The diet of moreporks (*Ninox novaeseelandiae*) in relation to prey availability, and their roost site characteristics and breeding success on Ponui Island, Hauraki Gulf, New Zealand.

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“A morepork at its nesthole with a weta” by Geoff Moon.

Abstract

The ecological importance of introduced mammalian predators is well acknowledged in New Zealand, however, little research has focused on the ecology of native avian predators and their role in communities. This study investigated the ecology of moreporks (*Ninox novaeseelandiae*) on Ponui Island, Hauraki Gulf, New Zealand between August 2007 and April 2008. The primary aim was to investigate the functional response of moreporks to availability of their prey. The contents of regurgitated morepork pellets were compared with relative abundance of prey taxa (invertebrates, small birds and rodents) over the study period. The diet consisted primarily of a range of invertebrate prey, particularly weta (Anostostomatidae and Raphidophoridae) and beetles (Coleoptera). Small numbers of vertebrate prey were recorded including rodents and birds. A positive relationship between the percentage contribution to pellet samples of certain taxa and their relative availability was found, and there were peaks in the occurrence of seasonally abundant taxa including cicadas (Cicadidae), and huhu beetles (*Prionoplus reticularis*). The tendency of moreporks to prey on abundant taxa indicates that they are unlikely to depress prey populations to low levels, and may have some degree of stabilising influence. A significant increase in the rodent component of the diet in April indicated that the risk to moreporks of secondary poisoning during mammalian pest control operations may vary considerably with the time of year. The secondary aims were to collect data on roost site characteristics and breeding success. Moreporks roosted at a mean height of 4m, and foliar cover at the 4-6m height tier appeared to be the most important characteristic of roost sites when compared with control sites. These findings suggested that moreporks were selecting roost sites with high overhead cover. Possible reasons for this include predator avoidance, avoidance of mobbing passerines, and the microclimate provided. None of three established pairs and two other birds were observed to establish a nest or breed successfully. Additionally, only three juvenile moreporks were sighted or heard across the 90ha study area suggesting low breeding success in 2007-08. This may have been influenced by a range of factors including 1), predation by the high densities of ship rats on Ponui, or other predators 2), a lack of suitable nest sites such as tree hollows in some areas or 3), competition for invertebrate prey with high densities of ship rats and North Island brown kiwi (*Apteryx mantelli*).

Preface

The specific focus of this thesis stemmed from the idea of my principal supervisor, Isabel Castro, for a study of predator-prey interactions on Ponui Island. Little research of this type has been carried out in New Zealand, although an understanding of the interactions between different species and their environment is essential for effective conservation and management. The importance of research on the ecology of introduced mammalian predators in New Zealand is well recognised. However, little work has focussed on the ecology of native avian predators such as the morepork, (*Ninox novaeseelandiae*) and their interactions with other species. The current study had two main aims:

- The primary aim was to investigate the diet of moreporks in relation to availability of their prey on Ponui Island.

- The secondary aims were to collect data on roost site characteristics and breeding success of moreporks on Ponui Island.

Chapter One is a general introduction that presents the importance of ecological studies, particularly those assessing the relationships between predators and their prey, and gives some background on predator-prey assemblages in New Zealand.

Chapters Two and Three present the findings from the primary aim above. Chapter Two focuses on the relative abundance of morepork prey groups (invertebrates, small birds and rodents) whilst Chapter Three describes the diet of moreporks on Ponui, and how this was related to relative abundance of prey. A separate chapter was dedicated to the relative abundance of prey in order to include more detailed results, and to discuss the findings on their own merits without detracting from the key focus of Chapter Three.

Chapter Four presents the findings from the secondary aims on roost sites and breeding success of moreporks on Ponui.

It is intended that chapters Two, Three and Four be relatively stand alone in nature. As such, there is necessarily some repetition of information in each.

Naturally, all aspects of an animal's ecology are of importance when considering its role in communities. As such, Chapter Five is a general discussion which synthesises the findings of the preceding chapters in relation to the Ponui Island ecosystem, and the broader context.

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Chapter One: Introduction

1.1 The abundance and distribution of organisms

Due to its broad scope and complex nature, the concept of ecology can be difficult to define in a succinct manner. However, Krebs (1972) described it as the scientific study of the interactions that determine the distribution and abundance of organisms.

The distribution of all living organisms is theoretically limited by basic environmental factors such as temperature and pH (Grinnell, 1917; Guisan & Zimmermann, 2000). However, within these constraints, distribution may also be limited by geographic factors and the dispersal abilities of the organism (Pulliam, 2000; Soberon, 2007; Soberon & Peterson, 2005). In addition, organisms require basic resources including food for survival and reproduction, and spaces in which to live (Grinnell, 1917).

Space itself may be a limiting resource in certain circumstances – for example, only a certain number of mussels can settle on a given surface area of rock (Begon et al., 1996). However, usually the resources within a given space such as food and nest sites are what determine its suitability for a species (Begon et al., 1996; Hirzel & Le Lay, 2008). Animals are often restricted to areas with a particular type of vegetation, generally because of the factors it is associated with, such as refuge from predation and climatic extremes, presence of prey species, and nest or den sites (Sachot et al., 2003; Schadt et al., 2002; Seoane et al., 2004). Accordingly, habitat loss or degradation is currently considered to be the most important factor in the loss of global biodiversity (Schmitz & Simberloff, 1997; Vitousek, 1992). It is clear that a reduction in absolute habitat size will generally reduce the number of a particular species it can support (Andrén, 1994; Newton, 1998). In addition, fragmentation of habitat can have detrimental effects on species due to increased edge effect, reduced dispersal, and greater risk of local extinction due to small population size (Andrén, 1994; Crooks et al., 2004; Diamond, 1984; Gilpin & Hanski, 1991). Not surprisingly, organisms with more specialised habitat or dietary requirements are likely to have restricted distributions to begin with, and be more vulnerable to habitat alteration or other perturbations (Blair, 1996; Jokimaki et al., 1996; Pianka, 2000).

Thus, the conditions and resources required by a species for survival and recruitment are important basic aspects of its ecology. Of central importance in the study of ecology is the realisation that species do not exist in isolation, therefore the direct and indirect relationships between species as predators, prey and competitors are of importance in determining their success, as well as the structure and function of the community as a whole (Chapin et al., 2000; Pearson & Dawson, 2003; Schlapfer et al., 1999; Zavaleta et al., 2001).

1.2 Predator-prey dynamics

The way that a predator responds functionally and numerically to the abundance of its prey may provide some indication of its role in ecosystems and the likely predator-prey dynamics (Andersson & Erlinge, 1977; Holling, 1959a). The numerical response involves a change in the number of predators in relation to prey density (Holling, 1959a; Solomon, 1949), due to recruitment, immigration or emigration (Andersson & Erlinge, 1977; Solomon, 1949). The functional response describes a change in the number of prey of a certain type killed per predator per unit time in relation to local prey density (Holling, 1959a; Solomon, 1949). The total response is the product of the numerical and functional responses (Holling, 1959a; Solomon, 1949).

The amplitude and speed of the numerical response may be affected by the basic reproductive rates of the predator. For example, a small rodent is likely to have a rapid numerical response to prey abundance, whereas a larger animal that breeds less frequently might respond with a substantial delay (Andersson & Erlinge, 1977; Holling, 1959a). Where the numerical response is achieved by means of recruitment, it may be closely related to the functional response, as breeding rates are influenced by an animal's nutritional state (Holling, 1959a). However, breeding may also be limited by other variables, such as availability of nest sites (Newton, 1998). In addition, the numerical response may be affected by whether an animal is a nomadic or resident species and factors such as territoriality (Andersson & Erlinge, 1977; Erlinge, 1987). The functional response on the other hand will be affected by the animal's dietary preferences, and variables such as the availability and palatability of alternative prey (Holling, 1959a).

Holling (1959a) described three basic types of functional response. In each scenario, the rate of predation must plateau at some point, if not due to predator satiation then simply because of the effect of handling time (Holling, 1959a, 1959b) - the time taken to pursue, subdue and consume a given prey type (MacArthur & Pianka, 1966).

In a type I response, the number of prey killed per predator is directly proportional to prey density during the rising phase of the response, producing a straight line. The type I response would apply to a predator that had a random search pattern and searched at a constant rate at all prey densities, such that it is theoretically unlikely for many predators (Holling, 1959a, but see Rigler, 1961).

In a type II response, the number of prey killed per predator rises at a continually decreasing rate in relation to prey density, approaching an asymptote. Thus, as the prey population increases, the predator takes a smaller proportion of it, and therefore the relationship is inversely density dependent. The type II response is most likely in the case of a resident specialist predator and may have a destabilising effect, resulting in either the outbreak or collapse of prey numbers (Andersson & Erlinge, 1977; Hanski et al., 1991; May, 1973; O'Donoghue et al., 2001). As the abundance of a specialist predator is closely linked to that of its primary prey, this type of predation may lead to large fluctuations in predator and prey numbers (Andersson & Erlinge, 1977; O'Donoghue et al., 2001; Pearson, 1966). For example, following the low phase of the snowshoe hare (*Lepus americanus*) cycle in Canada, numbers of lynx (*Felis canadensis*) decline allowing for recovery of the prey population. The lynx then responds to increasing abundance of its prey, but with a considerable delay, producing oscillations in predator and prey numbers (O'Donoghue et al., 2001). Despite its cyclic nature, the system is regulated, as numbers of lynx are limited by availability of hares.

The type III response is sigmoidal. The number of a given prey type killed per predator rises with abundance in a density dependent manner up until some point of inflection, after which it declines to an asymptote (Holling, 1959a). As such, this is the only functional response curve that may theoretically have a regulatory effect on prey populations (Holling, 1959a). A type III response is most likely to be shown by a generalist due to their ability to 'switch' between prey types, often showing increased predation on the most abundant prey species and negligible amounts of predation on those that are rare (Andersson & Erlinge, 1977; Erlinge, 1987; Hanski et al., 1991). Accordingly, generalist predators are often considered to have a stabilising influence on predator prey dynamics. For example, Erlinge (1987) found that the stability of a population of *Microtus agrestis* was due to predation, particularly by a number of resident generalists with an abundance of alternative prey available to them. The stabilising effect of the generalist predators in this case was thought to be enhanced by the fact that their numbers were generally controlled by some factor in addition to food, particularly territoriality (Erlinge, 1987).

Nomadic specialists such as some birds of prey can also have a regulatory effect on populations of their prey, as they are able to track changes in prey abundance with relatively little delay, and are likely to leave an area when prey becomes scarce (Andersson & Erlinge, 1977; Galushin, 1974; Korpimaki & Norrdahl, 1991; Maher, 1970).

In general, negative feed back mechanisms ensure that predator and prey populations persist in nature (Sinclair, 2003). However, when a predator is introduced to a novel environment, particularly an insular one, these relationships are disrupted and the introduced predator may have dramatic effects (Sinclair, 2003; Sinclair et al., 1998).

1.3 The impact of introduced predators

Animals that are not well adapted for transoceanic dispersal, such as terrestrial mammals, are generally under-represented in insular faunas (Hoeck, 1984). This may result in high niche opportunity for invading species, and vulnerability of insular fauna to predation and competition when exposed to functional groups with which they have not evolved (Carlquist, 1974; Whittaker & Fernandez-Palacios, 2007; Xu et al., 2004). In addition to having access to naïve prey species, the success of introduced predators is often enhanced as they are released from their natural predators, competitors and/or parasites (Colautti et al., 2004). As such, the contribution of invasive species to loss of biodiversity is considered to be second only to habitat modification (Schmitz & Simberloff, 1997). The two factors are closely linked as habitat modification often increases the likelihood of successful invasion (McKinney, 2006; Vitousek et al., 1997).

Regardless of the vulnerability of insular fauna, if a predator relies on a specific prey type, such as in the case of the lynx and the snowshoe hare above, then it is not likely to cause its extinction (Sinclair, 2003). However, when the predator is able to maintain its numbers by switching to alternative prey, this results in the maintenance of predation pressure even at low prey densities, increasing the possibility of extinction (Burbidge & McKenzie, 1989; Kinnear et al., 1998; Sinclair, 2003; Sinclair et al., 1998).

A well documented example is that of the brown tree snake (*Boiga irregularis*) on Guam, an island that was previously snake free. Since the arrival of the snake, large numbers of forest vertebrates have been extirpated (Engbring & Fritts, 1988). The snake has no natural predators on the island and is not affected by a reduction in native prey species, as it switches to alternative introduced prey (Fritts & Rodda, 1998). Similarly, in Australia, red foxes (*Vulpes vulpes*), whose primary prey are introduced European rabbits (*Oryctolagus cuniculus*) have driven some vulnerable native marsupials to extinction by prey switching (Burbidge & McKenzie, 1989; Kinnear et al., 1998; Sinclair et al., 1998).

Once such an exotic pest species becomes established, the question is how best to control or eradicate it without having unwanted effects on native species. Unplanned consequences become more likely when several trophically linked invasive species are present (Zavaleta et al., 2001). For example, removal of one exotic predator may result in increase of another, and associated detrimental impacts on native species, in a process known as mesopredator release (Courchamp et al., 1999a). Other unexpected outcomes may include prey switching, when eradication of an exotic prey species causes a predator to switch to native prey (e.g. Murphy & Bradfield, 1992), or poisoning of non-target species (Innes & Barker, 1999; Simberloff & Stilling, 1996). Knowledge of the trophic interactions between various species, both native and exotic, assists in effective management for conservation (Zavaleta et al., 2001).

