The Effects of Rodents on Ground Dwelling Arthropods in the Waitakere Ranges

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ATTESTATION OF AUTHORSHIP

“I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of a university or other institution of higher learning, except where due acknowledgement is made in the acknowledgements.”

Peter A. King

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ABSTRACT

The abundance and size classes of ground weta, cave weta, carabid beetles and prowling spiders were monitored in the La Trobe Forest Ecosystem Restoration Project, Karekare, West Auckland, where rodent populations had been reduced. These were compared with those in control sites, where the rodent populations had not been manipulated. The arthropods were sampled using pitfall traps set in young podocarp-broadleaf, mature kanuka and mature taraire forested sites, and each treatment site was matched with two control sites. Data was collected monthly from all nine sites from December to May, 2005–06. In kanuka forest, data collected during December to May, 2004–05 has also been used.

Rodent populations and possum populations were monitored during the course of the study. Tracking tunnel indices indicated that rat numbers were lower in the treatment sites than the control sites during 2005–06, and that rats were low in abundance at the treatment sites, apart from the occasional spike in numbers, in the three years prior to the start of this research. Mice tracking indices were relatively high at some specific sites, mainly in spring and autumn. Evidence indicated that possum abundance was low in both the treatment and the control sites.

Ground weta were more abundant at the kanuka treatment site than the control sites in 2005–06, but were rarely found in the podocarp-broadleaf and taraire forest types. Carabid beetles were trapped in greater numbers in podocarp-broadleaf and kanuka forest

treatment sites in 2005–06, than in their respective control sites, and an increase in carabid beetle abundance was recorded between the 2004–05 and 2005–06 sampling seasons at the kanuka treatment site. Prowling spiders were more abundant at the podocarp-broadleaf treatment than at the control sites. Cave weta abundance at the podocarp-broadleaf and kanuka treatment sites was similar to their respective control sites. The arthropod abundance data from the taraire forest sites was confounded by many differences between the treatment and the control sites, which may have masked any effects caused by the suppression of rodent numbers at the treatment site.

Ground weta and cave weta in the larger size classes appeared to be selectively preyed upon by predators, however, it was unclear whether rodents were entirely responsible because stoats and cats are also known to target larger arthropod prey, and their presence was not monitored.

Ground weta in kanuka forest, carabid beetles in kanuka and podocarp-broadleaf forest and prowling spiders in podocarp-broadleaf forest are identified as potential indicators for monitoring the effects of rodent control in the Waitakere Ranges.

This study was limited by a lack of knowledge of life histories and basic ecology of the arthropods. Further research at these sites is required to establish the long term population patterns of the arthropods.

1 INTRODUCTION

Arthropods are regarded as the most diverse component of terrestrial ecosystems, occupying a wide variety of niches (Kremen, Colwill, Erwin, Murphy, Noss & Sanjayan, 1993). Two out of three of all organisms are arthropods, and they are found in most habitats in the biosphere (Campbell & Reece 2002). It has been suggested that New Zealand has approximately 80,000 species of invertebrates, compared to 350 terrestrial bird species, and 2,000 endemic vascular plant species (McGuinness, 2001). Some endemic invertebrates are endangered. Twenty percent of New Zealand's flora is considered to be threatened, and if the same percentage of endemic invertebrates is threatened, then there could be 16,000 threatened invertebrate species.

Phylum Arthropoda consists of the insects (class Insecta), the crustaceans (class Crustacea), the millipedes (class Diplopoda), the centipedes (class Chilopoda), and the spiders (class Arachnida), (Campbell & Reece, 2002). Arthropods in general also provide the most biomass and numbers in any ecosystem (Wilson, 1985), and have many vital roles. They are involved in nutrient cycling, pollination, seed dispersal, decomposition, predator-prey relationships and soil formation (Cone, Gordon, Frampton, Keesing, Miskell & McFarlane, 2001; Wilson, 1985). Wilson (1987) describes arthropods as "the little things that run the world". If arthropods are being negatively impacted by introduced mammals, then many ecological processes may be disrupted.

1.1 GONDWANALAND ORIGINS OF NEW ZEALAND’S ARTHROPODS

New Zealand split from the supercontinent Gondwanaland about 80 million years ago (Young, 2004), and because of this long period of isolation, New Zealand’s biota has a high degree of endemism. Ninety percent of New Zealand’s arthropods are endemic and 100% of reptiles and amphibians (ibid.). Mammals evolved around the world after New Zealand split from Gondwanaland, and in some regions large herbivorous mammals and their predators became common (King, 2005). In New Zealand, large flightless birds and their avian predators, e.g. eagles and hawks, occupied comparable niches, whilst the niches held overseas by rodents and lagomorphs, i.e. rabbits and hares, were filled in New Zealand by large flightless insects (ibid.).

Mammals such as mustelids, cats and rodents were introduced into New Zealand without their predators. The absence of the top predators of these introduced mammals has lead to what is described as ‘mesopredator’ release (Terborgh, 2000). This causes a large increase in the numbers of small carnivores (cats, mustelids and rodents), which are the major predators of birds, other vertebrates, and some invertebrates (Crooks & Soule, 1999). ‘Mesopredator’ release has lead to a rapid decrease in prey diversity and abundance on islands. For example, lizards introduced onto a small island caused a large reduction in spider diversity and abundance (Schoener & Spiller, 1996).

Introduced mammals may have had some significant effects on food webs in the forests that they colonized. Innes & Barker (1999) developed models to explore some possible outcomes of pest control at the community level. Their model demonstrated that if possums and rodents were nearly eradicated from podocarp-hardwood forest the number of trophic interactions declined by one third, because possums and rodents are omnivorous. More food was available for up to 70% of the other links in the food web (Innes & Barker, 1999). However, their model also predicted that predators that formerly ate possums and rodents would now need to eat more other prey. Prey-switching by mustelids, from rodents to birds and arthropods has already been verified (Murphy & Robbins et al., 1999; Rickard, 1996).

The presence of mesopredators such as rodents and mustelids in forest communities may have other non-trophic effects. For example, the decline of the parasitic New Zealand mistletoe (*Peraxilla* spp.) may be due to the shortage of pollinating birds such as the tui (*Prosthemadera novaeseelandiae*) and the bellbird (*Anthornis melanura*), which may be predated by mustelids, rodents, possums and cats (Ladley, Kelly, Robertson, 1997).

Trends in New Zealand terrestrial arthropods towards gigantism, ground dwelling, extended lifecycles, low rates of reproduction, along with the high rates of endemism, are factors that made many of New Zealand species vulnerable to predation by introduced mammals (Daugherty, Gibbs & Hitchmough, 1993; Diamond, 1990). Many New Zealand endemic insects communicate using pheromones, which makes them easy to locate by predators with a good sense of smell (McGuiness, 2001). Large-bodied arthropods, such as the wetapunga (*Deinacrida* sp.), would find it hard to locate secure refuges and would be attractive prey, because of their high energy content and the low energy investment needed to catch them (Gibbs, 1998). These features, plus a nomadic lifestyle have probably contributed to the loss of *D. rugosa* and *D. heteracantha* from all but rat free habitats (Gibbs, 1998). In contrast, tree weta (*Hemideina spp*.), have behavioural adaptations that allowed them to survive in the presence of small mammal predators such as rodents and mustelids. For example they live in tree galleries with small external diameters, secure from mammal predators, during the day, and furthermore exhibit some predator avoidance behaviours (Gibbs, 1998). Cave weta, also demonstrate avoidance behaviour in the presence of mammalian predators, which may enhance their survival chances (Powlesland, Stringer, Hedderley, 2005)

Some carabid beetles, for example *Mecodema oconnori, Megadromus turgidiceps* and *Plocamostethus planiusculus* carry a small number of eggs (Hutchison, 2007). This low egg load may be an indication of low fecundity, which would make arthropods with these features vulnerable to predation by mammals.

In this chapter the impacts of human colonisation on New Zealand's unique biota will be discussed, but the main focus will be to assess how destructive introduced predators have been on the abundance and faunal diversity of native arthropod populations in native forests, both on the mainland of New Zealand and offshore islands. The strong evidence that introduced mammals have had a negative impact on New Zealand's native vertebrate populations will be discussed in contrast to the paucity of evidence that introduced mammals have had a similar effect on native arthropod populations. The use of native arthropods as indicators of habitat change will also be discussed.

1.2 IMPACTS OF HUMAN COLONISATION

Human colonisation of New Zealand over the past 1000 years has resulted in the exploitation of forests, habitat loss and fragmentation, and together with the introduction of alien species, especially mammals, has devastated the country's biodiversity (Department of Conservation, 2000; Ministry for the Environment, 1997).

Approximately 85% of New Zealand was forested when the Maori arrived about 1000 years ago and as much as one third of this was destroyed before European settlers arrived in the 19th century (Atkinson & Cameron, 1993; King, 2005; Ministry for the Environment, 1997). Many bird species were hunted to extinction, including all moa species which were unique to New Zealand, and 18 species of water fowl and rail. In fact, 25% of endemic land bird species become extinct, in this period of Maori occupation of New Zealand (Ministry for the Environment, 1997). The first of the invasive mammals, the kiore (*Rattus exulans*), that are thought to have devastated native biota, was introduced by Maori. Indigenous predators of arthropods such as the tomtit (*Petroica macrocephala*) and tuatara (*Sphenodon punctatus*) hunt by sight and touch, (Field, 2001; McGuiness, 2001) and the main defense mechanism of their prey was to remain still. This behaviour was of little use as a defense against introduced mammals, such as the kiore, which rely on scent to locate their prey, are nocturnal and are very persistent hunters (King, 2005).

The next colonists, the Europeans, increased the speed of environmental modification. In less than 200 years since their arrival, native forest has been reduced to just 23% of the land it originally occupied (Atkinson & Cameron, 1993) and 54 mammal species have been introduced (King, 2005). Fifty two percent of native forest has been converted to grassland, compared to the world average of 37% (Ministry for the Environment, 1997). By the time the Europeans arrived, large native herbivores such as the moa had already become extinct, and in their place complete communities of invasive organisms were introduced, including animals, plant crops and their parasites and diseases (King, 2005). The loss of forest habitat and the introduction of alien organisms have put native ecosystems under serious pressure in a short period of time.

Over geological time New Zealand's present biota has withstood large environmental changes such as climate change, mountain building, glaciation, and volcanism (McGuinness, 2001). However, native faunal and floral communities have been unable to cope with the rapid rate of change that has occurred since the Maori and European colonisation of New Zealand. Forty percent of terrestrial native bird species have been lost, and 40% of the remaining bird species are classified as threatened (Department of Conservation, 2000). In addition, many endemic reptile, arthropod and plant species are threatened (Department of Conservation, 2000). Despite the ever increasing land area allocated to reserves, Clout (2001) argues, that having more than 30% of New Zealand's land area in reserves will not protect threatened plants and animals, because the main threats are invasive species such as rodents, possums and mustelids. This is perhaps evidenced by the fact that extinctions have continued. For example, the bush wren (*Xenicus longipes*), a bird with poor reproductive capacity and a limited ability for dispersal, disappeared from the isolated Great South Cape Islands (south of Stewart Island) soon after they were invaded by rats in 1962

(Towns & Broome, 2003). The North Island piopio (*Turnagra capensis*) also became extinct after the ship rat (*Rattus rattus*) was introduced in 1860 (Dowding & Murphy, 1994).

1.3 ARTHROPODS IN THE DIETS OF INTRODUCED PREDATORS

It is well established that arthropods constitute a significant proportion of ship rat diets. Most New Zealand studies have found that, of the arthropods, ship rats mainly consume weta, beetles and spiders, though their diet was dependent on the season, with arthropods largely eaten in spring and summer, whilst plant material was eaten in winter (Best, 1969; Clout, 1980; Craddock, 1997; Innes, 2005; Miller & Miller, 1995). In addition, in his study in taraire forest, Craddock (1997) found that rats consumed a variety of sizes of arthropods, but especially those greater than 12 mm in length. He also suggested that rats may select some prey in quantities disproportionate to their abundance in their environment, for instance weta.

A number of workers have investigated the diet of the house mouse (*Mus musculus*) in New Zealand forests. The consensus is that mice are omnivores and those arthropods such as butterflies, moths, beetles, weta and spiders form an important part of their diet (Baden, 1986; Fitzgerald, 2001; Jones & Toft, 2006; Ruscoe & Murphy, 2005). Ruscoe and Murphy (2005) reported that in a long term study in the Orongorongo Valley, arthropods were found to be important in the diet of mice during spring and summer. Mice also exhibit some size selection of their prey. For example, Craddock (1997) found that mice commonly ate arthropods in the 3–12 mm length range although a wider range was available. He also found that mice consumed a disproportionate number of caterpillars, spiders and cockroaches, compared to their abundance.

Whilst ship rats and mice are known to consume large quantities of arthropods, other introduced mammals also include arthropods in their diet. Cowan (2005) describes the brush-tailed possum (*Trichosorus vulpecula*) as an opportunistic herbivore, eating most plant parts, but when the opportunity presents itself, consuming other items including arthropods. Cowan and Moeed (1987) reported that possums ate arthropods mainly during the summer and autumn in the Orongorongo Valley, but that arthropods only formed a small proportion of their diet.

Mustelids (stoats, weasels and ferrets) are small active carnivores that were introduced to New Zealand to control introduced rabbits. Stoats are mammals with a high metabolic rate, and it is more energy efficient to hunt larger prey such as rodents to satisfy their energy needs (King, 2005). King and Murphy (2005) report that stoats (*Mustela erminea*) eat mainly large prey, such as birds, mice, rabbits, hares, rats and possums, but some insects do appear in their diet, mainly large-bodied weta species. However, stoats do target arthropods at the times of the year when rodents are scarce (Purdey & King, 2004; Rickard, 1996). Rickard (1996) found that arthropods formed a large proportion of the diet of stoats, but this was at a time of the year when rat abundance was low in the podocarp forest where his study was located.

Two other mustelids occur in New Zealand forests, but their effect on arthropod numbers, whilst unknown, is likely to be small. Weasels (*Mustela nivalis*) occur in

New Zealand forests in very small numbers (King, 2005), and stomach content analysis of weasels from Pureora, Mapara and Kaharoa Forests did reveal an insect component in their diet (ibid.). Ferrets (*Mustela furo*), are mainly found in pastureland and forest margins, and studies indicate that arthropods (mainly weta, beetles and spiders) only form a minor component of their diet (Clapperton & Byron, 2005).

Two other introduced mammalian predators are present in New Zealand forests, one is the feral cat (*Felis catus*). However arthropods form only a small proportion of their diet (Gillies & Fitzgerald, 2005). The other is the European hedgehog (*Erinaceus europaeus*), a nocturnal insectivore, that feeds on beetles, weta and millipedes (Berry, 1999; Jones, Moss & Sanders, 2005). While research into their dietary preferences suggests that hedgehogs could be significant predators of arthropods in New Zealand forests, the few studies investigating their population densities in forest habitats found them in very low numbers (Hendra, 1999; Jones & Toft, 2006).

Another introduced group of animals must be added to the list of arthropod predators and its impact may yet prove to be as significant as that of introduced mammals. Social wasps of the genus *Vespula*, represented in New Zealand by two species, have been shown to have an effect on arthropod populations. In ecosystems where there is an abundant carbohydrate source, e.g. in beech forests (Beggs, 2001), wasp numbers can sometimes reach epidemic proportions. Toft and Rees (1998) showed that the predation rate by wasps on orb web spiders (*Eriophora pustulosa*) was so high that the probability of an individual surviving a season was nil. Moreover, they contend that the arthropod taxa most vulnerable to wasp predation may have already been eliminated from beech forest ecosystems in the 40 years since wasps have been present.

1.4 IMPACT OF INTRODUCED PREDATORS ON NATIVE VERTEBRATES

There has been a lot of focus on the impact of introduced mammals on native vertebrate populations. Holdaway (1989) described a vast avifaunal diversity prior to human settlement in New Zealand, and contends that some small flightless birds that lived and nested on the ground would have been particularly vulnerable to predation by kiore. He describes a "rat blitzkrieg advancing across the landscape turning everything edible into rat protein" (ibid.).

Birds, in particular, have benefited in ecosystems where invasive pests such as possums, ship rats and stoats have been maintained at low levels. James and Clout (1996) demonstrated that when poison baits were used at Wenderholm (North Auckland) to suppress ship rats to low levels, kereru (*Hemiphaga novaezealandia*) breeding success dramatically improved. In the 1991–92 breeding season, when baits were used, young pigeons were fledged at 5 of the 11 nests observed. In the preceding summers no pigeons fledged from the 27 nests observed. Similar results were obtained by Innes, Nugent, Prime and Spurr (2004) at Motatau (North Auckland), where tracking indices of ship rats and possums were maintained below 4%. Innes, Nugent et al. (2004) also used video cameras to capture direct evidence of nest predation by ship rats and possums. In a separate study, kokako populations

(*Callaeus cinerea wilsoni*) responded in a similar manner to suppression of possum and ship rat numbers to very low levels. Innes, Brown, Jansen, Shorten and Williams (1996) reported that at Rotoehu (Bay of Plenty), in the absence of predator control, 83% of nesting attempts failed, whereas on Hauturu (Little Barrier Island) where possums and ship rats are absent, juvenile survival was high. Video evidence again implicated ship rats and possums as nest predators at Rotoehu.

Recent research has demonstrated that the native Hochstetter's frog (*Leiopelma hochstetteri*) has also benefited from intensive predator control. Relative densities of frogs in the Hunua Kokako Management Area (KMA), where introduced mammal predators are maintained at low levels, are from 4 to10 times higher than an adjacent unmanaged area (Mussett, 2005; G. Ussher pers. comm.). Moreover, in the KMA, the frog population age structure indicated that recruitment of young frogs was successful, in contrast to the non-management area (Mussett, 2005).

Increases in the abundance of lizards have been reported after kiore elimination from some sites. Towns (1994) reported thirty fold increases in the numbers of five species of resident lizards five years after kiore were removed from Korapuki (Mercury Islands). The numbers of the rare Whitaker's skink (*Cyclodena whitakeri*) transferred onto Korapuki Island, after kiore eradication, had also increased after five years. Towns contends that these increases demonstrate that predation, rather than habitat deficiencies was responsible for the previously depleted lizard populations on the island.

Similarly, Gorman (1996), after surveying the lizard populations on Kapiti Island, concluded that the lizard fauna was depauperate for an island the size of Kapiti and proposed that rats were responsible. Towns (2002) concluded that seven species of gecko and ten species of skink have probably increased in abundance due to the eradication of rats from islands.

1.5 EFFECTS OF PREDATORS ON NATIVE ARTHROPODS

Consistent evidence that arthropods have benefited from the control of introduced mammals in New Zealand has been difficult to obtain.

1.5.1 Research on Offshore Islands

Towns and Broome (2003) suggested that the evidence that kiore affect populations of arthropods on islands is circumstantial, and is based mainly on comparing islands with and without kiore, and by examining the fossil record. These lines of evidence indicate that kiore were responsible for the extinction of large flightless arthropods, such as the darkling beetle (*Mimopeus elongatus*), from Korapuki Island (ibid.). Investigations into the response of arthropods to the removal of kiore from islands indicate that ground weta (*Hemiandrus* sp.), and other flightless arthropods, have been suppressed by the predators presence (Green, 2000). However, rat removal may also effect forest regeneration, for example when kiore are present on an island, they may compete with kereru (*Hemiphaga novaeseelandiae*) for large fruit. The reduction in the amount of available fruit may result in fewer pigeon visits to the trees, and consequently less seed spread. On islands from which kiore have been removed forest structure is reportedly changing, e.g. in terms of seedling abundance, depth of leaf litter and soil moisture, and these changes, as well as the removal of kiore predation pressure, may also affect the arthropod communities (Towns & Broome, 2003).

The successful release of the large flightless Mahoenui weta (*Deinacrida mahoenui*) onto Breaksea Island, the tree weta (*Hemideina*) onto Korapuki Island and the Mercury Island tusked weta (*Motuweta isolata*) onto other islands in the Mercury group after kiore eradication, have been used as evidence of the impact of kiore on arthropods (Towns and Broome, 2003). However, it is impossible to isolate the effects of kiore predation from the habitat changes that would also occur when kiore were eliminated from the ecosystem.

The lack of a control site, with no predator control, is a feature of most island eradication operations and this makes the results less robust. However, Towns (2002) argues that unmodified nearby islands can be used as controls, though care must be taken when interpreting data, because community succession pathways may be different due to different environmental conditions on adjacent islands.

Ecosystem regeneration on islands after rodent removal is slow and the benefits may take many years to become apparent, so short term studies may fail to detect any benefits. For example, the presence of the large native flax weevil (*Anagotus fairburni*) was only recorded five years after Norway rats were removed from Hawea Island (Fiordland) (Towns and Broome, 2003).

Another study investigating the effects of rat removal from Kapiti Island (Wellington), on arthropod populations, highlighted some of the problems associated with such research. Sinclair, McCartney, Godfrey, Pledger, Wakelin and Sherley (2005) reported that three years after rat removal, there had been a significant decrease in catch frequency and diversity of arthropods, especially carabid beetles and amphipods. This study was confounded by weather differences between the years (fluctuations between El Niño, bringing wet and windy conditions, and La Niña, bringing drier conditions), which may have affected the recovery of arthropod populations. A similar pattern of decline in arthropod numbers was reported, which coincided with similar weather fluctuations on Tiritiri Matangi Island (Hauraki Gulf, Auckland), and apparently the amphipods have yet to recover to their original levels (Green, 2002). On Kapiti Island (Wellington), another confounding factor that may have affected the abundance of arthropods was an increase in the conspicuousness of insectivorous ground-feeding birds, such as the saddleback (*Philesturnus carunculatus*), robin (*Petroica australis*), blackbird (*Turdus merula*), weka (*Gallirallus australis*) and little spotted kiwi (*Apteryx owenii*). It has been suggested that the rats may suppress other predators and food competitors, thereby contributing to the higher numbers and diversity of the arthropods (Sinclair,McCartney et al., 2005), leading the authors to provocatively ask the question "Is a rat free Kapiti Island actually beneficial to arthropods?" However, the pitfall traps used in this investigation were active for only three months of each year, and this may have been too short a sampling period to detect population trends, which can vary temporally (Chris Green pers. comm.).

Atkinson and Towns (2001) reported a seven year pitfall capture study on Tiritiri Matangi before and after kiore (*Rattus exulans*) removal. Ground weta (*Hemiandrus* sp.) and large prowling spiders (*Miturga* sp.) appear to have benefited from the kiore eradication. A similar increase in abundance of ground weta and darkling beetles (*Mimopeus opaculus*) was reported after kiore removal from Lady Alice Island (Hauraki Gulf) (Atkinson & Towns, 2001). In both cases the increases were greater than would have been expected because of changes in environmental conditions. Capture rates of other species in the same studies varied widely and correlated well with weather changes over the same period.

In contrast, the invasion of Big South Cape Islands (south of Stewart Island) by ship rats in 1962 provided evidence of the possible effects of rodents on native arthropods. Ship rats colonising these islands coincided with the extinction of the large weevil *Hadramphus stilbocarpae* (Towns & Broome, 2003).

Ruscoe (2001) reported an increase in the numbers of eight different species of arthropods after mice were eradicated from Allport Island (Fiordland). It is difficult to attribute these increases entirely to the eradication of mice, because concurrently, five species of arthropods at an adjacent mainland site, where mice were present, also increased in number, so other environmental changes were suggested as contributing to these observed changes (Ruscoe, 2001).

Van Aarde, Ferreira and Wassenaar (2004) investigated the impact of mice on arthropod communities on sub Antarctic Marion Island. They also found that even though the abundance of some arthropod prey species changed significantly, these changes could not be isolated from the effects of environmental change over time. They found that small variations in rainfall and temperature could obscure any effects on the arthropod populations due to predation by mice. They also commented that before the effects of mice on arthropod populations can be isolated, we need more knowledge of arthropod life histories.

There is circumstantial evidence that the wetapunga (*Deinacrida heteracantha*) on Hauturu (Little Barrier Island) had been affected by the presence of kiore. Gibbs and McIntyre (1997) surveyed the population of wetapunga around the Ranger's house on Hauturu, and concluded that the population in this area was at an all-time low. Kiore were still present on Hauturu when this survey was done, but no evidence was gathered of direct predation of wetapunga by kiore. Gibbs and McIntyre (1997) commented that the habitat around the Ranger's house on Hauturu had not deteriorated and that the most likely cause of the decline in the wetapunga population was predation. Cats were eliminated from the island in 1980 (Veitch, 1983), which would have removed some predation pressure, and rat poisoning around the Ranger's house was no longer being carried out. In 1984 saddlebacks were introduced onto Hauturu (Meads and Notman, 1993). These insectivorous birds feed on the ground, and whilst no direct evidence of them feeding on wetapunga had been gathered, a group of saddlebacks were observed around a ponga, with a known population of young wetapunga that subsequently could not be located (Gibbs & McIntyre, 1997). So the evidence that kiore predation had caused the decline of this wetapunga population is circumstantial and cannot be attributed to any one predator. In the two years since kiore have been eradicated from Hauturu, whilst there has only been a small increase in wetapunga numbers in the areas surveyed, there has been an increase in juvenile wetapunga detected and this indicates that recruitment is occurring, because young are surviving (Chris Green pers. comm.). Adult wetapunga have large spines on their back legs which they can use for defense, a feature lacking in juveniles, which could make them more vulnerable to predation (ibid.).

Moeed and Meads (1987) commented that large arthropods, for example weta and ground beetles, are in low numbers on rat infested islands (such as Long and Motuara Islands, Fiordland), where kiore were present. They also made the point that the abundance of arthropods on smaller islands is low because there is less habitat diversity to support large populations. However, it is difficult to attribute these losses solely to kiore predation. Gibbs (1999) makes the point that forest habitat modification, with the loss of logs and deep forest litter, could be contributing factors.

1.5.2 Research on the Mainland

Studies of the impact of introduced mammal predators on arthropod populations on the mainland have yielded similarly variable results. Spurr and Berben (2004) assessed the recovery of arthropods after a pest control operation using 1080 in the Tararua Forest Park. They monitored the arthropods, in artificial tree-mounted refuges, for 12 months before and 4 months after the application of 1080 and found that there was no significant effect on arthropod numbers. However, given the flax weevil example mentioned previously, a four month time lag after the application of toxin may not be long enough for benefits to arthropods to appear. These results were in contrast to those of Powlesland, Stringer and Hedderley (2005), who in a similar study showed that tree weta may have benefited from pest control. Unlike the previous study, monitoring continued for 12 months after poison application, adequate time for the tree weta to respond to the reduced numbers of possums

(*Trichosorus vulpecula*) and rodents. No such benefit was found for spiders, harvestmen, cockroaches and cave weta. They did observe a time lag of five months before the tree weta numbers increased, but this may have been caused by a temporary increase in mouse numbers.

Craddock (1997), in a study in taraire forest at Wenderholm (North Auckland), found that arthropod groups eaten by rodents, such as beetles, wetas and caterpillars, benefited from pest control. However, other arthropod groups that were not targeted by rodents, such as millipedes, springtails and flies, were in significantly higher numbers in the control area than the treatment area, and habitat variation may have been responsible for this difference.

