (Bunn 1979). In the stomach, seeds and nuts are often represented by amorphous starchy material (Bunn 1979; Daniel 1973), whereas invertebrate remains, such as fragments of antennae or leg, are often rigid and obvious. Thus seed and nut items can be easily overlooked. Shapiro (2005) found very little evidence for plant material in the diet of ship rats on Ponui Island, with only 7 of 101 stomachs analysed found to contain evidence of vegetative material for rats trapped June 2004 to February 2005. Shapiro (2005) commented on the difficulty of identifying plant material and concluded that the importance of vegetation in the diet of ship rats on Ponui Island cannot be discounted. With the proposed competition between ship rats and North Island brown kiwi for invertebrate foods it is important to accurately measure the proportion of plant material versus animal material in the ship rat diet. Proportion of each food type in the diet would impact upon the degree of competition existing between the two species, as months in which plant material intake increases,

competition will decrease. Clout (1980), Gales (1982) and Bunn (1979) stained plant material in stomach contents, thus making it more identifiable for the estimation of dietary volume. Bunn (1979) used the line intercept method after Seber and Pemberton (1979) to quantitatively compare the food items found in the diet of kiore (*Rattus exulans*) on Tiritiri Matangi Island. This technique is more accurate than visual estimation, however it suffers in that accurate results often require tedious preparation and execution. However, by using this method, Bunn (1979) was able to precisely identify seasonal variability in the monthly proportions of food categories in the diet of kiore.

4.1.5 *Chapter aims*

It is the aim of this chapter to examine the diet of ship rats on Ponui Island during August 2005 to November 2005, thus partially overlapping the period in which Shapiro (2005) examined the diet of ship rats in 2004. Plant material in stomach contents will be stained and using the line intercept method this chapter aims to accurately quantify the importance of vegetation in the diet of ship rats during this time. Given the ship rat diet is dominated by two main food groups, plant and animal, and that the majority of animal material is invertebrate, remaining 'other' food type will be assumed to be invertebrate. Results will be compared with those of Shapiro (2005) and used to assess the degree of potential competition between ship rats and kiwi chicks for surface-dwelling invertebrates. Ship rats from three different habitat types, swamp, forest and scrub, will be analysed to investigate any difference in food type consumption with habitat type.

4.2 Methodology

4.2.1 Study site

The study site was located on Ponui Island in the Hauraki Gulf (36°55'S, 175°11'E), a privately owned island that is thought to have one of the highest densities of North Island brown kiwi in New Zealand (Miles & Castro 2000). A patch of mixed podocarp-broadleaf forest about 1.5 km² in size, composed of four main gullies, contains 36 adult kiwi, and up to five kiwi chicks at one time, with transmitters attached that have been monitored by the Ponui Island Research Programme since March 2004. Kill-trapping was conducted in this forest in red stony hill gully (RSHG), adjacent to pipe gully (PG), thus avoiding the marked individuals used for mark-recapture in the live trapping area (Chapter 2). Kill-trapping was carried out in three separate habitats identified along RSHG, swamp, forest and scrub (Plate 4.1). Trapping was conducted in these three habitats due to the distinction in the vegetation between them (Table 4.1).

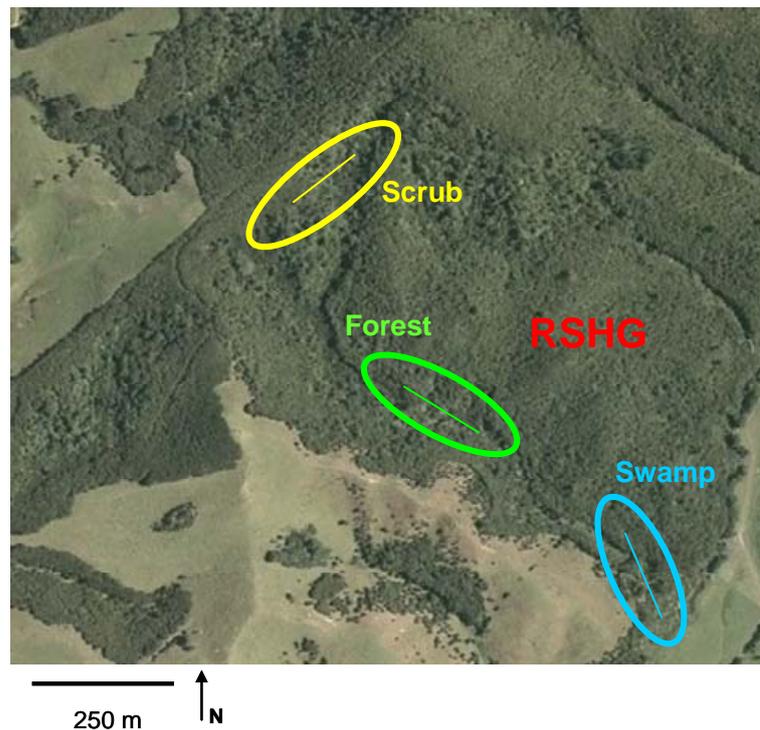


Plate 4.1 Aerial photograph of RSHG, identifying the three habitats where kill-trap lines were placed; swamp (blue), forest (green) and scrub (yellow). Image supplied by I. Castro.

Swamp habitat, at the base of RSHG, had the lowest elevation of the three and was dominated by raupo (*Typha orientalis*). Traps were laid adjacent to the swamp in relatively open vegetation bordering on pasture with a kanuka (*Leptospreum ericoides*) and manuka (*Leptospreum scoparium*) canopy.

The next trap line was roughly 350 m into the gully, within the gully basin. This forest was mixed podocarp-broadleaf with a relatively sparse understorey, but dense sub-canopy and canopy. Species such as taraire (*Beilschmiedia tarairi*), pohutukawa (*Metrosideros excelsa*), puriri (*Vitex lucens*) and kanuka (*Leptospreum ericoides*) were found in this habitat type. Cattle frequently seek shelter within both the forest and the swamp habitat type (D. Chamberlin pers. comm.; pers. obs.) perhaps explaining the sparse understorey within each due to browsing and trampling.

Further up into the gully on the top ridge was the third habitat, scrub. This had the highest elevation and was the steepest of the three habitats. With fewer broadleaf species than swamp and forest, kauri (*Agathis australis*) and kanuka (*Leptospreum ericoides*) dominate this habitat.

Seven Standard Victor snap-traps (Pest Management Services, Waikanae) were placed 25 m apart in a straight line adjacent to the swamp habitat at the bottom of the gully. Identical trap lines were also placed within the forest and scrub habitat. Traps were left without bait for two nights prior to trapping to acclimatise rats to their presence.

Shaprio (2005) conducted kill-trapping of ship rats in Hook Gully, at least 1 km away from RSHG. However, both gullies are within a 1 km² patch of forest on Ponui Island and habitats were assumed to be similar.

Table 4.1 The main plant species observed within swamp, forest and scrub habitats, in RSHG.