1.4 Predator-prey dynamics and conservation in New Zealand

New Zealand provides another example of an island where introduced species have had a large impact on the native flora and fauna (Worthy & Holdaway, 2002). The New Zealand archipelago began to separate from Gondwana around 100 million years ago, and has been isolated from other continents for at least 80 million years (Lomolino et al., 2005). As a result of this long period of isolation, New Zealand has evolved a unique flora and fauna with a high level of endemism (Bell, 1991; Worthy & Holdaway, 2002).

The pre-human terrestrial vertebrate fauna was dominated by a wide diversity of birds and reptiles; the only land mammals native to New Zealand are three species of bat (Chiroptera) (Bell, 1991; Holdaway, 1989; Worthy & Holdaway, 2002). The avian fauna evolved to fill a wide variety of niches including those often occupied by mammals on other continents (Craig et al., 2000). For example, there were large and medium sized grazing herbivores such as moa (Dinornithiformes) and takahe (*Porphyrio hochstetteri*), and small flightless insectivores such as Lyall's wren (*Traversia lyalli*) (Worthy & Holdaway, 2002). Furthermore, in the absence of large terrestrial mammals, New Zealand's predatory guild was also dominated by avian species such as the huge Haast's eagle (*Harpagornis moorei*), that preyed on moa and other large species, Eyle's harrier (*Circus eylesi*) and the laughing owl (*Sceloglaux albifacies*). In addition, there were many omnivorous or primarily insectivorous bird and reptile species including rails (Rallidae) and the tuatara (*Sphenodon punctatus*) that also took some vertebrate prey (Worthy & Holdaway, 2002).

During New Zealand's long period of geographical isolation, many of the endemic bird species evolved to be flightless or have reduced flight ability. This is a feature of a number of other oceanic islands (Balouet & Olson, 1989; Cheke, 1987; Olson & James, 1982), particularly Hawaii (James & Olson, 1991; Olson & James, 1982, 1991) and is thought to be associated with reduced energy expenditure in the absence of mammalian predators (McNab, 1994). The large body size, longevity and infrequent breeding typical of K-selected species (Pianka, 1974) are also common adaptations of the New Zealand fauna (Bell, 1991; Worthy & Holdaway, 2002).

The composition of New Zealand's flora and fauna began to undergo dramatic changes following the arrival of humans (Bell, 1991; Holdaway, 1989; Worthy & Holdaway, 2002). Native species were naïve to the threat posed by mankind, therefore birds such as moa and other large rails were easy targets for hunters, and their numbers were rapidly decimated. In addition, this had flow on effects for large predators that relied on them as prey, such as Haast's eagle (Worthy & Holdaway, 2002).

Another effect of human colonisation was the destruction of habitat. Following the arrival of Polynesians between AD 1250 and 1300 (Hogg et al., 2003) forest cover was reduced from around 78%, to 53% by 1840 (King, 1984). Following a rapid period of European colonisation around this time, and the associated agricultural activity, there was a further decline to approximately 23% by 1984 (King, 1984). This would have resulted in range reduction and an associated decrease in absolute population size of many native species, particularly forest specialists (Bell, 1991). Habitat fragmentation results in small populations with fewer resources available to them, and reduced gene flow (Andrén, 1994; Diamond, 1984; Gilpin & Hanski, 1991). These factors increase the likelihood of local extinction (Diamond, 1984; Hanski et al., 1991; Williamson, 1981), particularly when considered in conjunction with other threats including hunting by humans, and the effects of other introduced species (Bell, 1991).

Mankind introduced numerous exotic species to New Zealand – the most devastating being the mammalian predators such as the Pacific rat or kiore *(Rattus exulans*), Norway rats (*Rattus norvegicus*), ship rats (*Rattus rattus*), cats (*Felis catus*), and mustelids (stoats, *Mustela erminea*, ferrets, *M. furo* and weasels, *M. nivalis*) (King, 2005; Worthy & Holdaway, 2002). Having evolved in the absence of mammalian predators, the native fauna were not adapted to protect themselves. Hawks and eagles hunt mainly by sight; therefore, the adaptive traits for potential prey species included drab colouration, being nocturnal or crepuscular, and behaviours that reduced visibility from above (Worthy & Holdaway, 2002). Such adaptations were ineffective against the new guild of mammalian predators which hunt by scent as well as sight, and are largely nocturnal (Worthy & Holdaway, 2002). These introduced mammals also have high recruitment rates, and when presented with suitable conditions can undergo explosive population increases (King, 2005). In addition, many of the adaptations that had previously been advantageous for the New Zealand fauna, such as flightlessness and low breeding rates, increased their vulnerability to the effects of introduced predators (Bell, 1991; Holdaway, 1989; Worthy & Holdaway, 2002).

As a result, a large number of endemic species went extinct or declined dramatically, including several avian vertebrate predators (Worthy & Holdaway, 2002). The native species that are relatively common today include those which are more generalist in their dietary and habitat requirements and/or have retained strong flight ability and relatively fast breeding rates. These species include the fantail (*Rhipidura fuliginosa*), grey warbler (*Gerygone igata*) and morepork (*Ninox novaeseelandiae*) (Heather & Robertson, 2005), and species that were self introduced from Australia following human colonisation including the pukeko (*Porphyrio porphyrio*) and the Australasian harrier (*Circus approximans*) (Worthy & Holdaway, 2002).

Many native species are now restricted to offshore islands that are free of exotic mammals, either naturally or as a result of management (Daugherty et al., 1990). This extreme restriction in range means populations are often small and vulnerable to extinction due to stochastic events (Diamond, 1984; Williamson, 1981). Additionally, although mammalian predators are absent, habitat-related factors may inhibit species' success (Armstrong et al., 2002). For example, hihi (*Notiomystis cincta*) population size is limited by food availability on Tiritiri Matangi Island due to a lack of mature nectar producing trees (Armstrong & Ewen, 2001). Similarly, hihi populations on Mokoia Island appear to be limited by food (Armstrong & Perrott, 2000; Castro et al., 2003) in addition to high prevalence of Aspergillosis (*Aspergillus fumigatus*) infection (Alley et al., 1999). On both islands nest boxes are provided for the birds due to a paucity of mature, cavity containing trees (Armstrong et al., 1999; Armstrong & Ewen, 2001). All of these factors are related to the highly modified nature of these island reserves (Armstrong & Ewen, 2001; Perrott, 2001; Perrott & Armstrong, 2000).

Thus, the effects of humans and introduced mammals on New Zealand ecosystems have been great; only a fraction of the native biodiversity remains, and the predator-prey dynamics have been irrevocably altered. The extant native species may have to contend with competition for food resources with exotics (Fitzgerald, 1984; Mills & Mark, 1977) as well as the loss of suitable habitat and the threat of predation by introduced mammals (Worthy & Holdaway, 2002).

The impact of introduced mammalian predators on native fauna is well acknowledged, and there have been numerous studies investigating aspects of the ecology of these animals (King, 2005), including some studies of the way they respond functionally or numerically to their prey (Harper, 2005; King, 1983; Murphy et al., 1998; Murphy & Dowding, 1995; Murphy et al., 2008). For example, Murphy et al. (1998) found that stoats responded functionally to rat abundance in podocarp/hardwood forest, and that they switched to bird prey when rat numbers declined following a rodent control operation. Prey switching was also apparent following natural fluctuations in rat populations (Murphy et al., 2008). In contrast, King (1983) and Murphy and Dowding (1995) found that, although stoats responded functionally to increased mouse (*Mus musculus*) abundance in Fiordland, they didn't switch to native birds when mouse numbers were low. However, King (1983) observed that the overall predation on birds increased following population explosions of mice due to the numerical response of stoats, in a process known as hyperpredation (Courchamp et al., 1999b; Roemer et al., 2002). Additionally, Rayner et al. (2007) found reduced breeding success in Cook's petrels (*Pterodroma cookii*) on Little Barrier Island following the eradication of cats, considering it due to the 'release' of a mesopredator – the kiore.

Accordingly, knowledge of the relationships between introduced predators and their prey, and their interactions with each other, has important applications to the conservation of native species, particularly when planning predator control. However, it is preferable to have an understanding of all key components of an ecosystem and how they interact when making management decisions for conservation (Caut et al., 2007; Zavaleta et al., 2001). Native avian predators may interact with exotic and native species as predators, prey, and potential competitors (see Higgins, 1999 and Marchant & Higgins, 1993 for summaries), and therefore must also be considered as an important constituent of natural systems (note that the term 'avian predator' will be used to refer to raptors, and other birds that take vertebrate prey). In New Zealand these species include the morepork, as well as the New Zealand falcon (*Falco novaeseelandiae*), Australasian harrier, sacred kingfisher (*Halcyon sancta*), and more omnivorous species such as pukeko and weka (*Gallirallus australis*). Although some research has been done on these species (see Higgins, 1999 and Marchant & Higgins, 1993 for summaries), little has focussed on how they respond functionally or numerically to the abundance of their prey. However, some observations on the role of avian predators in New Zealand ecosystems are discussed below.

Harriers have been observed to exploit temporary sources of food (Baker-Gabb, 1978; Barton, 1978, as cited in McKenzie, 1979; Buller, 1888), including seasonally abundant rodents (Baker-Gabb, 1981). As such, it is possible that the harrier contributes to control of pest species by hastening the decline of peak populations (Newsome, 1969).

However, harriers sometimes prey on native birds and their eggs (Baker-Gabb, 1981; Morgan et al., 2006), including rare species such as the black stilt (*Himantopus novaezealandiae*) (Pierce, 1986; Sanders & Maloney, 2002) and kokako (*Callaeas cinerea*) (Innes & Flux, 1999; Innes et al., 1999). Eggs and nestlings appear to be an important food source during the spring and summer (Baker-Gabb, 1981; Redhead, 1969).

The endemic New Zealand falcon, which preys largely on small birds, including many exotic species (Fox, 1977; Seaton, 2007) is much less abundant than the harrier (Fox, 1977; Gaze & Hutzler, 2004). Its decline has been attributed to habitat destruction, predation by introduced mammals and persecution by humans (Fox, 1975, 1977). On the positive side, the 'Falcons for Grapes' project is currently looking at how falcons can thrive in vineyards, and also act as a biological control agent by preying on pest species of passerines (*The New Zealand Falcon*, n.d.). Similarly, exotic pine plantations may support large numbers of falcons if managed appropriately, creating another opportunity for partnership between industry and conservation (Seaton, 2007).

Weka are often perceived as a threat to other native fauna, and, for this reason have been eradicated from some offshore islands subsequent to their introduction (Blackburn, 1968; Brothers & Skira, 1984; Veitch & Bell, 1990). Although weka feed mostly on native fruit and insects, and have themselves suffered large range reductions, they do also prey on a number of native bird and lizard species, and their eggs and young (see Beauchamp et al., 1999 and Marchant & Higgins, 1993 for summaries).

Although the effects of avian predators on their prey are unlikely to be as dramatic as those of introduced mammalian predators, knowledge of their ecology is of importance in understanding how natural communities function, particularly when management decisions are to be made. When predation by native avian species is considered in combination with that by introduced mammals it may be contributing to regulation of a prey population or even its decline. When numbers of the prey population in question are very low, then species such as the harrier, morepork or weka may threaten its persistence if their numbers are not controlled. For example, Innes and Flux (1999) state that control of harriers may be justified where kokako populations are very small.

Another issue for consideration is that the poisoning operations aimed at introduced mammalian predators may also affect native avian predators through secondary poisoning. Harriers, weka, moreporks, sacred kingfishers and pukeko have all been found dead following poisoning operations (Eason & Spurr, 1995; Ogilvie et al., 1997), with weka and pukeko populations being particularly susceptible to a reduction in numbers (see Eason et al., 2002 and references therein).

1.5 Study species

The present study focuses on the morepork (*Ninox novaeseelandiae*) or ruru - a small native owl found throughout much of New Zealand. The morepork's natural habitat is native forest, but many have adapted to life in farmland or suburban areas as well as exotic plantations (Higgins, 1999). Although reasonably common throughout most of the country they are more scarce in Canterbury and Otago (Higgins, 1999), which may be due to habitat loss (Stephenson, 1998). The morepork is New Zealand's only native owl, following the extinction of the laughing owl in the early 1900s (Worthy & Holdaway, 2002).

1.5.1 Taxonomy

Moreporks belong to the genus *Ninox* (family Strigidae), representatives of which may be found throughout much of Australasia, as well as the south-west Pacific Islands and the Indonesian archipelago (Schodde & Mason, 1980). The genus is made up of relatively small owls, often referred to as 'hawk owls' as they have more hawk-like features than other owls, such as longer or narrower wings and tails and a reduction in the size of the facial disc (Harrison, 1973).

The *Ninox novaeseelandiae* species complex includes the Australian boobooks (*N. novaeseelandiae leucopsis*, *N. n. boobook, N. n. lurida, N. n. ocellata, N. n. albaria* (extinct), as well as the Norfolk Island boobook (*N. n. undulata*) and the New Zealand morepork (*N. n. novaeseelandiae*) (Higgins, 1999). Accordingly, throughout the present study, the species name *N. novaeseelandiae* will be used to refer to both moreporks and boobooks. When specificity is required, the New Zealand form will be referred to as the morepork, the Norfolk Island boobook will be referred to as such, and the Australian boobooks will be referred to collectively as the boobook, or, if appropriate, by their separate subspecies names. Although classed as the same species, there are differences between moreporks and boobooks. For example, the boobooks are generally larger, have larger clutches, and also appear to catch slightly larger prey than moreporks (Olsen & Moon, 1990). The boobook will be referred to briefly during discussion of the literature; however, the focus will be predominantly on the morepork, as the current research examined moreporks as part of a New Zealand ecosystem.

1.5.2 Species description

Moreporks are about 30cm long and have a mean body mass of around 170g (Robertson et al., 1983; Stephenson, 1998). Although Stephenson (1998) found females to be heavier on average than males, with greater wing length and bill width, all measurements showed large amounts of overlap and, like Imboden (1985), he concluded that male and female moreporks are indistinguishable in the field. However, moreporks can be sexed using molecular techniques (Stephenson, 1998).