As on off-shore islands, it may be necessary to monitor arthropods for several years on the mainland before the benefits of pest control become apparent. At the Boundary Stream Mainland Island (Hawkes Bay), arthropod monitoring has been carried out since 1995 (Ward-Smith, Abbott, Macdonald, Nakagawa, Stephenson & Sullivan, 2004). Whilst the general trend over that time has been for a greater overall abundance of arthropods (ibid.), the numbers of some arthropod groups have oscillated. For instance, weta numbers significantly increased and then significantly decreased between 2000–01 and 2003–04.

Hutcheson (1999), in a study at the Mapara Wildlife Reserve (Te Kuiti) that investigated the changes in beetle communities over time, found that the greatest changes occurred after eight years of pest control. Species richness, abundance and diversity were higher in the reserve, where grazing mammals were fenced out and mammalian predators suppressed, than in the control area where grazing mammals were present and mammalian predators were not suppressed. This study also demonstrates the importance of habitat characteristics and resource availability in driving insect biodiversity. A lack of grazers in the reserve resulted in a large increase of mid-level woody vegetation, compared to the control area where grazers were not restricted. In the control area this tier of vegetation decreased over time, resulting in less woody debris for detritivore beetles to utilise (ibid.). In the reserve there were fewer mammal carcasses available after eight years of pest control, and the reduction in the amount of this resource also resulted in lower numbers of carrion eating beetles (ibid.).

Sim (2005) investigated the effects of pest control on arthropod populations at the Rotoiti Nature Recovery Project (Nelson) using one treatment site and five control sites. He was unable to detect any differences between the treatment site and the control sites in abundance, species richness and size of individuals. However, the rodent tracking indices revealed that the rodent population at the treatment site had not been significantly suppressed. He recommended that if arthropod populations are to be targeted for recovery, rodent numbers would need to be significantly reduced.

Watts (2004) investigated the effects of mammalian pest removal on ground beetles at the Karori Wildlife Sanctuary (Wellington). No differences were detected in species richness and abundance. However, there was some indication of benefit to beetles because there were significantly more beetles in the >30 mm length at the treatment site. There are several factors that could be responsible for the lack of response of beetles in this investigation. Mice numbers were not suppressed and mice are known predators of beetles (Baden, 1986; Jones et al., 2006; Ruscoe et al., 2005; Fitzgerald, 2001). Also brown teal (*Anas aucklandica*), weka, saddleback, North Island robin and kiwi have been introduced, and they are all ground-feeding, insectivorous birds. Predation pressure from mice and insectivorous birds may have replaced that from the pests removed from the site. Hunt, Sherley and Wakelin (1998) claimed that the apparent high mice numbers may be responsible for their inability to detect any benefits to large-bodied arthropods in their study.

Hutcheson (2001) observed that pest control at the Papaitonga Reserve (Horowhenua) had no effect on carabids and other arthropod taxa, and noted that carabids were not a major food item of rodents.

1.6 IMPACT OF HABITAT STRUCTURE ON ARTHROPOD POPULATIONS

Habitat structure is regarded as one of the most important factors influencing the composition and distribution of arthropod groups in forests. Lassau, Hochuli, Cassis and Reid (2005) constructed a scale of habitat complexity based on the percentage cover of the various plant tiers, ground characteristics and soil moisture, and found that habitat complexity was a good predictor of the species richness and abundance of pitfall-trapped beetles. It has been argued that areas with greater habitat diversity, because of the presence of varying amounts of leaf litter, debris, logs and rocks, provide more micro-habitats for arthropod populations (Crisp, Dickinson & Gibbs, 1998; Ings & Hartley, 1999; Lassau, Hochuli et al., 2005; Taylor & Doran, 2001). In addition, Moeed and Meads (1985) found that more botanically diverse sites supported a greater abundance of forest arthropods. However, determining the reasons for habitat preferences in New Zealand forests is difficult because of a lack of detailed knowledge of the life histories and general ecology of arthropods (Crisp, Dickinson et al. 1998).

1.7 ARTHROPODS AS INDICATORS OF ENVIRONMENTAL CHANGE

It has been suggested that arthropods could be used as indicators of environmental change, and may provide an early warning system of environmental degradation, because they have rapid breeding rates, short generation times, and are more sensitive to environmental change than plants or vertebrates (Hilty & Merenlender, 2000; Hutcheson, 1994; Kremen,Colwell et al., 1993). Furthermore, arthropods respond to environmental change more rapidly than do vertebrates (Kremen, Colwell et al., 1993). In addition, many invertebrate groups are closely linked to a particular region, ecosystem, and specific anthropogenic disturbance (Hutchison, Walsh, & Given, 1999).

New Zealand has high rates of endemism in most invertebrate groups (Hutchison, Walsh, et al., 1999). Mollusc assemblages in the East Cape region have shown close affinity to specific indigenous vegetation assemblages (Hutcheson, Walsh, et al. 1999).

However, insects, because they carry out many functions in terrestrial ecosystems, have many characteristics that make them good candidates for use as environmental indicators. For example, they are important pollinators, are involved in the decomposition of plant material, as well as being scavengers, parasites and predators, and a major food source for many vertebrates (Hutcheson, Walsh, et al., 1999). Because of their varied ecological roles in forest ecosystems, insects cause the retention of organic material, and control mineral cycling (Hutcheson, Walsh et al., 1999).

There is another characteristic of insects that makes them suitable as environmental indicators, especially for assessing the progress of restoration projects. They often have large population sizes, which allows for the collection of statistically robust information without depleting their populations (Longcore, 2003). However, Kremen, Colwell et al., 1993, contend that not all arthropod taxa would be effective as environmental indicators, and the ones selected should have high species diversity, and high endemism, and be sensitive to environmental change.

Very little work has been done on determining taxa that may be suitable for use as indicators of forest ecosystem quality. Harris and Burns (2000) investigated the beetle assemblages of kahikatea forest fragments in the Waikato, and their potential as indicators of these fragment’s ability to resist invasion by adventive species. It was suggested that such assemblages could be used as indicators of habitat quality in the forest fragments, and if a large proportion of adventive species were found, this would indicate that the fragment had lost its resistance to invasion (Harris & Burns, 2000).

To monitor the effects of poisoning programmes that target invasive mammals, tree weta (*Hemideina*) has been proposed as a suitable genus, as they are abundant and large. Spurr & Berben (2004) and Powlesland,Stringer et al. (2005) used tree weta to monitor the impact of 1080 poisoning on non-target arthropod species.

There is research currently underway by the Department of Conservation that aims to identify suitable arthropod species or groups to use as indicators to monitor the effects of mammal control in mainland islands (Potter, Stringer, Wakelin, Barrett & Hedderley, 2006). This is a five year study looking at three different sites in podocarp-broadleaf forest.

1.8 SUMMARY

New Zealand's Gondwanaland origins have resulted in a diverse, distinctive yet vulnerable biota. The introduction of invasive species, and habitat loss and fragmentation, has devastated ecosystems resulting in the extinction of many native species. The benefits to vertebrates, such as birds, amphibians and reptiles, of suppressing introduced mammal populations has been, in the main, clearly established. However, the benefits associated with reducing the numbers of introduced mammal predator populations to arthropods have been more difficult to ascertain. Whilst the importance of arthropods, both in sheer numbers and their contribution to ecological processes, is widely recognised, very little is known about their biodiversity, taxonomy, and basic biology and ecology.

Arthropod populations seem to be particularly sensitive to changes in environmental variables, both biotic and abiotic. Many studies that aim to determine if pest reduction or elimination benefits arthropod populations have been limited by sampling periods of inadequate length and confounded by variations in environmental conditions.

Currently there is interest in using arthropods as indicators of environmental change; however, selecting appropriate arthropod taxa for this purpose is limited by the lack of basic knowledge of their life histories, taxonomy and ecology.

1.9 AIMS OF THIS RESEARCH

This research will investigate the effects of rodent control on ground weta (Stenopelmatideae), cave weta (Anastostomatidae), carabid beetles (Carabidae) and prowling spiders (Zoropsidae) in mature kanuka forest, young podocarp-broadleaf forest and mature taraire forest. The selected arthropods will be monitored within treatment sites, in the La Trobe Forest Ecosystem Restoration Project (LTFERP) in the Waitakere Ranges, west of Auckland, where intensive rodent control has been carried out since 2002. These arthropods will also be monitored at control sites in the same forest types, outside of the LTFERP, where rodent populations have not been manipulated. The abundance of rodents and possums will be compared at the treatment and control sites. Vegetation and ground-cover features at all sites will also be assessed.

The hypotheses tested in this research are:

1. That ground weta, cave weta, carabid beetles and prowling spiders will be found in greater abundances in rodent treated (treatment) areas than in non-rodent treated (control) areas within mature kanuka forest, young podocarp-broadleaf forest and mature taraire forest.
2. That rodents are selecting particular size classes of the arthropods being monitored in this research.
3. That ground weta, cave weta, carabid beetles and prowling spiders would be suitable indicators of the effects of intensive rodent control at the La Trobe Forest Restoration Project.

2 METHODS

2.1 INTRODUCTION

The Waitakere Ranges are situated 25 km to the west of Auckland city and run roughly north to south (Fig. 2.1). Their topography is rugged, with the highest point being 474 m a.s.l. Sixty percent of the ranges are within the Waitakere Ranges Regional Park, and the area surrounding the park is in private ownership (Harvey and Harvey, 2006). The nature of the original forest is not documented, but may have been kauri, northern rata and rimu forest (Esler, 2006). Most of the original forest had been milled and burnt by the 1930's (Cranwell-Smith, 2006). Forest regeneration has been influenced by its past history of timber milling and farming (Esler, 2006). Esler (2006) recognises the following forest zones: unmilled and lightly milled forest, cut-over forest with tall trees, cut-over forest without tall trees, and tea tree scrublands.

All of the study sites in this research were located between Piha and the Pararaha Valley, on the western side of the Waitakere Ranges.

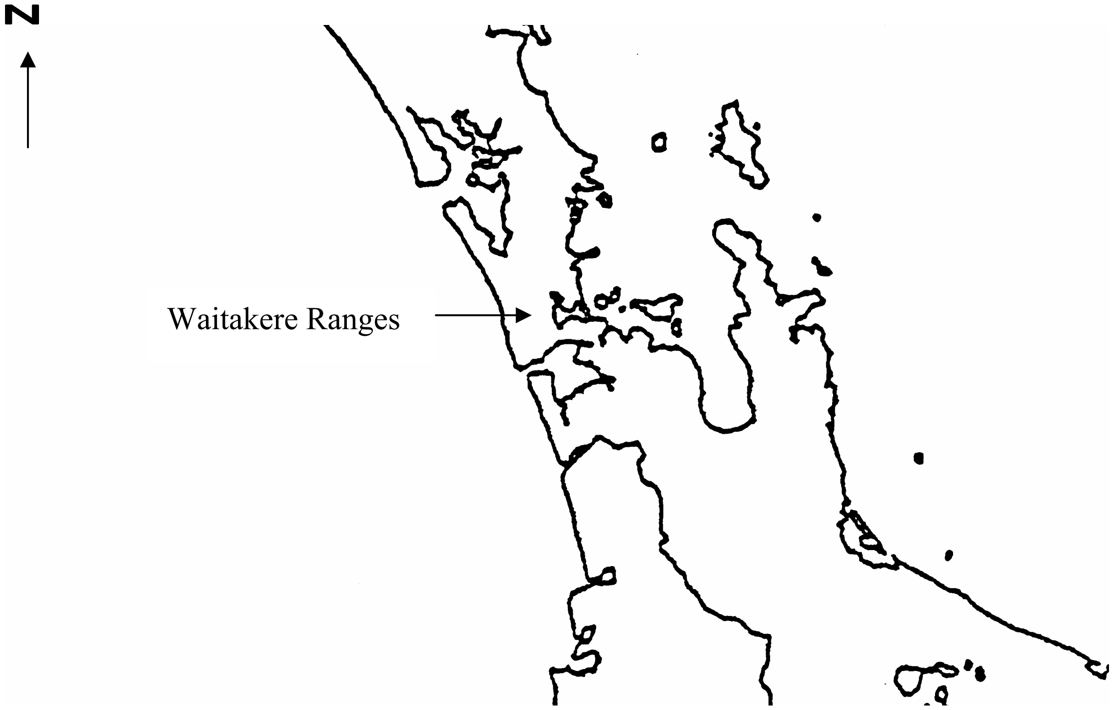

Figure 2-1 Location of Waitakere Ranges in the North Island of New Zealand.

2.2 SITE DESCRIPTIONS

Within each of three forest types, mature kanuka forest, young podocarp-broadleaf forest and mature taraire forest, two control sites and one treatment site were chosen. The three sites for each forest type were selected to be as similar as possible with respect to the variables of vegetation, age, aspect, altitude, plant species present, slope and drainage.

The treatment sites were all situated within the La Trobe Forest Ecosystem Restoration Project (LTFERP) at Karekare (36^{o} 59' South, 174^{o} 28' East) (Fig. 2.2). The LTFERP is a community-based ecosystem restoration project, established in 2002, that aims to suppress rats (*Rattus rattus*), mice (*Mus musculus*) and possum

(*Trichosorus vulpecula*) numbers to low levels, to minimize their negative influence on ecosystem regeneration.

The LTFERP encompasses an area of approximately 200 hectares of regenerating forest that was farmed up until 55 years ago. It is composed exclusively of areas of mature kanuka (*Kunzea ericoides*) forest, young podocarp-broadleaf forest and mature taraire (*Beilschmiedia tarairi*) forest. The six control sites were located in the Piha to Pararaha area (Fig. 2.3).

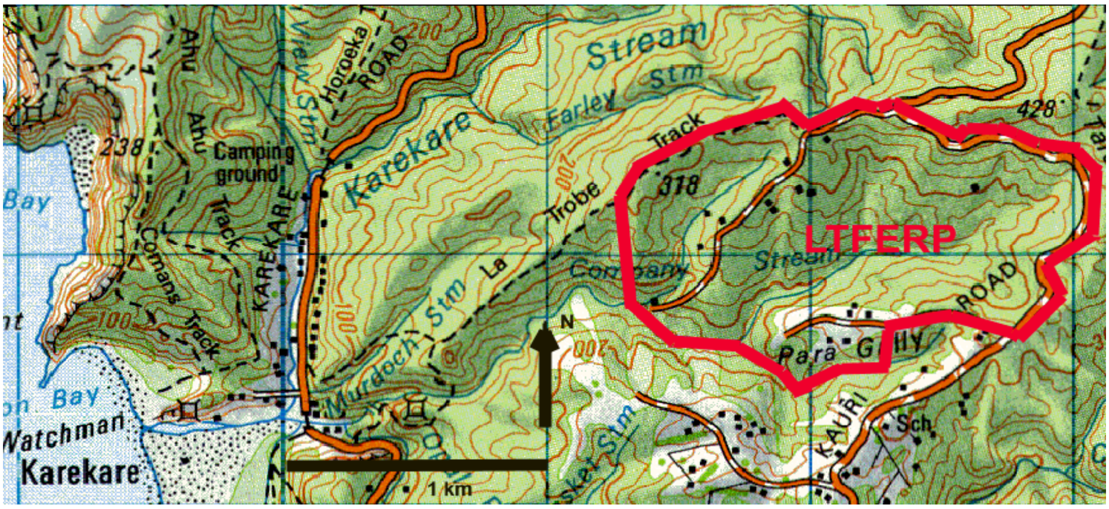

Figure 2-2 Location of the LTFERP at Karekare.

Figure 2-3 Study sites in the Waitakere Ranges.

1	Podocarp control site 1	7	Taraire control site 1
2	Podocarp control site 2	8	Taraire control site 2
3	Podocarp treatment site (LTFERP)	9	Taraire treatment site (LTFERP)
4	Kanuka control site 1		
5	Kanuka control site 2		
6	Kanuka treatment site (LTFERP)		

2.2.1 Treatment Sites

Podocarp-broadleaf forest

This site was located along the south-west side of the Lone Kauri Road, approximately 2 km from the Piha Road intersection (Fig. 2.3). The site consisted of secondary-growth forest with a canopy of rewarewa (*Knightia excelsa*), whitey wood (*Melycytus ramiflorus*), pigeonwood (*Hedycarya arborea*), black ponga (*Cyathea medullaris*), mapou (*Myrsine australis*), lacebark (*Hoheria populnea*), rimu (*Dacrydium cupressinum*), miro (*Prumnopitys ferruginea*) and nikau palm (*Rhopalostylis sapida*). The understorey plants consisted mainly of mapou, rewarewa, lacebark, silver fern (*Cyathea dealbata*), kiekie (*Freycinetia banksi*i), pigeonwood, lancewood (*Pseudopanax crassifolius*), toropapa (*Alseuosmia macrophylla*), and various *Coprosma* species. There were also large numbers of lianes: supplejack vines (*Ripogonum scandens*), kiekie, various rata species (*Metrosideros spp*), and mangemange (*Lygodium articulatum*). Some trees also supported epiphytes such as kauri grass (*Astelia trinervia*), and hanging spleenwort (*Asplenium flaccidum*). This site had a south-westerly aspect, and was situated on medium to steep sloped hills, with well drained soil, at an elevation of 250–300 m a.s.l. (Plate 2.1).

Plate 2-1 Understorey of podocarp-broadleaf forest in the Company Stream valley, LTFERP, with dense kiekie growth and supplejack vines.

Kanuka Forest

This site was situated between La Trobe Track and La Trobe Road (Fig. 2.3). It consisted of secondary-growth forest, with a canopy dominated by mature kanuka (*Kunzea ericoides*). The understorey consisted mainly of rewarewa, lancewood, pigeonwood, silver fern, various *Coprosma* species, hangehange (*Geniostoma rupestre*), and crown fern (*Blechnum discolor*). There were very few lianes and epiphytes present. This site had a south-easterly aspect, and was situated on steep hills, with well drained soil, at an elevation of 250–300 m a. s. l. (Plate 2.2)

Plate 2-2 Understorey plants in mature kanuka forest.

Taraire Forest

This site was located in the Company Stream valley between the stream and the La Trobe Road (Fig. 2.3). It was comprised of mature taraire (*Beilschmiedia tarairi*), with a canopy dominated by taraire, black ponga, tawa (*Beilschmiedia tawa*), and nikau. The understorey consisted mainly of hangehange, kohekohe (*Dysoxylum spectabile*), juvenile nikau palm, kiekie, various *Coprosma* species and silver fern. There were a large number of supplejack vines, and also kiekie growing as a liane, as well as many epiphytes, the most common of which were ferns such as hanging spleenwort. The forest floor was covered in a thick layer of leaf litter. This site had a south-easterly aspect, and was sited on medium to steep slopes with well-drained soil, at an elevation of 180–200 m a.s.l. (Plate 2.3).

Plate 2-3 Mature taraire forest in the LTFERP, showing the thick layer of leaf litter.

2.2.2 Control Sites

Podocarp Control Site 1

Situated beside the Arthur Mead Track, off the Piha Road, and towards the Lone Kauri Road (Fig. 2.3), this site was comprised of secondary-growth forest with a canopy of rimu (*Dacrydium cupressinum*) black ponga, heketara (*Olearia rani*), lancewood, kohuhu (*Pittosporum tenuifolium*) and rewarewa. The understorey consisted mainly of kiekie, toropapa, hangehange, heketara, hohere and cutty grass (*Gahnia setifolia*). There were large numbers of lianes such as supplejack, mangemange, rata species and kauri grass, and ferns growing as epiphytes. This site had a south-easterly aspect, and was sited on medium to steep slopes, with well drained soils, at an elevation of 250–300 m a. s. l.

Podocarp Control Site 2

This site was situated approximately 400 m along the Home Track, which is located off the Piha Road (Fig. 2.3). It consisted of secondary-growth forest with a canopy of tawa, houpara (*Pseudopanax lessoni*), pigeonwood, black ponga, rewarewa, heketara and kahikatea (*Dacrycarpus dacrydioides*). The understorey consisted mainly of nikau palm, black ponga, hangehange, pigeonwood, mapou, various *Coprosma* species, whitey wood, miro (*Prumnopitys ferruginea*) and houpara. There were large numbers of lianes such as supplejack, rata and mangemange, and various epiphytic ferns. This site had both a southerly and a northerly aspect, and was located on both steep and gentle slopes, with well-drained soils, at an elevation of 250–300 m a. s. l.

Kanuka Control Site 1

This site was located approximately 2 km down La Trobe Track, between the track and the Company Stream (Fig. 2.3). It was comprised of secondary-growth forest with a canopy dominated by mature kanuka. The understorey consisted mainly of silver fern, black fern, hangehange, pigeonwood, rewarewa, various *Coprosma* species, toropapa, whitey wood and heketara. There were only a few lianes and epiphytes. This site had a south-easterly aspect, and was located on steep slopes, with well-drained soils, at an elevation of 180–200 m a. s. l.).

Kanuka Control Site 2

This site was located approximately 800 m down the Winstone Track, off the Piha Road, between the track and the Ussher Stream (Fig. 2.3). It was comprised of secondary-growth forest with a canopy dominated by mature kanuka. The understorey consisted mainly of silver fern, various *Coprosma* species, kohuhu, pigeonwood, hangehange, kauri (*Agathis australis*), toropapa, rewarewa, miro, and cutty grass. There were only a few lianes and epiphytes. This site had an east to north-westerly aspect and was located on gentle to medium slopes, with medium-drained soils, at an elevation of 180–200 m a. s. l.

Taraire Control Site 1

This site was located in the Farley Stream valley, which is a tributary of the Karekare Stream (Fig. 2.3). It was comprised of mature taraire, with a canopy dominated by taraire, nikau and karaka (*Corynocarpus laevigatus*). The understorey consisted mainly of silver fern, nikau palm, hangehange, pigeonwood, whitey wood, various *Coprosma* species, taraire, kohekohe, and tawa. The trees supported large numbers of lianes such as rata species and supplejack, as well as the epiphytes spleen wort, and hounds tongue. The forest floor was covered in a thick layer of leaf litter. This site had a northerly aspect, and was located on steep slopes, with well drained soils, at an elevation of 200–240 m a.s.l.

Taraire Control Site 2

This site was located up the side of Baldy in the Pararaha Stream valley (Fig. 2.3). It was comprised of mature taraire, with a canopy dominated by taraire, small numbers of kowhai (*Sophora microphylla*), and puriri (*Vitex lucens*). The understorey plants consisted mainly of nikau palm, silver fern, hangehange, pigeonwood, whitey wood, and waiu-atua (*Rhabdothamnus solandri*), with very few lianes and epiphytes. The forest floor was covered in a thick layer of leaf litter. This site had a south-easterly aspect, and was located on very steep slopes, with well drained soils, at an elevation of 200–240 m a.s.l.

2.3 ASSESSMENT OF SITE CHARACTERISTICS

2.3.1 Vegetation Parameters

The assessment of selected vegetation parameters is based on the RECCE method, and all of the parameters recorded were visually assessed to allow for rapid data collection (Allan, 1993).

The different plant species in the prescribed height-tier classes were recorded using line transects, running along the pitfall trap lines, at each site. Plants in height-tiers one to five were recorded; plants in height-tier six were recorded using the point intercept method (see section 2.3.3). The presence of any epiphytes and lianes were noted in each height-tier. In addition to the height-tier information, the mean height of the canopy was estimated at each site, and the canopy percentage cover, estimated to the nearest 10% of the proportion of sky blocked out by vegetation at a height of 1.35 m, was also estimated at each site.

2.3.2 Physical Parameters

At each pitfall trap site the aspect was measured with a compass, the slope estimated, and the soil depth measured with a gum digger’s spike. Drainage was estimated following Allan (1993) as:

- Good - where there is fast runoff and little accumulation of water
- Medium - where runoff is slow and water accumulates for a few days after rain
- Poor - where water stands for long periods

2.3.3 Ground Cover

Ground cover was assessed using the Point Intercept method (Handford, 2000). At each pitfall trap site a measuring tape was extended for 10 m, horizontal to the slope, and the ground cover category was recorded under each 1 m mark of the tape i.e. a point. A total of 220 points were recorded at each site. The following ground cover categories were recorded:

- Vegetation – any vegetation less than 15 cm in height other than mosses or ferns
- Live tree roots
- Mosses
- Ferns – any ferns less than 15 cm in height
- Leaf litter – including dead sticks < 3 cm in diameter
- Wood – dead wood, branches and logs, ≥ 3 cm in diameter
- Bare soil
- Exposed rock

2.4 WEATHER MEASUREMENTS

Temperature and rainfall measurements were recorded at a home-based weather station located in the LTFERP.

2.4.1 Temperature

Daily maximum and minimum temperatures have been recorded since March 2004. The recordings were taken in the shade, 1.56 m above the ground. The monthly minimum temperatures have been used for comparisons between 2004–05 and 2005–06, because the arthropods being captured in the pitfall traps are nocturnal and the night-time temperatures are more relevant to their activity pattern.

2.4.2 Rainfall

Rainfall data has been collected using a standard calibrated rain gauge, and monthly totals calculated and recorded, since December 1999.

2.5 POSSUM AND RODENT CONTROL AT THE TREATMENT SITES (LTFERP)

In 2002 a network of poison bait stations was established over the entire LTFERP area, using lines with the bait stations at 50 m intervals, and the lines 100 m apart. Initially, brodifacoum, a second generation anti-coagulant, was used to control rodents (*Rattus rattus* and *Mus musculus*) and possums (*Trichosorus vulpecula*). However, because of concerns about the persistence and toxicity of brodifacoum to non-target species (Booth, Eason & Spurr, 2001; Booth, Fisher, Heppelthwaite & Eason, 2003*)*, other pest control methods have also been trialed at the LTFERP. In July 2003, diphacinone, a first generation anti-coagulant, was used in the podocarp-broadleaf forest. However, this trial did not adequately suppress rat numbers and consequently the use of brodifacoum was resumed and is still currently in use.

Rat snap-traps were used to control rodents in the kanuka forest in 2003. Lines of paired traps baited with peanut butter, oats, and fish sauce were placed in Black Trakka ™ tracking tunnels using the 50 m by 100 m grid. This trial ended in July 2004, because mice numbers increased during autumn, so brodifacoum use was resumed.

2.6 RODENT MONITORING

2.6.1 Previous Research

At the LTFERP tracking tunnels were used to provide an index of rodent abundance, because they are reported to be able to detect the presence of rodents at low abundance (Gillies & Williams, 2003).

Seven rodent monitoring lines, each at least 200 m from any other line (ibid.), were established in 2002, encompassing all three forest types in the project. Black Trakka ™ plastic tracking tunnels (Plate 2.4) were permanently located at 50 m intervals along each line, and the number of tunnels along each line varied between 8 and 16. A total of 74 tunnels were installed.

Plate 2-4 Black trakka ™ tracking tunnel containing card for rodent monitoring.