Habitat	Plant species	
Swamp	Adjacent to swamp	Canopy : Kanuka (<i>Leptospremum ericoides</i>) Manuka (<i>Leptosprema scoparium</i>) Subcanopy : <i>Coprosma arborea</i> Understorey : Mingimingi (<i>Leucopogon fasciculatus</i> & <i>Cyathodes juniperina</i>) Occasional lancewood (<i>Pseudopanax crassifolius</i>)
	Within swamp	Tutu (<i>Coriaria arborea</i>) Swamp Maire (<i>Syzygium maire</i>) Raupo (<i>Typha orientalis</i>) Cabbage tree (<i>Cordyline australis</i>)
Forest	Taraire (<i>Beilschmiedia tarairi</i>) Kohekohe (<i>Dysoxylum spectabile</i>) Tawa (<i>Beilschmiedia tawa</i>) Kanuka (<i>Leptospremum ericoides</i>) Nikau (<i>Rhopalostylis sapida</i>) Kamahi (<i>Weinmannia racemosa</i>) Puriri (<i>Vitex lucens</i>) Pohutukawa (<i>Metrosideros excelsa</i>) Karaka (<i>Corynocarpus laevigatus</i>) Hinau (<i>Elaeocarpus dentatus</i>) Miro (<i>Prumnopitys ferruginea</i>) Rewarewa (<i>Knightia excelsa</i>) Pukatea (<i>Laurelia novae-zelandiae</i>) <i>Collopermum hastatum</i> Occasional Black Maire (<i>Nestegis cunninghamii</i>) Regenerating Kauri (<i>Agathis australis</i>) Kiekie (<i>Freycinetia baueriana</i>)	
Scrub	Kauri (<i>Agathis australis</i>) Kanuka (<i>Leptospremum ericoides</i>) Mingimingi (<i>Leucopogon fasciculatus</i> & <i>Cyathodes juniperina</i>) <i>Coprosma arborea</i> Mapou <i>Myrsine australis</i> Lancewood (<i>Pseudopanax crassifolius</i>)	

4.2.2 *Kill-trapping*

Kill-traps were baited with a mixture of peanut butter and rolled oats for six consecutive nights per month for four consecutive months from August to November 2005. A sample of five rats per site per month was targeted and trapping was terminated at each site once the target was achieved. Traps were covered by a rectangular wire mesh cage (31 cm long x 18 cm wide x 12 cm high) with a small square opening (7 cm x 7 cm) to reduce capture of non-target animals. Traps were tied to adjacent vegetation with string to prevent their removal by injured rats. Traps were checked the morning following every trapping night.

4.2.3 *Dissection*

Ship rats caught in kill traps were also used to provide information on breeding condition (Chapter 2). Dissection was carried out the day following capture. Dead ship rats were sexed, weighed using a 300 g Pesola scale (PESOLA AG, Switzerland) and head-body length and tail length measured with a mounted 30 cm ruler. A body condition index (C) was calculated for all ship rats (Moors 1985) using the formula:

$$C = \left(\frac{W}{HBL} \right) \cdot 10^5$$

Where W is weight (g) and HBL is head-body length (mm) of the ship rat. Male rats with scrotal testes and female rats with a perforate vagina were considered mature (Cunningham and Moors 1993). A mid-ventral incision was made from the ribcage to the pubic region to expose the digestive system of the rat. The stomach of each rat was removed and placed into a labelled specimen jar containing 10% formalin solution. Maturity was confirmed with further inspection of the reproductive anatomy, with the presence of epididymal tubules in the testes of male ship rats and the occurrence of pregnancy, placental scars, or the condition of the uterus in female ship rats (Chapter 2).

4.2.4 *Stomach content analysis*

Stomachs were cut along their greater curvature and the contents washed gently into a 180 μ m mesh sieve with water. Where present in the stomach of ship rats, the peanut butter and oat bait was a noticeable bolus and was removed. The remaining material

was then sieved and transferred with as little water as possible into a glass Petri dish. Gram's iodine was then applied to the contents of the Petri dish to stain the starch material present in the stomach contents. The contents were bathed in the iodine solution for at least twenty minutes to allow sufficient staining and then re-washed with water in the 180 μm mesh sieve. The contents were then transferred back to the Petri dish with a little water to allow for microscopic inspection. Items in the stomach containing starch were now dyed black by the iodine solution and so vegetative material in the diet could be differentiated from all other material.

Stomach contents were inspected under a Nikon SMZ-2B (Nikon Inc., U.S.A.) dissecting microscope at $0.8\times$ magnification. Any nematodes in the stomach were removed and counted. The removed bait was sieved separately to recover any nematodes to be included in the count. The sieved remainder was also inspected briefly for any obvious diet items that were accidentally included in the bait removal. If present these items were placed with the other stomach contents into the Petri dish for staining.

4.2.5 *Statistical analysis*

The method used to analyse the stomach contents was after Seber and Pemberton's line intercept method (1979), modified for this particular use by Bunn (1979). This method involves taking a number of transects for each stomach and finding the individual sums of the lengths of the food types found intercepting these transects. This was carried out for each stomach by taking a digital image of the stomach contents. Each Petri dish containing one stained stomach sample was placed under a Leica M8 (Leica Microsystems GmbH, Wetzlar, Germany) dissecting microscope with a mounted Spot Insight digital camera (SPOT, Diagnostic Instruments Inc., USA). Using Spot Advanced version 4.0.3 (2004) a digital image of the contents was photographed at $6\times$ magnification. For each Petri dish two digital images were photographed, each taken after moving the Petri dish randomly so that different perspectives were observed. Five calibration lines 100000 μm in length were drawn onto each digital image, giving ten transect lines in total for each stomach. Transect placement was randomly chosen to ensure no assumptions about the distribution of each food type within the microscope field is necessary. The number of transects was represented by K , here $K = 10$.

Along each transect the sums of the lengths of food type ‘vegetation’, stained black, intercepting each transect was measured. The sums of the lengths of food type ‘other’, all other unstained material intercepting each transect, was then also measured (Plate 4.2). In some cases items of food type other appeared black under the microscope and could be mistakenly counted as food type vegetation. However, due to the initial examination of each stomach’s contents under the dissecting microscope, these items were identified as food type other and were not confused when this analysis took place. Slugs (Gastropoda), for example, were fairly frequent and appeared very dark in stomachs. However, they were clearly identifiable and included as food type other when the final analysis took place. Plant material that was not stained by the Gram’s iodine, such as herbage, was also pre-identified in the initial microscopic inspection, and so included as food type vegetation in the analysis. The sums of the lengths of both food types were then used to calculate \hat{p} for each stomach, the proportion of vegetative food in the diet. The remaining proportion of the diet belonged then to food type other.

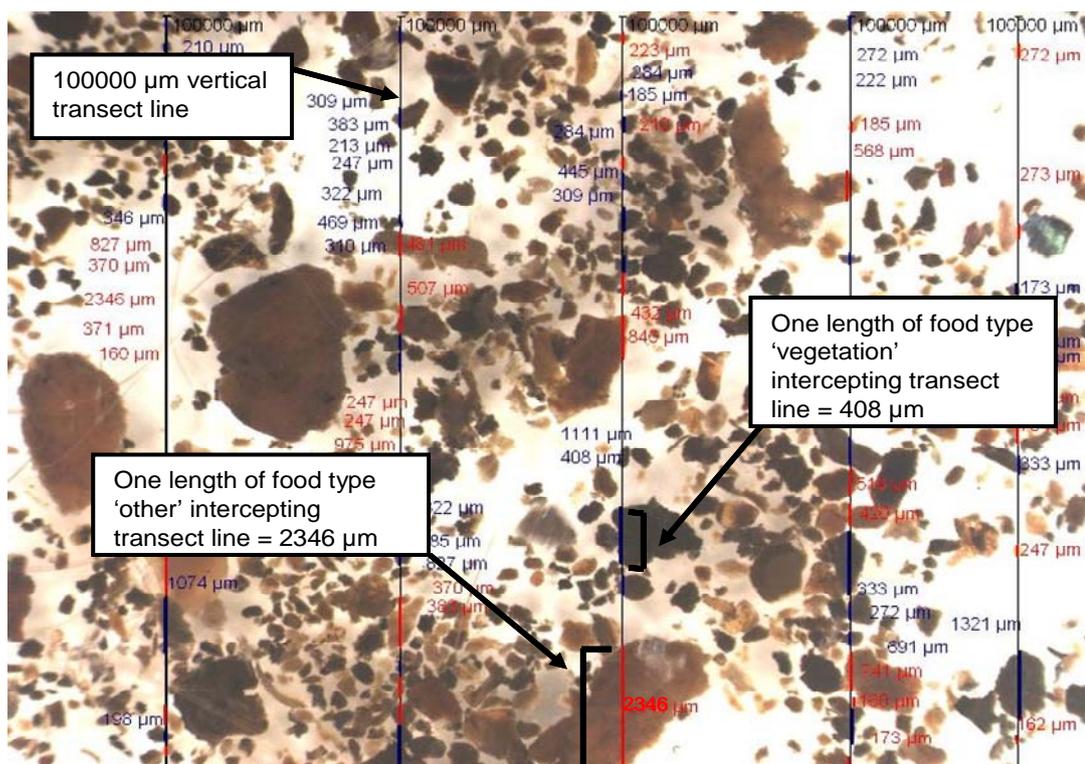


Plate 4.2 Magnified (6×) contents of one ship rat stomach sample. For clarity, the image is of a nearly empty stomach. One vertical transect line is drawn across the picture and the lengths of food type vegetation (blue font) and food type other (red font) measured where intercepting the transect. This process is repeated four times on each image, giving five transect lines per picture, and ten per stomach.