Plumage colouration was found to be highly variable between individuals by both Imboden (1985) and Stephenson (1998), being of various shades of brown with lighter white to fawn markings. There is no apparent relationship between colouration and sex (Stephenson, 1998).

1.5.3 Diet

The morepork is a generalist predator, preying on a variety of invertebrates (Clark, 1992; Cunningham, 1948; Haw & Clout, 1999; Haw et al., 2001; Lindsay & Ordish, 1964; Moon, 2005; Stephenson, 1998), as well as smaller amounts of vertebrate prey including rodents (Haw & Clout, 1999; Haw et al., 2001; Saint Girons et al., 1986; Stephenson, 1998), small birds (Cunningham, 1948; Hogg & Skegg, 1961; Stephenson, 1998), bats (Worthy & Holdaway, 2002), and lizards (Moon, 2005; Ramsay & Watt, 1971). The boobook has a similar diet (Campbell & Rose, 1996; Green et al., 1986; Penck & Queale, 2002), but also includes small marsupials (Rose, 1996).

1.5.4 Habitat

Home range

Very little research has been conducted on the home range size of moreporks or boobooks. However, they have been found to be territorial with largely exclusive home ranges that are usually occupied over extended periods (Imboden, 1975; Olsen &

Bartos, 1996; Olsen & Trost, 1998; Stephenson, 1998). Imboden (1975) found two morepork pairs to have combined home range sizes of 3.5 and 5.3ha over a period of 15 tracking nights in the Orongorongo Valley. Similarly, Stephenson (1998) found a mean home range size for five moreporks of 3.37ha over a period of several months on Mokoia Island. The female boobook may leave the family territory after her chicks have hatched (Olsen & Trost, 1998), whereas, in New Zealand, the adult female morepork is thought not to leave her territory (Stephenson, 1998).

Roosting

Moreporks and boobooks roost during the day either alone (Cunningham, 1948; Imboden, 1975; Olsen & Trost, 1998; Stephenson, 1998), in pairs (Green et al., 1986; Imboden, 1975; Stephenson, 1998) or in family groups (Olsen & Trost, 1998; Stephenson, 1998). The roost is usually amongst foliage of trees and shrubs including epiphytes and the tops of tree ferns (see Higgins, 1999 for summary). Sometimes caves, crevices or ledges are used, and occasionally animal burrows, holes in creek banks, exposed roots of trees or even buildings (see Higgins, 1999 for summary).

1.5.5 Breeding

The breeding season of moreporks and boobooks is from September to February (Higgins, 1999). Nest sites are reportedly most often in tree hollows (Higgins, 1999), however, they may also be found in tree forks, in caves or burrows, in nest- boxes or on the ground (Anderson, 1992; Hogg & Skegg, 1961; Imboden, 1985; Ramsay & Watt, 1971; Stephenson, 1998).

The clutch consists of one to five eggs, but normally two or three for the morepork (Higgins, 1999). Laying and hatching are both asynchronous, usually being two days apart (Higgins, 1999). Females exclusively incubate the eggs for around 30 days whilst being fed by the male (Olsen, 1996; Stephenson, 1998).

Chicks fledge 32 to 42 days after hatching (Olsen, 1996; Olsen & Trost, 1998; Stephenson, 1998), after which juveniles have been found to be at least partially dependent on parents for feeding for between 6 and 8 weeks (Olsen & Trost, 1998; Stephenson, 1998). Few data are available on breeding success in either the boobook or the morepork (Olsen & Trost, 1998; Stephenson & Minot, 2006).

1.5.6 Past work on the morepork

Relatively little research has been conducted on morepork ecology, perhaps due to the strong research focus on New Zealand's threatened bird species. The research that has been carried out includes several dietary studies (Clark, 1992; Cunningham, 1948; Haw & Clout, 1999; Haw et al., 2001; Lindsay & Ordish, 1964; Stephenson, 1998). However, only those of Haw and Clout (1999) and Haw et al. (2001) were sufficient for analysis of seasonal differences in the contribution of different invertebrate taxa to the diet, and none considered the functional response of the morepork to its prey.

Other research includes a small amount of work on home range (Imboden, 1975; Stephenson, 1998), roost site characteristics (Imboden, 1975; Stephenson, 1998) and breeding behaviour (Anderson, 1992; Chambers et al., 1955; Hogg & Skegg, 1961; Moon, 2005; Ramsay & Watt, 1971; Stephenson & Minot, 2006). Much of the work that has been done involves small sample sizes or opportunistic observations (Anderson, 1992; Chambers et al. 1955, Cunningham, 1948; Hogg & Skegg, 1961; Imboden, 1975; Moon, 2005; Ramsay & Watt, 1971).

The morepork is currently considered common and widespread in New Zealand (Higgins, 1999). However, in order to detect any future changes in their status it is necessary to have baseline data on morepork ecology, particularly those factors affecting its productivity. Accordingly, there is a need for further research on the morepork's basic biology and ecology as well as its interactions with other animals both native and introduced.

1.6 Study site

The study site for this project was Ponui Island located in the Hauraki Gulf 30km east of Auckland (36°50′S, 175°10′E) (Fig. 1.1). Ponui Island is 1770ha, of which just under a third remains covered with mixed broadleaf-podocarp forest, the rest having been cleared for agriculture in the early 1900's (Brown, 1979). Additionally, considerable amounts of kauri (*Agathis australis*) were logged on the southern end of Ponui around the same time, and many of the ridges in the main stand of bush were burnt off to graze cattle (D. Chamberlin, Ponui farmer, pers. comm.). Accordingly, these ridges are now covered with regenerating forest and scrub. Ponui has a relatively low degree of floral diversity (Brown, 1979), probably due to a combination of historical logging and browsing by stock. Grazed pastureland borders the bush, which is not fenced, and thus is freely accessible to sheep (*Ovis aries*) and cows (*Bos taurus*). This has resulted in an open understorey with reduced numbers of palatable plants in the browse layer, and soil compaction in some areas (D. Chamberlin, Ponui farmer, pers. comm.). As well as a high density of rats (mostly ship (e.g. Shapiro, 2005) but also Norway), Ponui also supports populations of mice and cats, but no known populations of mustelids, possums (*Trichosurus vulpecula*) or rabbits (*Oryctolagus cuniculus*).

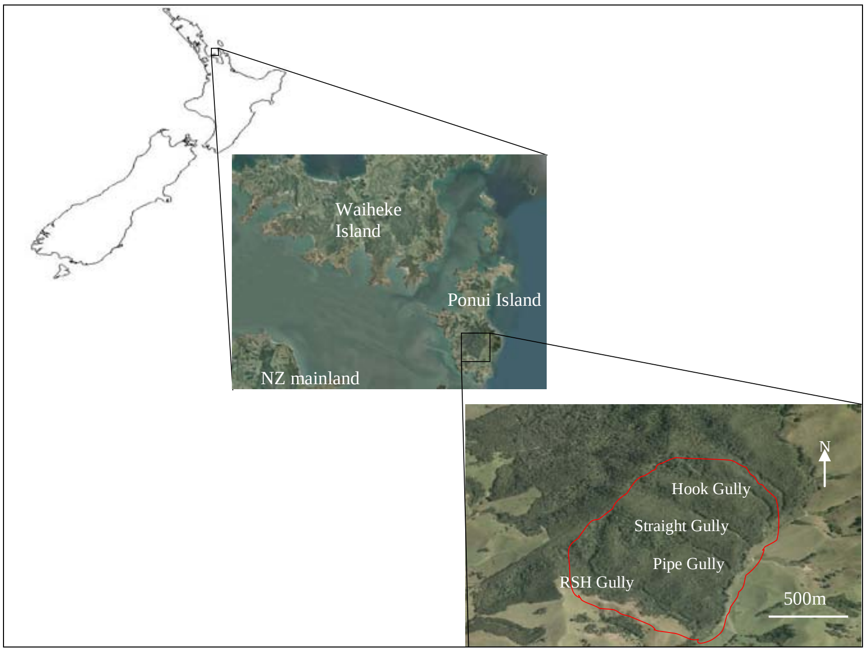

Fig. 1.1 Map showing the approximate location of Ponui Island in the Hauraki Gulf, and the study site (as indicated by the red outline) consisting of four gullies. Outline of New Zealand sourced from Look4™ (http://schools.look4.net.nz), aerial photographs from Google™ Earth (http://earth.google.com).

The avian fauna includes native bird species such as the grey warbler (*Gerygone igata*), fantail (*Rhipidura fuliginosa*), silvereye (*Zosterops lateralis*), tui (*Prosthemadera novaeseelandiae*) and kereru (*Hemiphaga novaeseelandiae*). There are also high densities of North Island brown kiwi (*Apteryx mantelli*) (Miles & Castro, 2000) following a translocation of six individuals from Little Barrier Island, and eight from Northland in 1964.

Research on Ponui Island has been underway since the year 2000, including study of kiwi (Cunningham, 2006, in prep.; Cunningham et al., 2007; Hojem, 2006; Shapiro, 2005; Ziesemann, in prep.) and rat (Latham, 2006; Shapiro, 2005) ecology, and the potential for competition between these species (Latham, 2006; Shapiro, 2005). In addition, a research programme is currently in place focusing on predator-prey interactions on Ponui.

The research area consisted of four gullies adjacent to each other – Red Stoney Hill (RSH) Gully, Pipe Gully, Straight Gully and Hook Gully (Fig. 1.1), covering approximately 90ha within a continuous tract of broadleaf/kauri forest (approximately 250ha) on the southern end of the island. These gullies were chosen for ease of access and representativeness of forest types, along with the fact that previous research (e.g. Latham, 2006; Shapiro, 2005) has been carried out in this area, such that the present study will add to overall knowledge of the site.

1.7 Aims of the study

The primary aim of this study was to investigate the diet of the morepork (*Ninox novaeseelandiae*) on Ponui Island in relation to the relative abundance of its main prey groups. The secondary aims were to 1), assess morepork roosting sites and determine whether there appears to be selection for particular site characteristics, and 2), monitor breeding success of moreporks on Ponui. Accomplishment of these aims will add to the base of knowledge on morepork ecology and provide some indication of their role as a native predator in New Zealand ecosystems. As research is also being carried out on Ponui Island on feral cats, ship rats and North Island brown kiwi, it is hoped that collection of such data will also make a small contribution to a better understanding of this insular system as a whole.

All work was carried out with the approval of the Massey University Animal Ethics Committee (permit 07/44) and the New Zealand Department of Conservation (permit AK-20950-FAU). Birds were banded under the New Zealand bird banding scheme (permit 2007/11).

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Chapter Two: Temporal variation in the availability of morepork (*Ninox novaeseelandiae*) prey on Ponui Island

2.0 Abstract

Data were collected on the relative abundance of three key prey groups of moreporks (*Ninox novaeseelandiae*) on Ponui Island from August 2007 until April 2008: 1), invertebrates using pitfall traps and interceptor traps 2), birds using five minute bird counts (5MBCs) and 3), mice (*Mus musculus*), using a 2.56ha grid of live-capture traps. In addition, although the relative abundance of ship rats (*Rattus rattus*) was not measured as part of the present study, density estimates were obtained from a concurrent study. Generally, higher numbers of invertebrates were caught in pasture and scrub pitfall traps than in bush traps, however, seasonal trends in abundance were similar in all habitats. There were significant differences in pitfall catch between some months for beetles (Coleoptera), weta (Anostostomatidae and Raphidophoridae), spiders (Araneida) and crickets (Gryllidae). Additionally, there was a significant (spiders and crickets) or near significant (beetles and weta) correlation between pitfall catch and mean monthly temperature. Invertebrates caught in interceptors were mostly moths (Lepidoptera), numbers of which were highest in February. The mean number (± s.e.) of small birds (<100g) counted per 5MBC station ranged from 3.25 ± 0.62 in February to 7.00 ± 0.62 in November. Grey warblers (*Gerygone igata*), fantails (*Rhipidura fuliginosa*) and silvereyes (*Zosterops lateralis*) were the most frequently recorded species throughout the study period. No mice were caught over 1213 corrected trap nights in the 81 trap grid, which suggested that mice were either not present, or in numbers too few to detect in this area. In contrast, high ship rat densities ranging from 8.7 ± 1.7 rats ha^{-1} to 16.4 ± 2.4 rats ha^{-1} were measured in the study area. These findings are discussed in the context of the morepork diet and the Ponui ecosystem in Chapters Three and Five.

2.1 Introduction

2.1.1 Invertebrates

Invertebrates are found at all trophic levels and are important prey in forest ecosystems, as well as contributing to the breakdown of dead organisms and nutrient cycling (Moeed & Meads, 1987b). Invertebrates are preyed on by a variety of bird species in New Zealand including numerous small passerines (see Higgins & Peter, 2002; Higgins et al., 2006 and Higgins et al., 2001 for summaries), moreporks (*Ninox novaeseelandiae*) (e.g. Clark, 1992; Haw & Clout, 1999; Haw et al., 2001; Lindsay & Ordish, 1964), and kiwi (*Apteryx* spp.) (Colbourne et al., 1990; Colbourne & Powlesland, 1988; Shapiro, 2005), as well as bats (Chiroptera) (Lloyd, 2001; O'Donnell, 2001) and lizards (Reptilia) (Gill & Whitaker, 1996). In addition, invertebrate prey are taken by introduced mammals including mice (*Mus musculus*) (Badan, 1986; Fitzgerald et al., 1996), Norway rats (*Rattus norvegicus*) (Beveridge & Daniel, 1965; Moors, 1985), ship rats (*Rattus rattus*) (Daniel, 1973; Gales, 1982; Innes, 1979; Miller & Miller, 1995), and cats (*Felis catus*) (Fitzgerald & Karl, 1979; Harper, 2005).