Rodent monitoring surveys were carried out over one night, with fine weather conditions. Pre-inked footprint tracking cards were baited with a tablespoon of crunchy peanut butter and placed inside the tunnels. The next day the cards were retrieved and any rodent foot print tracks identified and recorded as rat or mouse (Plate 2.5). Possum (Plate 2.5) and hedgehog prints were also recorded. In 2002 and 2003 rodent monitoring was carried out at approximately two monthly intervals, and in 2005 at three monthly intervals, however, in 2004 rodent monitoring was only done at six monthly intervals, because of time constraints.

For each monitoring event the percentage of cards with rat or mouse footprints was calculated, and this total was recorded as the tracking index. A tracking index of above 5% was used as the threshold limit. If the index was higher than 5%, the bait stations were rebaited.

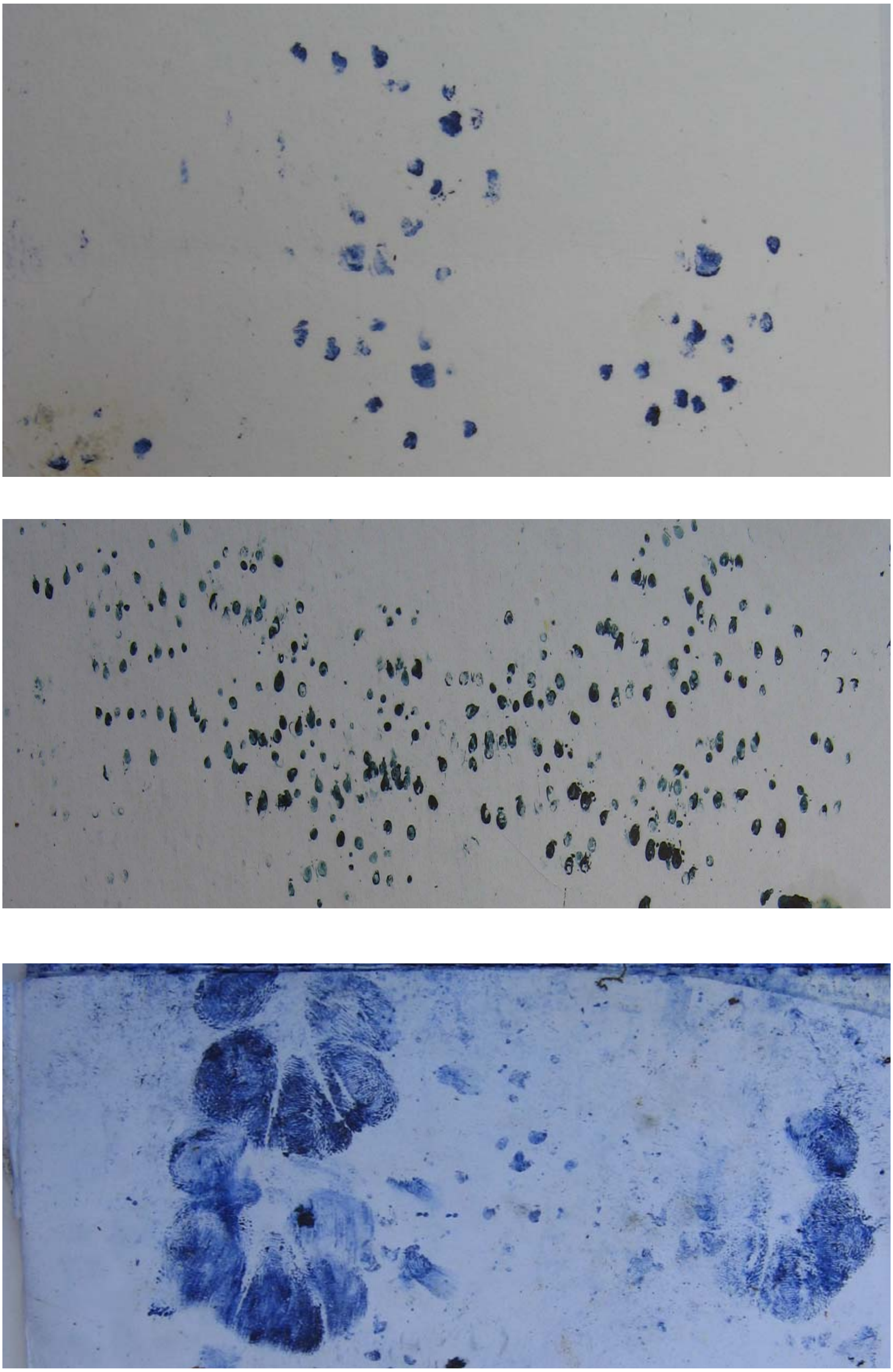

Plate 2-5 Monitoring cards showing footprints of rat (top), mice (middle) and possum (bottom). Scale life size.

2.6.2 This Study

An existing rodent monitoring line was used to estimate the rodent population in the kanuka treatment site for this study. New rodent monitoring lines were installed in November 2005, in the podocarp-broadleaf treatment and taraire treatment sites. In addition, rodent monitoring lines were also established in each of the kanuka, podocarp-broadleaf and taraire control sites. Each line consisted of 10 tracking tunnels, which were spaced at 50 m intervals and left in place for three weeks before use, to allow any resident rodents to become acclimatised to their presence (Gillies & Williams, 2003). A total of 90 tracking tunnels were installed (30 in the treatment sites and 60 in the control sites). The rodent populations were sampled in November–December 2005, March–April 2006 and October 2006, using the same methodology as previously described.

2.7 POSSUM CONTROL IN THE WAITAKERE RANGES

Possum control was carried out throughout the Waitakere Ranges, in 1998, including the LTFERP and control areas, in an operation called Project Forest Save, run by the Auckland Regional Authority. Brodifacoum placed in bait stations was used to reduce possum numbers.

2.8 POSSUM MONITORING

2.8.1 Previous Research

Five lines of 10 leg-hold traps, with the traps at 20 m intervals in each line, were installed giving 50 traps in total. Each leg-hold trap was attached to a tree, and a mixture of plain white flour and icing sugar was spread up the tree beyond the trap as a lure. The traps were left out for two nights of fine weather, and checked each day, giving a total of 100 trap nights. The number of possums captured per trap night was calculated. This was done only once, in September 2002, and thereafter the presence of possum footprints on the tracking cards in tunnels was used to monitor possums (Plate 2.5).

2.8.2 This Study

Treatment Sites

Possum footprints found on the rodent tracking cards used in 2005–06 were recorded, and the number of cards with possum prints used to indicate the presence of possums in the treatment site.

Control Sites

The relative abundance of possums was determined by the Auckland Regional Council in the Piha and Whatipu areas, between February and March 2006. Twenty lines of leg-hold traps were installed in each area, with 10 traps per line. In each line the traps were spaced at 20 m intervals and left out for three nights, giving a total of 1200 trap nights. The Karekare area was monitored during October 2006, using similar methodology, except 10 lines of leg-hold traps were installed, giving a total of

300 trap nights. The number of possums captured per 100 trap nights was calculated from the data obtained. In addition to the possum monitoring done by the Auckland Regional Authority, any possum footprints found on the tracking cards, used for rodent monitoring, were also recorded.

2.9 ARTHROPOD MONITORING

In this research, ground weta (Plate 2.6), cave weta (Plate 2.7), carabid beetles (Plate 2.8), and prowling spiders (Plate 2.9), have been monitored, to determine whether they were being affected by the presence of rodents. These arthropods have been selected because they are largely nocturnal, live on the ground, are flightless and large bodied and have extended life histories and therefore low rates of reproduction. According to Gibbs (1998), these are features that make them vulnerable to rodent predation, because rodents are predominantly nocturnal and spend much of their time hunting on the ground (Green, 2000).

Plate 2-6 Ground weta, *Hemiandrus* sp. 22 mm body length.

Plate 2-7 Auckland cave weta, *Gymnoplectron acanthocera,* 25 mm average body length.

Plate 2-8 Carabid beetle, *Mecodema spiniferum,* 30 mm body length.

Plate 2-9 Prowling spider, *Uliodon* sp. 25 mm body length.

2.9.1 Pitfall Traps

Pitfall traps were used to monitor the selected arthropods in this research, because they have been used extensively to sample ground-dwelling arthropods in New Zealand forests (Chapman, Alexander & Ussher, 2004; Craddock, 1997; Hutcheson, 2001; Moeed and Meads, 1986; Sim, 2005; Ward-Smith, Sullivan et al., 2004; Watts, 2004). They are effective at capturing larger organisms (New, 1998). Pitfall traps collect only a fraction of the available fauna and cannot be used for measuring population density; instead they provide an index of arthropod activity (Southwood & Henderson, 2000).

A large range of factors affect the catch, including such things as: temperature, weather conditions, food supply, amount of vegetation impeding the movement of ground-dwelling arthropods, and the sex and age of the individual. They must also be left unset for a few weeks to avoid the "digging in effect", because the ground is disturbed when they are first installed and some organisms are attracted to the disturbed ground whilst others are repelled by it (New, 1998). Despite these limitations, pitfall traps do have many advantages. For instance, they are inexpensive and easily constructed, can be transported in large numbers through dense forest, and can be left unattended for long periods of time, and therefore can provide a continuous record of arthropod fauna for comparison between sites (Watts, 1999).

The pitfall traps used in this study consisted of 160 mm lengths of 80 mm diameter cylindrical plastic down-pipe (Green, 2000), dug into the ground with a small post-hole borer, so that the rim was level with the ground (Fig. 2.4). Surplus soil was discarded several metres away from the traps, which were then left unset for several weeks before being activated, to avoid the "digging in effect". During the course of the trapping season, any cracks that appeared between the trap and the surrounding ground were repaired, and the rims of the traps were maintained level with the ground. A tight-fitting plastic cup was pushed to the bottom of the down-pipe, leaving a distance of at least 60–70 mm between the top of the cup and ground level. This distance reduces the chance of any arthropods climbing out of the trap and escaping (Green, 2000). Six small drainage holes were burnt into each cup with a hot nail, about 30 mm from the top, to prevent loss of arthropods during heavy rainfall. To locate the trap site, the position of each was marked by attaching flagging tape to a near-by tree. When operating the trap line, the same route was taken to each trap site to minimize damage to the ground cover and disturbance to any other material that may be used by arthropods to shelter during the day (Green, 2000).

Each trap was covered with a plastic, 2 litre ice-cream container lid that was positioned 2 cm above the surface of the ground on wire supports. The purpose of the cover was to reduce the amount of rain and solid objects falling into the trap.

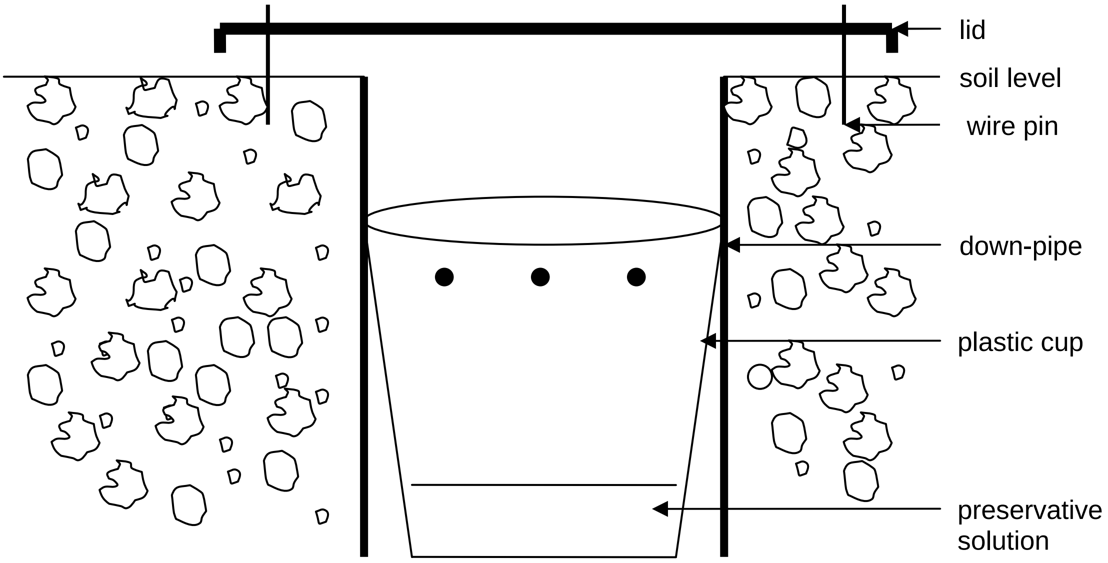

Figure 2-4 Diagram of pitfall trap *in situ.*

The preservative used was a mixture of 30% monoethylene glycol (vehicle antifreeze) solution, 70% unfiltered tank water, plus a tablespoon of table salt to supersaturate the solution (Green, 2000). A few drops of detergent were added to reduce the surface tension of the liquid, so that captured arthropods would sink quickly. Approximately 80 ml of this solution was poured into each cup. During trap clearances, the preservative and captured arthropods were poured into plastic screw top containers, labeled with the trap number, location and date, and the plastic cup refilled with new preservative solution.

2.9.2 Sampling Regime

This Study

Pre-existing pitfall trap lines were used in kanuka forest in the LTFERP (the treatment site) (Fig. 2.3), and in control site 1 (Fig. 2.3).

New pitfall trap-lines were located at the treatment sites in young podocarp-broadleaf and mature taraire, within the LTFERP (Fig. 2.3) In addition, two control sites in each of podocarp-broadleaf and taraire forest, and one additional control site in kanuka forest were established (Fig. 2.3). All of the control sites were located at least 400 m outside of the treatment site, in order to avoid rodent control at the treatment sites affecting the control sites (Chapman, Alexander & Ussher, 2004). This provided a total of one treatment and two control sites for each forest type. According to Underwood (1992), several control sites are required because natural populations fluctuate, both temporally and spatially, but while it is usually not feasible to have more than one treatment site, it is possible to have multiple control sites. In this study two control sites per forest type were used given the time frame available

At each site, two lines of pitfall traps were installed a minimum of 50 m apart. Each line consisted of 10 traps, located at intervals of at least 10 m. A 10 m interval between traps is sufficient to ensure that they are independent of each other (Green, 2000). Each pitfall trap line was located a minimum of 50 m away from different forest types that may have different characteristics and could influence arthropod numbers and species present (ibid.). Pitfall traps were placed 20 m away from streams to prevent flooding during heavy rainfall, and away from ridge tops to avoid the drying effect of higher winds. Traps were located at least 10 m away from public walking tracks so they would not be disturbed by foot traffic. To minimise variable drying effects, each trap was placed at a site with a minimum of 80% canopy cover.

Traps were installed in October 2005 and samples collected approximately every 30 days, from December 2005 until May 2006. This gave a total of six months of sampling for each trap. A total of 1080 samples were collected during 2005–06.

The contents of each sample were grouped into ground weta, cave weta, carabid beetles and prowling spiders, and the numbers of each of these were recorded and voucher specimens kept. Other arthropods in the samples were stored in 70% ethanol for future study. Capture rates of each arthropod group, as the number per trap night, were used to provide the indices of abundance at each site. The targeted arthropods were sorted into different size class groups (Table 2.1), and the number of individuals in each size class was recorded.

Previous Research

The pitfall trap lines in the kanuka treatment site, within the LTFERP, and control site 1 were established in November 2004. The same methodology, as described below, was used, except there was only one control site, and the pit fall traps were cleared at approximately 28 day intervals (from December 2004 to May 2005). A total of 240 samples were collected. This data was also used in this study.

Table 2-1 Arthropod by size classes.

Arthropod Group	Ground Weta	Cave Weta	Carabids	Prowling Spiders
Size Classes (mm)	<10	4–9	10–14	<11
	10–19	10–14	15–19	11–20
	>19	15–19	20–24	>20
		>19	>24	

2.10 STATISTICAL ANALYSIS OF DATA

2.10.1 Ground Cover

Chi-square tests from StatPro software were used to determine whether there was an association between site and ground cover proportions in each forest type. Significance was assigned at the 95% confidence level.

2.10.2 Rat Tracking

The tracking tunnel data for rats during 2005–06 were analysed using the Mann-Whitney U-test http://eatworms.swmed.edu/~leon/stats/utest.html, to determine whether the samples from the treatment and control sites had different medians. Significance was assigned at the 95% confidence level.

2.10.3 Pitfall Trap Samples

Each data set was tested for normality using the Lilliefors Test from StatPro software, and homogeneity of variance using the F max test (Fowler, Cohen & Jarvis, 1999). Data sets that were not normally distributed or had non-homogenous variances were logarithmically transformed using StatPro software. If data transformation was not possible (because of the presence of too many zero results), non-parametric statistical tests were used. For two-sample comparisons, the Mann-Whitney U test http://eatworms.swmed.edu/~leon/stats/utest.html was used, and the Kruskal-Wallis test (using SPSS software), for three-sample comparisons. One-way Analysis of Variance (ANOVA) was used to analyse data that was normally distributed with homogenous variances. The statistical significance of differences in the size class frequencies of each arthropod group, at each site or between different years, was tested using Chi-square contingency tables, from StatPro software. All tests were two-tailed and significance was assigned at the 95% confidence level.

3 RESULTS

3.1 KANUKA FOREST

3.1.1 Study Site Physical Characteristics

Both the treatment site and control site 1 have similar site characteristics, in contrast to control site 2, which has a more northerly aspect, is less steep, has poorer drainage, and a taller canopy. In addition, soil depths were similar at all three sites (Table 3.1).

Table 3-1 Comparison of site characteristics in kanuka.

Characteristic	Aspect	Slope	Drainage	Canopy height	Mean soil depth
Treatment site	SW–SE	20°–40°	Good	15 m	>1.1 m
Control site 1	SE	25°–30°	Good	15 m	>1.1 m
Control site 2	E–NW	5°–10°	Medium	20 m	>1.1 m

3.1.2 Vegetation Assessment

Ground Cover

The ground cover categories of vegetation, moss, fern, and rock were not used because they occurred in frequencies too low for statistical comparisons to be made. There was a statistically significant relationship between ground cover categories and place (Chi-square = 16.9, P = 0.01).

The proportion of bare soil was greater at kanuka control site 1, than at kanuka control site 2 (Table 3.2). In addition, the proportion of dead wood at kanuka control site 1 was less than the other two sites.

Table 3-2 Proportions of ground cover in kanuka by site.

Ground Cover Category	Leaf Litter	Tree Roots	Bare Soil	Dead Wood
Treatment site	0.83	0.02	0.05	0.10
Control site 1	0.82	0.01	0.10	0.07
Control site 2	0.86	0.03	0.01	0.10

Canopy Cover

The treatment site had fewer plant species in tier two than either of the control sites which may indicate that it has been regenerating for less time. At all three sites the number of plant species decreases with the height of the tier. However, the total number of plant species at each site was similar (Table 3.3).

Table 3-3 Numbers of plant species in the different height tiers by site.

Tier number	1 (>25 m)	2 (12–25 m)	3 (5–12 m)	4 (2–5 m)	5 (0.3–2 m)	Totals
Treatment site	0	1	12	18	23	54
Control site 1	0	3	10	23	23	59
Control site 2	0	7	14	16	23	60

3.1.3 Rodent Monitoring

Rats

The annual rat tracking index in kanuka has only twice been below the target figure of 5% since 2002 (2003 and 2004), nevertheless, all the tracking indices were well below those of control sites 1 and 2 for 2005–06 (Tables 3.4 and 3.5). During the time period 2002–06, rats were detected at the kanuka treatment site in autumn (March, April, and May), and in spring (September and November) only (Table 3.4).

The rat tracking index, for the kanuka treatment site, during the 2005–06 pitfall trapping season was 20%. This was higher than the historical indices, which varied between 0% and 10.6% (Table 3.4 and Fig. 3.1). The tracking index for rats at the treatment site during 2005–06 was not statistically significantly different from that of control site 1 (Mann-Whitney U = 507.7, P = 0.176). In contrast, the tracking index for rats at the treatment site was statistically significantly lower than that of control site 2 (Mann-Whitney U = 765, P <0.001).

Table 3-4 Rat tracking indices at kanuka treatment site from 2002–2006.
* No monitoring done

Year	Jan	Mar	Apr	May	Jun	Jul	Sep	Oct	Nov	Mean	SE
2002	*	*	*	0	*	*	25	*	0	8.3	4.0
2003	0	19	*	6	*	0	*	0	*	5	2.0
2004	0	*	*	*	*	*	*	0	*	0	0.0
2005	0	*	30	*	0	*	*	*	30	10.6	3.0
2006	*	30	*	*	*	*	*	0	*	15	8

Table 3-5 Rat tracking indices in kanuka during 2005–06 by site.

Month	Nov	Mar	Oct	Mean	SE
Treatment site (6)	30	30	0	20	7.4
Control site 1 (4)	20	78	30	42.6	9.3
Control site 2 (5)	80	100	100	93.3	4.6

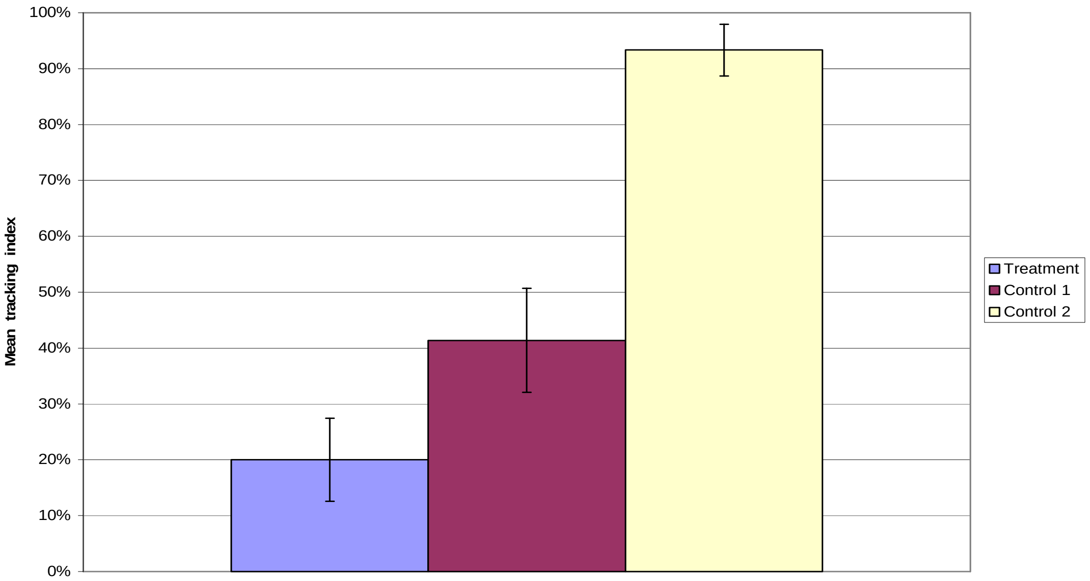

Figure 3-1 Rat tracking indices in kanuka during 2005–06 by site (+/- SE).

Mice

The target 5% mice tracking index, at the kanuka treatment site between 2002 and 2006, was achieved in 2002, 2004, and 2005, and similarly to rats, mice were detected at the kanuka treatment site in spring and autumn (Table 3.6). However, rodent monitoring in the whole kanuka forest in the LTFERP between 2003 and 2005 produced high mice tracking indices in March 2003, October 2003 and April 2005 (39.4%, 33.3% and 36.4%

respectively). During the 2005–06 pitfall trapping season, mice were more abundant at control site 1 than either control site 2 or the treatment site (Table 3.7). However, because of the large amount of variation in the results the standard errors are large (Tables 3.6, 3.7 and Fig.3.2).

Table 3-6 Mice tracking indices at the kanuka treatment site by year.

* No monitoring done

Month	Jan	Mar	Apr	May	Jun	Jul	Sep	Oct	Nov	Mean	S.E.
2002	*	*	*	0	*	*	0	12.5	*	4.2	2.9
2003	0	31	*	0	*	0	*	25	*	11.3	3.6
2004	0	*	*	*	*	*	*	0	*	0	0.0
2005	0	*	12.5	*	*	0	*	*	0	3.4	2.4
2006	*	*	20	*	*	*	*	0	*	10	6.8

Table 3-7 Mice tracking indices in kanuka during 2005–2006 by site.

Month	Nov	Apr	Oct	Mean	SE
Treatment site	0	20	0	6.6	5.0
Control site 1	0	30	20	16.7	6.9
Control site 2	0	10	0	3.3	3.3

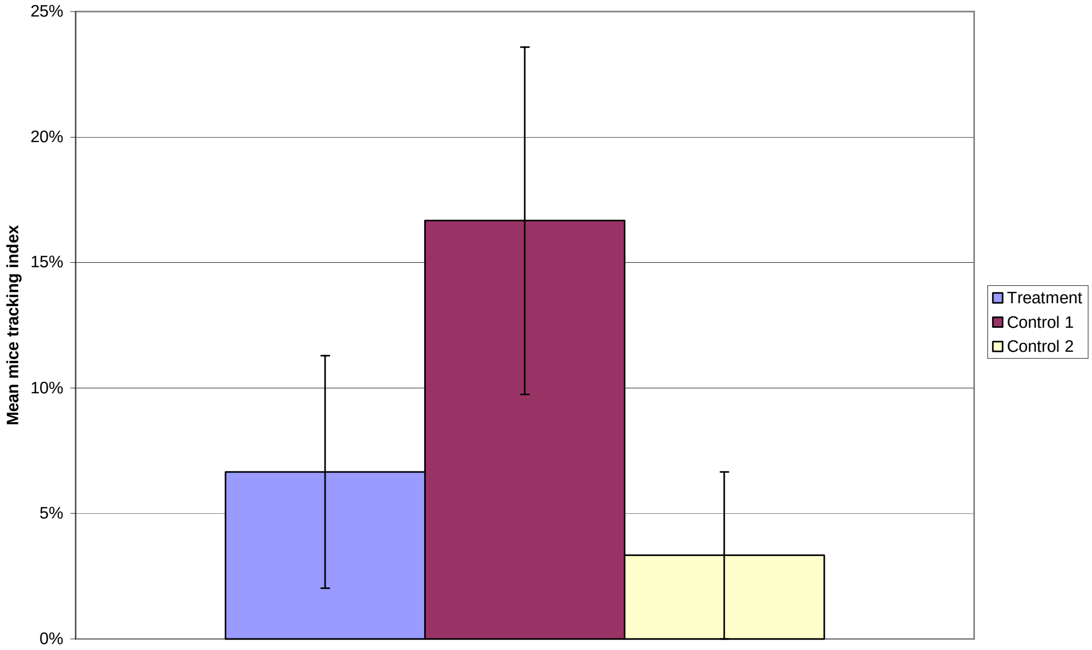

Figure 3-2 Mice tracking indices in kanuka during 2005–06 by site (+/- SE).

3.1.4 Ground Weta

Seasonal Abundance

The monthly abundance patterns of ground weta within kanuka forest were very similar for the sampling seasons in 2004–05 and 2005–06, with peaks in January, followed by a general decline until May when sampling was concluded (Figs. 3.3 and 3.4). However, in April 2006 at the treatment site (Fig.3.4), there was a second, smaller peak in numbers. Both control site 1 and control site 2 had similar monthly means during the 2005–06 sampling season (Fig 3.4). The monthly means for both 2004–05 and 2005–06 had large standard errors and this indicates a large amount of variation in the number of ground weta trapped in each pitfall trap. The increase in abundance from December to January was much greater in 2005–06 than in 2004–05 (Fig. 3.4).