The value of \hat{p} was found from:

$$\hat{p} = \sum_k Y_k / \sum_K (Y_k + Y'_k) \quad (1)$$

Where Y_k is the sum of the lengths of vegetative food and Y'_k is the sum of the lengths of all other food types intercepting each transect.

Bias due to K can be eliminated using the Jackknife technique. Jackknifing is a technique for reducing bias by exploiting the dependence of the bias on the sample size (Sharot 1976). The unbiased proportion of vegetation, the jackknife estimate (\bar{p}_j), was found from:

$$\bar{p}_j = \sum_{k=1}^K \hat{p}_k / K \quad (2)$$

Where:

$$\hat{p}_k = K \cdot \hat{p} - (K-1) \hat{p}_{-k} \quad (3)$$

Where \hat{p}_{-k} is the estimate with the same form as \hat{p} (Eq. 1) but based on $K - 1$ lines with the data from line k omitted. Any lines with no intersections of either food type are ignored so that K refers to the number of 'useful' lines.

The variance, $V(\bar{p}_j)$ of \bar{p}_j was then estimated from:

$$V(\bar{p}_j) = \sum_{k=1}^K (\hat{p}_k - \bar{p}_j)^2 / K(K-1) \quad (4)$$

The proportion vegetation in each ship rat stomach was then averaged according to trapping month and trapping habitat, by calculating the weighted mean (\bar{X}). The weighted mean is calculated when there is some variation in the relative contribution of individual data values to the mean. Each data value has a weight assigned to it (w_i); data values with larger weighting factors contribute more to the weighted mean. This restores some balance to the mean as less weight is placed upon any over-represented estimates and greater weight on under-represented estimates. The weighted mean was calculated as follows:

$$\bar{X} = \sum_1^i w_i (\bar{p}_j)_i \quad (5)$$

Where the weighting factor (w_i) is estimated from the variance ($V(\bar{p}_j)$) of each jackknife estimate:

$$w_i = \frac{1/V(\bar{p}_j)}{\sum_{i=1}^n \left(\frac{1}{V(\bar{p}_j)} \right)_i} \quad (6)$$

The standard error (S.E.) for each mean (\bar{X}) was then calculated from:

$$\text{S.E.} = \sqrt{\frac{\sum \frac{1}{V(\bar{p})_j} \cdot (\bar{X} - x_i)}{\frac{\sum_{i=1}^n \left(\frac{1}{V(\bar{p})_j} \right)}{n}}} \quad (7)$$

The 95% confidence interval for each weighted mean was then determined from:

$$\bar{X} \pm t_{0.05(n-1)} \times \text{S.E.} \quad (8)$$

The statistical software package JMP 5.1 (2003) was used to carry out univariate analyses of variance (ANOVA) to examine differences in the number of nematodes, ship rat body condition and weighted mean proportion of vegetation in the diet, for ship rats kill trapped per month and per habitat. In certain stated cases, data were Box Cox X transformed to infer the normal distribution assumed by this test. Chi square (χ^2) analyses were used to analyse the observed sex ratio in the trapped sample.

4.3 Results

A total of 49 individual ship rats were caught in kill traps between August and November 2005. Despite efforts to trap at least five rats from each habitat type per month, trapping success rates declined after October with only one ship rat caught in the swamp habitat and two in the forest habitat. No ship rats were caught in the scrub habitat in October and November (Figure 4.1). This is thought to be due to changes in food availability between months with the behaviour of the ship rats shifting as a response (Chapter 2).

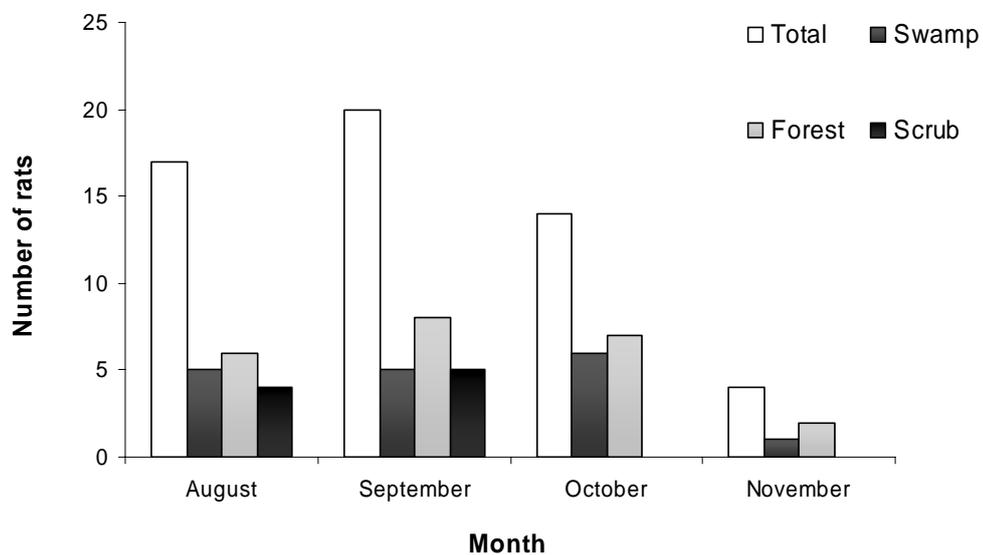


Figure 4.1 Total numbers of rats caught in kill traps between August and November 2005 in RSHG, and numbers caught in each of the three habitats each month.

4.3.1 Stomach analysis

Two samples of the 49 ship rats caught in kill-traps were used to practice techniques, and thus were not included in any subsequent stomach analysis. Nematodes were found in the stomachs of all ship rats analysed (Table 4.2), with numbers ranging from 3-118. Nematodes were not identified to species, but are presumed to be either *Physaloptera getula* or *Mastophorus muris* as these are the most prevalent nematodes in ship rat stomachs (Charleston & Innes 1980) and were found in the ship rat stomachs analysed by Shapiro (2005) on Ponui Island. The mean number of nematodes found in each stomach was highest for rats caught in September, though there was no significant

difference in the number of nematodes in ship rat stomachs when compared with month caught ($F_{3,43} = 1.0015$, $p > 0.05$), with data normalised using the Box Cox X transformation. Ship rats trapped in the scrub habitat had the highest mean number of nematodes in their stomachs; however rats were only caught here in two of the four months. The number of nematodes in ship rat stomachs did not differ significantly according to habitat caught ($F_{2,44} = 0.3996$, $p > 0.05$), with data normalised using the Box Cox transformation.

Table 4.2 Average number of nematodes present in the stomachs of ship rats caught in RSHG between August and November 2005. Numbers in parenthesis are \pm one standard error. Numbers are given according to month and habitat trapped.