A large proportion of native New Zealand insect species are restricted to native forest habitat (Walker, 2000). Thus, as for other animals, deforestation is likely to have contributed to the extinction or decline of many species (Walker, 2000). Reductions in invertebrate diversity and abundance may also be attributed in part to the introduced predators such as rats and mice that feed on them (Craig et al., 2000; Towns et al., 2009). For example, numbers of nocturnal ground dwelling invertebrates (spiders of the family Zoropsidae, and ground weta, *Hemiandrus* spp.) were found to increase following eradication of kiore (*Rattus exulans*) from Tiritiri Matangi Island (Green, 2002).

A series of studies carried out in the Orongorongo Valley in Wellington using pitfall traps (Moeed & Meads, 1985), emergence traps (Moeed & Meads, 1987a), cone shaped aerial traps (Moeed & Meads, 1984), litter samples (Moeed & Meads, 1986), core samples (Moeed & Meads, 1987b) and tree-mounted up-traps (Moeed & Meads, 1983), found that invertebrate catch was greater in the warmer months, with many taxa showing significant positive correlations with temperature (Moeed & Meads, 1984, 1985, 1987a, 1987b). Certain invertebrate types were found to be active throughout the year, including spiders (Araneida) (Moeed & Meads, 1985, 1987a), beetles (Coleoptera) (Moeed & Meads, 1984, 1985, 1987a, 1987b) and weta (Anostostomatidae and Raphidophoridae) (Moeed & Meads, 1985, 1987a), although there were peaks in abundance, which were often positively correlated with temperature (Moeed & Meads, 1985, 1987a, 1987b). Moths (Lepidoptera) were also generally more abundant in summer and autumn (Moeed & Meads, 1984, 1985), although present throughout the year (Moeed & Meads, 1984, 1985), whereas adult forms of the cicada (Cicadidae) were recorded only during the warmer months (Moeed & Meads, 1983). Fluctuations in invertebrate abundance have also been attributed to rainfall, and moisture content of the leaf litter (McColl, 1975; Mooed & Meads, 1985, 1987b).

2.1.2 Mice

The house mouse was first recorded in New Zealand on Ruapuke Island in Foveaux Strait, after a shipwreck in 1824 (McNab, 1907). By the beginning of the twentieth century, mice were widespread throughout the mainland of New Zealand, having been introduced as stowaways on Australian and European ships (Taylor, 1984). Today, mice are still widely distributed throughout the mainland and on many offshore islands, in native and exotic forests, pasture, croplands and subalpine tussock as well as in urban habitats (Ruscoe & Murphy, 2005; Taylor, 1978).

The suitability of a habitat for mice may be greatly affected by the refuge it provides from predation as well as the availability of food (Brown et al., 1996; Ji et al., 1999; Ylonen et al., 2002). King et al. (1996) noted that the environmental conditions most favouring a high density of mice included dense vegetative ground cover and, accordingly, Brown et al. (1996) found that mice were more often caught in scrubland than mature forest.

Mice are omnivorous and show great dietary flexibility (Badan, 1986; Fitzgerald et al., 1996; Mutze, 1991). Arthropods, especially lepidopterans, are important prey (Badan, 1986; Fitzgerald et al., 1996; Miller & Miller, 1995; Pickard, 1984). Mice may also take small eggs and nestlings, and lizards (Moors, 1978; Whitaker, 1978), although these are not major prey items (Ruscoe & Murphy, 2005).

Studies have shown that mouse abundance is strongly correlated with beech (*Nothofagus* spp.) seed fall in beech forest habitat (Fitzgerald, 1978; Fitzgerald et al., 1996; King, 1983; Murphy, 1992). In environments not dominated by sporadic heavy seeding events, mouse populations tend to peak in summer and autumn, declining through winter (Badan, 1979; Murphy, 1989; Pickard, 1984) due to reduced availability of invertebrate prey (e.g. Moeed & Meads, 1985, 1987a, 1987b) and seasonality of breeding (King et al., 1996).

Mouse populations may also be affected by competition and predation from other species, and play a role in supporting predator populations (Alterio et al., 1997; Alterio & Moller, 1997; Brown, Alterio et al., 1998; Murphy et al., 1998; Murphy & Dowding, 1995). There is evidence that mice are affected by the abundance of ship rats, for example, Brown et al. (1996), Clout (1980), Innes et al. (1995) and Miller and Miller (1995) all noted higher abundance of mice when ship rat numbers were reduced. The key mammalian predators of mice are stoats (*Mustela erminea*) and cats (King & Moody, 1982; Ruscoe & Murphy, 2005), and to a lesser extent weasels (*Mustela nivalis*) and ferrets (*Mustela furo*) (Ruscoe & Murphy, 2005). Avian predators of mice include moreporks (Haw & Clout, 1999; Lindsay & Ordish, 1964; Stephenson et al., 1999), weka (*Gallirallus australis*) (Beauchamp, 1987), kingfishers (*Halycon sancta*) (Fitzgerald et al., 1986), New Zealand falcons (*Falco novaeseelandiae*) (Fox, 1977; Seaton, 2007), little owls (*Athene noctua*) (Marples, 1942) and Australasian harriers (*Circus approximans*) (Baker-Gabb, 1981; Redhead, 1969).

2.1.3 Ship rats

Ship rats originated in India but have spread throughout much of the world, largely aboard ships (Atkinson, 1985; Yosida et al., 1974). Some may have come ashore in New Zealand in the early 19th century but did not spread in the North or South Islands until after 1860 and 1890 respectively (Atkinson, 1973). Ship rats are found in most habitats throughout the country, including urban areas (Innes, 2005). However, they are generally most abundant in mature lowland podocarp-broadleaved forests and scarce in beech forest except after heavy seedfall (Alterio et al., 1999; Dilks et al., 2003; Innes et al., 2001; King & Moller, 1997).

Ship rats are generalist predators, taking plant matter as well as arthropods and, to a lesser extent, birds and their eggs, and lizards (Atkinson, 1978; Best, 1969; Daniel, 1973; Innes, 1979; Latham, 2006; Shapiro, 2005; Whitaker, 1978). Breeding of rats is strongly seasonal; pregnant or lactating females are generally trapped between mid September and mid April (Best, 1973; Daniel, 1972; Innes, 1979; Innes et al., 2001), such that populations usually reach peak densities in autumn (Daniel, 1978; Innes et al., 2001). Although vertebrate prey makes up a small percentage of the diet of ship rats (Atkinson, 1978; Best, 1969; Daniel, 1973; Innes, 1979; Latham, 2006; Shapiro, 2005; Whitaker, 1978), their impact on native vertebrate as well as invertebrate prey can be great due to their ubiquity, the high densities they reach, and the degree of arborealism they display (Atkinson, 1973; Dingwall et al., 1978; Innes et al., 2001; Moors, 1983; Russell & Clout, 2004; Towns & Broome, 2003).

In addition to having a direct impact on native species through predation (e.g. Brown, 1997; Innes et al., 1999; Innes et al., 2004; Mudge, 2002) and, possibly, competition (Latham, 2006; Shapiro, 2005), rats can be important to the maintenance of populations of other mammalian predators such as stoats (McLennan et al., 1996; Murphy et al., 1998) and cats (Harper, 2005). Some native species also prey on rats including weka (Brothers & Skira, 1984), falcons (Fox, 1977), Australasian harriers (Baker-Gabb, 1981) and moreporks (Haw et al., 2001; This study, Chapter Three).

2.1.4 Birds

The avifauna of New Zealand has undergone major changes since colonisation by humans. Many native bird species have gone extinct or are currently threatened (Bell, 1991; Bell & Merton, 2002; King, 1984; Worthy & Holdaway, 2002). Two main forces are thought to be of importance, which are not mutually exclusive; habitat destruction, and exotic mammalian predators (Bell, 1991; King, 1984; Worthy & Holdaway, 2002). Habitat loss and fragmentation leads to shortage of resources such as food and nest sites (Hirzel & Le Lay, 2008), and reduced dispersal, resulting in smaller, more isolated populations (Andrén, 1994; Gilpin & Hanski, 1991; Levins, 1970). Likewise, predation by introduced species is associated with the depletion of prey populations (Atkinson, 1978; Bell & Merton, 2002; Innes et al., 1999; Innes et al., 2004; Sinclair et al., 1998). Moreover, small populations are more susceptible to extinction due to the effects of demographic and environmental stochasticity (Caughley, 1994; MacArthur & Wilson, 1967; May, 1973), as well as genetic drift (Wright, 1931) and inbreeding depression (Frankel & Soulé, 1981). Numerous exotic bird species have also been introduced to New Zealand, however, generally are not a direct threat to native birds, appearing simply to be better suited to modified landscapes (Clout & Gaze, 1984; Diamond & Veitch, 1981; van Heezik et al., 2008).

Native forest-dwelling birds may require the higher cover and structural diversity provided by mature forest for shelter from predation, or nesting sites (Armstrong et al., 2002; Clout & Gaze, 1984). Native floristic diversity may also be associated with the food sources required by certain species including invertebrates, fruits, buds, and nectar (Armstrong et al., 2002; Clout & Gaze, 1984; Heather & Robertson, 2005).

Many of New Zealand’s native birds cannot coexist with introduced mammalian predators and are restricted to offshore islands where pest eradication has been carried out, or intensively managed ‘mainland islands’ (Bell & Merton, 2002; Daugherty et al., 1990). In addition to being vulnerable to introduced mammalian predators (King, 2005), small birds, particularly nestlings and fledglings may be preyed on by native species including harriers, moreporks, weka, and pukeko (*Porphyrio porphyrio*) (see Higgins, 1999 and Marchant & Higgins, 1993 for summaries).

Seasonal changes in the number of birds counted during a study may be related to food availability (Clout & Gaze, 1984; Craig et al., 1981), recruitment of juveniles (Spurr et al., 1992), or behaviours that increase conspicuousness such as flocking (Gill, 1980) or song intensity (Cunningham, 1955; Dawson et al., 1978; Gill, 1980; Miller & Anderson, 1992). Higher calling rates over the breeding season may increase conspicuousness of many bird species (Dawson et al., 1978; Spurr et al., 1992).

2.1.5 The aim of this study

The aim of the current study was to assess the relative abundance of key prey taxa of the morepork (invertebrates, small birds and mice) on Ponui Island, from August 2007 until April 2008. The density of ship rats was not estimated as part of the present study, but density estimates were obtained on Ponui Island as part of a concurrent study (Morgan et al., unpubl. data). These data are discussed in the context of morepork diet and the Ponui Island ecosystem in Chapters Three and Five.

2.2 Methods

2.2.1 Study site

The study site for this project was Ponui Island (36°50′S, 175°10′E) in the Hauraki Gulf 30km east of Auckland (Chapter One; Fig. 1.1). The research area consisted of approximately 90ha of regenerating broadleaf-kauri forest and scrub, and the immediately surrounding pasture. This section of bush, containing four gullies adjacent to each other – Red Stoney Hill (RSH) Gully, Pipe Gully, Straight Gully and Hook Gully, is located within a continuous tract covering approximately 250ha of the southern end of the island (Chapter One; Fig. 1.1). These gullies were chosen for ease of access and representativeness of forest types, and because previous research (e.g. Latham, 2006; Shapiro, 2005) has been carried out in this area, such that the present study will add to overall knowledge of the site.

Ponui has a relatively low degree of floral diversity (Brown, 1979). This is probably due to a combination of historical logging, and browsing by stock. Ship rats may also have had an effect although this is a contentious issue, as they destroy some seeds, but disperse others (Williams et al., 2000), and no negative effects on regeneration have been proven to date (Innes, 2005, but see Wilson et al., 2003).

As well as a high density of rats (mostly ship rats (Shapiro, 2005), but also Norway), Ponui also supports populations of mice and cats, but no known populations of mustelids (*Mustela* spp.), possums (*Trichosurus vulpecula*) or rabbits (*Oryctolagus cuniculus*). The avian fauna includes common native forest species such as the grey warbler (*Gerygone igata*), fantail (*Rhipidura fuliginosa*), silvereye (*Zosterops lateralis*), tui (*Prosthemadera novaeseelandiae*) and morepork. In addition there are numerous species of shorebirds, seabirds and introduced passerines. There are also high densities of North Island brown kiwi (*Apteryx mantelli*) (Miles & Castro, 2000).

2.2.2 Collection of climatic data

Environmental data including temperature, relative humidity and dew point were recorded using a HOBO^{TM} data logger attached to a tree on the floor of Pipe Gully. The unit recorded the temperature (°C), dew point (°C) and relative humidity (%) on a threehourly basis. The mean of these readings was calculated for each month of the study. Data on daily precipitation (mm) was also obtained for the period of the study from the nearest known weather station on Waiheke Island, c. 1km from Ponui (data are available from NIWA; http://clifo.niwa.co.nz).

2.2.3 Relative abundance of morepork prey

Data were collected on the relative abundance of the taxa considered to be important prey of moreporks (as indicated by previous studies; see Higgins, 1999 for summary, as well as Haw & Clout, 1999 and Haw et al., 2001) between August 2007 and April 2008. Unless otherwise stated, no data were collected during January 2008.

2.2.3.1 Relative abundance of invertebrates

The relative abundance of invertebrates on Ponui Island was monitored using pitfall traps to sample invertebrates on the ground, and interceptor traps to sample flying invertebrates.