Ground weta were more abundant in 2005–06 than 2004–05 at the treatment site (0.056 per trap night compared to 0.031 respectively); however, this difference was not statistically significant (U = 250.5, P = 0.17). Conversely, ground weta were more abundant in 2004–05 than 2005–06 at control site 1 (0.016 per trap night compared to 0.014 respectively), but this difference was not statistically significant (U = 455, P = 0.39). Ground weta were more abundant at the treatment site in 2004–05 than at control site 1 over the same time period (0.03 per trap night compared with 0.016 respectively); however, this difference was not statistically significant either (U = 262.5, P = 0.09). In contrast, ground weta abundance in 2005–06 at the treatment site was greater than those of control site 1 and control site 2 (0.06, 0.01, and 0.01 per trap night respectively), and these differences were statistically significant (Kruskal-Wallis, P = 0.008). Conversely, the means of the control sites one and two were very similar.

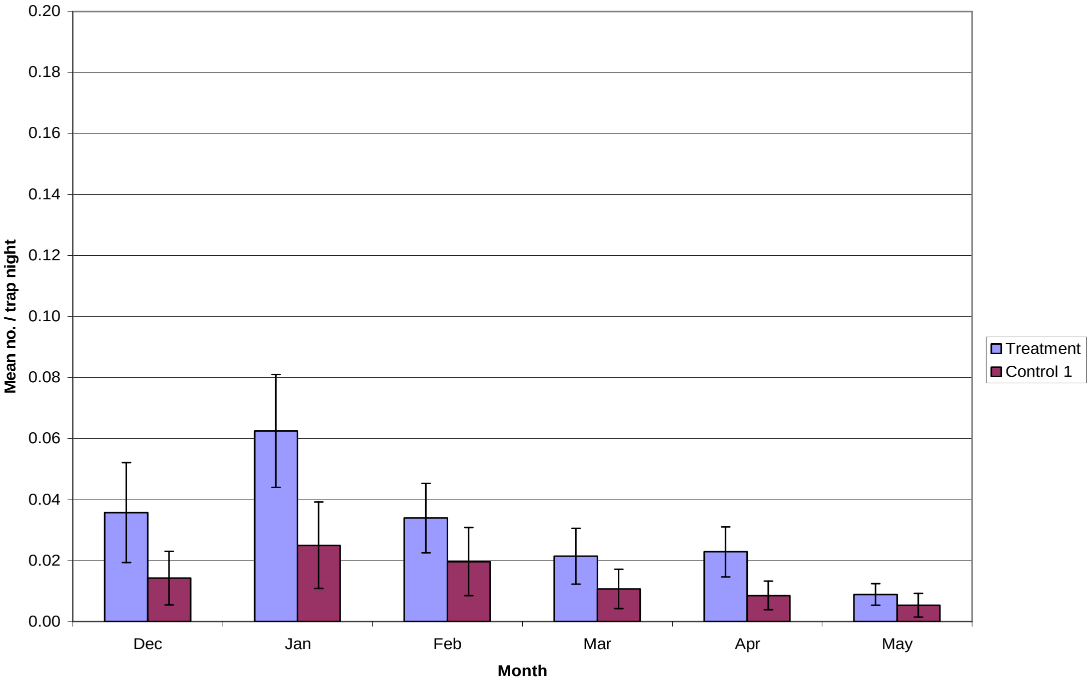

Figure 3-3 Mean abundance of ground weta in kanuka during 2004–2005 (+/- SE).

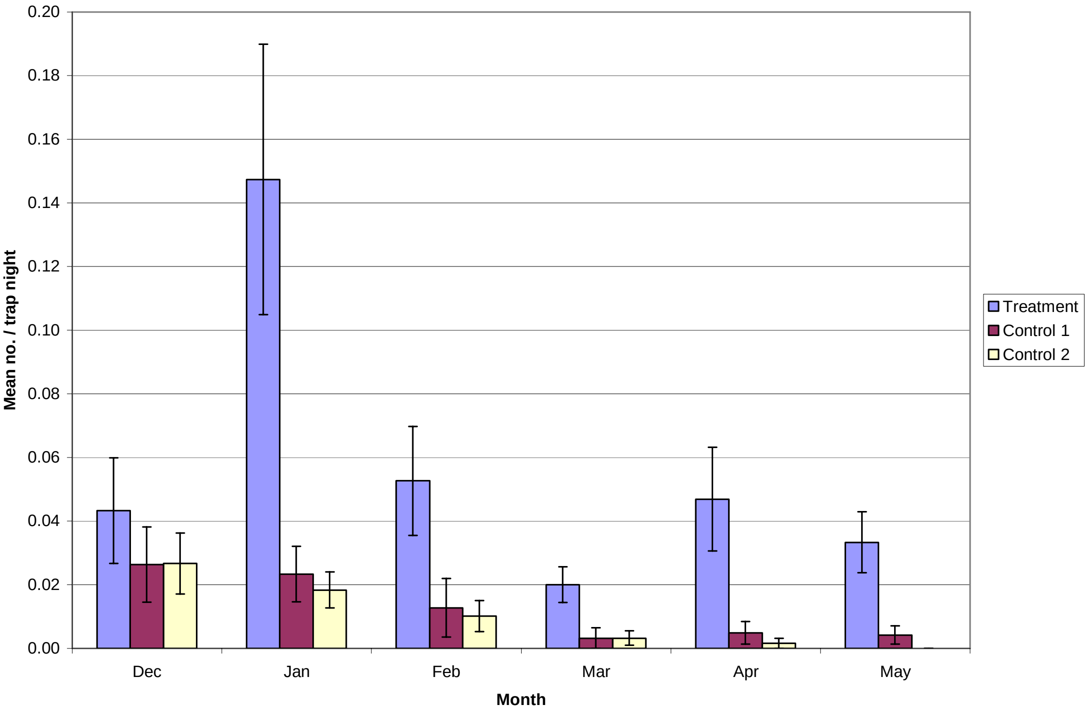

Figure 3-4 Mean abundance of ground weta in kanuka during 2005–2006 (+/- SE).

Trapped Ground Weta Size Classes

In the 2004–05 sampling season, the proportions of the different size classes were similar to those of the 2005–06 sampling season. There was a statistically significant relationship between the size classes <10 mm and >19 mm of ground weta, and site (Chi-square = 9.8, P = 0.007). In particular, there was a large proportion of ground weta in the <10 mm size class at control site 1 and a small proportion of ground weta in the >19 mm size class (Table 3.8). However, there was a small proportion of ground weta in the <10 mm size class at the treatment site, whereas, there was a large proportion of ground weta in the >19 mm size class.

Table 3-8 Ground weta mean size class proportions in kanuka during 2004–05 by site.

Size class (mm)	<10	10–19	>19
Treatment site	0.42	0.32	0.26
Control site 1	0.68	0.23	0.09

In the 2005–06 sampling season there was a large proportion of ground weta in the <10 mm size class in both control sites 1 and 2, but a small proportion at the treatment site. In contrast, at the treatment site there was a large proportion of ground weta in the >19 mm size class, whereas at control sites 1 and 2, there was a small proportion of ground weta in this size class (Table 3.9). There was a statistically significant relationship between the ground weta size classes < 10 mm, >19 mm and site (Chi-square = 12.53, P = 0.014).

Table 3-9 Ground weta mean size class proportions in kanuka during 2005–06 by site.

Size class (mm)	<10	10–19	>19
Treatment site	0.24	0.40	0.36
Control site 1	0.44	0.35	0.21
Control site 2	0.46	0.34	0.20

In kanuka control site 1, between 2004–05 and 2005–06, there was no significant relationship between ground weta size classes and sampling season (Chi-square = 5.686, P = 0.058) (Table 3.10).

Table 3-10 Ground weta size class proportions in kanuka control site 1 by sampling season.

Size class (mm)	<10	10–19	>19
2004–05	0.68	0.23	0.09
2005–06	0.44	0.35	0.21

There was a statistically significant relationship between size classes and sampling season at the kanuka treatment site (Chi-square = 10.49, P = 0.005). In particular, there was a large proportion of ground weta in the <10 mm size class in 2004–05, and a small proportion in 2005–06. There was a small proportion of ground weta in the >19 mm size class in 2004–05 and a larger one in 2005–06 (Table 3.11).

Table 3-11 Ground weta size class proportions in the kanuka treatment site by sampling season.

Size class (mm)	<10	10–19	>19
2004–05	0.42	0.32	0.26
2005–06	0.24	0.40	0.36

3.1.5 Cave Weta

Seasonal Abundance

Cave weta numbers peaked in summer during 2004–05 (February) and 2005–06 (January), and then declined until May when sampling was concluded (Figs. 3.5 and 3.6).

The cave weta abundance (0.077 mean number per trap night) at control site 1 was similar to that of the treatment site (0.074 mean number per trap night) in 2004–05, and not statistically significant ($F_1 = 0.102$, $P = 0.75$). Cave weta abundance at control site 1 was similar between 2004–05 and 2005–06, from 0.077 to 0.075 mean number per trap night, and not statistically significant ($F_1 = 0.013$, $P = 0.91$). In contrast, the difference in means between 2004–05 and 2005–06 (from 0.074 to 0.103 mean cave weta per trap night), at the treatment site was statistically significant ($F_1 = 5.82$, $P = 0.02$). The mean abundance of cave weta in 2005–06 at control site 2 was 0.123 per trap night, higher than the means at either the treatment site (0.103 per trap night) or control site 1 (0.075). The difference in cave weta means between control sites 1 and 2 was statistically significant ($F_2 = 5.90$, $P = 0.003$); however, the differences in means between control site 2 and the treatment site, and between the treatment site and control site 1 were not statistically significant (Tukey test).

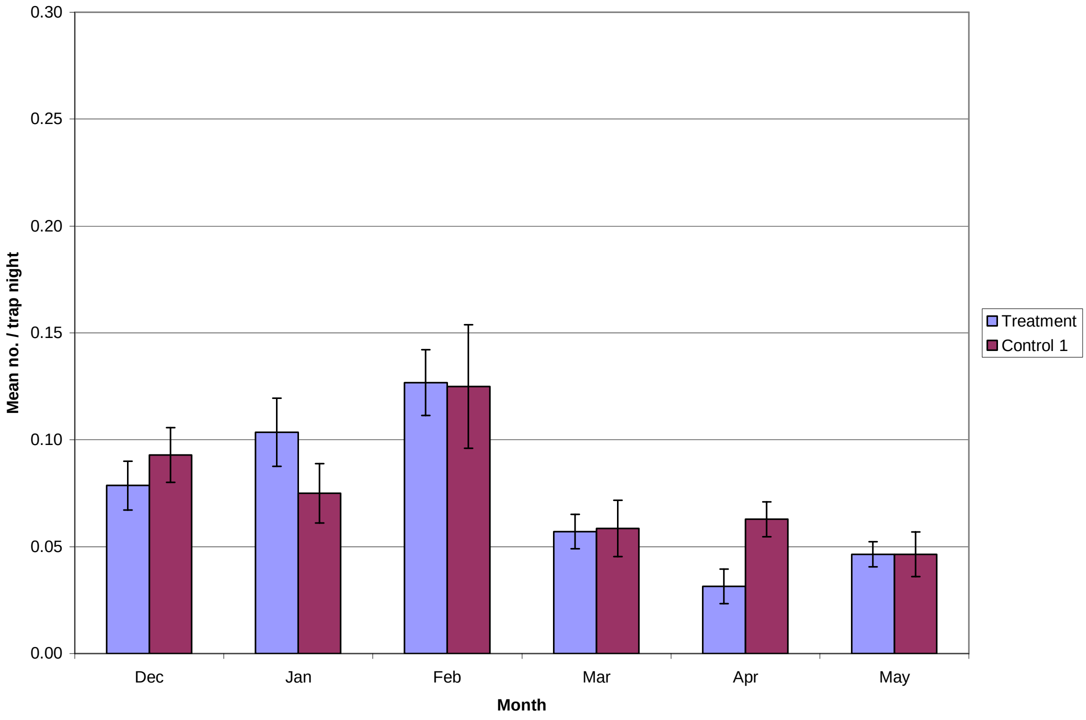

Figure 3-5 Mean cave weta abundance in kanuka during 2004–05 by site (+/- SE).

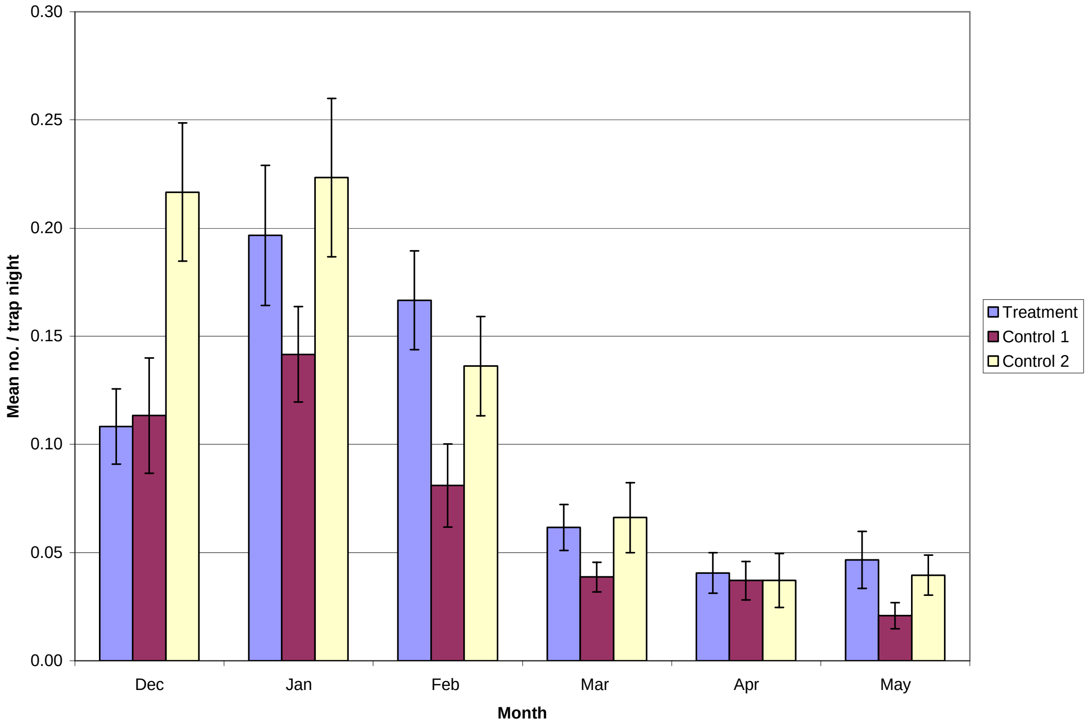

Figure 3-6 Mean cave weta abundance in kanuka during 2005–06 by site (+/- SE).

Trapped Cave Weta Size Classes

The frequencies of size classes 15–19 mm, and >20 mm were combined because there were insufficient captures in the >20 mm size class for statistical comparisons (these size class frequencies were also combined for the podocarp-broadleaf, and taraire results).

Treatment site and control site 1 2004–05

There was no significant relationship between cave weta size classes and site (Chi-square = 0.53, P = 0.77) (Table 3.12).

Table 3-12 Cave weta size class proportions in kanuka by site.

Size class (mm)	<10	10–14	>14
Treatment site	0.72	0.24	0.04
Control site 1	0.71	0.24	0.05

Treatment site 2004–05 and 2005–06

There was no significant relationship between cave weta size classes and sampling season (Chi-square = 1.40, P = 0.24) (Table 3.13)

Table 3-13 Cave weta size class proportions in kanuka treatment by sampling season.

Size class (mm)	<10	10–14	>14
2004–05	0.72	0.24	0.04
2005–06	0.68	0.26	0.06

Control site 1 2004–05 and 2005–06

There was no significant relationship between cave weta size classes and sampling season (Chi-square = 1.89, P = 0.39) (Table 3.14).

Table 3-14 Cave weta size class proportions in kanuka control site 1 by sampling season.

Size class (mm)	<10	10–14	>14
2004–05	0.71	0.24	0.05
2005–06	0.76	0.20	0.04

Treatment site, control sites 1 and 2, 2005–06

There was a statistically significant relationship between cave weta size classes and site (Chi-square =12.85, P = 0.01). For example, there was a small proportion of cave weta in the <10 mm size class at the treatment site, whereas, there was a large proportion of cave weta in the 10–14 mm size class. Furthermore, there were small proportions of cave weta in the 10–14 mm size class at control site 2, and the >14 mm size class at the control site 1 (Table 3.15).

Table 3-15 Cave weta size class proportions in kanuka by site.

Size class (mm)	**<10**	**10–14**	**>14**
Treatment site	0.68	0.26	0.06
Control site 1	0.76	0.20	0.04
Control site 2	0.78	0.17	0.05

3.1.6 Carabid Beetles

Seasonal Abundance

In 2004–05 there were two peaks of seasonal abundance at the treatment site, a large one in January and a small one in May, but only one at control site 1 (Fig. 3.7). In 2005–06 there were two peaks of seasonal abundance at the treatment site; however, in contrast to 2004–05, the smaller peak was in January and the larger one in May. Similarly, at control sites 1 and 2 there were also two peaks of abundance in 2005–06, although the difference between the peaks was very small.

At the treatment site the overall mean number of carabid beetles per trap night increased from 0.070 to 0.138 between 2004–05 and 2005–06, and this increase was statistically significant, (F_1 = 11.92, P = 0.001). Over the same time period at control site 1, whilst there was an increase in means from 2004–05 to 2005–06 (0.053 to 0.062), this increase was not statistically significant (F_1 = 0.353, P = 0.558).

The overall mean number of carabids per trap night at the treatment site for 2004–05 was greater than that of control site 1 (0.07 and 0.06 respectively); however, this difference was not statistically significant (F_1 = 2.15, P = 0.14). The overall mean number of carabids per trap night at the treatment site (0.138) for 2005–06 was significantly greater than those of control site1 (0.059) and control site 2 (0.050), over the same time period (F_2 = 29.75, $P < 0.001$), whereas, the difference in means between control sites 1 and 2 was not statistically significant (Tukey test). Furthermore, the monthly means for control sites 1 and 2 were very similar (Fig.3.8).

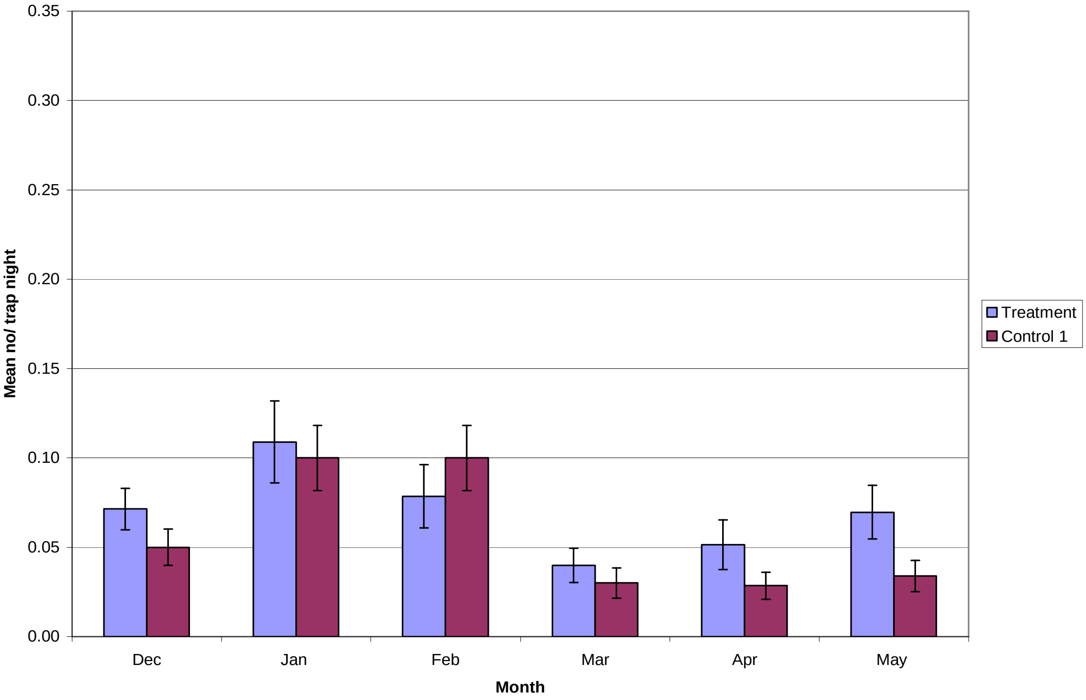

Figure 3-7 Mean carabid abundance in kanuka during 2004–05 (+/- SE).

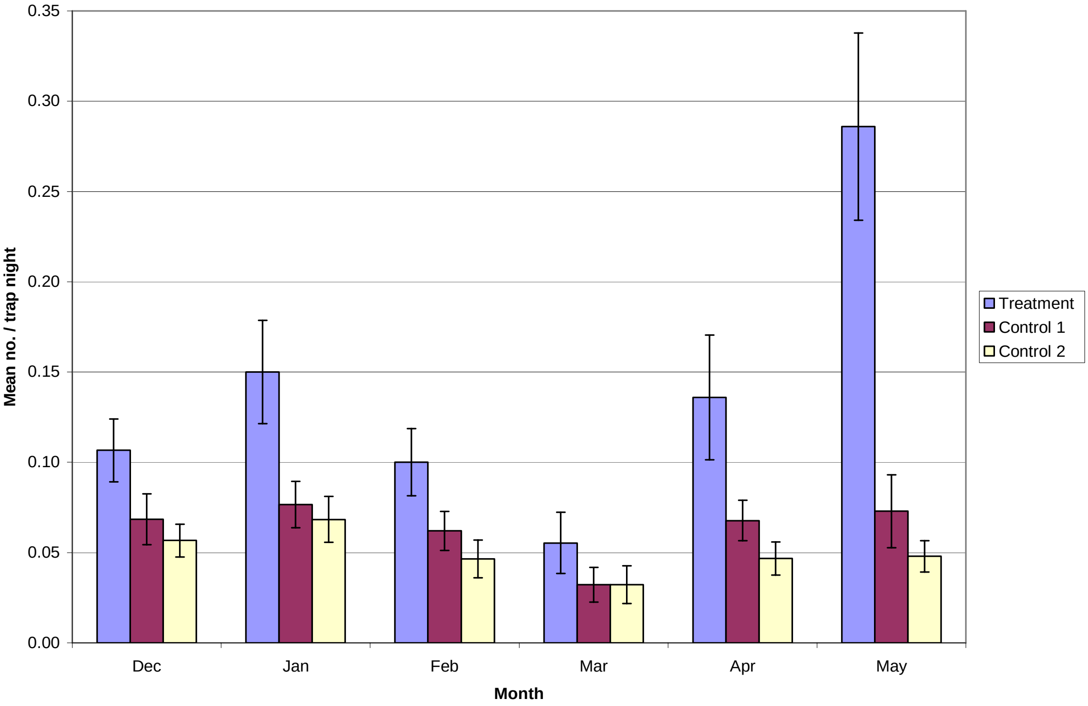

Figure 3-8 Mean carabid abundance in kanuka during 2005–2006 (+/- SE).

Trapped Carabid Beetle Size Classes

Kanuka treatment site 2004–06

There was a statistically significant relationship between size classes and sampling season (Chi-square = 64.40, P <0.001). In 2004–05, there was a large proportion of carabid beetles in the 10–14 mm size class, and a small proportion in the 15–19 mm size class, whereas, in 2005–06 the opposite applied. Also, in 2004–05 there was a large proportion of carabids in the >24 mm size class, but in 2005–06 the proportion of carabids in this size class was less. The number of carabid beetles captured in the 2004–05 trapping season in the 20–24 mm size class was too low for statistical comparisons to be made (Table 3.16).

Table 3-16 Carabid beetle size class proportions in kanuka treatment by sampling season.

Size class (mm)	10–14	15–19	20–24	>24
2004–05	0.34	0.36	0.00	0.30
2005–06	0.13	0.64	0.02	0.21

Kanuka control site 1 in 2004–06

There was a statistically significant relationship between size classes and sampling season (Chi-square = 12.29, P = 0.006). In particular, the proportion of carabids in the 15–19 mm size class increased over the two sampling seasons. In contrast, the frequency of the >24 mm size class declined. The number of carabid beetles trapped in the 20–24 mm size class, in 2004–05, was too low for meaningful comparisons to be made (Table 3.17).

Table 3-17 Carabid beetle size class proportions in kanuka control 1 by sampling season.

Size class (mm)	10–14	15–19	20–24	>24
2004–05	0.49	0.39	0.00	0.12
2005–06	0.40	0.50	0.04	0.06

Kanuka treatment site and control site 1 in 2004–05

There was a statistically significant relationship between carabid size classes and site (Chi-square = 18.94, P = 0.0003). There was a higher proportion of carabids in the 10–14 mm size class at control site 1 compared to that at the treatment site. In contrast, the proportion of carabids in the >24 mm size class at the treatment site was higher than that at control site 1. The numbers of carabid beetles captured in the 20–24 mm size class, at both the treatment site and control site 1, were too low for statistical comparisons to be made (Table 3.18).

Table 3-18 Carabid beetle size class proportions in kanuka during 2004–05 by site.

Size class (mm)	10–14	15–19	20–24	>24
Treatment site	0.34	0.36	0.01	0.29
Control site 1	0.49	0.39	0.01	0.12

Kanuka treatment site, control site 1 and control site 2 in 2005–06

There was a significant relationship between carabid size classes and site (Chi-square = 124.49, P < 0.0001). The proportion of carabids in the 10–14 mm size class was smaller at the treatment site than that at control site 1. In the 15–19 mm size class, the proportion of carabids was higher at the treatment site compared to that at control site 2. There were a much lower proportion of carabids (in the > 24mm size class) at control site 1 than at the treatment site or control site 2 (Table 3.19).

Table 3-19 Carabid size class proportions in kanuka during 2005–06 by site.

Size class (mm)	**10–14**	**15–19**	**20–24**	**>24**
Treatment site	0.13	0.64	0.02	0.21
Control site 1	0.40	0.50	0.04	0.06
Control site 2	0.20	0.37	0.04	0.39

3.1.7 Prowling Spiders

Seasonal Abundance

There was a similar pattern of monthly abundance for prowling spiders in 2004–05 and 2005–06, with peak abundance either in February (control site 1 and 2) or March (treatment site), followed by a decline until sampling was concluded in May (Figs. 3.9 and 3.10). However, in contrast to 2005–06, in 2004–05 there was another, smaller peak in numbers of prowling spiders, at the treatment site (in May), and at control site 1 (in April).

At the treatment site prowling spider abundance increased from 2004–05 (0.052 per trap night) to 2005–06 (0.060 per trap night); however, this mean difference was not statistically significant (F_1 =1.26, P = 0.26). Likewise prowling spider abundance increased from 2004–05 (0.048 per trap night) to 2005–06 (0.065 per trap night) at control site 1, and furthermore this mean difference was statistically significant (F_1 = 4.71, P = 0.04). In 2005–06 the mean number per trap night at the treatment site (0.060) was less than either control site 1 (0.065) or control site 2 (0.074), but these mean differences were not statistically significant (F_2 = 1.22, P = 0.30).