	August	September	October	November	Habitat Average
Swamp	21 (\pm 6)	22 (\pm 7)	22 (\pm 4)	33	22 (\pm3)
n	4	5	6	1	16
Forest	23 (\pm 8)	37 (\pm 13)	21 (\pm 4)	30 (\pm 3)	29 (\pm 5)
n	5	8	7	2	22
Scrub	22 (\pm 6)	42 (\pm 11)	-	-	33 (\pm 7)
n	4	5	-	-	9
Month Average	22 (\pm 4)	34 (\pm7)	21 (\pm3)	31 (\pm0)	Total Average: 28 (\pm 3)
n	13	18	13	3	47

Only four stomachs were found to be nearly empty, with bait forming the bulk of the contents. The four rats with nearly empty stomachs were all trapped in the forest

habitat, two in August and two in November. Fur was common in most stomachs, mostly likely as a result of grooming. A small fragment of eggshell, approximately 3 mm × 3 mm, was identified in the stomach of one rat caught in the forest habitat in October. Any colouring of the shell had been bleached by the formalin preservative and so identification of the species of bird it belonged to could not be made.

4.3.2 *Body condition of ship rats*

Rats trapped in October 2005 were found to be in slightly better condition than those trapped in any of the other months (Figure 4.2). No significant difference was found between the condition indices of ship rats when compared with month trapped ($F_{3,39} = 2.1814, p > 0.05$).

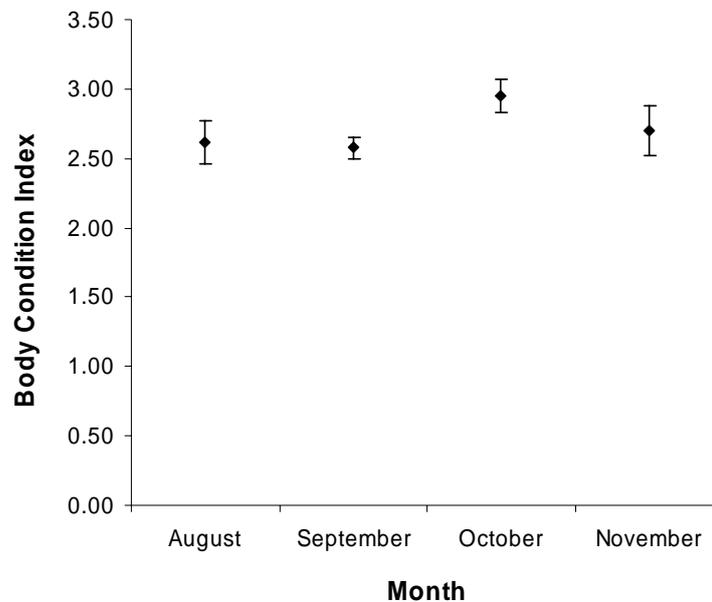


Figure 4.2 Average body condition index, \pm one standard error, of ship rats kill-trapped each month in all three habitats in RSHG.

The condition of ship rats differed when compared by habitat, with ship rats caught in swamp habitat in slightly better condition than those in the forest and the scrub (Figure 4.3). Ship rats caught in the forest habitat were in turn found to have slightly better mean body condition than those caught in the scrub habitat. Despite these differences, condition indices did not differ significantly across habitats ($F_{2,40} = 1.2384, p > 0.05$), with data transformed using Box Cox X to infer normality.

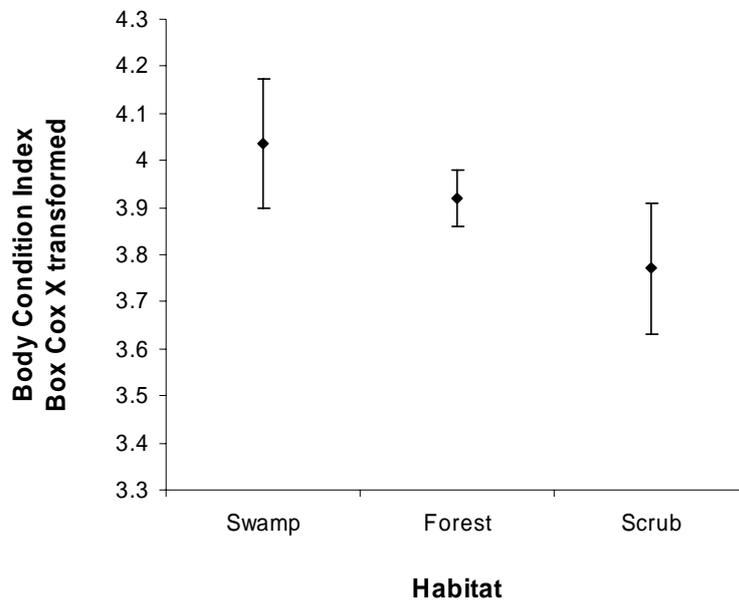


Figure 4.3 Box Cox X transformed average body condition index, \pm one standard error, of ship rats kill-trapped in each habitat during August-November 2005 in RSHG.

There was no correlation between the body condition of the ship rats and the number of nematodes which they carried ($R^2 = 0.0004$, $F_{1,41} = 0.016$, $p > 0.05$).

4.3.3 *Proportion of vegetation in the diet of ship rats on Ponui Island*

Plant material was present in the stomachs of all ship rats kill-trapped between August 2005 and November 2005. However, vegetation was not found to dominate the diet of ship rats for each month in all three habitats of RSHG (Figure 4.4). The majority of the diet of ship rats was composed of food type ‘other’. The weighted mean percentage of the vegetative diet of ship rats varied from 12% in August 2005 to 32% in November 2005. The proportion of vegetation consumed by ship rats increased slightly with each month of kill-trapping; however there was no significant difference between the proportion of vegetation in the diet when compared to the month in which ship rats were kill-trapped ($F_{3,43} = 2.4210$, $p > 0.05$).

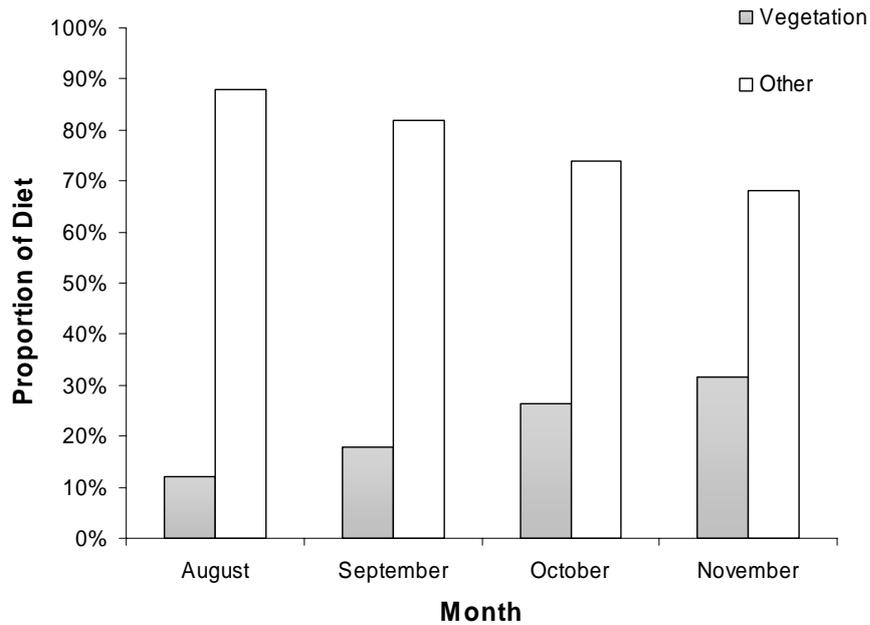


Figure 4.4 Proportion of vegetation and other diet items in the stomachs of ship rats trapped in all three habitats of RSHG according to month caught. One standard error is included but the values are too small to be noticeable.