Pitfall traps

Pitfall traps were established in 2004 for a previous project (Shapiro, 2005) at 25 sites within the study area (Fig. 2.1). The number of pitfall sites was determined based on available sampling time and the size of the study site. The proportion that each broad habitat type (bush, scrub or pasture) made up of the study site was determined using a high quality aerial map with an overlapping 20x20m grid which allowed for calculation of the number of squares comprising each type of vegetation in the area. The habitat type was confirmed on site using modified Recce surveys (see Shapiro, 2005). The number of pitfall traps in each vegetation type reflected the proportion that each contributed to the entire study area. The specific location of each pitfall site was determined using random numbers to generate coordinates within the main study area. In this way, ten sites were allocated to each of scrub and bush habitat, and five to pasture.

At each site, five traps were arranged in a square with one trap in the middle. Corner traps were placed 15m apart giving a total site area of 225m^2. Each individual trap consisted of a 20cm deep by 8cm wide circular hole containing a plastic pipe level with the ground. Within this, a 200ml plastic cup was placed flush with the ground containing 20ml of ethylene glycol (antifreeze). Traps were covered with a stainless steel lid (30x30cm), 2-3cm above the ground to reduce the entry of water and plant material into the trap. Each trap was cleared and reset monthly. Antifreeze was reused wherever possible. Samples were stored in the freezer until ready to be processed. Specimens were sorted to order or a lower taxonomic level using a microscope, and identified using an invertebrate identification reference (Crowe, 2002; Grant, 1999; McColl, 1981; Walker, 2000), or the reference collection held at Auckland Museum.

The contents of the five individual pits at each site were averaged for each month to give an index of relative abundance for that site. The data from each pitfall site (1-25) were also averaged for each month to produce a monthly measure of abundance for each key prey type in 1), each habitat type and 2), all habitats combined. In addition, in order to describe the overall pitfall composition over the period of the study, the monthly indices for each prey type were also averaged.

For all analyses of pitfall content (except for an initial summary of all taxa caught), only the orders of invertebrate that appeared as part of the morepork diet were included. From within these orders, very small (<1cm long) representatives such as the *Saphobius* genus of scarab beetles, and small jumping spiders were excluded. This protocol was followed as a previous study (Haw & Clout, 1999), indicated that most invertebrate prey taken by moreporks were >1cm long, and this also appeared to be the case in the current study (Chapter Three, pers. obs.).

Statistical analysis of pitfall data

Using the indices for each pitfall site for each month, a type one analysis of similarities (ANOSIM) test was conducted to look at assemblage differences in pitfall contents between months using the programme PRIMER v.5.2. (Clarke & Gorley, 2002). A separate type one ANOSIM was conducted to look at differences between habitat types.

An ANOSIM is similar to the univariate one way ANOVA tests, but is non-parametric, and allows for testing of assemblage differences between groups of samples (Clarke & Gorley, 2001). A test statistic (Global R) close to zero indicates that there are no assemblage differences between samples, as the similarities between and within sites are approximately equal, whereas a Global R value of one indicates that all samples from within sites are more similar to each other than any of those from different sites. A Global R value substantially less than zero would indicate that similarities were greater among sites than within sites. The p value indicates at which significance level the null hypothesis may be rejected (Clarke & Warwick, 2001). Unless otherwise stated, the significance level used for these tests was $\alpha = 0.05$. Pairwise comparisons between sites (having their own R and p values) may also be made in order to identify where the greatest differences lie (Clarke & Warwick, 2001), and were used to assess differences between bush, scrub and pasture pitfalls.

The Bray-Curtis coefficient was used as the measure of similarity because it has been shown to be the most appropriate for ecological studies, particularly those involving species composition (Clarke & Warwick, 2001; Faith et al., 1987). Data were square root transformed, to ensure that similarities were dependent on all species in the morepork diet rather than the most abundant ones only (Clarke & Warwick, 2001).

Standardisation results in the Bray-Curtis coefficient reflecting differences in samples due to differing proportional composition only, whereas analysis without standardisation also takes into account differences in total abundance (Clarke & Warwick, 2001). Unless otherwise stated, standardisation was not used.

A non-metric multidimensional scale (nMDS) plot was also produced using PRIMER to provide a visual representation of the similarity between samples. The ANOSIM and the nMDS are created from the same triangular similarity matrix. As the plot is non-metric, there are no axis scales; the information utilised is the rank order of the dissimilarities, such that the relative distances apart of the points indicate their degree of similarity (Clarke & Gorley, 2001). The ‘stress value’ indicates how accurately the 2d plot represents the actual, multidimensional relationship between the data points. A stress value of 0.0 represents a perfect map whereas 0.3 indicates low accuracy (Clarke & Warwick, 2001).

Differences in the number of each key prey type separately (weta, spiders, crickets, and beetles) between months, and between habitats were analysed using Kruskal-Wallis one-way analysis of variance tests (for analysis of differences between months, data from all vegetation types were combined due to similarity in seasonal trends). This test was used as the pitfall data were not normally distributed with equal variances according to the Kolmogorov-Smirnov and Levene's tests respectively. If significant differences were found, Mann-Whitney U tests were conducted to determine where these differences lay. Carrying out multiple tests simultaneously in this manner increases the chance of Type I errors (accepting results as statistically significant when they are not). One approach to this problem is to apply a Bonferroni correction so that the significance level for whole family of tests is not more than α. However, this correction is rather conservative and increases the chance of Type II errors (failing to detect statistically significant results). As such, this correction is not employed, but the reader is advised to interpret the results with caution when such multiple tests are performed. All univariate analyses were carried out in the package SPSS 15.0 (SPSS Inc., 2006), and, unless otherwise stated, the significance level used for these tests was $\alpha = 0.05$.

The relationship between mean monthly pitfall indices and mean monthly temperature, dew point, relative humidity and rainfall was assessed using Spearman's rank order correlation (Spearman's rho).

Interceptor traps

Interceptor traps consisted of two perspex baffles (75x20cm) intersecting each other at right angles, mounted on top of a funnel with a 200ml collection bottle below containing anti-freeze (ethylene glycol). A 30x30cm square of corrugated plastic was attached to the top of the baffles to protect against rainfall and aid in capture of invertebrates (Plate 2.1). Battery powered black lights (Blacklights USA, sales@blacklightsusa.com) were attached to the traps to attract insects (Plate 2.1). Ten traps were placed in Pipe Gully near known morepork roosting areas (Fig. 2.1; see Fig. 4.1, Chapter Four for locations of roost sites). Four of these were located in scrub, four in bush, one in the swamp, and one on the bush/pasture edge, and were suspended at various heights above ground (c. 1-10m). During the first month of sampling (November), the lights lasted for only five hours in total due to insufficient battery life. For this reason, they were then modified to run off 6v lantern batteries resulting in a life of approximately 22 hours. Thus, traps were open for one night in November and for two nights each month from December until April with the exception of January when no trapping occurred. Lights were turned on at dusk, and turned off early the following morning. Samples were collected on the morning of the final day of sampling and stored in the freezer until processed. They were sorted to order or a lower taxonomic level using a microscope and invertebrate identification references (Crowe, 2002; Grant, 1999; McColl, 1981; Walker, 2000) or the reference collection held at Auckland Museum.

Plate 2.1 Interceptor trap hanging from a tree in bush habitat on Ponui Island.

Analysis of interceptor data

The total number of each taxon caught in interceptor traps was counted for the entire study period and for each month. Numbers of beetles and moths (the taxa that were included in the morepork diet (see Chapter Three), and frequently caught in the traps) were compared between months (with the exception of November) using Kruskal-Wallis one-way analysis of variance tests. The difference in the number of moths and beetles caught per trap in bush and scrub habitats was analysed using Mann-Whitney U tests. Non-parametric tests were used as the data were not normally distributed with equal variances according to the Kolmogorov-Smirnov and Levene’s tests respectively.

2.2.3.2 Relative abundance of mice

A 2.56ha grid consisting of 81 live traps (25x5x17.5cm; Trapper 24/7 multi catch mouse trap, 5B Hicks Crescent Waikanae, Kapiti; Plate 2.2) spaced 20m apart was established in November 2007. The traps were designed to allow entry only to mice, although small juvenile rats could also enter. The grid was located in Pipe Gully (Fig. 2.1) in an area selected to contain approximately half scrub and half mature forest. The traps were half filled with shredded newspaper to keep the captured animals warm, and were baited with approximately one Tbsp. of peanut butter (Plate 2.2). Traps were set in the evenings and cleared the next morning for three consecutive nights during each trapping session. Rat excrement was cleaned from the traps each morning if present. Trapping was carried out once per month from November 2007 until April 2008, with the exception of January. Traps were left in the field unset between trapping sessions.

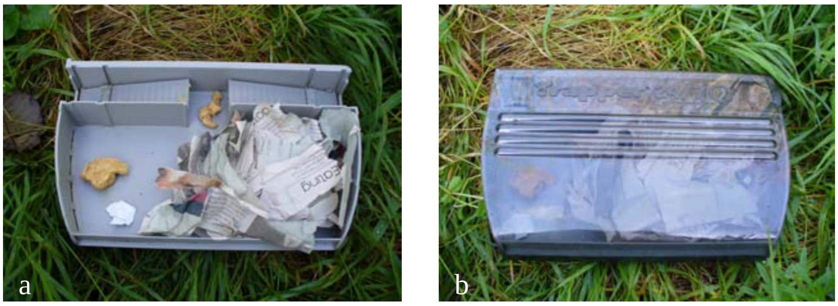


Plate 2.2 Live traps a), with lid off to show contents, and b), with lid on, used to target mice on Ponui Island.

Analysis of mouse data

Trapping rates were not high enough to carry out capture-mark-recapture analysis of mouse density. Therefore, the number of mice caught in the grid each month was utilised as a simple index of abundance. Snap trapping can be used to measure captures per 100 trap nights with correction being made for sprung traps by subtracting half a trap night for every sprung trap recorded (Nelson & Clark, 1973). This method was adapted for use in the current study, with half a trap night subtracted for every capture of a non-target animal. Technically, the live traps utilised may catch more than one animal. However, it has been suggested that mice may actively avoid ship rats (e.g. Brown et al., 1996), such that they are not likely to enter a trap if a rat is already present.

2.2.3.3 Relative abundance of birds

The relative abundance of diurnal birds was estimated each month (including January) from September 2007 until April 2008 using the five minute bird count (5MBC) protocol of Dawson and Bull (1975). During each 5MBC an observer recorded all birds seen or heard from a station within a five minute time period, with no bird knowingly counted twice. The observer also noted time, date, locality, weather and noise levels at each station following Dawson and Bull (1975). Stations were located at least 250m apart along three transects within the study area. Each transect was 850m long and in total there were 12 stations (Fig. 2.1). Birds were counted at each station once a month between 07:00 and 18:00hrs by the same two observers.

Analysis of 5MBC data

An index of bird abundance was obtained for each month by dividing the number of birds seen and heard by the number of stations. The results presented in this chapter are for the small (<100g) bird species most likely to be prey items for moreporks based on past records of morepork predation on birds (see Higgins, 1999 for summary).

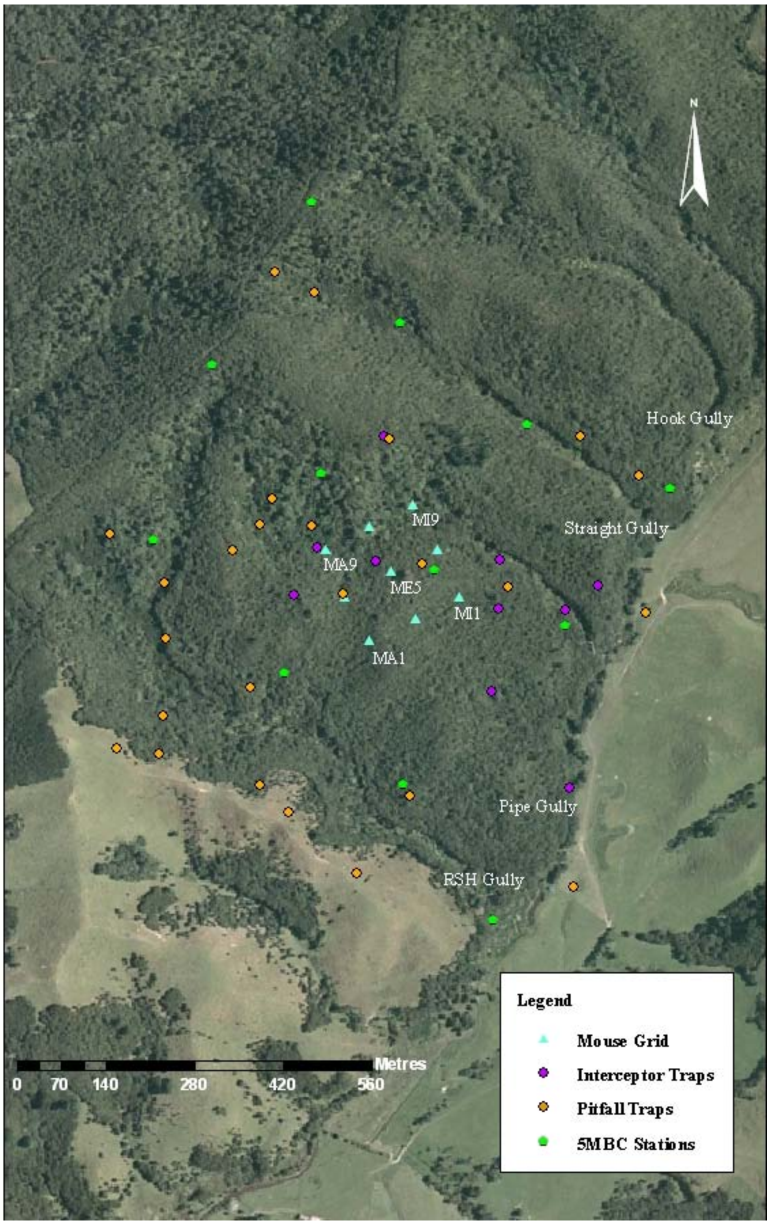


Fig. 2.1 The location of pitfall traps, interceptor traps, 5MBC stations and the mouse trap grid on Ponui Island. Aerial photo sourced from Google™Earth. Coordinates of each site were taken using a hand held Garmin^{TM} GPS unit. Points plotted using ESRI®ArcMap™9.1.