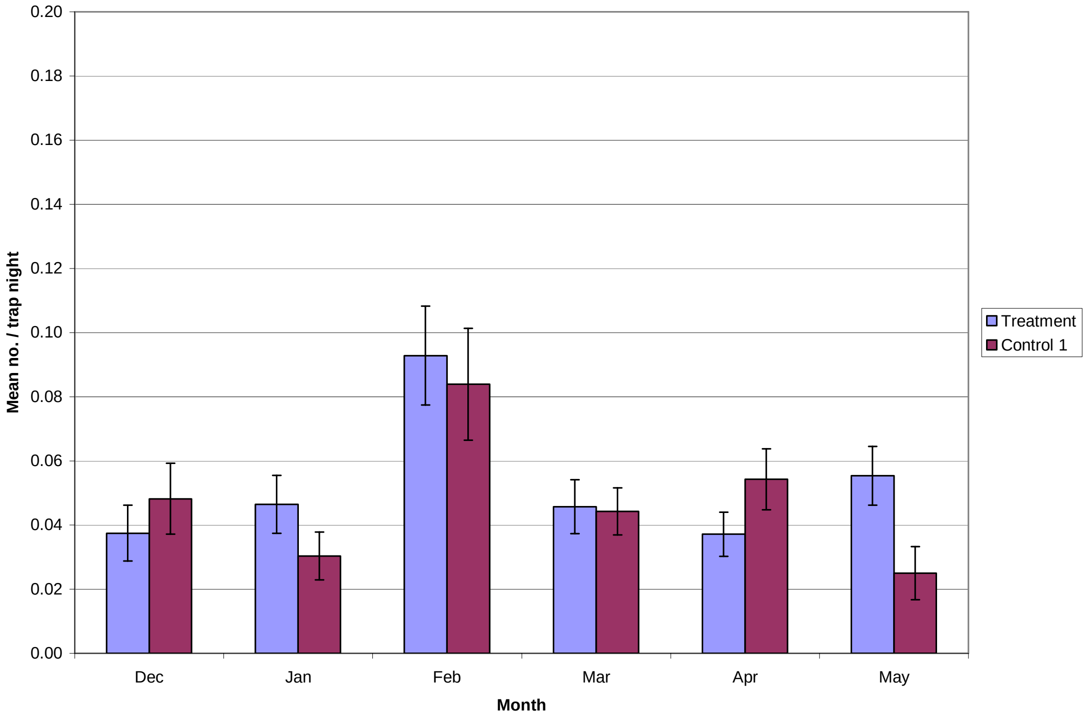

Figure 3-9 Mean prowling spider abundance in kanuka during 2004–2005 (+/-SE).

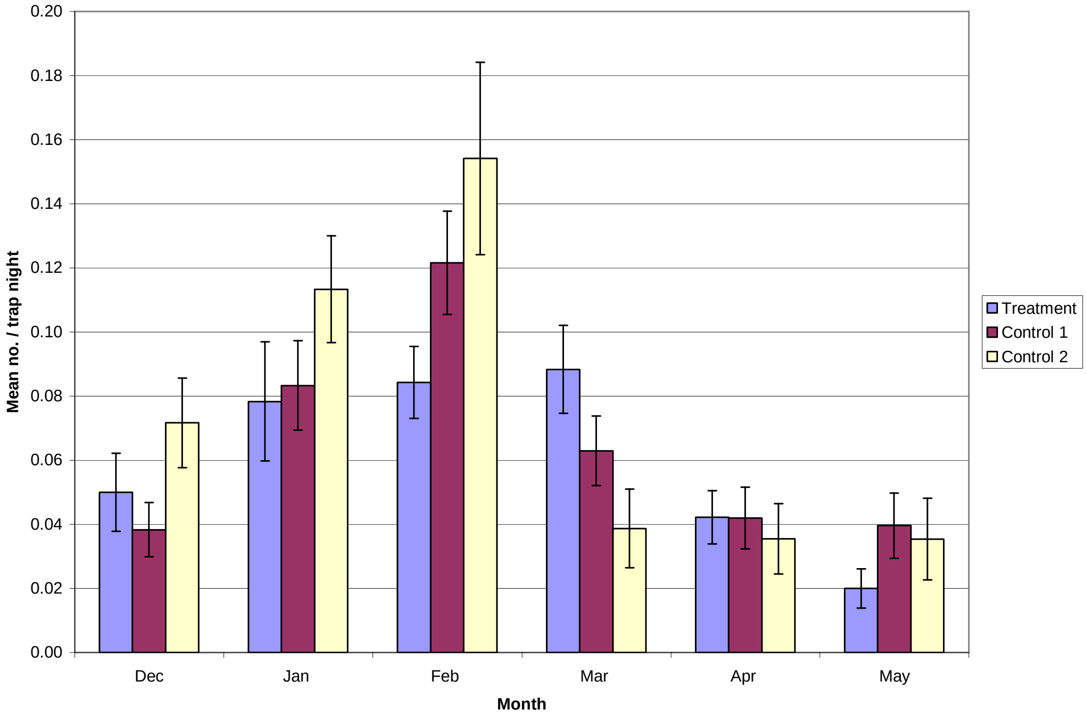

Figure 3-10 Mean prowling spider abundance in kanuka during 2005–2006 (+/- SE).

Trapped Prowling Spider Size Classes

Treatment site and control site 1 2004–05

The majority of prowling spiders captured were in the <11 mm size class with few captures in the >20 mm class (Table 3.20). There was no significant relationship between prowling spider size classes and site (Chi-square = 1.10, P = 0.58).

Table 3-20 Prowling spider size class proportions in kanuka during 2004–05 by site.

Size class (mm)	**<11**	**11–20**	**>20**
Treatment site	0.75	0.21	0.04
Control site 1	0.73	0.25	0.02

Treatment site 2004–05, and 2005–06

The majority of prowling spiders captured over both sampling seasons were in the <11 mm size class, with few captures in the >20 mm size class (Table 3.21). There was no significant relationship between prowling spider size classes and sampling season (Chi-square = 1.119, P = 0.57).

Table 3-21 Prowling spider size class proportions in kanuka treatment site by sampling season.

Size class (mm)	**<11**	**11–20**	**>20**
2004–05	0.75	0.21	0.04
2005–06	0.70	0.26	0.04

Control site 1 2004–05 and 2005–06

The majority of spiders captured, over both sampling seasons, were in the in the <11 mm size class with few captures in the >20 mm class (Table 3.22). There was no significant relationship between prowling spider size classes and time (Chi-square = 1.86, P = 0.395).

Table 3-22 Prowling spider size class proportions in kanuka control site 1 by sampling season.

Size class (mm)	**<11**	**11–20**	**>20**
2004–05	0.73	0.25	0.023
2005–06	0.78	0.19	0.027

Treatment site, Control sites 1 and 2

The majority of prowling spiders captured at all three sites were in the <11 mm size class, with few captures in the >20 mm size class (Table 3.23). There was no significant relationship between prowling spider size classes and site (Chi-square = 8.62, P = 0.07).

Table 3-23 Prowling spider size class proportions in kanuka during 2005–06 by site.

Size class (mm)	**<11**	**11–20**	**>20**
Treatment site	0.70	0.26	0.04
Control site 1	0.78	0.19	0.03
Control site 2	0.76	0.23	0.01

3.1.8 Kanuka Forest Results Summary

Physical Site Characteristics

- The treatment site and control site 1 had similar physical site characteristics, in contrast to control site 2, which had some different physical characteristics.

Vegetation

- The total number of plant species at each site was similar.

Groundcover

- At control site 1, there was a greater proportion of bare ground and a smaller proportion of woody material than at either the treatment site or control site 2.

Rodents

- Rodents were more abundant at the control sites than at the treatment site during 2005–06 (although not significantly lower at control site 1), and furthermore, the average annual rodent tracking indices for 2002–06 were much lower than those of the control sites for 2005–06.

Ground Weta

- Ground weta numbers peaked in January in both sampling seasons.
- Ground weta were more abundant at the treatment site in 2005–06 than at either of the control sites ($P = 0.008$)
- Ground weta abundances did not increase significantly at the treatment and the control 1 sites over the two years that they were sampled ($P = 0.17$ and $P = 0.39$ respectively). The difference in abundance at the treatment and control 1 site in 2004–05 was not significant ($P = 0.09$).
- There was a higher proportion of small ground weta at the control sites and a higher proportion of large ground weta at the treatment site in 2004–06 ($P = 0.007$).

Cave Weta

- Cave weta abundance peaked in January–February and then declined over both sampling seasons.
- The difference of cave weta abundance at the control 1site from 2004–06 was not significant ($P = 0.91$).

- There was a significant increase in cave weta abundance from 2004–05 to 2005–06 at the treatment site (P = 0.02).
- There was no significant difference in the cave weta abundances when the treatment site was compared with the control 1 and control 2 sites during 2005–06.
- The cave weta abundance at the control 2 site in 2005–06 was significantly greater than that of the control 1 site (P = 0.003).
- In 2005–06, there was a greater proportion of large cave weta at the treatment site than either of the control sites, and conversely, a lower proportion of small cave weta than at either of the control sites (P = 0.01).

Carabid Beetles

- There were two peaks in carabid beetle abundance in both sampling seasons they were sampled.
- There was a significant increase in carabid beetle abundance at the treatment site from 2004–05 to 2005–06 (P = 0.001). In 2005–06, there was a greater abundance of carabid beetle at the treatment site, compared to either control site 1 or 2, (P = < 0.001).
- The difference in the means of carabid beetles at the treatment and control 1 sites during 2004–5 was not significant (P = 0.14).
- The difference in means of the carabid beetles at the control 1 site from 2004–05 to 2006–06 was not significant (P = 0.558).

- There were significant relationships between carabid beetle size class, site and sampling season.

Prowling Spiders

- Prowling spider numbers peaked in February–March and then declined in both sampling seasons.
- There were no significant differences in the abundances of prowling spiders in the treatment area over the time period 2004–06 (P = 0.26).
- The increase in abundance of prowling spiders at the control 1 site over the 2004–5 and the 2005–6 sampling periods was significant (P = 0.04).
- The differences in the abundances, of prowling spiders, at the treatment, control 1 and the control 2 sites, during the 2005–06 sampling period, were not significant (P = 0.30).
- There were no significant relationships between prowling spider size classes, site and sampling season.

3.2 PODOCARP-BROADLEAF FOREST

3.2.1 Study Site Physical Characteristics

The physical site characteristics of aspect, drainage, and mean soil depth were similar at all sites, whereas, the canopy height at control site 2 was greater than that of either the treatment site or control site 1, and control site 1 had some steeper pitfall trap sites (Table 3.24).

Table 3-24 Comparison of site characteristics at podocarp-broadleaf.

Characteristics	Aspect	Slope	Drainage	Canopy height	Mean Soil depth
Treatment site	SW–NW	5°–30°	Good	8 –12 m	>1.1 m
Control site 1	SW–NW	5°–45°	Good	5 –12 m	>1.1 m
Control site 2	SW–NW	5°–30°	Good	10 –20 m	>1.1 m

3.2.2 Vegetation Monitoring

Ground cover

The ground cover categories of vegetation, moss, fern, and rock were not used because they occurred in frequencies that were too low for statistical comparisons to be made. There was no significant relationship between ground cover category and site (Chi-square = 5.52, P = 0.48) (Table 3.25).

Table 3-25 Proportion of ground cover in podocarp-broadleaf by site.

Ground Cover Category	Leaf litter	Tree roots	Bare soil	Dead wood
Treatment site	0.82	0.06	0.01	0.11
Control site 1	0.81	0.03	0.03	0.13
Control site 2	0.84	0.05	0.01	0.10

Canopy cover

The treatment site and control site 1 contained similar numbers of plant species, in contrast to control site 2, which contained far fewer plant species, especially in tiers 3 and 5 (Table 3.26).

Table 3-26 Number of plant species in different height tiers in podocarp-broadleaf by site.

Tier number	1 (>25 m)	2 (12–25 m)	3 (5–12 m)	4 (2–5 m)	5 (0.3–2 m)	Totals
Treatment site	0	5	22	22	25	74
Control site 1	0	4	18	29	22	73
Control site 2	0	7	12	25	15	59

3.2.3 Rodent Monitoring

Rats

Before pitfalls were established

Rodent monitoring has been carried out five times in the LTFERP, between December 2003 and May 2005 in line 10, which contains 10 tracking tunnels and runs through podocarp-broadleaf forest. The mean tracking index during this time period was 6% (+/- SE = 3.4).

After pitfalls were active

There were high tracking indices of rats at both control sites, for each monitoring event, in contrast to the treatment site, where rat tracking indices remained low during each monitoring event (Table 3.27 and Fig 3.11). The abundance of rats at the treatment site was statistically significantly lower than those of control site 1 (Mann-Whitney U = 840, P <0.001), and 2 (Mann-Whitney U = 914.5, P <0.001) during 2005–06.

Table 3-27 Rat tracking indices in podocarp-broadleaf during 2005–06.

Month	Nov	Mar	Oct	Mean	S E
Treatment site	0	10	0	3.33	3.33
Control site 1	70	90	100	86.7	6.31
Control site 2	100	100	100	100	0

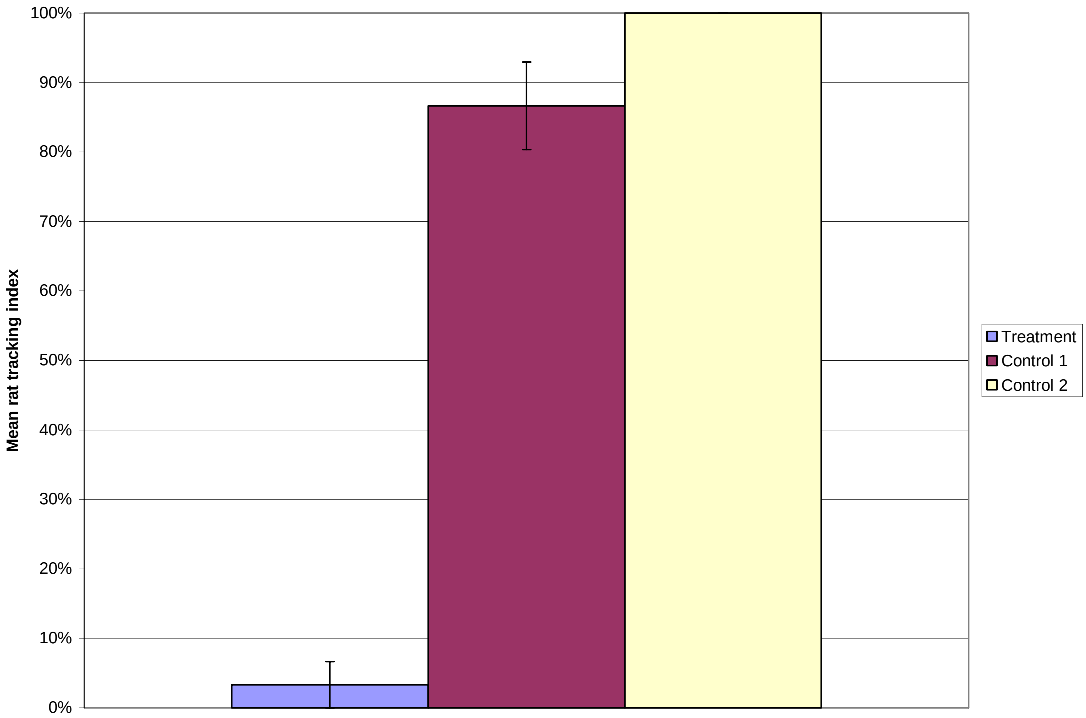

Figure 3-11 Mean rat tracking indices in podocarp-broadleaf during 2005–06 by site (+/- SE).

Mice

Before pitfall traps were established

There were no mice footprints, on any of the tracking cards used for the five rodent monitoring events in line 10, between December 2003 and May 2005.

After pitfalls were active

The mice tracking indices were much lower at the treatment site and control site 1, compared to that of control site 2, and furthermore the mouse tracking index at the treatment site was less than the target value of 5% (Table 3.28).

Table 3-28 Mice tracking indices in podocarp-broadleaf during 2005–06.

Month	Nov	Mar	Oct	Mean	SE
Treatment site	0	10	0	3.33	3.33
Control site 1	0	10	0	3.33	3.33
Control site 2	0	20	30	13.3	6.3

3.2.4 Ground Weta

Ground weta were trapped in very low numbers in podocarp-broadleaf throughout the December–May pitfall trapping season; for example, a total of eight ground weta were trapped at the treatment site, zero at control site 1, and two at control site 2.

3.2.5 Cave Weta

Seasonal Abundance

The pattern of monthly abundance was very similar at all three sites, with peak abundance in January, followed by a decline in numbers until sampling concluded in May, 2006 (Fig. 3.12). The overall mean number per trap night, for cave weta at the treatment site, was higher than those of control site 1 and control site 2 (0.093 compared to 0.076 and 0.071 respectively). Furthermore, the monthly means for control sites 1 and 2 were very similar (Fig. 3.12). However, the differences between the means at the treatment, control 1 and control 2 sites were not statistically significant ($F_2 = 1.91$, $P = 0.16$).

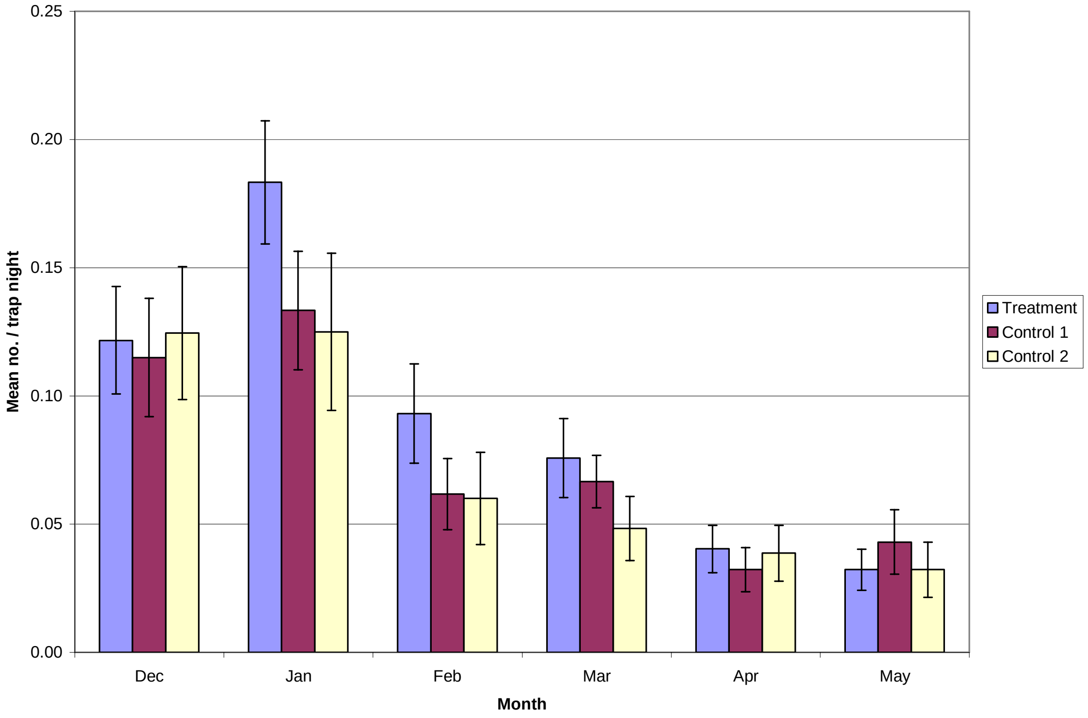

Figure 3-12 Mean cave weta abundance in podocarp-broadleaf during 2005–06 (+/- SE).

Trapped Cave Weta Size Classes

The original 15–19 mm and the 20–24 mm size classes were combined to form a >14 mm size class, because there were insufficient captures in the 20–24 mm size class for statistical comparisons.

There was a statistically significant relationship between cave weta size classes and site (Chi-square = 9.98, P = 0.04). In particular, there was a greater proportion of cave weta in the >14 mm size class, at the treatment site, than at each of the two control sites (Table 3.29).

Table 3-29 Cave weta size class proportions in podocarp-broadleaf during 2005-06 by site.

Size class (mm)	**4–9**	**10–14**	**>14**
Treatment site	0.59	0.29	0.12
Control site 1	0.65	0.29	0.06
Control site 2	0.62	0.32	0.06

3.2.6 Carabid Beetles

Seasonal Abundance

The treatment site had a small peak in numbers in January and a larger one in May; similarly, control site 1 also had a peak in numbers in May (Fig. 3.13). In contrast, at control site 2 the peak abundances were much earlier, in January and February (Fig. 3.13). The means of January, April and May at the treatment site, and those of April and May at control site 1, had large standard errors, because in these months there was large variation in trap captures. For example, in May at the treatment site, trap B4 captured 21 carabid beetles, whereas trap B9 captured zero. The overall mean number per trap night (0.145) was greater at the treatment site than that of either control site 1 (0.104) or control site 2 (0.100). The treatment site mean was significantly greater than those of either control site 1 or control site 2 ($F_2 = 4.3$, $P = 0.01$). In contrast, the difference between the means of control site 1 and control site 2 was not statistically significant (Tukey test).

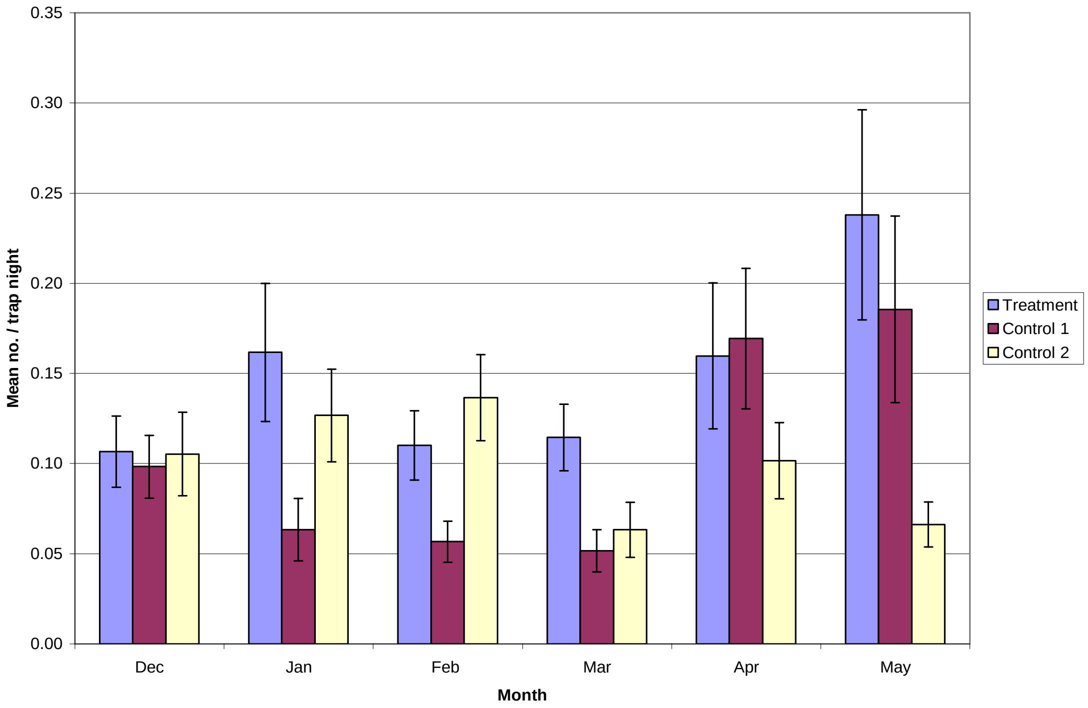

Figure 3-13 Mean carabid abundance in podocarp-broadleaf during 2005–2006 (+/- SE).

Trapped Carabid Beetle Size Classes

There was a statistically significant relationship between carabid beetle size classes and site (Chi-square = 106.44, P <0.0001). In particular, there was a larger proportion of carabid beetles in the >24 mm size class at the treatment and control 1 sites, compared with the control 2 site. Also there was a small proportion of carabids in the 15–19 mm size class at control site 2, whereas, there was a large proportion of this size class at the treatment site and control site 1 (Table 3.30).

Table 3-30 Carabid beetle size class proportions in podocarp-broadleaf during 2005–06 by site.

Size class (mm)	10–14	15–19	20–24	>24
Treatment site	0.16	0.56	0.12	0.16
Control site 1	0.14	0.58	0.11	0.17
Control site 2	0.17	0.34	0.07	0.42

3.2.7 Prowling Spiders

Seasonal Abundance

The patterns of abundance for prowling spiders were very similar at all sites, with increasing monthly means until January (control site 2) or February (treatment site and control site 1), and then generally declining monthly thereafter, until sampling concluded in May 2006 (Fig 3.14). In most months, except for February when the monthly mean was much greater at the control site 1, the means for control sites 1 and 2 were very similar (Fig. 3.14). In all months, the mean numbers per trap night were greater at the treatment site than either of the control sites (Fig. 3.14). The overall mean number of prowling spiders per trap night at the treatment site was greater than either of those for the control sites: 0.104, compared with 0.065 and 0.074 for control sites 1 and 2 respectively. The treatment site mean was significantly greater than that for either of the control sites ($F_2 = 8.17$, $P = 0.0003$). In contrast, the difference between the means of control sites 1 and 2 was not statistically significant (Tukey test).

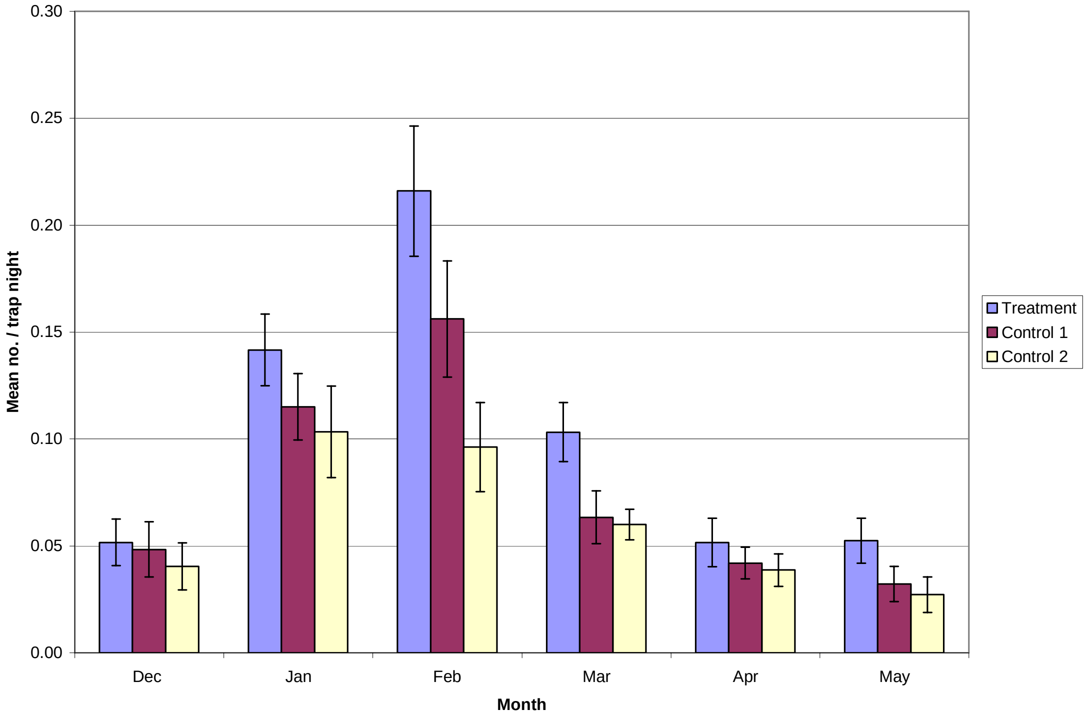

Figure 3-14 Mean prowling spider abundance in podocarp-broadleaf during 2005–06 (+/- SE).