Ship rats caught in the swamp habitat had the highest weighted mean proportion of vegetation in their diet when compared to ship rats caught in the two other habitat types, with those kill-trapped in the scrub habitat having the lowest (Figure 4.5). The weighted mean percentage of vegetation found in the diet of ship rats caught in either habitat varied from 13% in the scrub to 20% in the swamp. However, these differences in the proportion of vegetation in the diet of ship rats from each habitat were not significant ($F_{2,44} = 2.3293, p > 0.05$).

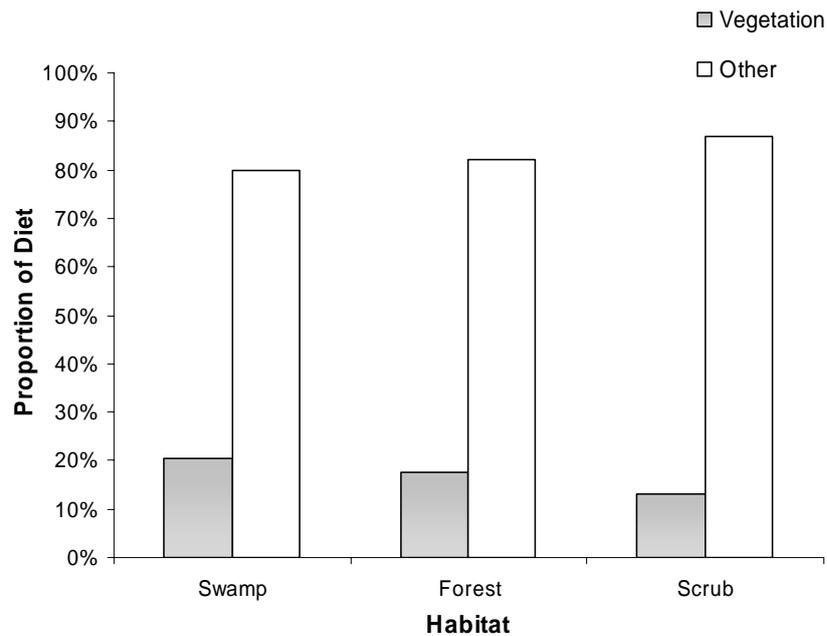


Figure 4.5 Weighted mean proportion of vegetation and other diet items occurring in the stomachs of ship rats kill-trapped between August and November 2005 within each habitat of RSHG. One standard error is included but the values are too small to be noticeable.

No significant difference in the proportion of vegetation in the diet of ship rats between habitat types was found when examined separately for each month. Likewise, no significant difference was found in the proportion of vegetation in the diet of male and female ship rats ($F_{1,45} = 0.036, p > 0.05$). The variance, $V(\bar{p}_j)$, of the proportion of vegetation calculated for each stomach sample was extremely small, ranging from 0% to 0.4%. The standard error of each weighted mean calculated per month and per habitat was also very small, ranging from zero to 7.58×10^{-10} .

4.4 Discussion

Plant material was evident in the stomachs of all ship rats analysed in this study. In contrast, Shapiro (2005) found only 7% of ship rat stomachs to contain plant material while trapping on Ponui Island one year previously. Even though more vegetation may have been available in the trapping habitat in this year of study, the discrepancy in results is believed to be due to increased accuracy in methodology rather than changes in the dietary habits of the ship rats. However, in agreement with Shapiro (2005), vegetation was a minor constituent of the diet of ship rats between August and November 2005, regardless of habitat trapped in. With all plant material stained and measured as food type vegetation, remaining 'other' is presumed to be animal. Given invertebrates form the majority of the animal material consumed by ship rats (Best 1969; Clout 1980; Daniel 1973; Gales 1982; Innes 1979; Miller & Miller 1995), all animal material is presumed to be invertebrate. Invertebrates are thus assumed to have formed the majority of food consumed by ship rats on Ponui Island between August and November 2005. Only one example of vertebrate food was found in the diet of ship rats trapped, with a small fragment of egg shell found in the stomach of one rat trapped in the forest habitat in October. It cannot be concluded that this was due to predation as no other obvious evidence of egg material was found in the stomach and the shell fragment could have been accidentally consumed while foraging.

4.4.1 *Vegetation consumption according to habitat*

While there was no significant difference between the proportions of vegetation eaten between the three habitats in which ship rats were kill trapped, there was a slight trend. Ship rats in the swamp habitat had the highest proportion of vegetation in their diet while those in the scrub habitat had the lowest regardless of month trapped. This could be due to the availability of vegetation at the time in the three habitats. Unfortunately, a complete phenology of vegetation in the study areas could not be carried out in the available time; this would have aided greatly the understanding of the observed differences in vegetation intake by ship rats between the habitats, as diet is thought related to food abundance. However, some observations on the species found in each habitat and obvious flowering or fruiting activity were made.

Mingimingi was observed to have some fruits in September and raupo was seeding in October/November in the swamp. The swamp habitat contained abundant raupo and swamp grasses (pers. obs.), the seeds of which could be an important diet item for the ship rats in this habitat type. On Tiritiri Matangi Island kiore consumed grass seed in large amounts from early November or December through to March or May depending on the year, even before seed fall had begun (Bunn 1979). Bunn (1979) concluded the kiore had actively sought out the seed by climbing the grass stalks. In addition, a few tutu, cabbage trees and rewarewa were flowering nearby the swamp trapping line in November.

In Wenderholm regional park, 55 Km north of Auckland, rodents were found to have a significant impact on the fruits of taraire and nikau palm, with predation also noted on kohekohe, ripe karaka fruits, rewarewa and to a lesser extent on puriri and tawa (Dijkgraaf 2002). All of these species are found in the forest habitat and are thus assumed to contribute to the vegetative component of the diet of ship rats in the area. However, few of these species were found to be fruiting or flowering at the time of trapping. Taraire had recently finished fruiting at the commencement of trapping in August, with numerous old fruits found on the forest floor at this time, many of which were observed with signs of rat predation. Numerous miro nuts were also found on the forest floor with obvious signs of predation, with the nuts gnawed open and the husks extracted. New miro seeds were beginning to develop at the end of trapping in November. Nikau was observed with new drupes in September, however, some were still unripe in November. Puriri had new, unripe fruits in November also, while both taraire and rewarewa were flowering at this time.

The scrub habitat contained less fruiting and seeding species than the other habitats, being dominated by kauri. This is most likely reflected in the very small proportion of vegetation in the diet of ship rats from this habitat type. The sample of ship rats from the scrub habitat was especially small with no rats caught there for two of the four months. Thus the degree of vegetation in the diet of rats in this habitat may have been over or underestimated.

Observations of food intake between habitat types are limited by the lack of replication in this study; ship rats from only one example of each habitat type were trapped. Thus any variation in ship rat diet from similar habitat types in different parts of the forest on

Ponui Island is not taken into account. Shapiro (2005) also trapped ship rats on one trap line within the forest habitat type of a neighbouring gully within the same patch of forest, and so any bias resulting from lack of replication will be comparable across studies.