2.3 Results

2.3.1 Relative abundance of invertebrate prey

2.3.1.1 Pitfalls

Overall, amphipods (Amphipoda) were the most frequently caught invertebrate taxon in pitfall traps, followed by woodlice (Isopoda), and beetles (Coleoptera) (most of which were small beetles of the genus *Saphobius*), then cave weta (Raphidophoridae) and crickets (Gryllidae) (combined as Orthoptera in Fig. 2.2), bees, wasps and ants (Hymenoptera) and spiders (Araneida) (Fig. 2.2).

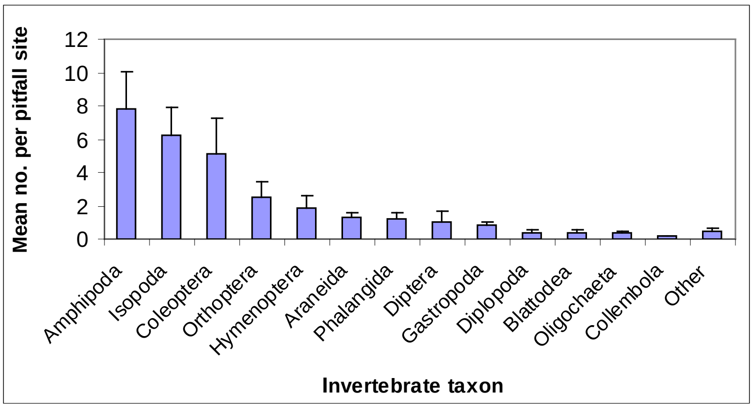


Fig. 2.2 Mean number (+ s.e.) of invertebrates of different taxa caught per pitfall site across bush, scrub and pasture habitats on Ponui Island between August 2007 and April 2008. The category 'Other' includes unknown larval forms, Hemiptera, Turbellaria, Pseudoscorpionidea, Acari, Chilopoda and Lepidoptera.

In addition to the invertebrate taxa caught, 13 copper skinks (*Cyclodina aenea*) were caught in pitfall traps between November 2007 and March 2008 with this equating to a mean (± s.e.) of 0.02 ± 0.01 per pitfall site. For a full list of the mean monthly number of each taxon identified per pitfall site over the period of the study see Appendix 2.1.

Composition of pitfall catch made up of invertebrate taxa consumed by moreporks

For the following analyses, only invertebrate taxa caught in pitfalls that were also consumed by moreporks during the study were included (see Chapter Three). Crickets were the most frequently caught taxon, followed by spiders, beetles and weta (Fig. 2.3).

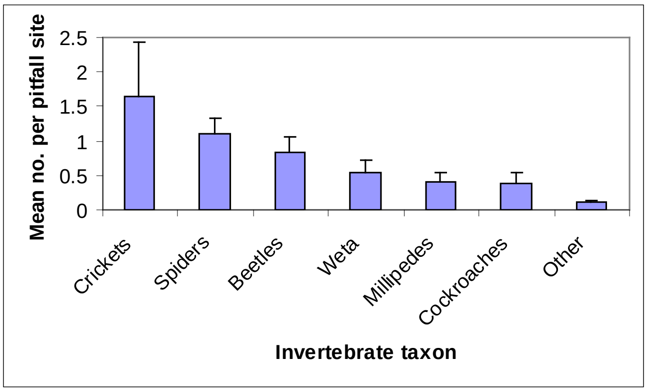


Fig. 2.3 Mean number (+ s.e.) of invertebrates of different taxa (in the diet of moreporks) caught per pitfall site across bush, scrub and pasture habitats on Ponui Island between August 2007 and April 2008. The category 'Other' includes centipedes (Chilopoda), moths, and cicadas.

Difference in invertebrate composition of pitfalls according to vegetation type

There was a significant difference in the invertebrate composition of pitfall traps between habitat types (bush, scrub and pasture) (One way ANOSIM; Global R = 0.418, p = 0.001). Pairwise comparisons showed that bush and scrub pitfalls were more similar to each other than to pasture pitfalls (Table 2.1). This is also illustrated graphically (Fig. 2.4), although the 2d representation provides only a moderately good representation of the true dimensionality of the data as indicated by the stress value of 0.2 (Fig. 2.4).

Table 2.1 Pairwise R and p values for the one way ANOSIM for difference in pitfall composition between vegetation types

Comparison	R statistic	p
Bush, Scrub	0.225	0.001
Bush, Pasture	0.494	0.001
Scrub, Pasture	0.728	0.001

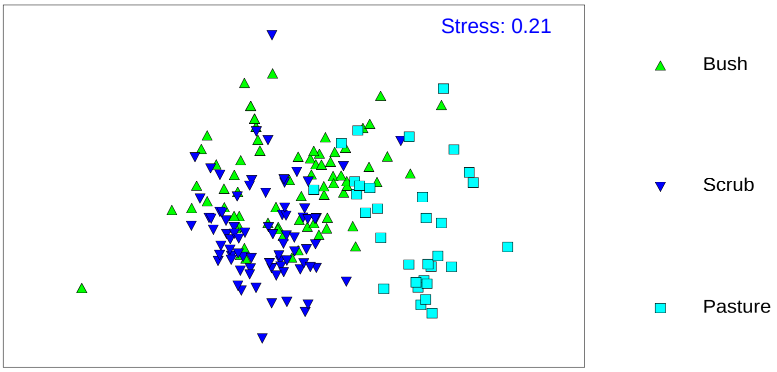


Fig. 2.4 nMDS plot showing the relative similarity of pitfall composition in bush, scrub and pasture sites.

There were significant differences between vegetation types in the relative abundance of each of the major prey taxa when they were analysed separately (all Kruskal-Wallis tests, $p \leq 0.01$; Table 2.2). Significantly more beetles were caught in pasture than in bush or scrub (both Mann-Whitney U tests, $p \leq 0.01$), but there was no significant difference between bush and scrub (Mann-Whitney U test, $p > 0.05$). Significantly more weta were caught in scrub pitfalls than in bush, and significantly more were caught in bush than in pasture (both Mann-Whitney U tests, $p \leq 0.01$). Significantly more spiders were found in scrub than in bush (Mann-Whitney U test, $p \leq 0.01$) with there being no significant difference between scrub and pasture (Mann-Whitney U test, $p > 0.05$). Significantly more crickets were caught in pasture than in bush or scrub (both Mann-Whitney U tests, $p \leq 0.01$). Note that the Mann-Whitney results should be interpreted with caution due to the increased chance of Type I errors when multiple comparisons are carried out.

Table 2.2 Mean number (± s.e.) of key prey types per pitfall site in each habitat type.

	Bush	**Scrub**	**Pasture**
Beetles	0.320 ± 0.063	0.493 ± 0.122	2.495 ± 0.406
Weta	0.130 ± 0.026	1.223 ± 0.188	0.018 ± 0.009
Spiders	0.755 ± 0.070	1.278 ± 0.121	1.444 ± 0.282
Crickets	0.005 ± 0.005	0.025 ± 0.014	8.200 ± 1.922
TOTAL	**1.210 ± 0.118**	**3.018 ± 0.326**	**12.157 ± 2.279**

Although moths were occasionally caught in pitfalls, their occurrence was too low (mean ± s.e. of 0.04 ± 0.01 per pitfall site) for a statistical comparison between habitats or months to be made.

Difference in monthly composition of pitfalls

As invertebrate composition differed significantly between habitats, a separate one-way ANOSIM for difference in pitfall composition between months was conducted for each vegetation type. There were significant differences between months for all habitat types, although the difference was greatest in pasture and least pronounced in bush (Table 2.3).

Table 2.3 Global R and p values from the one way ANOSIM for difference in pitfall contents between months in each habitat type.

Vegetation	**Global R**	**p**
Bush	0.123	0.001
Scrub	0.317	0.001
Pasture	0.614	0.001

Although the composition of pitfalls in the three habitats differed significantly (Table 2.3), it was apparent that the same general trends with regards to fluctuating abundance of taxa across months were occurring (Appendix 2.2). Accordingly, for the purpose of looking at monthly changes in invertebrate prey available to moreporks (which exploit all three habitats), catch data across all habitats were combined. There were significant differences between months for beetles, crickets, and spiders (all Kruskal-Wallis tests, d.f. = 7, $p \leq 0.01$) and a near significant difference for weta (Kruskal -Wallis, d.f. = 7, p = 0.071). Mann-Whitney U tests revealed few significant differences between consecutive months of the study, although the catch of crickets and spiders was significantly higher in November than October (both Mann-Whitney U tests, $p \leq 0.01$), spiders were caught in significantly higher numbers in December than November (Mann-Whitney U test, $p \leq 0.01$) . However, the catch of all taxa except weta was significantly higher in November than August (all Mann-Whitneys U tests, $p \leq 0.01$) and significantly higher numbers of all taxa were caught in December than in October (all Mann-Whitney U tests, $p \leq 0.05$). Significantly fewer beetles, weta, and spiders were caught in April than in December (all Mann-Whitney U tests, $p \leq 0.01$). These statistics are in accordance with the obvious peak in the catch of each taxon in December, followed by a decline (Fig. 2.5). Once again, it must be noted that carrying out multiple tests simultaneously increases the chance of a Type I error, such that these results should be interpreted with some degree of caution.

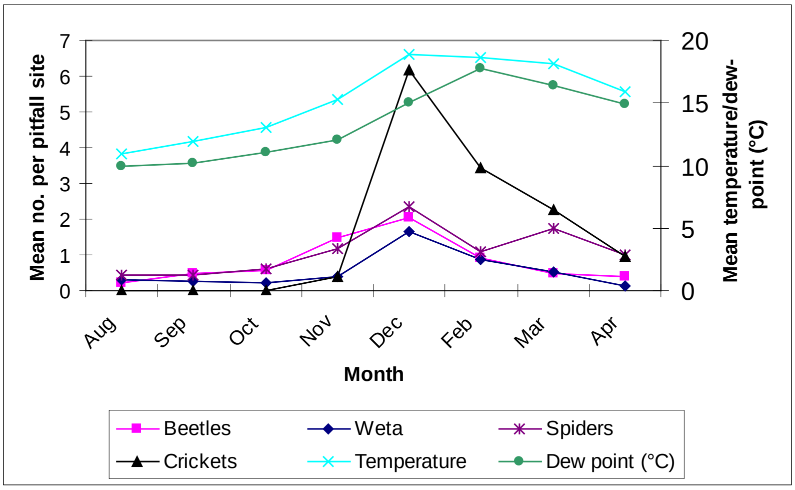


Fig. 2.5 Comparison of mean monthly temperature and dew point with the mean numbers of prey taxa per pitfall site from August 2007 until April 2008 on Ponui Island.

Correlation between pitfall catch and environmental variables

There were significant positive correlations between temperature and number of spiders (Spearman's rho; r_s = 0.786, p = 0.021) and crickets (Spearman's rho; r_s = 0.958, p = 0.001) caught, and near significant correlations between temperature and number of beetles (Spearman's rank order correlation (rho); r_s = 0.667, p = 0.071) and weta (Spearman's rho; r_s = 0.667, p = 0.071) caught. There were also significant positive relationships between dew point and the numbers of spiders (Spearman's rho; r_s = 0.786, p = 0.021) and crickets (Spearman's rho; r_s = 0.886, p = 0.003), and positive, but insignificant relationships between dew point and the number of beetles and weta in pitfalls (both Spearman's rho tests: p >0.05).

There were no significant relationships between relative humidity or rainfall and any of the abovementioned invertebrate taxa in pitfalls (all Spearman's rho tests; p >0.05). See Appendix 2.3 for monthly mean values for each of temperature (°C), dew point (°C), relative humidity (%) and rainfall (mm) over the period of the study.

2.3.1.2 Interceptor traps

Of the total number of invertebrates caught over all trapping sessions, 80.5% of items were moths and 13.8% were beetles. Small numbers of weta, cockroaches (Blattodea) and cicadas were also caught, as well as Diptera, Hymenoptera and some small spiders. (See Appendix 2.4 for a list of the total number of invertebrates of each taxon caught in interceptors over the period of the study). Some of the beetles caught were not represented in pitfall traps, including huhu beetles (*Prionoplus reticularis*) (which were caught during November only), and *Mitophyllus arcuatus*, a type of stag beetle, numbers of which were highest in March. The following data refer only to the invertebrate taxa that appeared in the morepork diet on Ponui (see Chapter Three).

Difference between habitats in interceptor catch

When the number of beetles and moths in bush interceptors (n=4) and scrub interceptors (n=4) were compared, slightly more moths were caught in bush and slightly more beetles in scrub (Table 2.4), however, these differences were not significant (both Mann-Whitney U tests; $p > 0.05$). All other taxa were caught in numbers too low to test for a difference between the two habitats (see Table 2.5).

Table 2.4 The number of moths and beetles caught in interceptors in bush and scrub habitats on Ponui Island between November 2007 and April 2008.

Taxon	Bush	Scrub
Moths	889	631
Beetles	103	121

Difference between months in interceptor catch

As there were no significant differences between habitat types, the data were combined to look at differences between months. Note that the interceptor traps were open for a reduced time in November which may account for the low catch. Accordingly, data from this month were not included in statistical analysis. There were significant differences between months in the numbers of beetles (Kruskal-Wallis, d.f. = 3, $p = 0.009$) and moths (Kruskal-Wallis, d.f. = 3, $p = 0.001$) caught in interceptor traps. Numbers of beetles caught were high in both December and March whereas the number of moths peaked in February (Table 2.5).