Trapped Prowling Spider Class Sizes

There was no significant relationship between prowling spider size classes and sites during the 2005–06 sampling season (Chi-square = 7.17, P = 0.127) (Table 3.31).

Table 3-31 Prowling spider size class proportions in podocarp-broadleaf during 2005–06 by site.

Size class (mm)	**<11**	**11–20**	**>20**
Treatment site	0.77	0.20	0.03
Control site 1	0.84	0.15	0.01
Control site 2	0.82	0.16	0.02

3.2.8 Podocarp-Broadleaf Results Summary

Physical Site Characteristics

- All three sites had similar aspect, drainage and mean soil depth characteristics. However, control site 1 had some steeper pitfall trap sites, and control site 2 some areas with a higher canopy.

Vegetation

- There was no significant relationship between site and ground cover category.
- The treatment and control site1 contained a similar number of plant species in contrast to control site 2, which contained fewer plant species.

Rodents

- The abundance of rats was much less at the treatment site than either of the control sites.
- The abundance of mice was greater at control site 2 than that of either the treatment site or control site 1.

Ground Weta

- Ground weta occurred in very low abundance in all the podocarp-broadleaf sites.

Cave Weta

- The abundance of ground weta was similar at the treatment site and the control sites (P = 0.16).
- The frequency of larger cave weta was greater at the treatment site than either of the control sites (P = 0.04)

Carabid Beetles

- Carabid beetles were more abundant at the treatment site than either of the control sites (P = 0.01).
- There was a significant relationship between carabid beetle size class and site (P = 0.0001). Control site two had the biggest proportion of the largest carabid beetle size class.

Prowling Spiders

- There was a greater abundance of prowling spiders at the treatment site than either of the control sites (P = 0.0003).
- There was no significant relationship between prowling spider size class and site (P = 0.127).

3.3 TARAIRE FOREST

3.3.1 Study Site Physical Characteristics

The treatment site and control site 1 had similar physical characteristics of slope, canopy height and mean soil depth; however, the treatment and control 2 sites had a southerly aspect, whereas the control site 1 had a northerly aspect (Table 3.32). All three sites had similar drainage, whereas, control site 2 had less soil depth and was steeper than the other two sites (Table 3.32).

Table 3-32 Comparison of site characteristics in taraire.

Characteristic	Aspect	Slope	Drainage	Canopy height	Mean soil depth
Treatment site	SE	5°–30°	Good	10–20 m	>1.1 m
Control site 1	NW	5°–30°	Good	10–20 m	>1.1 m
Control site 2	SE	30°–40°	Good	15–20 m	0.42 m

3.3.2 Vegetation Assessment

Ground Cover

The ground cover categories of vegetation, moss, fern, and rock were not used because they occurred in proportions that were too low for statistical comparisons to be made.

There was a statistically significant relationship between ground cover category proportions and site (Chi-square = 24.39, P = 0.0004). In particular, the proportion of bare soil at control site 2 was greater than the other two sites, whereas the proportion of bare soil at the treatment site was lower than the other two sites. Furthermore, the proportion of dead wood at control site 2 was smaller than the other two sites, whereas the proportion of dead wood at the treatment site was higher than the two control sites (Table 3.33).

Table 3-33 Proportion of ground cover categories in taraire by site.

Ground Cover Category	Leaf litter	Tree roots	Bare soil	Dead wood
Treatment site	0.84	0.03	0.01	0.12
Control site 1	0.86	0.03	0.03	0.08
Control site 2	0.88	0.01	0.07	0.04

Canopy Cover

Control site 1 contained a much greater variety of plant species than either the treatment site or control site 2; furthermore, the variety of plant species present at the treatment site was greater than that of control site 2 (Table 3.34). When comparing the treatment site and control site 1, tiers three and four at control site 1 contained four and ten more species respectively, whereas, tiers two and five contained approximately the same number of species (Table 3.34). Control site 2 had fewer species in all tiers than either the treatment site or control site 1.

Table 3-34 Number of plant species in different height tiers in taraire by site.

Tier number	1 (>25 m)	2 (12–25 m)	3 (5–12 m)	4 (2–5 m)	5 (0.3–2 m)	Totals
Treatment site	0	6	9	14	19	48
Control site 1	0	5	13	24	19	61
Control site 2	0	1	9	7	8	25

3.3.3 Rodent Monitoring

Rats

2002–05 Monitoring

With the exception of 2004, when only one rodent monitoring was carried out, the annual rat tracking indices in taraire forest at the LTFERP, for the time period 2002–05, were higher than that of 2005–06 at the treatment site (Tables 3.35 and 3.36). However, high tracking indices in September 2002, July 2003, May 2005 and July 2005 inflated the annual indices for these sampling seasons (Table 3.35), and all the other months when rat monitoring occurred had 0% to 10% tracking indices.

2005-06 Monitoring

The rat tracking index for the treatment site was much lower than that of either control site 1 or 2, during the 2005–06 pitfall trapping season; in addition, the rat tracking index for control site 2 was much greater than that for control site 1 over the same time period (Fig. 3.15). The abundance of rats at the treatment site was significantly lower than those of control site 1 (Mann-Whitney U = 600, P = 0.026), and control site 2 (Mann-Whitney

U = 736.6, P <0.00l). There was a similar pattern of tracking indices over the times that rat monitoring was carried out at control sites 1 and 2, with higher rat tracking indices during March 2006 and October 2006, than in November 2005 (Table 3.36). In contrast, the rat tracking indices at the treatment site were low, and varied less during the three monitoring events (Table 3.36).

Table 3-35 Rat tracking indices in taraire by year.

Month	Jan	Mar	May	Jul	Aug	Sep	Oct	Nov	Dec	Mean	SE
2002	*	*	*	10	0	50	*	0	*	15	5.7
2003	10	10	0	80	*	*	10	*	0	18	5
2004	*	*	*	*	*	*	*	0	*	0	0
2005	0	*	40	20	*	*	*	*	*	20	7.4

Table 3-36 Rat tracking indices in taraire during 2005–06 by site.

Month	Nov	Mar	Oct	Mean	SE
Treatment site	20	10	10	13.3	6.30
Control site 1	20	60	50	43.3	9.20
Control site 2	40	100	100	80	7.66

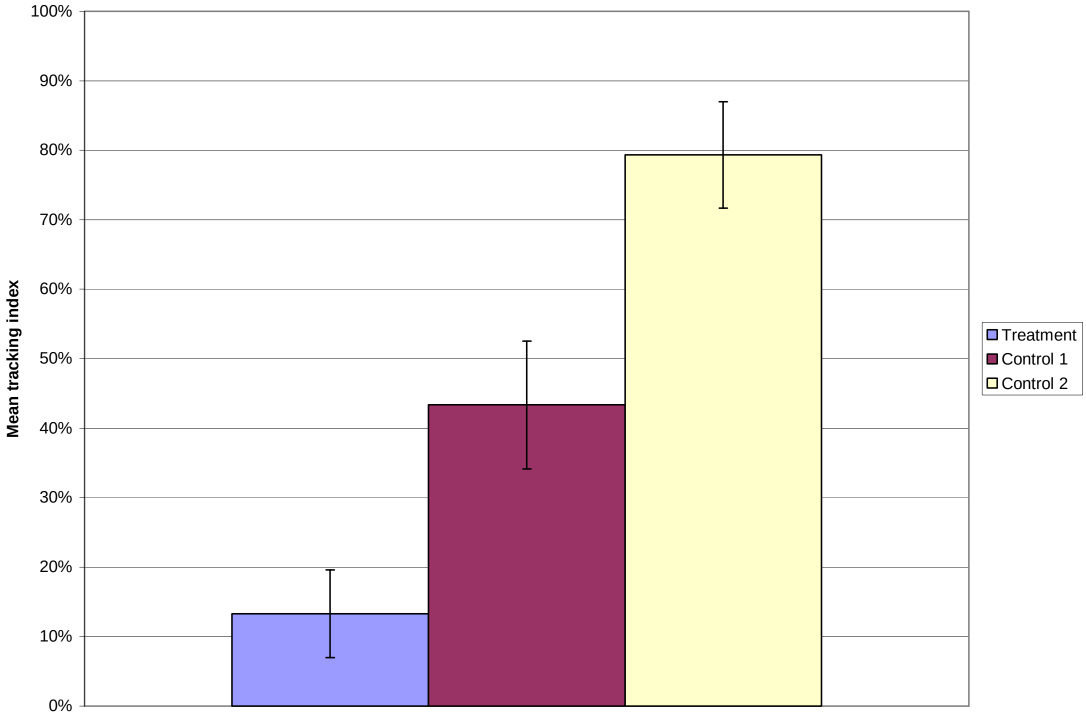

Figure 3-15 Mean rat tracking indices in taraire during 2005–2006 (+/- SE).

Mice

2002–05 Monitoring

Between 2002 and 2005 there were no mice footprints on the tracking cards used to monitor rodent tracking lines in taraire forest in the LTFERP.

2005–06 Monitoring

Mice were not detected at the treatment site or control site 1 during any of the rodent monitoring done during 2005–06 (Table 3.37). However, a relatively high tracking index of 40% occurred in the March 2006 rodent monitoring at control site 1, in contrast to those done in November 2005 and October 2006 when no mice were detected (Table 3.37).

Table 3-37 Mice tracking indices of in taraire during 2005–06 by site.

Month	Nov	Mar	Oct	Mean	S E
Treatment site	0	0	0	0	0
Control site 1	0	40	0	13.3	0.06
Control site 2	0	0	0	0	0

3.3.4 Ground Weta

Ground weta occurred in very low abundance at the taraire sites during the 2005–06 sampling season. For example, no ground weta were trapped at the treatment site and control site 1, and only four at control site 2.

3.3.5 Cave Weta

Seasonal Abundance

In all three sites, there was a similar pattern in the mean number per trap night over time, with higher numbers over the summer months (December–February), followed by a general decline in numbers during autumn (March–May) (Fig. 3.16). However, the monthly totals for the treatment site and control site 1 were greater than those of control site 2, and the monthly totals for control site 1, except for May, were greater than those for the treatment site. The overall mean number per trap night for the treatment site, control site 1 and control site 2 were: 0.048, 0.094 and 0.020 respectively, and there were significantly more cave weta trapped at control site 1, than either of control site 2 or the treatment site, and significantly more trapped at the treatment site than control site 2 (Kruskal-Wallis test, P <0.0001).

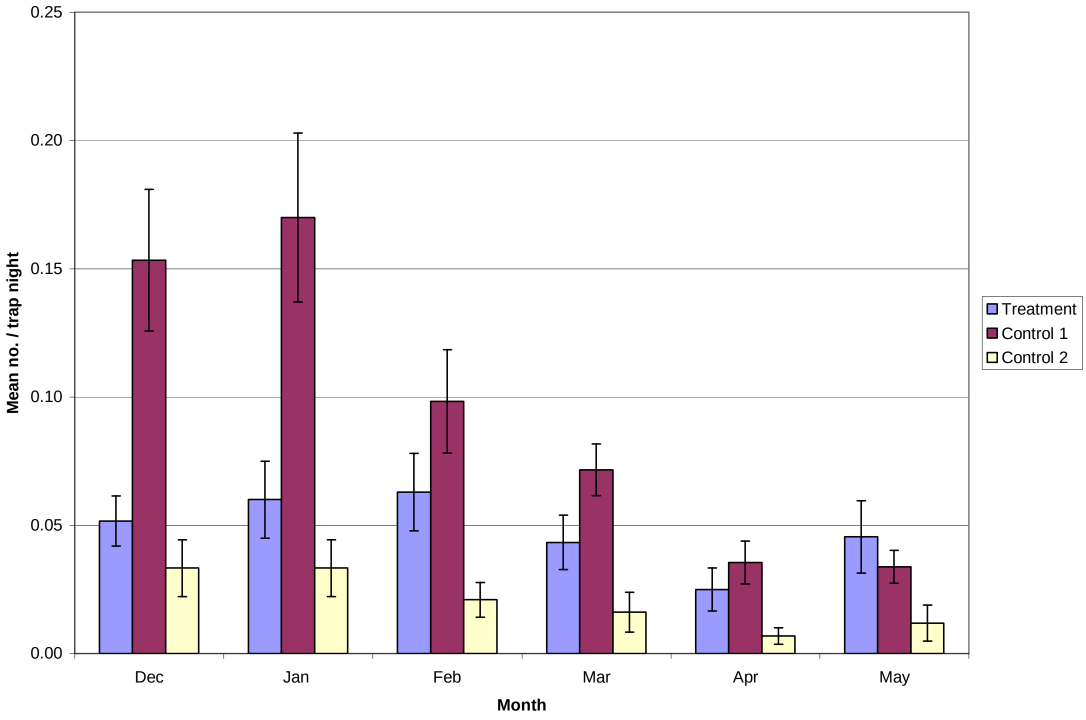

Figure 3-16 Mean cave weta abundance in taraire during 2005–2006 (+/- SE).

Trapped Cave Weta Size Classes

The original 15–19 mm and the 20–24 mm size classes were combined to form a >14 mm size class, because there were insufficient captures in the 20–24 mm size class for statistical comparisons. There was no significant relationship between cave weta size class and site (Chi-square = 3.88, P = 0.42) (Table 3.38).

Table 3-38 Cave weta size class proportions in taraire 2005–06 by site.

Size class (mm)	4–9	10–14	>14
Treatment site	0.60	0.30	0.10
Control site 1	0.59	0.32	0.07
Control site 2	0.51	0.40	0.09

3.3.6 Carabid Beetles

Seasonal Abundance

The trends in mean number of carabid beetles per trap night are very similar at the treatment site and control site 1, with numbers of carabid beetles remaining relatively low until March and then increasing suddenly, with a peak in numbers in May (Fig 3.17). In contrast, at control site 2, numbers of carabid beetles peaked in December, and then generally declined until sampling concluded in May 2006. The overall mean number of carabids per trap night, for the treatment site (0.132), was greater than that of either control site 1 (0.122) or control site 2 (0.083), however, these differences were not statistically significant (Kruskal-Wallis test, P = 0.105).

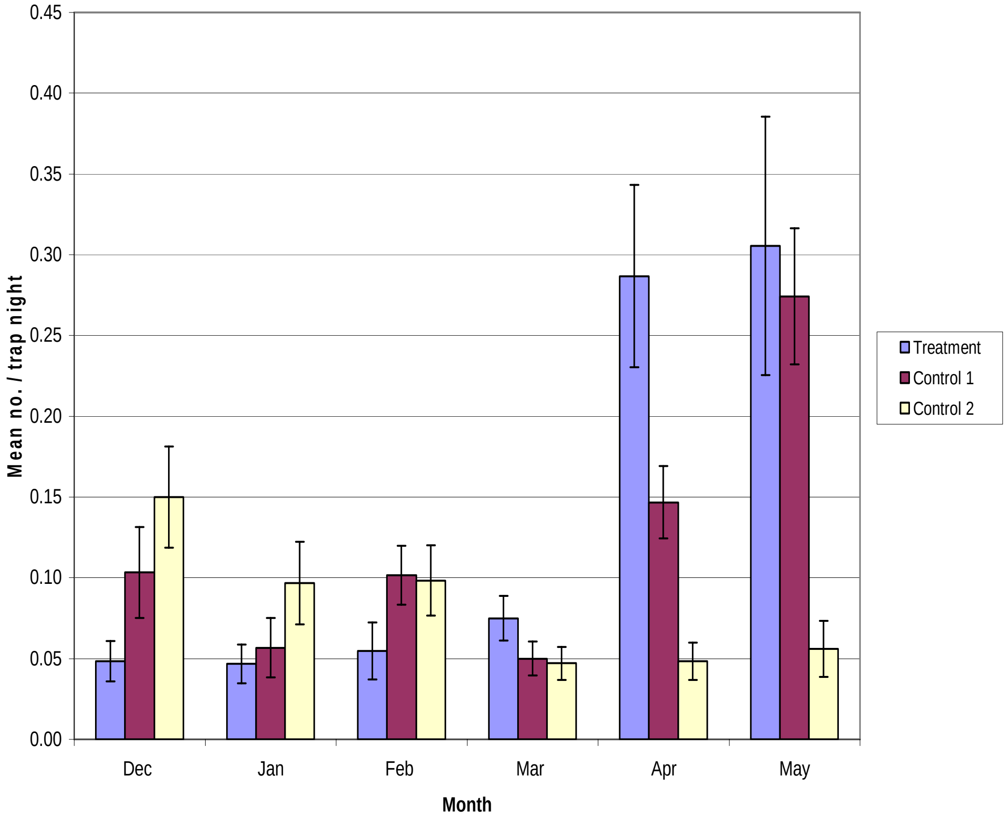

Figure 3-17 Mean carabid abundance in taraire during 2005–2006 (+/- SE).

Trapped Carabid Beetle Size Classes

There was a significant relationship between carabid beetle size class and site (Chi-square = 411.73, P <0.0001). In particular, there was a large proportion of the 10–14 mm size class at control site 2, whereas, at the treatment site and control site 1 the proportion of carabids in this size class was small. In contrast, there was a large proportion of the 15–19 mm size class at the treatment site and control site 1, and a small proportion at control site 2. At the treatment site, the proportion of the >24 mm size class was larger than that at control sites 2. At control site 1, the proportion of the >24 mm size class was greater than those of the treatment site and control site 2. At control site 2, only one carabid beetle in this size class was trapped over the entire sampling season (Table 3.39).

Table 3-39 Carabid beetle size class proportions in taraire during 2005–06 by site.

Size class (mm)	**10–14**	**15–19**	**20–24**	**25–34**
Treatment site	0.12	0.75	0.08	0.05
Control site 1	0.24	0.53	0.03	0.20
Control site 2	0.71	0.26	0.02	0.003

3.3.7 Prowling Spiders

Seasonal abundance

The monthly abundance pattern was similar at all three sites, with peaks in February, at the treatment site and control site 2, and January at control site 1, followed by a decline in numbers until May, when sampling concluded (Fig. 3.18). The overall mean number of prowling spiders per trap night was greater at control site 1 than those at control site 2 and the treatment site (0.083, 0.057, and 0.043 respectively). Furthermore, the differences in means between control site 1 and control site 2, and between control site 1 and the treatment site were significant ($F_2 = 15.05$, $P < 0.0001$). In contrast, the difference between the means of the treatment site and control site 2 was not statistically significant (Tukey test).

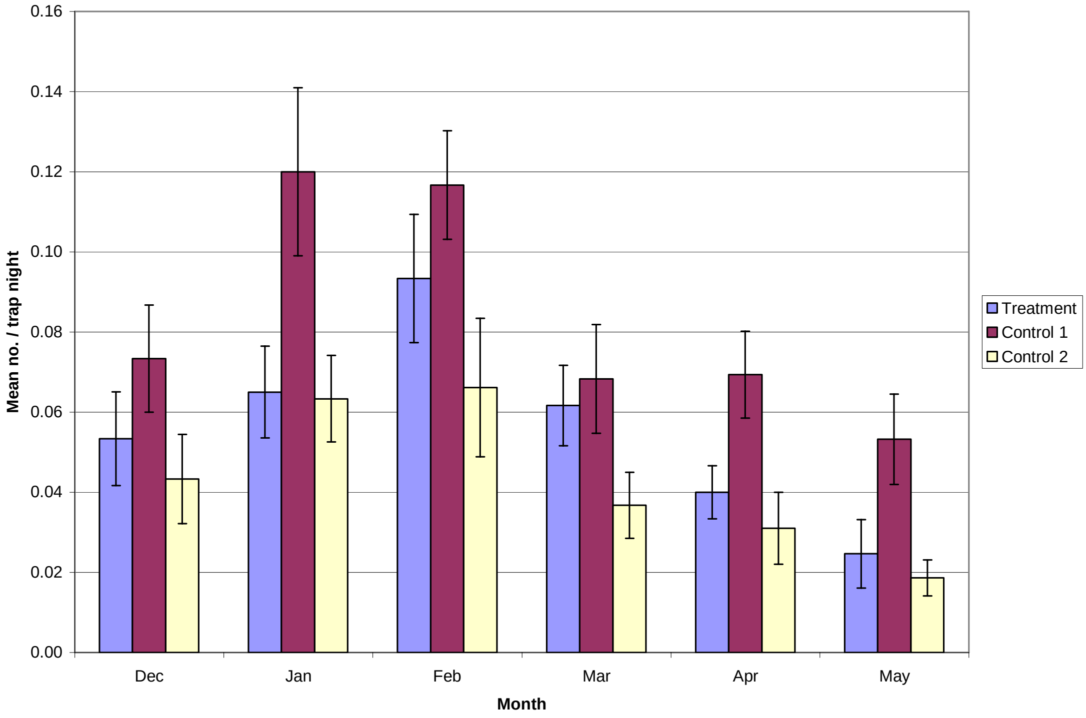

Figure 3-18 Mean prowling spider abundance in taraire during 2005–2006 (+/- SE).

Trapped Prowling Spider Size Classes

The original 11–20 mm and the >20 mm size classes were combined to form a 10+ size class, because there were insufficient captures in the >20 mm size class for statistical comparisons to be made.

There was a significant relationship between prowling spider size class proportions and site (Chi-square = 11.68, P = 0.003). The proportion of the <10 mm size class at control site 2 was smaller than the other two sites, whereas the proportion of the 10+ mm size class was larger than those of the other two sites. In addition, the proportion of the 10+ mm size class at control site 1 was less than the other two sites (Table 3.40).

Table 3-40 Prowling spider size class proportions in taraire during 2005–06 by site.

Size class (mm)	<10	10+
Treatment site	0.75	0.25
Control site 1	0.80	0.20
Control site 2	0.65	0.35

3.3.8 Taraire Results Summary

Physical Site Characteristics

- The treatment site and control site 1 had similar physical site characteristics with the exception of soil depth and slope, whereas, control site 1 differed from the treatment site in aspect only.

Vegetation Assessment

- There was a relationship between ground cover categories and site (P = 0.0004).
- Control site 1 contained a greater variety of plant species than either the treatment site or control site 2. In addition, the variety of plant species was greater at the treatment site than at control site 2.

Ground Weta

- Ground weta occurred in very low abundance in all three sites.

Cave Weta

- The abundance of cave weta was greater at control site 1 than at either the treatment site or control site 2 (P = <000.1), moreover, the abundance of cave weta at the treatment site was greater than at control site 2.
- There was no significant relationship between cave weta size class and site.

Carabid Beetles

- The difference in abundance of carabid beetles at the treatment site and control sites 1 and 2 was not significant (P = 0.105).
- There was a significant relationship between carabid beetle size classes and site. In particular there was a larger proportion of carabid beetles in the >24 mm size class at the control site 1 (P = >0.0001).

Prowling Spiders

- The abundance of prowling spiders at control site 1 was greater than at either control site 2 or the treatment site, and in addition, the abundance of prowling spiders at the treatment site was greater than at control site 2 (P = <0.0001).
- There was a significant relationship between prowling spider size class and site. In particular the proportion of larger prowling spiders was greater at control site 2 (P = 0.003).

Rodents

- The abundance of rats was significantly less at the treatment site than at control sites 1 and 2 (P = 0.026 and 0.001 respectively).
- Mice were only detected at control site 1.

3.4 OVERVIEW OF ARTHROPOD ABUNDANCE AT TREATMENT SITES

Ground Weta

Ground weta appeared infrequently in pitfall traps in podocarp-broadleaf and taraire, with a total capture of eight at the podocarp treatment site and zero at the taraire treatment site, during the six months that the pitfall traps were active. In contrast, ground weta were trapped frequently at kanuka sites, with a total capture of 191 at the kanuka treatment site, during the same time period. It was noted that there was kanuka forest directly adjoining one of the pitfall trap lines in taraire.

Carabid Beetles

Carabid beetle abundance was very similar at all three treatment, ($F_2 = 0.19$, $P = 0.83$).

Cave Weta

Kanuka and podocarp-broadleaf had similar abundance of cave weta, and the difference of means was not significant (Tukey test). In contrast, the mean number of cave weta per trap night in taraire was much less than in kanuka and podocarp-broadleaf, ($F_2 = 13.93$, $P < 0.001$).

Prowling Spiders

The abundance of prowling spiders in podocarp-broadleaf was much greater than those of kanuka and taraire, ($F_2 = 15.02$, $P < 0.001$). However, the abundance of prowling spiders in kanuka and taraire was very similar (Tukey test).

3.5 POSSUM MONITORING

3.5.1 At the LTFERP

The September 2002 possum monitoring event resulted in a zero possum count and therefore a trap catch of 0%. Since 2002 no further possum monitoring has been done using NPCA 2000 protocols. However, any possum footprints present on the tracking cards were recorded during rodent monitoring events, and between late 2002 and October 2006 a total of four tracking cards had possum foot prints on them (one in October 2004, and three in 2005 in January, February and November).

3.5.2 At the Control Sites

After possum control was carried out in the Waitakere Ranges in 1998, the average trap catch was 1.6%. The latest possum monitoring (February and March 2006), in Piha and Whatipu, and Karekare (November 2006), achieved trap catches of 2.5%, 0.83% and 0.033% respectively. In addition, recent possum monitoring done by the Auckland Regional Council in the other regions of the ranges, achieved low possum trap catches (southern region 2%, middle region 3% and northern region 0%).

3.5.3 Possum Footprints on Rodent Tracking Cards used in 2005–06 at the Control Sites

Possum footprints were not detected on tracking cards used at the kanuka and podocarp control sites and taraire control site 1. However, possums were detected at taraire control site 2 during each rodent monitoring (Table 3.41).

Table 3-41 Tracking cards with possum footprints (%) at taraire control site 2 during 2005–06.