4.4.2 *Vegetation consumption according to month*

The proportion of vegetation in the diet of ship rats trapped in all habitats increased slightly with each month of trapping, although these differences were not significant. Between August and November 2005 the proportion of vegetation eaten by the ship rats increased by 20%. Thus, the consumption of vegetation by ship rats increased slightly from the end of winter into spring. Previous studies on the diet of ship rats in New Zealand native forest have found that plant material forms the majority of the diet in autumn and winter, and animal material dominates in spring and summer (Daniel 1973; Innes 1979). Given this, the proportion of plant material in the diet of ship rats would be expected to decrease with the onset of spring. In this study an opposite trend was observed, perhaps due to different methods utilised or the difference in the habitats in which ship rats were studied. The ship rat is an omnivorous generalist, consuming items that are most available at the time (Innes 2005). Seasonal trends observed by previous investigation into the diet of ship rats reflect the seasonal availability of food items, not a strict preposition of ship rats to switch food type with each season. The increase in vegetation seen here could thus reflect an increase in plant material available to the ship rat as spring developed on Ponui Island. Radio-collared ship rats on Ponui Island were found to be highly arboreal in December 2005 (Chapter 3), with this thought to reflect the seasonal shift in foraging focus as suggested by Best (1969). With arboreality proposed to have been increasing as kill-trapping continued in this study, any fruits and seeds available in the trees will be more accessible to the ship rats. This perhaps explains the slight increase in vegetation consumption observed with each month of kill-trapping, regardless of habitat, on Ponui Island.

Trapping in this study did not coincide with the timing of abundant fruiting by plant species on Ponui Island. Thus the proportion of vegetation seen here in the diet of ship rats most likely does not reflect the potential intake of vegetation during times of plentiful plant material. In particular, proportion of vegetation consumed may increase during autumn months, as this is the period that previous studies have noted an increase

in vegetation intake (Best 1969; Daniel 1973; Innes 1979) and fruits are thought to be more abundant during this time in North Island native forests (Leathwick 1984). Although, at the end of winter vegetation was found to be only 12% of the diet of ship rats, and so if vegetation was predominant in the diet in previous months its consumption would have had to decrease dramatically. In future it would be extremely worthwhile for a 12 month study using similar methods to ascertain seasonal changes in plant and animal abundance in the diet of ship rats.

Stomach analysis from deceased animals is limited in that only one sample can be taken from one animal at one point in time, and that the contents will only reflect what that animal has eaten recently. Thus it is favourable to accumulate a high number of stomach samples with which to investigate the dietary habits of a species, to decrease variability and increase confidence in conclusions drawn. The lack of replication of trapping lines for each habitat type also limits the results of this study, as any variation in ship rat diet across similar habitats within the forest patch are not addressed. Thus observations only relate to the particular habitat type trapped, and not all areas of that habitat found on Ponui. However, notwithstanding these limitations, evident trends have been observed in this study.

4.4.3 *Condition of ship rats on Ponui Island*

The body condition indices of ship rats on Ponui Island were within range of ship rats killed trapped on Goat Island (MacKay & Russell 2005). Body condition indices did not vary dramatically with each month; however a trend was seen when compared between habitat types. The mean body condition of ship rats from each habitat type would suggest that swamp habitat is better for ship rats and scrub habitat the worst, but there was a lot of variation in the data and thus any trends must be observed with caution. Again, lack of replication between habitat types limits the extent to which observations can be applied to all areas of the patch of forest on Ponui Island.

Prevalence of nematodes was very high in the ship rats trapped on Ponui Island between August and November 2005, with all animals trapped parasitized. This is high when compared with previous records. Miller and Miller (1995) found 59% of ship rats were infected with nematodes, Charleston and Innes (1980) 66.5%, and Clout (1980) 23.5% infected. However, Shapiro (2005) also found a high prevalence of nematodes on Ponui

Island while trapping between June 2004 and February 2005. Both species of nematode frequently found in ship rat stomachs have obligatory indirect life cycles with arthropod intermediate hosts, and it has been suggested that weta may be the principal intermediate hosts of *P. geluta* (Charleston & Innes 1980). Thus, the high prevalence of nematodes in Ponui Island ship rats could reflect the predominance of invertebrate food in the diet. Shapiro (2005) found the number of nematodes in the stomachs of ship rats was significantly higher in summer than in the winter, perhaps reflecting the seasonal shift in food type consumption by ship rats. It has been suggested that population density could affect parasite infestation (Roberts et al. 1992). The estimated high population density of ship rats on Ponui Island (Chapter 2) may also be contributing to the high infestation rate of nematodes seen in the population.

4.4.4 *Implications for competition between ship rats and kiwi chicks*

Shapiro (2005) only found seven out of 101 stomachs contained plant material when trapping between June 2004 and February 2005, suggesting this food type was of little importance to the ship rats. Shapiro (2005) did, however, comment on the difficulty of identifying plant material in stomach contents and cautioned that its relevance to the diet could not be discounted. In this study, while kill-trapping between August 2005 and November 2005, all ship rats caught were found to have plant material in their stomach. The method utilised in this study is believed to be more accurate when quantifying proportions of food types in stomach contents than a visual estimate. Thus vegetation is of greater importance to the diet of ship rats on Ponui Island than originally thought by Shapiro (2005). Even with this increase in importance, 'other' material, assumed invertebrate, was found to be predominant over vegetation in the diet of ship rats during the study period. Thus the potential competition between ship rats and North Island brown kiwi chicks proposed by Shapiro (2005) remains possible. Ship rats are omnivorous generalists and the relative intake of food types is thought to reflect their availability. Thus in times of abundant fruiting, not seen during this study, the proportion of vegetation in the diet is proposed to increase. Therefore, the degree of dietary overlap for surface invertebrates between ship rats and kiwi chicks may simultaneously decrease.

A clear and significant habitat preference by young North Island brown kiwi for scrub and regenerating forest over mixed podocarp-broadleaf and kauri forest was noted by

both Gibbs (2000) and Chan (1999). In addition Shapiro (2005) also observed that kiwi chicks spent more time in the scrub habitat on Ponui Island. The scrub habitat had the highest elevation of the three habitat types and thus soil there is presumed to be drier and of lower penetrability. In a study on North Island brown kiwi foraging behaviour on Ponui Island, Cunningham (2006) did not find any significant difference in probe-hole density between scrub habitat and forest, gully and swamp habitat. This suggests kiwi in scrub habitat do not forage for soil-dwelling invertebrates any less than in other habitat types. However, probe-hole depth was significantly shallower in the scrub habitat than in the gully and forest habitats, and soil penetrability in the scrub was lower than the other habitat types (Cunningham 2006). Thus, in periods of drought when soil can become denser, the already limited probing depths of kiwi may be reduced in this habitat type. Kiwi chicks that have a preference for this habitat may then be restricted to foraging for surface invertebrates. Although the scrub habitat sample only comprised nine ship rats due to decreasing trapping success, a trend was observed for ship rats in this habitat type to have the lowest proportion of vegetation in their diet. 'Other' material was found to comprise 87% of the diet of ship rats caught in this habitat. Given invertebrates form the bulk of the animal material eaten by ship rats, and their inability to access invertebrates below the soil, this material is assumed to be composed mainly of surface-dwelling invertebrates, some that are also eaten by kiwi chicks. Thus competition between the two species for surface-dwelling invertebrates could indeed become problematic in times when numbers of soil-dwelling invertebrates are low in number or soil density is high in scrub habitat type.

4.4.5 *Conclusions*

The aim of this chapter was to accurately assess the proportion of two food types found in ship rat diet, 'vegetation' and 'other'. This is believed to have been accurately quantified with the use of the line intercept method. Kill-trapping and stomach analysis was conducted in a period in which Shapiro (2005) conducted stomach analysis one year previously, with the intention of comparing results. Vegetation was found in the stomach of all rats analysed, contrary to the finding of Shapiro (2005) where only 7 out of 101 stomachs were found to contain plant material during seven months of kill-trapping. The wide discrepancy in results is probably better explained by differences in methodology than by changes in the diet of ship rats. Despite the increase in

importance of vegetation in the diet of ship rats than previously thought, the proportion of food type 'other', presumed invertebrate, was found to constitute the majority of the diet. Given that the period of study did not coincide with the timing of most plant species fruiting it is believed that the importance of vegetation in the diet of ship rats in this study does not reflect the potential role that vegetation can assume in the diet. Similar analysis of the diet of ship rats on Ponui Island is recommended for 12 consecutive months in order to visualise the seasonality of food types consumed.