Table 2.5 Total number of invertebrates of each taxon caught in interceptors each month, with the percentage of the monthly total in parentheses.

	Nov	Dec	Feb	Mar	Apr
Beetles	4 (2.7)	86 (20.0)	43 (4.6)	86 (21.9)	25 (28.1)
Moths	144 (97.3)	340 (78.9)	882 (95.1)	300 (76.3)	63 (70.8)
Weta	0	3 (0.7)	2 (0.2)	4 (1.0)	1 (1.1)
Crickets	0	0	0	2 (0.5)	0
Cockroaches	0	1 (0.2)	0	0	0
Cicadas	0	1 (0.2)	0	1 (0.3)	0

2.3.2 Relative abundance of mice

No mice were captured in any of 81 traps during the 15 nights they were opened (three nights in each of November, December, February, March and April). However, four juvenile ship rats were caught (one in February, trap C1; two in March, traps I6 and D4; and one in April, trap G5 - refer to Fig. 2.1 in methods section for locations of these traps. After correction for the fact that traps containing a rat were no longer available to mice, this equated to zero mice over 1213 trap nights. Empty traps were often covered with rat faeces and urine.

2.3.3 Relative abundance of birds

Grey warblers were the most frequently recorded bird during every month except January, with numbers counted being highest in October and November (Table 2.6). Fantails and silvereyes were also frequently recorded throughout the study period, with numbers of fantails counted peaking in April, and numbers of silvereyes in January. Counts of both fantails and silvereyes were also high in November (Table 2.6). A number of birds of unknown species were also counted each month and are included in Table 2.6 below as they were all estimated to be of a small size. Smaller numbers of small exotic birds including chaffinches (*Fringilla coelebs),* house sparrows (*Passer domesticus*) and yellowhammers (*Emberiza citronella*) were also counted during the surveys, particularly at the stations closest to the pasture. The total number of small birds counted was highest in November and December (Table 2.6). A number of larger birds were also recorded during 5MBCs including Australasian harriers, kereru (*Hemiphaga novaeseelandiae*) and tui – monthly indices for these species are provided in Appendix 2.5.

Table 2.6 The mean number (±s.e.) of each species of small (<100g) bird, and all small birds as an aggregate counted per 5MBC station each month from October 2007-April 2008 on Ponui Island.

		Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**
Grey warbler	*Gerygone igata*	2.5 ± 0.29	2.42 ± 0.19	1.75 ± 0.28	0.92 ± 0.23	0.83 ± 0.21	1.17 ± 0.27	1.42 ± 0.26
Fantail	*Rhipidura fuliginosa*	1.25 ± 0.25	1.41 ± 0.36	0.92 ± 0.26	0.58 ± 0.19	0.25 ± 0.18	0.92 ± 0.36	1.50 ± 0.36
Silvereye	*Zosterops lateralis*	0.33 ± 0.26	0.92 ± 0.38	0.58 ± 0.31	1.08 ± 0.45	0.67 ± 0.26	0.67 ± 0.28	0.75 ± 0.33
Kingfisher	*Halcyon sancta*	0.33 ± 0.19	0.92 ± 0.29	0.92 ± 0.29	0.33 ± 0.19	0.58 ± 0.23	0.33 ± 0.19	0.08 ± 0.08
Unknown	Unknown	0.33 ± 0.14	0.33 ± 0.22	0.50 ± 0.23	0.50 ± 0.26	0.25 ± 0.13	0.25 ± 0.13	0.50 ± 0.26
House sparrow	*Passer domesticus*	0	0	0.33 ± 0.26	0.25 ± 0.18	0.58 ± 0.31	0.33 ± 0.26	0.17 ± 0.17
Chaffinch	*Fringilla coelebs*	0.08 ± 0.08	0.25 ± 0.13	0.58 ± 0.29	0.17 ± 0.17	0.08 ± 0.08	0	0
Skylark	*Alauda arvensis*	0.08 ± 0.08	0.42 ± 0.15	0.25 ± 0.18	0.33 ± 0.14	0	0	0.08 ± 0.08
Yellowhammer	*Emberiza citronella*	0	0.08 ± 0.08	0.33 ± 0.19	0.17 ± 0.11	0	0.08 ± 0.08	0
Blackbird	*Turdus merula*	0.08 ± 0.08	0	0.25 ± 0.18	0	0	0	0
Song thrush	*Turdus philomenos*	0.08 ± 0.08	0.25 ± 0.13	0	0	0	0	0
Greenfinch	*Carduelis chloris*	0	0	0.08 ± 0.08	0.08 ± 0.08	0	0	0
Shining cuckoo	*Chrysococcyx lucidas*	0	0	0.17 ± 0.11	0	0	0	0
	TOTAL	**5.08 ± 0.62**	**7.00 ± 0.62**	**6.67 ± 0.64**	**4.42 ± 0.67**	**3.25 ± 0.62**	**3.75 ± 0.70**	**4.5 ± 0.54**

Comment [K1]: Bold?

2.4 Discussion

2.4.1 Relative abundance of invertebrates

2.4.1.1 Pitfall traps

The invertebrate composition of pitfall traps differed significantly between habitats (bush, scrub or pasture), however, the fluctuations in relative abundance from month to month followed similar patterns in all three habitats. When data from all habitats were combined, there were significant differences between months, with relative abundance being positively correlated with temperature. The range of invertebrate taxa caught was similar to that found by Shapiro (2005) on Ponui Island using the same pitfall traps, with there being high representation of amphipods, woodlice, beetles and cave weta.

The overall number of invertebrates caught in pitfall traps was higher in scrub than in bush, and higher again in pasture. This finding is consistent with the suggestion that ground dwelling invertebrates are generally more abundant in areas with dense ground vegetation (such as scrub or pasture in the present study; pers. obs.), than in more open environments (Badan, 1986; Mutze, 1991). More weta and beetles were caught in scrub pitfalls than in bush, as was the case for Shapiro (2005) and, in the current study, more spiders were also caught in scrub.

Similarly, the positive correlation between mean monthly temperature and the number of invertebrates in pitfalls in the current study was not unexpected based on previous research on New Zealand invertebrates (e.g. Moeed & Meads, 1984, 1985, 1987a, 1987b). Mean monthly dew point showed a comparable trend to temperature over the period of the study, and thus the correlation with pitfall catch was also similar. The apparent relationship between temperature and dew point was probably related to the fairly high relative humidity throughout the study period (Appendix 2.3).

Seasonality of breeding may have influenced the observed increase in relative abundance of some invertebrate taxa with higher temperature in the present study. For example, Moeed and Meads (1985) found more weta in pitfalls during summer and autumn due to the presence of large numbers of juveniles, and in both the current study and that of Shapiro (2005), more weta were caught in summer than at other times of the year. Similarly, Moeed and Meads (1985) suggested that the positive relationship between catch rates and temperature recorded for many species of ground and scarab beetles (Moeed & Meads, 1985, 1987a) was probably due to the timing of their breeding seasons. Additionally, Walker (2000) noted that scarab beetles emerge from the ground in large numbers in early summer, supporting this suggestion.

In the present study, all of the main prey taxa of moreporks (weta, beetles, spiders and crickets) caught in pitfalls showed a positive relationship with temperature. However, during 2004/05 more spiders were recorded in spring than in summer, and more crickets in winter than in other seasons in the same pitfall traps (Shapiro, 2005). The reasons for these differences are not known, but climatic variations between years may be one explanation (Moeed & Meads, 1987a, 1987b).

Additionally, the reasons for the drop in invertebrate catch in February following the December peak in the current study are not clear, but factors such as reduced soil moisture over the hot summer period, or high juvenile mortality may have been influential. Additionally, seasonal changes in activity levels could have been a factor (Baars, 1979; Lang, 2000), as will be discussed in the section on limitations below. Further work on the ecology of invertebrates in New Zealand is needed in order to better understand the factors influencing their abundance.

Limitations of pitfall data

Pitfall traps are commonly used to investigate the relative abundance of ground-dwelling invertebrates including beetles, spiders and weta (Luff, 1975; Moeed & Meads, 1985; Southwood, 1978; Topping & Sunderland, 1992). However, pitfall catch is a combined measure of activity and abundance; therefore, numbers of a particular species caught will depend not only on its density but also its activity levels and other biological factors that affect its susceptibility to being caught (Duffey, 1956; Lang, 2000; Luff, 1975). Additionally, comparison of pitfall catch between habitats (i.e. bush, scrub and pasture in the present study), might be affected by the influence of vegetation structure on the likelihood of capture (Lang, 2000; Topping & Sunderland, 1992).

One of the most obvious factors affecting the likelihood of capture is the amount of time spent on the ground. Body size also appears to be an influential factor, with relatively larger species being more frequently caught (Lang, 2000), although this may depend on the size of the trap (Luff, 1975). In the present study these factors may have affected the rates of capture of ground based spiders (mostly Zoropsidae), which made up a larger percentage of the overall catch than beetles, many of which are flighted (Crowe, 2002) and weta, some of which exploit arboreal microhabitats (e.g. Moeed & Meads, 1983). Note that interceptor traps were used to target flying insects, the results of which are discussed later in this section.

Due to such biases, pitfall traps may not provide an entirely accurate measure of community composition; however, this does not necessarily imply that seasonal changes in relative abundance of each taxon will not be apparent. For example, Topping and Sunderland (1992) found that there were major discrepancies between pitfall samples, and density samples obtained using a suction sampler with regards to numerical species composition of spiders. Nonetheless, when the density and pitfall samples were compared over time, the two generally showed the same seasonal trends, with all species peaking during summer.

Pitfall catch may be influenced by seasonal changes in the activity of invertebrates in addition to changes in their density (Baars, 1979; Duffey, 1956; Lang, 2000). However, this was considered to be of minor concern in the present study, as increased activity would also increase conspicuousness of invertebrates to predators. As such, pitfall traps were considered to be an appropriate technique for the purposes of sampling ground-based invertebrates. However, the potential sources of bias should be considered when interpreting the results of the present study, and during subsequent comparisons with changes in the morepork diet (Chapter Three).

2.4.1.2 Interceptor traps

Moths were the most frequently caught invertebrate taxon in interceptors, followed by beetles. Several species of beetle caught in interceptor traps were not recorded in pitfall traps, including the most frequently captured species, *Mitophyllus arcuatus*, and huhu beetles (*Prionoplus reticularis*) (see Appendices 2.1 and 2.4). Both of these species were included in the morepork diet (Chapter Three), emphasising the importance of using more than one technique when assessing invertebrate diversity. The number of moths caught in interceptors was highest in February, in accordance with the findings of other studies, that moths are most abundant during summer and autumn (Moeed & Meads, 1984, 1985). The number of beetles caught was quite variable between months for unknown reasons, but may have been affected by some of the factors discussed in the section on limitations below.

Limitations of interceptor data

Ultraviolet light traps are probably the most widely used traps for sampling aerial insects (Henderson, 2003). However, as in the case of pitfalls, there are a number of potential biases affecting the catch – for example, some types of invertebrates may be attracted to light whilst others are repelled (Henderson, 2003). The main rationale for use of interceptor traps in the present study was to look at relative abundance of flying insects, particularly moths, which are important prey for moreporks (see Chapter Three and references therein). Variables such as moon phase, temperature, wind and humidity may have affected catch rate from month to month (Henderson, 2003). I intended to open the traps each month during the same phase of the moon; however, this was not always possible due to time constraints and equipment failures. It was also difficult to control for variations in weather conditions (especially wind speed), however, traps were opened for two consecutive nights each month and rainfall over these two nights was always negligible.

2.4.1.3 Comparison of pitfall and interceptor data

The trends in overall beetle abundance differed slightly between pitfall and interceptor traps over the four month period when both techniques were in operation. Whereas the number of beetles in pitfalls declined after December 2007, in interceptor traps there was a substantial spike in numbers in March 2008. This was likely due to the aforementioned differences in the species targeted by the traps.

Some beetle species were clearly not well targeted by either technique, for example, just one *Stethaspis* spp. beetle was caught in pitfall traps in November, and none were caught in interceptors despite substantial numbers occurring in morepork pellet samples in December, February and March (Chapter Three). Accordingly, future studies that aim to measure the relative abundance of this species should utilise different trapping techniques such as emergence traps (see Southwood, 1978).

For the purposes of comparison with the morepork diet, the results from pitfall traps were considered to be more appropriate than those from interceptors for all prey groups besides moths. This was due to them being in operation for the entire study period, but also because they were open all month rather than for just two nights. This was of particular relevance as environmental conditions on these two nights may have varied between months. Future studies utilising interceptor traps might consider opening them for longer periods of time.

2.4.2 Relative abundance of rodents

2.4.2.1 Mice

No mice were captured in the grid of live traps during the present study, nor were any mice observed in the study area by the author, suggesting low abundance. However, mice are present on the island (pers. obs.) and have been sighted in the bush on occasion (B. Ziesemann, Massey University, pers. comm.).

Previous studies in non-beech forest also yielded very low trapping rates, with trap lines often not catching any mice (Ruscoe & Murphy, 2005). Similarly, Ji et al. (1999) caught only 5 mice over 1936 corrected trap nights on Motukorea Island, which is largely grassland, with no captures occurring until the third night of each trapping session. By comparison, the present study yielded 0 mice over 1213 corrected trap nights. As such, it may have been necessary to carry out many more nights of trapping on Ponui in order to catch any mice.

The capture of juvenile rats in the live traps indicated that the trap mechanism was probably not the reason for there being no mouse captures. Tracking tunnels that were deployed as part of a concurrent study also detected no mice, supporting the idea that their numbers are low in the bush on Ponui.