Month	Dec	Mar	Oct
Tracking cards with possum footprints (%)	30	50	50

3.6 WEATHER MONITORING

3.6.1 Rainfall Data

The months where the rainfall deviated greatly from average were: January 2005 (lower), February 2006 (lower), April 2005 (lower) and April 2006 (higher) (Table 3.42)

Table 3-42 Monthly rainfall data (mm) at La Trobe Track by year.
(The historical average was calculated from data collected monthly since 1995)

Month	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Rainfall (mm)						
Historical Average	131	106	112	106	135	164
2004–05	172	37	106	82	59	194
2005–06	110	143	21	86	246	170

3.6.2 Temperature Data

The greatest difference between the mean monthly minimums is between December 2004 and December 2005, with the mean minimum temperature for 2005 being 3.8 °C greater (Fig. 3.19). The other monthly differences varied between 0.5 °C and 1.2 °C, and from February to May were mainly higher in 2004–05 than 2005–06 (Fig. 3.19).

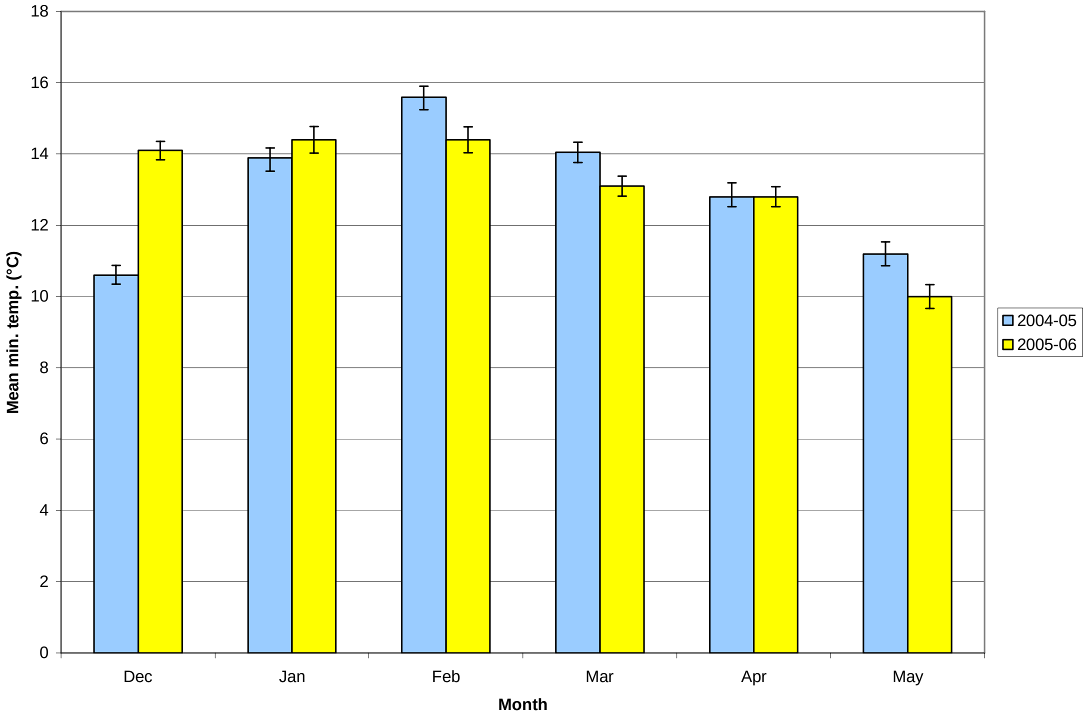

Figure 3-19 Mean minimum monthly temperatures (°C) at La Trobe Tack (+/- SE).

4 DISCUSSION

4.1 INTRODUCTION

In this chapter the rodent tracking indices, from 2002 to 2006 in the LTFERP and in 2005–06 in the LTFERP and control areas are discussed. The reason for including historical rodent tracking data is that it may take several years for the benefits of rodent control to be detected.

The impact of rodents on ground weta, cave weta, carabid beetles and prowling spiders, in kanuka and podocarp-broadleaf forest types is variable, and each arthropod group is treated separately in this discussion. The taraire forest results were confounded by some differences in environmental features at the treatment and control sites, and therefore the results for this forest type will be dealt with separately.

There were some other predators of arthropods that were not monitored in this study. However they may have had an impact and their potential to influence arthropod abundance and size class distribution in this study will be assessed. The ability of rodents to influence the size class distribution of the arthropod populations, monitored in this research, is also considered. Finally, the potential of these arthropods to be used as indicators of the effect of rodent control at the LTFERP will be discussed.

4.2 RODENT MONITORING

At the LTFERP, where the treatment sites for this research are located, rodent control procedures have been in place since 2002, and rodent tracking indices have been used to provide information about the size of the rodent populations. The relationship between rat tracking index and density has been quantified in several studies e.g. Brown, Moller, Innes and Alterio 1996 and Blackwell, Potter, Murray and McLennan 2002, found strong correlations between rat tracking indices and density. In contrast, Ruscoe (2001) could find no relationship between mouse density and tracking tunnel indices. However, Blackwell, Potter et al. (2002) suggested that tracking tunnels should only be used to compare the relative abundance of rats within similar habitat types.

In kanuka forest at the LTFERP, between 2002 and 2005, the mean rat tracking index was 8%, 6% in podocarp-broadleaf and 13% in taraire. These rat tracking rates indicate low rat densities, especially in the kanuka and podocarp-broadleaf areas. Rodent monitoring at control sites, in the absence of pest control, was not carried out concurrently with that in the LTFERP from 2002–05, consequently, it is assumed that the rodent density was lower in the treatment than the surrounding areas. In support of this assumption, in a study at Mapara (Hutchinson, 1999), bait stations containing brodifacoum, spaced at 50 m intervals, as at the LTFERP, achieved a tracking index reduction of 91% (Innes, Warburton, Williams, Speed and Bradfield, 1995), moreover, rat tracking rates were significantly lower at sites where brodifacoum was used than sites where this toxin was not used. Similarly, the rat tracking indices at podocarp-broadleaf and taraire forest treatment sites, at the LTFERP during 2005–06, were significantly lower than their control sites. This clearly indicates that rat densities at these treatment sites were lower than their control sites. However, in the 2005-06 sampling season the tracking indices at the kanuka treatment site indicated a significantly lower rat density than control site 2, but not control site 1. It is possible that the kanuka control site 1 (and also the taraire control site 1) may be close enough to the treatment area to be influenced by the pest control operations carried out at the LTFERP. Unfortunately no research has yet been published that investigates how far beyond pest control operations the suppression of rodent numbers extends. Nevertheless, when the average rat tracking index in kanuka for 2005–06 (20%), is compared to the historical average for this area (8%), it can be seen that the result for 2005–06 was unusual. The LTFERP encompasses a relatively small area (200 hectares), and therefore has a large boundary length to area ratio, making it susceptible to incursions of rodents from the surrounding forest areas, where no rodent control has been carried out.

Unexpectedly, mice were rarely detected at the podocarp-broadleaf and taraire treatment sites between 2002 and 2006. It is usual that when rat numbers have been significantly reduced, mouse abundance increases markedly (Innes, Warburton, Williams, Speed & Bradfield, 1995; Murphy, Robbins, Young & Dowding, 1999). This was the case in the Tawharanui Open Sanctuary, where a 70% mouse tracking index was reported when the rat tracking index was 0% (Ussher, 2006). The reasons for these observed increases in mouse abundance are not fully understood, although it has been suggested that they could be caused by an increase in mouse food supply, because of less competition from rats or release from predation pressure by rats (Miller and Miller, 1995). Alternatively, it has been suggested by Brown et al., (1996), that mice were deterred from entering tracking tunnels by rat scent marks left in them. They found that mice significantly increased their use of tracking tunnels as rats were removed by trapping, even though mice were being trapped at the same time.

The absence of mouse prints on the tracking tunnel cards, during rodent monitoring in taraire at the LTFERP, between 2002 and 2005, may be explained by periodic high rat tracking indices (50% in September 2002, 80% in July 2003 and 40% in May 2005) in this area. High rat numbers at these times may have deterred mice from entering the tunnels (Brown, Moller et al., 1996).

Mice were present in kanuka forest in the LTFERP during 2002–06, in spring and autumn (except for autumn 2006), and tracking indices of between 20% and 39% were recorded. According to Blackwell, Potter et al., (2002), the preferred habitat of mice is areas with dense undergrowth, which is common in podocarp-broadleaf forest at the LTFERP due to the presence of large numbers of kiekie plants (pers. obs.). Since the ground cover in kanuka is much more sparse than that in the podocarp-broadleaf (pers. obs.), the higher mice tracking indices in kanuka were surprising.

At kanuka control site 1, mouse tracking indices of 30% in April 2006 and 20% in October 2006 were recorded, whereas, at control site 2, mice were only detected once, in April 2006, with a low tracking index of 10%. The rat tracking index at kanuka control site 2 was significantly higher than that of kanuka control site 1, and consequently a higher rat density at kanuka control site 2 may be causing a suppression of mice numbers and / or tracking index, as previously described.

Furthermore, this same effect was observed at the taraire control sites with high rat tracking indices recorded at taraire control site 2, with no evidence of the presence of mice, whilst much lower rat abundance was recorded at taraire control site 1, and a 40% mouse tracking index, in March 2006.

4.3 IMPACT OF RODENTS ON ARTHROPODS

4.3.1 On Ground Weta

Ground weta, which were mainly confined to kanuka forest, appear to have benefited from rodent control. There were more captures of ground weta at the kanuka treatment site than the two control sites in 2005–06 (P = 0.008). However there was no significant difference between the ground weta abundances at the kanuka treatment site and the kanuka control 1 site during the 2004-05 sampling period. Predator control at the LTFERP was initiated in 2002 and consequently insufficient time may have elapsed for a significant difference in abundance of ground weta at the kanuka treatment site to have accrued.

There are no published studies that link the distribution of the ground weta *Hemiandrus* sp. to kanuka forest. However, Booker (2001) captured large numbers of ground weta in pitfall traps in forest dominated by kanuka at the Matuku Reserve, Auckland, where rodent numbers had been suppressed using brodifacoum. In this same study, only a few ground weta were found in pitfall traps in the nearby Cascade Kauri Reserve, an area with few mature kanuka, although at the time no rodent control was being carried out. Since that study was conducted, the Cascade Kauri Park has been included in the Ark in the Park Mainland Island, and despite the fact that rodent numbers have been maintained at low levels, ground weta are only infrequently captured in pitfall traps (Peter Maddison, pers. comm.). There is no published data that directly implicates rodents as predators of *Hemiandrus* sp. However if *Hemiandrus* sp. is restricted to kanuka forest, as found in this research and by Booker (2001), it is unlikely that it would be found in rodent stomach content analyses, unless the rodents had been captured in or nearby kanuka forest. Nevertheless, considering that tree weta and cave weta, which are large-bodied arthropods, are eaten by rodents (Best, 1969; Clout, 1980; Miller & Miller, 1995), it is probable that such a potential food source, as large as a ground weta, would also be eaten by rodents. There is some indirect evidence that ground weta (*Hemiandrus* sp.) may be eaten by rodents. After kiore were removed from Tiritiri Matangi Island, capture rates of the ground weta *Hemiandrus* sp. increased significantly (Atkinson and Towns, 2001).

Previous research (McColl, 1975; Moeed and Meads, 1985) reported that the ground weta *H. pallitarsis* was captured in pitfall traps in greater numbers at higher temperatures. McColl (1975) found that there was a positive correlation between the numbers of pitfall-trapped ground weta, in beech forest at Kaitoke, and daily temperatures of 15–20 °C. The abundance of ground weta increased dramatically in the kanuka treatment site from December 2005 to January 2006, before declining markedly in February 2006. December 2005 was the third warmest December on record (Gregory, 2006), and the minimum mean temperature during December 2005 was 3.8 °C higher than during December 2004 at La Trobe Track. However, ground weta abundance at the kanuka control sites did not increase and then decrease, in a similar manner, over the same time span. Consequently, it is unlikely that the high temperatures of December 2005 were a major influence on the January 2006 ground weta abundance at the kanuka treatment site.

The rat tracking indices at kanuka control site 1 were much lower than those of kanuka control site 2 during 2005–06. Despite these differences, the monthly ground weta abundance at kanuka control sites 1 and 2 were very similar. However, there may have been enough mice present at kanuka control site 1, during the autumn and spring of 2006, to increase predation pressure sufficiently to cause ground weta numbers to be suppressed.

4.3.2 On Cave Weta

Cave weta abundance at the kanuka treatment site was similar to the control sites during both sampling periods. However, there was a significant increase in cave weta abundance at the kanuka treatment site from 2004–05 to 2005–06, which may have been caused by habitat changes or weather differences that occurred over the two years of sampling. Further research will be needed, to establish whether cave weta abundance continues to increase at the kanuka treatment site over time.

Cave weta abundance at the podocarp-broadleaf forest treatment site, in 2005–06, was similar to those of the control sites.

However, cave weta have a pronounced escape response in areas where mammalian predation occurs (Bremner, Barratt, Butcher and Patterson, 1989). Because of this escape response, the level of predation by rodents may have been insufficient to affect the cave weta population size. Most of the cave weta pitfall trap captures were in the

4–9 mm size range, with very few captures in the largest size class. The Auckland cave weta, *Gymnoplectrum acanthocera*, is a large bodied weta, and while common under houses and out-buildings in the LTFERP (pers. obs.), was rarely captured in pitfall traps. *G. acanthocera* has very long legs, in fact some individuals have been measured at 355 mm from the tip of the antennae to the end of the back legs (Crowe, 2002), and consequently may readily avoid pitfall traps. If this weta is being targeted by rodents, a different methodology, other than pitfall trapping, may need to be employed to detect changes in abundance that might be caused by rodent predation.

4.3.3 On Carabid Beetles

Carabid beetles have benefited from pest control in kanuka and in podocarp-broadleaf forest at the LTFERP but not in taraire forest. Statistically significant differences were recorded when the abundance of carabids at the kanuka and podocarp-broadleaf treatment were compared with those of their respective control sites. In addition, there was a statistically significant increase in the abundance of carabid beetles at the kanuka treatment site between 2004–05 and 2005–06, whereas, at kanuka control site 1 there was no difference in abundance between these two years. However, there seems to be only limited evidence that carabid beetles are eaten by rodents. Craddock (1997), when investigating the stomach contents of rodents living in taraire forest, found few carabid remains. Similarly, Ussher (1999) found that carabid beetles formed only 0.13% of kiore diet on the Chicken Islands group.

Gibbs (1997) argued that carabid beetles are distasteful to rodents. Some carabid beetles emit a compound with a repulsive smell and unpalatable taste from their pygidial glands (Larochelle & Lariviere, 2001; Lovei & Sunderland, 1996), which may be an effective defense against rodent predation. The larvae of carabid beetles are unlikely to be eaten by rodents, because they are fossorial i.e. burrow underground, and are rarely seen at the surface (Larochelle & Lariviere, 2001).

The greater abundance of carabid beetles in these areas may be because of habitat changes, caused by the reduction of rodent numbers at the kanuka and podocarp-broadleaf treatment sites.

An indirect consequence of rodent control is that an increase in bird abundance has been reported after introduced mammal numbers in forests have been reduced (James & Clout, 1995; Saunders, 2000). At the LTFERP the abundance of tui (*Posthemadera novaeseelandiae*) and grey warbler (*Gerygone igata*) increased significantly between 2002 and 2004 (King unpublished data). Seventy percent of New Zealand’s forest birds eat fruit and disperse seeds (Clout & Hay, 1989). It is possible that a greater number of birds, at the kanuka and podocarp-broadleaf treatment sites, compared to their respective control sites, led to an increase in seedling recruitment at these sites. An outcome of greater seedling numbers, at the kanuka and podocarp-broadleaf treatment sites, may be the provision of more leaf litter. Greater quantities of leaf litter may lead to the retention of more soil moisture.

Watts and Gibbs (2002) found that the abundance of beetles was significantly higher at sites on Somes Island (Wellington) that had greater habitat and vegetational heterogeneity, and stated that beetles are sensitive to microclimatic conditions such as temperature and humidity. The amount of leaf litter may be an important influence on arthropods in forest habitats, especially for predators such as carabid beetles. This is because leaf litter, as well as maintaining moisture, also provides refuges for prey species (Uetz, 1979). Lovei and Sunderland (1996) suggested that carabid larvae, because they have weak chitinisation, are vulnerable to desiccation and consequently, the larval stage of the carabid life cycle may be the most responsive to micro-climate differences.

4.3.4 On Prowling Spiders

Prowling spiders appeared to have benefited from rodent control in podocarp-broadleaf, but not in kanuka forest, despite the fact that rat abundance in both treatment sites was lower than their respective control sites. Spiders have been reported as a major item of rat diet (Best, 1969; Craddock, 1997). However, spiders are also a major food item of mice (Craddock, 1997; Jones & Toft, 2006; Ruscoe & Murphy, 2005), and when mice were eradicated from Allports Island, spider numbers increased (Fitzgerald, 2001). Mouse tracking indices for the podocarp-broadleaf forest in the LTFERP from 2002–06 were low, in contrast to the kanuka forest area, where periodically high mouse tracking indices have occurred from 2003 to 2006, especially in March–April. Considering that mice are major predators of spiders, it is possible that prowling spider abundance at the kanuka treatment site has been suppressed, because of mouse predation. However, this interpretation should be viewed with caution, as there was a statistically significant increase in abundance of prowling spiders at kanuka control site 1 between 2004–05 and 2005–06. Although mice were present at kanuka control site 1 in 2005–06, no rodent monitoring was carried out in this area in the previous year, and consequently, it is unknown whether the mouse abundance was higher in 2004–05 than 2005–06. Future monitoring of mice abundance, at kanuka control site 1, would be needed to determine whether prowling spider and mouse abundance are related.

4.4 ARTHROPODS IN TARAIRE FOREST

Although the two taraire control sites had some different features when compared to the treatment site, they were the only areas of taraire forest available. Other sites that were more closely matched to the treatment site, either contained bait stations or were too close to bait stations in a neighbouring restoration project. It was felt that the results should be included in this study as some of the comparisons with the other forest types used may be of value.

4.4.1 The Impact of Rodents on Arthropods

In contrast to the podocarp-broadleaf and kanuka forest sites, there appear to be no benefits to the cave weta, carabid beetle and prowling spider populations caused by rodent control in taraire, even though rat tracking indices were lower at the treatment site compared with the control sites. Moreover, the abundance of cave weta and prowling spiders was greater at control site 1 than those of the treatment and control 2 sites. The abundance of cave weta at the treatment site was greater than that of control site 2, and this was the only abundance comparison that favoured the treatment site.

However, there were several confounding variables that may have masked the effect of rodent control on arthropod abundance.

4.4.2 The Influence of Site Aspect on Arthropods

The taraire treatment site and control site 2 both had a southerly aspect, whereas, taraire control site 1 had a northerly aspect. It is likely that control site 1, because of its northerly aspect, would have higher average temperatures than the treatment and control site 2. Arthropod activity has been found to be positively correlated to temperature (McColl, 1975; Moeed & Meads 1985, 1986). Higher ground temperatures at control site 1 may have resulted in increased activity of cave weta and prowling spiders, compared to that at the treatment and control site 2. A consequence of increased activity of cave weta and prowling spiders at control site 1 may have been greater pitfall trap captures, compared to those of the other two sites.

4.4.3 The Influence of Habitat Diversity on Arthropods

Control site 1 had a greater diversity of plant species than either the treatment site or control site 2. Moreover, the density of plants at control site 2 was noticeably less than that of the treatment and control 1 sites. In addition, control site 2 had less dead wood in its ground cover, and a greater proportion of bare ground than the other two sites. Habitat diversity strongly influences the abundance of arthropods at forest sites. Watts and Gibbs (2002) found that the abundance of beetles on Matiu/Somes Island, (Wellington), was greater in sites that had greater vegetation heterogeneity. Furthermore, Lassau, Hochuli et al., (2005) showed that habitat diversity was strongly related to the abundance of pitfall-trapped beetles in Sydney sandstone forest

(Australia). Crisp, Dickinson & Gibbs, (1998), in an investigation into the relationship between native arthropod diversity and native plant diversity in a lower North Island forest, found that sites with the greatest number of plant species contained the most beetle species. The greater number of plant species at control site 1 may support a greater diversity of arthropod species, which may provide more food for predators such as prowling spiders.

4.4.4 The Influence of Soil Depth on Arthropods

The average soil depth was much less at control site 2 than at the treatment and control 1 sites, and as a result of this soil depth difference, the soil moisture level was likely to be lower at control site 2, especially in periods of low rainfall. The rainfall for February 2006 (21 mm) was much lower than the 112 mm average for this month. There was some indication that a shortage of water was having an effect on the taraire trees at taraire control site 2, because the ripe taraire fruit that had fallen from the trees in February–March, were very small compared to those seen during April–May. Carabid beetles at the taraire control site 2 may also have been affected by the low rainfall in February 2006, because their abundance declined considerably between February and March 2006, whereas, over the same time period, carabid abundance at the other two taraire sites increased. Carabid beetles are hygrophilous (Larochelle & Lariviere, 2001), and are therefore likely to be sensitive to extreme shortages of water in their environment. The >24 mm size class was largely absent from taraire control site 2, but was present at the other taraire sites, and it is possible that periodic drought conditions were a limiting factor, preventing carabids of this size class from occupying this area. Carabid distribution can also be influenced by temperature and humidity extremes (Lovei & Sunderland, 1996), and both of these could occur in summer when there has been low rainfall, especially at control site 2.

4.5 THE EFFECTS OF OTHER PREDATORS ON ARTHROPODS

4.5.1 Possums

Possums include some arthropods in their diet. For example, Cowan and Moeed (1987) found arthropod remains, including weta and beetles, in 48% of the possum pellets that they analysed. However, arthropods contributed less than 5% of the total biomass eaten. Similarly, Cochrane, Norton, Miller and Allen, (2003) found that arthropods contributed only 7.6% of the dietary intake of the possums that they sampled from north Westland mixed beech forest.

It is assumed that possum numbers, at both the treatment and control sites used for this research are too low to have any impact on the abundance of arthropods. In the LTFERP, a zero residual trapping catch was achieved in 2002. Possum monitoring, using NPCA (2000) protocols, has not been done since 2002, but other data gathered suggested that possum numbers still remained low in the LTFERP between 2002 and 2006. For example, during this time period, few possum footprints were detected on the rodent tracking cards. The close spacing of the bait stations, at 50 m intervals (when possums are targeted, bait stations are typically placed at 150 m intervals), as well as the fact that the bait stations were replenished at least twice annually, means that it was unlikely that many possums would survive in the LTFERP.

Possum monitoring at the control sites during 2005–06, using NZPA protocols, indicated that possum abundance was very low. However, possum footprints were present on the tracking cards each time rodents were monitored at taraire control site 2, which suggested that a possum population had become established. Unfortunately the presence of possum footprints on rodent tracking cards gives no information about the size of the possum population in this area. It is possible that a small number of possums were able to find the tracking tunnels by locating the peanut butter scent. Many of the taraire berries found on the ground during February and March 2006 had their seeds removed (pers. obs.). It is unclear whether the taraire seeds were removed by possums or by rats, because both were present in this area at this time. However, at taraire control site 1, when ripe taraire berries were on the ground (October 2006), no seed removal from fruit was observed. Tracking tunnel data collected at this time indicated the presence of rats, but not possums. Although possums were present at taraire control site 2, and may have been eating large numbers of taraire seeds, it cannot be assumed that this indicated the possum population in this area was large, because over a period of time a small number of possums could have been responsible for eating a large number of taraire seeds. Even though the presence of possums at taraire control site 2 was a confounding variable, there is not enough evidence to determine whether possums had a significant impact on arthropod abundance at this site.

4.5.2 Stoats, Hedgehogs, Weasels, Ferrets and Cats

While stoats, hedgehogs, weasels, ferrets and cats are not targeted for control at the LTFERP, and their relative abundance has not been directly monitored, they are known to include arthropods in their diet. Consequently, the likely impacts of these small introduced mammals on forest arthropod populations need to be assessed.

Stoats

Although stoats mainly eat large prey such as rodents, lagomorphs and possums (King & Murphy, 2005), arthropods are included in their diet. Large bodied insects, such as the ground weta *Hemiandrus* sp., and the cave weta *Gymnoplectrum* sp. (ibid.), as well as carabid beetles (Purdey & King, 2004) have been found in the stomach contents of stoats in New Zealand forests.

When rodent numbers in the forest are low, stoats have the ability to switch to other prey, for example, Murphy, Keedwell, Brown & Westbrooke (2004) found that birds were eaten more frequently when rat numbers were low. Similarly, Purdy & King, (2004), in research in Fiordland, found that when mice were scarce the largest component of stoat diet was birds, although they ate large carabid beetles such as *Mecadema* spp. and *Megadromus* spp. Furthermore, Rickard (1996) found arthropods in 81.8% of stoat stomachs, when rats were in low numbers, in lowland podocarp forest in South Westland.

Because rodent numbers were lower at the treatment sites used in this research, it is probable that any stoats present would respond by targeting other prey, especially birds and to lesser extent arthropods. It is also possible that stoat numbers were lower at the treatment sites than the control sites, because when brodifacoum is used to suppress rodent numbers, stoats are killed when they eat the poisoned rodents (Alterio & Moller, 2000; Gillies & Pierce, 1999; Murphy, Clapperton, Bradfield & Speed, 1998). However, in all of these studies the secondary kill effect only lasted for a few months, and Gillies and Pierce (1999) found at Trounson Kauri Park (Northland), that with the ongoing use of brodifacoum, none of the stoats that they monitored died, although they did contain brodifacoum residues It is possible, therefore, that stoat numbers at the treatment sites used for this research were unaffected by the continual use of brodifacoum. However because the preferred food of stoats is rodents, and their territories large (King & Murphy, 2005), it is unlikely that they would spend much time in an area of low rodent numbers, when there are large numbers of rodents nearby. Unfortunately, though, there has been no New Zealand research carried out that attempted to quantify the effect of stoat predation on arthropod abundance.

Hedgehogs

While hedgehogs are insectivorous, and do target carabid beetles, weta and spiders (Berry, 1999), their footprints have only once been present on rodent tracking cards used in the LTFERP (October 2005 at the kanuka treatment site). Furthermore, during 2003–04, when rat traps were used to control rodents, only two hedgehogs were trapped. Trap catch rates of hedgehog at Trounson Kauri Park, and Pureora Forest Park were up to 1.3 hedgehogs/100 CTN (corrected trap nights), and between 0.10 and 1.51 hedgehogs/100 CTN respectively (Jones and Toft, 2006), all low values. It is unlikely therefore, that the hedgehog is having a major impact on arthropod abundance in the LTFERP.

Weasels

While weasels mainly eat mice and birds, insects such as weta are included in their food intake (King, 2005). However, data gathered on weasel abundance suggests that weasels are scarce in New Zealand forests. For example, at the Pureora Forest Park in 1983–87 only 16 weasels were captured in 24,272 Fenn trap nights, and similarly on the Puketukutuku Peninsula (in Lake Waikaremoana), only 11 weasels were captured in 66,000 trap nights in 1994–96 (ibid). If the abundances of weasels at the treatment and control sites used for this research, are similar to those described above, then it is unlikely that they are having a significant impact on the abundance of arthropods.