With the majority of the diet of ship rats composed of invertebrate material in this time period, the potential for competition outlined by Shapiro (2005) between ship rats and chicks of North Island brown kiwi for surface-dwelling invertebrates is maintained. Ship rats from three different habitats within forest on Ponui Island were trapped and analysed, with the aim of assessing any difference in food type consumption between habitats. A trend for ship rats in the scrub habitat to consume more, of what is presumed to be, invertebrate material than the other two habitats was observed. This is of importance when considering the preference of kiwi chicks for this area and the potential for decreased soil penetrability, increasing the possibility of surface-dwelling invertebrates becoming more important to kiwi chick diet and thus the possibility for competition.

5

General Discussion

This investigation had three aims. First, to determine the population density of ship rats (*Rattus rattus*) in the same area of Ponui Island in which previous estimates were made, thus allowing any fluctuations to be observed. Second, to calculate home ranges of ship rats on Ponui Island, and to determine the level of overlap in habitat occupied by ship rats and North Island brown kiwi (*Apteryx mantelli*). Third, to accurately quantify the importance of vegetation in ship rat diet on Ponui Island. All three aims are believed to have been achieved. It was intended that two overall outcomes be reached through accomplishment of these aims. Information amassed about the ship rat population dynamics and use of habitat will add to the body of knowledge on island ship rat populations. This information may prove valuable in the design of future ship rat control or eradication programmes, either on Ponui Island itself or on another of the many islands that constitute the New Zealand archipelago. In addition, by merging observations made in this study with those of Shapiro (2005) the more informed representation of the ship rat population that results will aid the assessment of the degree of competition between ship rats and chicks of North Island brown kiwi.

5.1 The ship rat population on Ponui Island: implications for management

The population of ship rats within the study site on Ponui Island was found to fluctuate seasonally. Densities estimated in this study in winter/spring 2005 were double those estimated by Shapiro (2005) in summer 2004/2005 in the same area (Chapter 2). Thus the ship rat population exhibits a combination of the effects of the hypothesised island syndrome in rodent populations. This theory states that rodent populations on islands

will have higher, more stable densities than those within mainland areas, and that these effects would increase with an increase in island isolation and decrease in island area (Adler & Levins 1994). While the density on Ponui Island is higher than those found on the mainland, it is not particularly stable. Fluctuations observed in this study are in agreement with population irruptions described by previous investigations of ship rat population dynamics, where fluctuations were attributed to availability of food, seasonal breeding and predation (Alterio et al. 1999; Blackwell et al. 2001; Daniel 1972; Harper et al. 2005; King & Moller 1997). The difference in density between this investigation and that of Shapiro is thought to be due to recruitment from the recent breeding season. It is hypothesised that the density immediately following the breeding season, in autumn, would have been higher than seen here due to the influx of new individuals into the population. This could then have been immediately followed by a decline due to death or emigration of some individuals to the population density observed in this study.

Home ranges of ship rats on Ponui Island are believed to be smaller than those calculated by previous studies (Daniel 1972; Dowding & Murphy 1994; Hooker & Innes 1995; Innes & Skipworth 1983; Pryde et al. 2005) (Chapter 3). This is believed to be due to the high density of ship rats within the study site. While radio-tracking in December, ship rats were observed to be highly arboreal with 99% of location recordings finding ship rats active in the canopy (Chapter 3). This degree of arboreality is thought to reflect the food sources being utilised by the ship rats at the time. With summer approaching, some invertebrates will leave the soil they inhabited as larvae to continue their life cycle in their adult form. Thus invertebrates may be abundant in the canopy during this time, and in addition fruits of some canopy species may be ripening. The trapping success rates seen during the study are thought to mirror the degree of arboreality exhibited by the ship rats. It is proposed that the high trapping success seen during the winter months reflects a tendency for ship rats to be less arboreal during this time. Thus the degree of arboreality is proposed to be high in late spring and summer while lower in autumn and winter.

If a control or eradication programme were to be executed on Ponui Island in the future, it is suggested that optimum success would be achieved during autumn. Trapping success is proposed to be high during these months, facilitated by the lesser degree of arboreality hypothesised during this time. With the high density presumed at this time

and the availability of nutritious bait on the forest floor, trapping success could be enhanced and so output maximised. The relatively small ship rat home ranges on Ponui Island indicate that more individuals could be trapped within an area than would be on mainland populations, thereby perhaps reducing the normal costs of such operations.

5.2 Potential competition between ship rats and kiwi chicks

By combining the observations of this study with those made by Shapiro (2005), fluctuations in the density and habits of the ship rats on Ponui Island have been observed. With this, more informed assessment of the potential competition between ship rats and kiwi chicks can be made. The higher density estimated for winter/spring in this study means more ship rats are sharing the same area with kiwi than estimated by Shapiro the previous summer. Thus with higher numbers of competitors in the same area, potential competition may have been more intense during this time. With the high density calculated for ship rats in the area, and the supposed high density of kiwi on the island, home ranges of both will overlap, and the encounter rate between species will be high. However, ship rats are able to traverse the three dimensional habitat while kiwi are restricted to the forest floor. The extent to which ship rats utilise the canopy will directly affect the rate of possible encounters between the two species, and also the degree to which they are foraging in a similar manner. The high incidence of arboreality observed in ship rats during December is thought to reflect the food sources being utilised by the animals at the time. Thus similarity in foraging behaviour between species will be reduced during this time, with ship rats in the canopy, and consequently competition for food might decrease. The invertebrates overlapping in both the kiwi chick and ship rat diet were identified by Shapiro (2005) as spiders (Arachnida), weta (Orthoptera) and scarabaeid beetles (Coleoptera), all surface litter dwellers. However, these three invertebrate groups are not restricted to the forest floor and could be found in the canopy also (Miller 1971; Tillyard 1926). Therefore, while ship rats may be foraging in the canopy while kiwi forage on the ground, the same food items could still be eaten. In addition, the invertebrate larvae that form the bulk of the kiwi diet, scarabaeid larvae, tipulid larvae (Coleoptera) and elaterid larvae (Diptera), will also be available to ship rats as adult stages in the forest canopy. Thus, while larval invertebrates from the soil stratum are not available to ship rats, adult forms are. Despite the lack of direct overlap between ship rat diet and kiwi diet of these items, if

these invertebrates are limited in number competition may still exist. The proportion of vegetation in the ship rat diet, while higher than that estimated by Shapiro (2005), formed the minority food type consumed in winter/spring (Chapter 4). Thus with ship rat diet verified to be dominated by what is assumed to be invertebrate food, potential for competition between ship rats and kiwi chicks for surface invertebrates exists. However, trapping was not carried out in autumn, the period of abundant fruiting in the forest. It is proposed that vegetation will be more important to ship rat diet during this time, perhaps alleviating any competition for invertebrate food.

By combining this study with that of Shapiro (2005) and including hypothesised trends for the only season remaining un-recorded (autumn), seasonal fluctuations in the degree of competition can be illustrated (Figure 5.1). It is proposed that ship rat density will be highest in autumn, and that this would coincide with decreased arboreality. Collectively, this may mean more ship rats foraging on the ground in a manner similar to kiwi chicks. However, it is also proposed that autumn would see an increase in the vegetative proportion of the ship rat diet. If vegetation were the dominant food type during this time, this could conversely mean a reduction in competition.

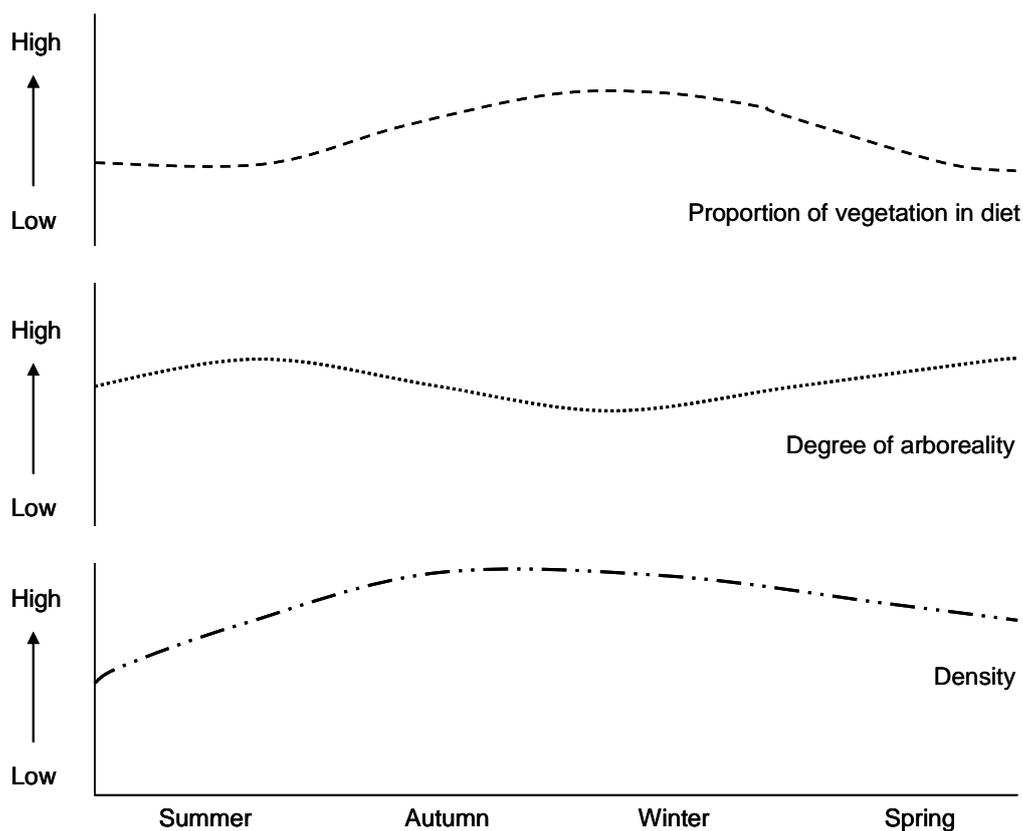


Figure 5.1 Abstract observed and hypothesised seasonal fluctuations in ship rat density, degree of arboreality and dietary proportion of vegetation on Ponui Island.

During live trapping sessions, a trend was observed for increased trapping success on the slopes of the gully, in more scrub-like vegetation (Chapter 2). Ship rats in scrub habitat had a tendency to consume more invertebrate material than ship rats from either of the other habitats (Chapter 4). However, this was observed with caution, as lack of replication means this may not apply within all scrub habitat types. It is within the scrub habitat in particular that competition between ship rats and kiwi chicks is thought to be more problematic (Shapiro 2005). Scrub habitat is associated with higher elevation and drier soil, and thus it is thought that soil penetrability is decreased in this area. On Ponui Island, kiwi in the scrub habitat were not found to probe the ground for soil-dwelling invertebrates any less than in other habitat types (Cunningham 2006). However, probe-hole depth was found to be significantly shallower and soil penetrability lower in the scrub habitat than in the other habitat types (Cunningham 2006). Thus, probing for soil-dwelling invertebrates is restricted in this habitat type. With North Island brown kiwi chicks seemingly preferring scrub and regenerating

forest over mixed podocarp-broadleaf and kauri forest (Chan 1999; Gibbs 2000; Shapiro 2005) these findings are of particular concern. The study by Cunningham was carried out during winter and early spring, and not during the hotter summer months when soil would be expected to be drier, and so probing perhaps more restricted. Most of the permanent soil-dwelling invertebrates such as worms migrate to lower, moister soil levels in the summer and invertebrate forms important to the kiwi diet as larvae will leave the soil to continue their life cycle as imagoes (Kleinpaste 1990). Consequently, it would be of interest to conduct a similar study to that of Cunningham (2006) in the summer to ascertain the degree that kiwi probing is restricted in the, often driest, summer months of the year.

The densities of ship rats and kiwi on Ponui Island suggest any potential competition between the two is not particularly severe. Since their introduction to the island, numbers of North Island brown kiwi have grown from 14 adults to an estimated 350 in a little over 40 years. However, since monitoring began by the Ponui Island Research Programme in 2000, a low survival rate of chicks has been observed (Shapiro 2005). The death of at least one chick was concluded by post-mortem to be due to starvation, however predation by feral cat (*Felis catus*) could not be ruled out. Thus, while competition may not have been a problem in the past, with increasing numbers of both species within the same available habitat the dietary overlap between the two species may only now be having an effect.

In conclusion, this research has resulted in two overall applications. In estimating the population density of the ship rat population in winter/spring, and consequently judging the causal factors for fluctuating numbers, population dynamics of an island rodent population have been illustrated. In addition, investigating the habitat use and dietary habits of ship rats, and proposed seasonal changes in these, a more complete representation of the ship rat population has been derived, upon which judgements on their potential competition with kiwi chicks have been based.

5.3 Recommendations for future research

It is recommended that a study into the ship rat density, their diet and use of habitat be conducted over twelve consecutive months. By carrying out a 12 month study of this kind any effects of year can be eliminated when addressing seasonal observations made

between different years. This would aid assessment of fluctuations in the degree of potential competition between ship rats and kiwi chicks, and add a complete seasonal account of island rodent population dynamics to the existing body of knowledge.

Replication of diet analysis used in this study within repeated habitat types on Ponui Island will enable more sound conclusions to be made on dietary proportions of food types according to habitat. In addition, by carrying this out in autumn, the time of proposed abundant fruiting, actual importance of vegetation to the ship rat diet can be realised.

Most importantly, a quantification of the invertebrate fauna biomass on Ponui Island is recommended. This would greatly aid judgement of the extent of potential competition between ship rats and kiwi chicks. It is suggested that invertebrate abundance within the canopy be compared with that on the surface of the forest. The canopy and ground may be partitioned in that surface-dwelling invertebrate numbers in one are independent of the other. If this is the case, the high degree of ship rat arboreality in summer, and thus high incidence of ship rats foraging in the canopy, may have no effect upon the invertebrate fauna on the ground. Consequently, competition for surface-dwelling invertebrates on the forest floor may be of no concern. Competition only exists when the resources in demand are limited in supply. Perhaps the invertebrate fauna is the principal casualty on Ponui Island with such high densities of predatory kiwi and ship rats. It must also be remembered that other insectivorous species inhabit Ponui Island, including mice (*Mus musculus*) and numerous other avian fauna such as fantails (*Rhipidura fuliginosa*) and Tomtits (*Petroica macrocephala*), adding to the predation pressure on the invertebrate fauna of the island. Conversely, however, the numbers of invertebrates on Ponui Island may be large enough to support the high numbers of their predators, and so overlap in diet may not necessarily equate to competition.

It is noted that the low survival of kiwi chicks observed recently on Ponui Island (Shapiro 2005, I. Castro pers. comm.) may not be solely due to competition with ship rats. With the high density of kiwi on the island and the limited area of forest due to farming, it may be that the kiwi population is in fact reaching carrying capacity. Indeed, kiwi chicks may be experiencing competition for resources from established adults. Continued observation of the kiwi population and chick survival, including regular investigation into invertebrate biomass, is thus recommended.

6

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A view from Ponui

Photo by author