Ferrets

The primary prey of ferrets is rabbit, but they do eat weta, spider and beetles (Clapperton & Byron, 2005). However, ferrets are most common in pastoral habitats (ibid.), and scat and stomach samples from ferrets captured in forest at Mapara and Pureora did not contain any arthropod remains (ibid.). Consequently, it is unlikely that ferrets, if present, are having a significant impact on arthropod abundance at the treatment and control sites used in this research.

Feral Cats

Feral cats living in forests mainly eat rats or rabbits (Gillies & Fitzgerald, 2005). Although arthropods are frequently eaten by cats, it is thought that the numbers consumed are too small to contribute much to their diet (ibid).

Individually stoats, hedgehogs, weasels, ferrets and cats may have had little impact on arthropod populations in the study sites of this research; however, their collective impact may have had some influence on arthropod abundance, although there is no evidence to support or dispute this.

4.5.3 Morepork

Morepork are nocturnal native owls that are mainly insectivorous, eating ground weta, cave weta, tree weta, beetles, including carabids, and spiders (Haw, 1998; Haw, Clout & Powlesland, 2001) and typically targeting prey in the 2–5 cm size range (Haw, 1998). The benefits of intensive pest control to birds have already been discussed (see section 1.4). It might be expected that morepork abundance would increase in forests with low numbers of introduced mammalian predators, and consequently may affect the populations of their arthropod prey, although there is no evidence for this. However, morepork do include mice in their diet, although in small numbers (Haw, Clout et al., 2001), and are therefore also vulnerable to secondary poisoning in rodent control areas. Dead morepork have been found after pest control operations that have used brodifacoum, and tissue analysis of these dead morepork found traces of brodifacoum (Eason, Murphy, Wright & Spurr, 2001; McClelland, 2002; Murphy, Clapperton et al., 1998). Nevertheless, there are anecdotal reports from residents of La Trobe Track of more frequent morepork sightings and calling at night, since brodifacoum has been used to suppress rodent numbers. Although no formal morepork monitoring has been done in the LTFERP, their predation cannot be disregarded as having an affect on the arthropod populations, especially considering that morepork eat larger arthropods including the taxa being monitored in this research.

4.5.4 Introduced Wasps

Social wasps (*Vespula* spp.) are common in the Waitakere Ranges during summer and autumn (pers. obs.), and research in other forests, primarily beech (*Nothofagus*), suggests that they may have a profound effect on some native arthropod populations. In honeydew beech forests, the arthropod prey of wasps is commonly spiders, caterpillars, ants, flies and bees (Beggs, 2001). Research by Toft and Rees (1998) predicted that the probability of a spider surviving to the end of the wasp season was very low in sites where wasp numbers were not reduced by poisoning.

Vespulid wasps may also influence arthropod populations in ways other than by direct predation. For example, Barr, Moller, Christmas, Lyver & Beggs, (1995) found that experimentally placed mealworms (*Tenebrio molitor*) survived longer at sites, in beech forest, where wasps had been poisoned. It is possible therefore, that those arthropod predators, such as carabid beetles, could be competing for some of the same prey items as vespulid wasps, but their specific diet is unknown. There is evidence that vespulid wasps have the potential to alter the structure of some arthropod communities. Beggs and Rees (1999) found that experimentally placed lepidopteran caterpillars, in beech forest, had a high probability of survival in spring, when wasp density was low, but a low probability of survival at the peak of the wasp season in summer and autumn. They predicted that the heavy predation of Lepidoptera caterpillars by wasps that occurred mainly in summer and autumn, could lead to the loss of some species from the ecosystem, whereas Lepidoptera prey species that occurred predominantly in spring, would be common.

There are few studies of the food intake of social wasps in non-beech honeydew habitats; however, Harris and Oliver (1993) found that the arthropod prey items of two species of wasps (*V. vulgaris* and *V. germanica*) at two sites in Hamilton were broadly similar to those of wasps in South Island beech forests. Furthermore, of the two species *V. germanica* spent more time foraging amongst forest litter and carried heavier loads back to their nests (Harris & Oliver, 1993). Most of the vespulid wasps in the Waitakere ranges are *V. germanica* (G. Hoskins pers. comm.), and consequently may be having an impact on forest floor arthropods. However, there is no published research that has established the densities of vespulid wasp nests in the Waitakere Ranges, nor have there been any studies that have manipulated wasp density and monitored the response of prey populations. Until these studies are done, the affects of vespulid wasps on arthropod populations in the Waitakere Ranges are speculation.

4.6 RODENTS SIZE CLASS SELECTION OF ARTHROPOD PREY

During the research for this thesis, rats were in lower abundance at the treatment sites compared to the control sites. However, mice tracking indices at the kanuka treatment, kanuka control 1 and the taraire control 1 sites, especially in autumn, indicated their presence in reasonably high numbers, consequently, the impact of rats in these areas cannot be separated from those of mice. Because neither mustelid nor cat monitoring was done during this research, and considering that stoats and cats target larger arthropods as prey, these predators cannot be discounted from having an impact on the size frequencies of the ground weta, cave weta, carabid beetles and prowling spiders monitored in this research.

There is some evidence from previous research that rodents selectively target certain size classes of arthropods as prey. Craddock (1997), in research in coastal broadleaf forest north of Auckland, found that mice targeted arthropods in the 3–12 mm size range, whereas, rats targeted a broader size range of arthropods.

Other research attempting to determine whether predators target certain size classes of arthropods, has not isolated the impact of rodents from other mammalian predators such as possums, mustelids and cats.

Chapman, Alexander et al. (2004), in a study in broadleaf forests spread across the Auckland region, found that there were a higher proportion of larger individuals of the arthropods in most of the localities where pest control was carried out. Similarly, Watts (2004) found that the numbers of ground beetles, in the >30 mm size class, had increased in the Karori Wildlife Sanctuary after mammalian pest eradication. On the other hand, Sim (2005), in a study in the Rotoiti Nature Recovery Project Nelson, found that there was no measurable size differences in the beetles caught when he compared sites with and without pest control. In fact, most of the beetles caught were in the <10 mm size class, and Sim suggested that the larger beetles may have been eradicated from these sites. However, rodent populations may not have been suppressed to a low enough level at the treatment site in Sim’s research, and consequently may have been influencing the arthropod populations.

In the research for this thesis there was some evidence that there had been size selection of the ground weta (*Hemiandrus* sp.) in the kanuka forest, to which it was largely restricted. There was a greater proportion of the largest ground weta size class at the treatment site, compared to that at the control sites. In contrast, there was a larger proportion of the smallest ground weta size class at the control sites, compared to the treatment site. These differences in the relative proportions of ground weta size classes, when the treatment and control sites are compared, occurred over both years of sampling (from 2004–06). Greater predation pressure on adult ground weta, by rodents at the control sites, could explain why there was a smaller proportion of large ground weta at the control sites, compared to the treatment site.

The proportion of prowling spiders, in the >10 mm size category, was larger at taraire control site 2 than the other taraire sites. This site had high rat tracking indices, indicating the presence of a large rat population. However, it is unlikely that rats were selecting small spiders as prey. It is possible that there were some environmental features at the taraire control 2 site that favoured large prowling spiders. There was no other apparent association between prowling spider size classes, location or year. However, the abundance of the largest prowling spiders trapped in all areas was very low, and it is possible that most of the spiders in this size class were able to avoid the pitfall traps, and if this was the case, another sampling methodology would be needed to determine whether these larger spiders were being eaten by rodents. The abundance of large prowling spiders on Tiritiri Matangi Island increased by 400% in the six years after rodents were eradicated (Chris. Green, pers. comm.), and unlike the pitfall traps used to monitor arthropods in the LTFERP, which had a diameter of 80 mm, most of the pitfall traps used on Tiritiri Matangi Island had a diameter of 110 mm (Chris. Green, pers. comm.).

Cave weta in the 10–14 mm size class at the kanuka treatment site, and those in the >14 mm size class at the podocarp-broadleaf treatment site, were trapped in greater proportions compared to their respective control sites, indicating some selection of these larger cave weta by rodents. A similar pattern was reported by Chapman, Alexander et al. (2004), who found a significantly higher abundance of cave weta in the 10–19 mm size class at the treatment sites, where the numbers of a variety of mammalian predators were being controlled, compared to the control sites. However, because of the presence of a suite of introduced mammalian predators at the control sites, Chapman, Alexander et al. could not attribute this result to rodents alone.

As with the prowling spiders, very few of the largest cave weta (in the >20 mm size class) were captured at the sites in the LTFERP, and their associated control sites, and this may be because large cave weta, such as *Gymnoplectrum acanthocera*, can avoid pitfall traps and consequently are under-represented in the sampling.

Because carabid beetles may be avoided as prey by rodents (see section 4.3.3), any variation in the proportions of the different size classes captured is probably caused by environmental differences between the different sites. The largest carabid beetle size class (>24 mm) did not consistently occur in higher proportions at the treatment sites, compared to the control sites of the different forest types used in this research. For example, this size class was found in larger proportions at the podocarp-broadleaf control 2 and taraire control 1 sites, than their respective treatment sites.

Carabid beetle distribution has been shown to be affected by many environmental factors, including soil and litter moisture (Luff, Eyre & Rushton, 1992) and vegetation structural diversity (Webb & Hopkins, 1984; McCracken, 1994). There was a large proportion of the 15–19 mm size class, in this study, at the treatment site of each forest type, and carabid beetles in this size class may be responding to variation in soil and vegetation parameters, induced by low rodent numbers.

In this research, most of the arthropods were classified only to the family level. However, it is probable that several species were present in each of the Carabidae (carabid beetles), Zoropsidae (prowling spider), and Anastostomatidae (cave weta) families caught in the pitfall traps (Chris. Green pers.comm. & Peter Maddison, pers. comm.). Therefore, any effects at the species level caused by the suppression of rodent numbers would not have been detected at the taxonomic resolution used in this research.

4.7 ARTHROPODS AS INDICATORS OF RODENT CONTROL

Arthropods have been proposed as indicators of ecosystem change, because they respond rapidly to environmental change (Hutcheson, Walsh & Given, 1999). In New Zealand, arthropods have been used to characterise the different stages of restoring indigenous forests. Both Watts and Gibb (2000), and Reay and Norton (1999), found that there was a strong correlation between arthropod and plant community composition and the age of the study site. Similarly, Jansen (1997) used arthropod community structure to assess the success of a tropical rainforest restoration in Queensland. Furthermore, ants have been used as indicators of mine site rehabilitation (Majer, 1983), and to monitor biodiversity in Australian range-land ecosystems (Anderson, Fisher, Hoffmann, Read & Richards, 2004).

However, little research has been done to determine whether arthropods can be used to indicate the effects of mammal control in New Zealand forests. In fact, there have only been a small number of studies that have found evidence that suggest arthropods have benefited from the control of introduced mammals. The data in one New Zealand study was confounded by El Niño weather patterns and the presence of ground dwelling insectivorous birds (Sinclair, McCartney, Godfrey, Pledger, Wakelin & Sherley, 2005), and in another by the presence of large numbers of rodents in the treatment site (Sim, 2005). On the other hand, Craddock (1997, 2003) documented some benefits of intensive mammal control to arthropods in taraire-broadleaf forest at Wenderholm, north of Auckland, and in kauri forest at Trounson, Northland.

In this study, only the index of abundance is being considered for indicator use. None of the potential indicator groups were consistently in greater abundance at all of the treatment sites compared to the control sites. However, there were indications that some arthropod groups were responding to the control of pest species at particular sites, for example, although the ground weta *Hemiandrus* sp. seemed to have benefited from pest control, they effectively only occurred in kanuka forest. Hence, perhaps ground weta have the potential to be used as indicators of the effects of rodent control in the kanuka forest at the LTFERP. However, because of their patchy distribution, the sampling design will need to be addressed to minimize the standard error, for example increasing the number of pitfall traps or increasing the trap size.

Carabid beetles have also been regarded as being suitable for use as ecological indicators because they are taxonomically varied, abundant across the landscape, and are sensitive to anthropogenic environmental modification (Niemela, Kotze, Ashworth, Brandmayr, Desender, New, Penev, Samways & Spence, 2000). In addition, carabid beetles tend to migrate in response to change rather than adapting physiologically, which also makes them suitable for use as indicators of environmental change (Butterfield 1996). Furthermore, pitfall trapping is able to detect the population variation of carabid beetles within different habitats (Eyre & Luff, 1990).

Carabid beetle assemblages have been used in Great Britain as indicators of habitat quality in exposed riverine sediments (Eyre & Luff, 2002), and to classify different grassland habitats (Luff, 1996). Carabid beetles in the LTFERP, although probably not eaten by rodents, responded positively to pest control in both the kanuka and podocarp-broadleaf forest in the 2005-06 sampling season and have the potential to be used as indicators of the effects of rodent control in both these forest types. In addition, the kanuka and podocarp-broadleaf forest sites represent different stages of forest succession (Dugdale & Hutcheson, 1997), and may support different carabid beetle species assemblages that may facilitate discrimination between these two forest types (Watts & Gibb, 2002).

The use of spiders as potential biological indicators has also been proposed because they are abundant in many forests, possess a great variety of lifestyles, and are easily sampled (New, 1999). Bonte, Baert and Maelfait (2002) were able to identify spider species as being useful as indicators in discriminating between different coastal dune habitats in Belgium. In New Zealand, there has been some research that aims to determine if spiders could be useful as indicators in forest restoration programmes. For example, Reay and Norton (1999) found that the age of forest restoration plantings was strongly correlated to the spider species composition at each site. However, Chapman, Alexander et al. (2004) found that prowling spider abundance did not indicate the benefits of pest control, in Auckland broadleaf forest. The limited data collected during these studies is inconclusive. In the LTFERP, the abundance of prowling spiders indicated a lower abundance of rats at the podocarp-broadleaf treatment site than either of the control sites. In the other two forest types, statistically significant differences in abundance favoured some of the control sites, although confounding variables may have contributed to the greater prowling spider abundance at taraire control site 1 compared with the treatment and control 2 sites. Even though the number of large prowling spiders captured during this research was small, more were trapped at the kanuka and podocarp-broadleaf treatment sites than their respective control sites. Over time, the abundance of large prowling spiders may continue to increase at the kanuka and podocarp-broadleaf treatment sites. On the other hand, as has been previously mentioned, the diameter of the pitfall traps used in this research may have been too small to capture large numbers of prowling spiders.

It is well established that arthropods are sensitive to changes in weather and to microhabitat differences (Hutcheson, 1999; Van Aarde, Ferreira et al., 2004; Sinclair, McCartney et al., 2005). It will be necessary, therefore, to monitor the abundance of the arthropods suggested as potential indicators at the LTFERP, over many years, to ascertain whether their positive response to low rodent numbers persists if weather and other environmental conditions change.

Any discussion of the reasons for habitat preferences of the arthropods that could potentially be used as indicators is hampered by the lack of detailed knowledge of their life histories and general ecology (Crisp, Dickinson et al., 1998).

5 CONCLUSIONS

5.1 SUMMARY OF FINDINGS

Few studies have demonstrated the benefits to forest arthropods, of maintaining low pest numbers. However, this research has produced results that suggest that some arthropods are responding positively to the maintenance of low numbers of rodents, particularly ground weta in kanuka forest, carabid beetles in kanuka and podocarp-broadleaf forests, prowling spiders in podocarp-broadleaf forest and to some extent cave weta in kanuka forest. Furthermore, there is evidence that ground weta in kanuka forest, and cave weta in kanuka and podocarp-broadleaf forests, may be selected by predators on the basis of size, because there was a significant relationship between size class and their respective treatment sites. In addition, there was a significant relationship between carabid beetles in the 15–19 mm size class and their treatment sites, but because it is unlikely that carabids are selected as prey by rodents, it is possible that they are responding to habitat changes that suit them. This response suggests that carabids represented by this size range may have the potential to be used as environmental indicators, to monitor the effects of rodent control. However, there was no evidence to suggest that the largest carabid beetle size class (>24 mm) was benefiting from rodent control in the LTFERP. In fact, at some control sites this size class was trapped in larger proportions than at the associated treatment sites. No other arthropod species or group in this research responded to rodent control consistently in all three forest types. However, ground weta, which for some undetermined reason were largely restricted to kanuka forest, responded strongly to rodent control and may be suitable for monitoring the effects of rodent control in kanuka forest in the LTFERP. Prowling spiders appeared to be sensitive to the presence of both rats and mice, because they were abundant at the podocarp-broadleaf treatment site, which had low rat and mice tracking indices, whereas, at the kanuka treatment site their lowered abundance seemed to coincide with the periodic presence of mice.

5.2 LIMITATIONS OF THIS STUDY

Some of the data, particularly those collected from the taraire forest sites, were compromised by confounding variables such as differences in aspect, soil depth, plant species variety and density. These differences may have masked any variation in the arthropod abundance with or without rodent control. New control sites in taraire forest, with suitable sampling and experimental designs, would need to be established to mitigate the confounding effects of environmental differences between the sites.

The effect of rodent control on the arthropod populations used in this study could have been masked by the taxonomic resolution used. Larger cave weta, for example, were found in greater proportions in some forest types. However, this size class may have contained several species, not all of which may have been affected by rodents. Furthermore, cave weta abundance was not greater at any treatment site than its corresponding control site, so any individual species that may have benefited from rodent control would not have been apparent using such a broad taxonomic grouping.

The sampling methodology used was unable to detect whether the largest arthropods collected, i.e. the cave weta (e.g. *Gymnoplectrum acantocera*) and the prowling spider (*Uliodon* sp.), were being eaten by rodents. Including some pitfall traps with a larger diameter in pitfall trap-lines may have addressed this problem.

The effects of other predators were unable to be separated from those of rodents in this research. Stoats and feral cats, for example, eat larger arthropods and consequently their predation on these animals may have depressed the proportions of larger weta, spiders and carabid beetles that were trapped. In addition, morepork may have been more abundant in the treatment areas of this research, than the control areas, and because they target larger arthropods may also have had an impact on the abundance of larger arthropods. However nothing is known about morepork territory or home range sizes, and consequently it is possible that some morepork hunted in both the LTFERP and nearby control sites.

5.3 APPLICATIONS OF THIS STUDY

5.3.1 Recommendations for Further Research

There has been very little research investigating the effect of introduced wasps (*Vespula* spp.) on other animal populations in non-beech forest ecosystems. Research to determine the density of wasp nests and numbers of wasps per nest in the LTFERP needs to be carried out, and furthermore, the effects of wasp predation on arthropods need to be established. Vespulid wasps, at the time of the year that they reach peak abundance, may compete with native insectivorous birds for prey and the effects of such competition merits investigation.

Research carried out over many years, similar to that done in this thesis, is needed to gain comprehensive knowledge of the seasonal patterns of ground and cave weta, carabid beetles and prowling spiders, in the LTFERP. This would allow seasonal effects to be separated from the effects of mammal predation on these arthropods, while maintaining rodent control and monitoring. Also, further research is needed to investigate arthropod life histories, basic biology and population dynamics. Studies need to be initiated with experimental designs that allow the specific effects of rodents on arthropods to be separated from those of other arthropod predators such as mustelids and cats. The differences between the effects of rats and those of mice on arthropod abundance could be investigated by setting up exclusion/inclusion experiments. The effect of environmental conditions on arthropod abundance in the forest types used in this study also need to be investigated, because arthropods are very sensitive to small variations in microclimate. In addition, the ideal pitfall trap size to capture larger arthropods, such as the largest cave weta and prowling spiders, needs to be established.

5.3.2 Practical Applications of this Research

The recognised standard for successful rodent control is often a 5% tracking index, and this may be necessary for protecting endangered bird species with low population sizes. However, this research has demonstrated that some arthropod populations can benefit when rodent tracking indexes are higher than 5%. Considering the effort required achieving a 5% rodent tracking index, and the amount of toxin that may be used, higher rodent tracking indices could be set as more appropriate targets in ecosystem restoration projects that are not designed to protect endangered species.

This research has demonstrated the importance of kanuka forest as a habitat for the ground weta *Hemiandrus* sp. In addition, it has shown that the abundance of carabid beetles and cave weta were similar in both the kanuka and podocarp-broadleaf forest treatment sites used in this research. Previous research has also established the importance of mature kanuka forests as repositories of high arthropod diversity and abundance (Dugdale & Hutcheson, 1997). Mature kanuka forest should therefore have a much higher conservation priority.

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APPENDIX 1

Plant Species List

Kanuka Treatment

Agathis australis
Alseuosmia macrophylla
Blechnum filiforme
Collospermum hastatum
Coprosma arborea
Coprosma lucida
Coprosma robusta
Cordyline australis
Cyathea dealbata
Cyathea medullaris
Lygodium articulatum
Dacrydium cupressinum
Dicksonia squarrosa
Freycinetia banksii
Gahnia setifolia
Geniostoma ruprestre
Hebe stricta
Hedycarya arborea
Hoheria populnea
Knightia excelsa
Kunzea ericoides
Lastreopsis glabella
Leucopogon fascilulatus
Lygodium articulatum
Melicytus ramiflorus
Metrosideros fulgens
Myrsine australis
Olearia rani
Phyllocladus trichomanoides
Pittosporum eugenioides
Pittosporum tenuifolium
Podocarpus totara
Prumopitys ferruginea
Pseudopanax crassifolius
Pseudopanax lessonii
Rhopalostylis sapida
Rubus cissoides
Schefflera digitata

Kanuka Control 1

Agathis australis
Asplenium fulcatum
Beilschmiedia tarairi
Blechnum filiforme
Coprosma arborea
Coprosma lucida
Coprosma robusta
Cyathea dealbata
Cyathea medullaris
Dacrycarpus dacrydioides
Freycinetia banksii
Gahnia setifolia
Geniosotoma rupestre
Hebe stricta
Hedycarya arborea
Knightia excelsa
Kunzea ericoides
Lygodium articulatum
Melicytus ramiflorus
Metrosideros fulgens
Olearia rani
Phormium tenax
Phyllocladus trichomanoides
Pittosporum tenuifolium
Pneumatopteris pennigera
Pseudopanax crassifolius
Pseudopanax lessonii
Rhopalostylis sapida
Rubus cissoides
Schefflera digitata
Tmesipteris lanceolata
Toronia toru

Kanuka Control 2

Blechnum filiforme
Brachyglottis repandra
Coprosma arborea
Coprosma lucida
Coprosma robusta
Cyathea dealbata
Cyathea medullaris
Freycinetia banksii
Geniostoma rupestre
Hedycarya arborea
Hoheria populnea
Knightia excelsa
Kunzea ericoides
Melicytus ramiflorus
Olearia rani
Phymatosorus pustulatus
Pseudopanax crassifolius
Pseudopanax lessonii
Rhopalostylis sapida
Schefflera digitata

Podocarp Treatment

Agathis australis
Alseuosmia macrophylla
Asplenium flaccidum
Beilschmiedia tawa
Brachyglottis repandra
Collospermum hastatum
Coprosma lucida
Coprosma robusta
Cyathea dealbata
Cyathea medullaris
Dacrycarpus dacrydioides
Dacrydium cupressinum
Elaeocarpus dentatus
Freycinetia banksii
Gahnia setifolia
Geniostoma rupestre
Hedycarya arborea
Hoheria populnea
Knightia excelsa
Lygodium articulatum
Melicytus ramiflorus
Metrosideros fulgens
Mida salicifolia
Myrsine australis
Nestegis cunninghamii
Olearia rani
Phymatosorus pustulatus
Pittosporum tenuifolium
Prumnopitys ferruginea
Pseudopanax crassifolius
Pseudowintera colorata
Rhopalostylis sapida
Ripogonum scandens
Rubus cissoides

Podocarp Control 1

Agathis australis
Asplenium flaccidum
Beilschmiedia tawa
Brachyglottis repandra
Collospermum hastatum
Coprosma arborea
Coprosma lucida
Coprosma robusta
Corokia buddleioides
Cyathea dealbata
Cyathea medullaris
Dysoxylum spectabile
Elaeocarpus dentatus
Freycinetia banksii
Geniostoma rupestre
Hedycarya arborea
Hoheria populnea
Knightia excelsa
Leucopogon fasciculatus
Lygodium articulatum
Melicytus ramiflorus
Metrosideros fulgens
Myrsine australis
Nestegis cunninghamii
Olearia rani
Phyllocladus trichomanoides
Pittosporum tenuifolium
Pseudopanax crassifolius
Pseudopanax lessonii
Rhopalostylis sapida
Ripogonum scandens
Rubus cissoides

Podocarp Control 2

Alseuosmia macrophylla
Asplenium flaccidum
Beilschmiedia tawa
Blechnum frazeri
Clematis paniculata
Collospermum hastatum
Coprosma grandifolia
Coprosma robusta
Cyathea dealbata
Cyathea medullaris
Dacrycarpus dacrydioides
Dicksonia squarrosa
Dysoxylum spectabile
Freycinetia banksii
Geniostoma rupestre
Griselinia lucida
Hedycarya arborea
Knightia excelsa
Lygodium articulatum
Melicytus ramiflorus
Metrosideros fulgens
Myrsine australis
Nestegis cunninghamii
Olearia rani
Phymatosorus pustulatus
Prumnopitys ferruginea
Pseudopanax lessonii
Quintinia serrata
Ripogonum scandens
Rhophalostylis sapida
Rubus cissoides
Schefflera digitata

Taraire Treatment

Alseuosmia macrophylla
Asplenium flaccidum
Astelia trinerva
Beilschmiedia tarairi
Beilschmiedia tawa
Blechnum filiforme
Coprosma grandifolia
Corynocarpus laevigatus
Cyathea dealbata
Cyathea medullaris
Dicksonia squarrosa
Dysoxylum spectabile
Freycinetia banksii
Geniostoma rupestre
Hedycarya arborea
Hoheria populnea
Knightia excelsa
Lastreopsis glabella
Lygodium articulatum
Melicytus ramiflorus
Pellaea rotundifolia
Pittosporum tenuifolium
Rhipogonum scandens
Schefflera digitata

Taraire Control 1

Asplenium flaccidum
Asplenium lucidum
Astelia trinervia
Beilschmiedia tarairi
Beilschmiedia tawa
Blechnum filiforme
Brachyglottis repandra
Coprosma arborea
Coprosma grandifolia
Coprosma lucida
Coprosma robusta
Corynocarpus laevigatus
Collospermum hastatum
Cyathea dealbata
Dysoxylum spectabile
Freycinetia banksii
Geniostoma rupestre
Griselinia lucida
Hebe stricta
Hedycarya arborea
Hoheria populnea
Knightia excelsa
Lastreopsis hispida
Leucopogon fasciculatus
Melicytus ramiflorus
Mertosideros fulgens
Metrosideros perforata
Myrsine australis
Phyllocladus trichomanoides
Phymatosorus pustulatus
Pneumatopteris pennigera
Pseudopanax crassifolius
Pseudopanax lessonii
Rhopalostylis sapida
Schefflera digitata
Uncinia uncinata

Taraire Control 2

Agathis australis
Astelia trinervia
Beilschmiedia tarairi
Brachyglottis repandra
Cordyline australis
Cyathea dealbata
Geniostoma rupestre
Griselinia lucida
Hedycarya arborea
Knightia excelsa
Melicytus ramiflorus
Metrosideros fulgens
Rhabdothamnus solandri
Rhopalostylis sapida
Sophora microphylla