The apparently low abundance of mice in the bush may be due to consistently high densities of ship rats on Ponui (Latham, 2006; Morgan et al., unpubl. data, see below; Shapiro, 2005), as several New Zealand studies have found that there is an inverse relationship between mouse and ship rat abundance (Brown et al., 1996; Innes et al., 1995; Miller & Miller, 1995). For example, Brown et al. (1996) found that mice were detected more frequently as ship rats were removed by trapping, even though mice were also being trapped. In addition, Ji et al. (1999) caught mice only in rocky areas covered by dense vines on Motukorea Island, which could have provided refugia from Norway rats, the dominant rodent species on the island. These observations could be due to competition or predation (Innes et al., 1995; McQueen & Lawrence, 2008; Miller & Miller, 1995).

Accordingly, it is possible that mice were present in the bush on Ponui during the period of the current study, but at a level that was difficult to detect. This may have been influenced by avoidance of rats (Brown et al., 1996; Ji et al., 1999; Tennyson & Taylor, 1999), particularly as, whilst adult rats were not able to enter traps, they often defecated on and around the traps. Regardless of the mechanism, it does not seem that availability of mice in the bush on Ponui as a prey item was high during the period of the study.

2.4.2.2 Ship rats

During the period of the current study, estimates of rat density (± s.e.) ranged from 8.7 ± 1.7 rats ha^{-1} to 16.4 ± 2.4 rats ha^{-1}(Morgan et al., unpubl. data) with the highest estimate occurring in early May, 2008. These estimates are comparable to estimates of rat density obtained during other studies conducted on Ponui Island using similar capture-mark-recapture trapping protocols (Latham, 2006; Shapiro, 2005).

Interestingly, the density estimates obtained by Shapiro (2005) for December 2004 (10.2 ± 2.53) and January 2005 (9.44 ± 3.32) were very similar to the estimates for December 2007 (10.1 ± 1.7) and January 2008 (8.7 ± 1.7) (Morgan et al., unpubl. data), with there being a lower estimate for February of 2005 (6.04 ± 1.73) (Shapiro, 2005). Latham (2006) found that rat densities from July until October of 2005 ranged between 6.73 ± 4.23 in September and 22.43 ± 5.23 in July. These figures suggest that rat densities on Ponui, although variable, may be consistently high.

Rats are generally thought to reach much higher densities on islands (where pest control has not been carried out) than on the mainland (Adler & Levins, 1994; Gliwicz, 1980), although not many estimates are available for New Zealand islands (Innes, 2005). However, Moller and Tilley (1986) estimated a density of 10 Norway rats ha^{-1} on an island in the Bay of Islands whilst, on Haulashore Island, a small (6ha) island which had abundant food supplies, a rough estimate of 25-50 rats ha^{-1} was made in 1991 (Taylor, unpubl., as cited in Innes, 2005). A tendency for increased densities on islands may be due largely to lack of a dispersal sink (Tamarin, 1978). Additionally, there are often fewer mammalian predators present on islands (Adler & Levins, 1994; Crowell, 1986). For example, on Ponui, high rat densities could be influenced by reduced predation pressure in the absence of stoats, which prey largely on rats (Murphy et al., 1998).

The increase in rat density from summer to autumn noted during the period of the current study (Morgan et al., unpubl. data) was in alignment with previous findings that numbers of ship rats are usually lower in spring and summer, and higher in autumn due to increased recruitment following breeding (Daniel, 1978; Innes et al., 2001). Other factors that may affect abundance of rats on Ponui include minor fluctuations in food availability (Daniel, 1978), and predation by cats (Daniel, 1978; Karl & Best, 1992), and to a lesser degree moreporks (Haw et al., 2001; This study, Chapter Three). As numbers of ship rats are high on Ponui (Latham, 2006; Morgan et al., unpubl. data; Shapiro, 2005), breeding may also be density dependent to a certain extent as noted in the case of mice at high densities (Fitzgerald, 1978).

2.4.3 Relative abundance of birds

Grey warblers, fantails and silvereyes were the most frequently counted small birds throughout the present study with smaller numbers of kingfishers, shining cuckoos and various introduced passerines also being recorded. Higher numbers of small birds as an aggregate were counted in November and December than in other months.

2.4.3.1 Change in relative abundance of birds over the period of the study

Most birds in New Zealand, including silvereyes, grey warblers, fantails and finches begin breeding from late winter to early spring (Heather & Robertson, 2005). Therefore, the increased number of birds counted during November and December in the present study may largely have reflected behavioural changes such as increased activity and calling rates over this period, which increase detectability (Dawson et al., 1978; Gill, 1980; Spurr et al., 1992). In accordance with the present study, Gill (1980), Miller and Anderson (1992), and Freeman (1999), recorded a peak in numbers of grey warblers counted in October, relating this to song intensity. Increased counts of grey warblers and fantails in April compared with January and February in the present study could be due to increased numbers of young birds at the end of the breeding season as suggested by Spurr et al. (1992).

2.4.3.2 Limitations of 5MBC methodology

The number of birds counted during 5MBCs may be influenced by their conspicuousness as well as their relative abundance as mentioned above. In particular, seasonal changes in behaviour of birds may influence the likelihood of detection (Norvell et al., 2003; Spurr et al., 1992). Methods such as distance sampling (using point or line transects) attempt to reduce this bias by correcting for detectability (Buckland, 2006). However, as with most methods, there are also downsides to distance sampling. Firstly, it requires greater investment of time and resources, and secondly, there are numerous assumptions that may be violated including 1), that all animals located on the line or at the point are certain to be detected 2), that objects are detected at their initial location prior to any movement in response to the observer, and 3), that distances are measured accurately (Buckland et al., 2001). Assumption 2 is likely to be violated as certain bird species are inclined to move towards people (e.g. fantails; Lindsey & Morris, 2000), whilst others may move away (Dawson & Bull, 1975). Additionally, as birds are far more often heard than seen in New Zealand forest, it may be difficult to accurately estimate distance (particularly for a relatively inexperienced observer) leading to violation of assumption 3.

The aim of the present study was to assess the seasonal variation in availability of birds to moreporks as prey. Increased conspicuousness of birds is likely to coincide with the breeding season, and to increase the likelihood of detection and predation by moreporks, particularly of vulnerable nestlings and fledglings (e.g. Brown, Moller et al., 1998). Accordingly, 5MBCs were considered to be an appropriate technique.

Other potential sources of bias in 5MBC data include changes in detectability between counts due to factors such as variation in vegetative density (e.g. Bibby & Buckland, 1987), different observers, and associated variation in detection ability, or changes in noise levels (Buckland, 2006; Dawson & Bull, 1975). However, these were not considered to be important confounding factors in the present study: Major changes in vegetation structure were unlikely over the period of the study, and the same two observers carried out all of the counts, in reasonably fine weather conditions. The detectability of birds may change during the day as well as from month to month (Dawson & Bull, 1975). Therefore, one factor that may have influenced the trends suggested by 5MBCs in the present study is that not all counts were carried out at the same time of day due to time constraints. However, in all cases, some counts were carried out in both the morning and the afternoon. Therefore it is hoped that the effect of time of day was minimal.

2.4.3.3 Overall abundance and diversity of small birds on Ponui

The small bird species that were most frequently counted on Ponui – grey warblers, fantails and silvereyes, were amongst the most conspicuous bird species in a number of other study sites in which mammalian predators were present (Clout & Gaze, 1984; Freeman, 1999; Gill, 1980, 1983; Innes et al., 2004; Onley, 1980; Spurr & Anderson, 2004), indicating that they are relatively successful in such conditions. Interestingly, grey warblers appeared to decline in abundance following predator control in a number of studies (Coad, 2001; Graham & Veitch, 2002; Jones, 2000; Spurr & Anderson, 2004).

The presence of cats and rats, which prey on birds and their eggs (e.g. Brown, 1997; Harper, 2005; Innes et al., 1999; Morgan et al., 2006; Mudge, 2002; Murphy et al., 2004) is likely to impact upon the avian fauna of Ponui. In particular, the high densities of rats on Ponui (Morgan et al., unpubl. data; Shapiro, 2005) may make it unsuitable for some bird species. Many native birds are now restricted to areas where mammalian predators are absent, or present only in low numbers, often as a result of active pest management (Bell & Merton, 2002; Daugherty et al., 1990). Additionally, studies have shown increased encounter rates or breeding success of native bird species including saddlebacks (*Philesturnus carunculatus*), red-crowned kakariki (*Cyanoramphus novaezelandiae*), hihi (*Notiomystis cincta*), and North Island robins (*Petroica australis longipes*) following the eradication of rats (Empson & Miskelly, 1999; Graham & Veitch, 2002; Miskelly & Robertson, 2002; Saunders, 2000), suggesting they have a detrimental effect on these species. Clearly, low diversity of small native species on Ponui Island can be expected in comparison with islands such as Mokoia and Tiritiri Matangi where predator control has been carried out, and translocations of species such as, hihi, North Island robins and North Island saddlebacks have been conducted (Armstrong, 1995; Armstrong et al., 1999; Armstrong & Craig, 1995; Armstrong & Ewen, 2001).

Predator control might also encourage higher overall abundance of birds - Howard (2000) counted higher overall numbers of birds in areas of Boundary Stream Mainland Island where poisoning had been conducted compared with control sites. Similarly, at the Northern Te Urewera Mainland Restoration Site, higher peaks in bird conspicuousness for all species appeared to be related to reduction in possum and rat numbers (Saunders, 2000).

2.5 Conclusions

In summary, distinct trends in the relative abundance of invertebrates and small birds, and the density of ship rats (Morgan et al., unpubl. data) were detected in the present study. Numbers of invertebrates caught in pitfalls peaked in December, showing a positive correlation with temperature, whilst numbers of birds counted were highest during November and December, and rat density peaked in early May. No mice were caught during the present study, suggesting that they are scarce in the bush on Ponui. It might be expected that these trends will influence the diet of Ponui Island moreporks if they respond positively to prey availability as has been suggested (Haw & Clout, 1999; Haw et al., 2001; Lindsay & Ordish, 1964; Stephenson, 1998). As such, the findings of the present chapter will be compared with the diet of Ponui moreporks in Chapter Three.

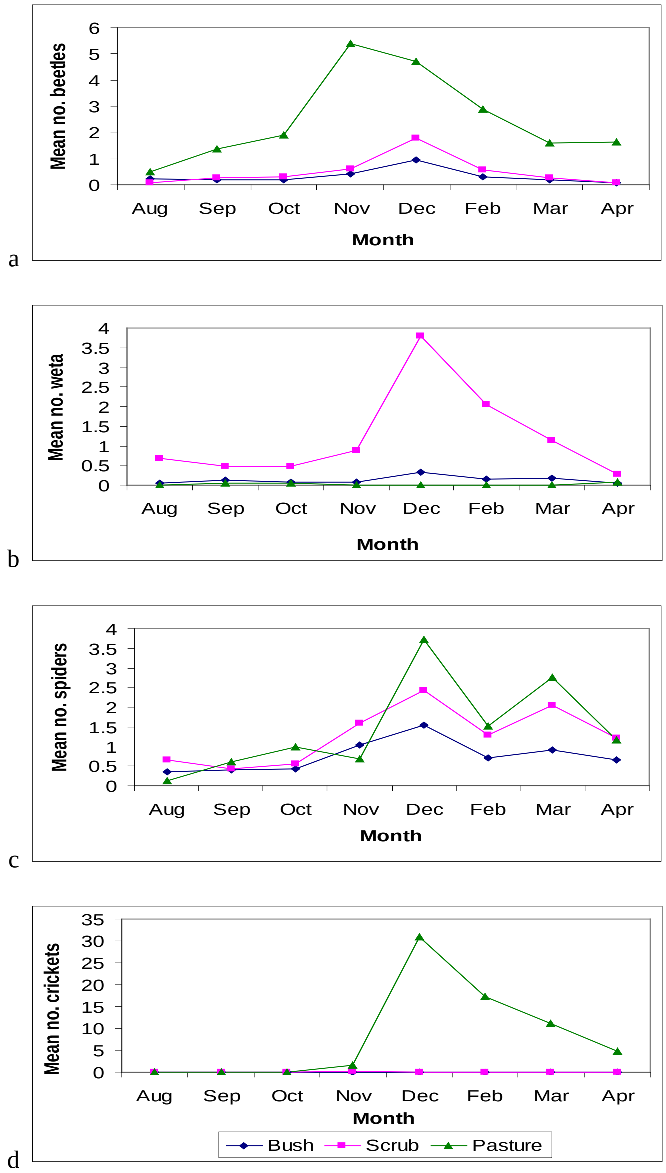
Appendix 2.1

The mean number (± s.e.) of each taxon identified per pitfall site between August 2007 and April 2008.

Taxon	**Mean number**
Arthropoda	29.696 ± 6.670
Coleoptera	5.138 ± 2.100
Scarabaeidae	4.503 ± 2.147
Saphobius spp.	4.306 ± 2.133
Heteronychus arator	0.166 ± 0.047
Costelytra spp.	0.008 ± 0.005
Odontria xanthosticta	0.014 ± 0.007
Pyronota spp.	0.001 ± 0.001
Stethaspis spp.	0.001 ± 0.001
Acrossidius tasmaniae	0.010 ± 0.010
Other	0.006 ± 0.005
Coccinellidae	0.005 ± 0.004
Coccinella undecimpunctata	0.005 ± 0.004
Carabidae	0.290 ± 0.114
Laemostenus complanatus	0.175 ± 0.060
Cicindela tuberculata	0.107 ± 0.060
Other	0.006 ± 0.004
Cerambycidae	0.001 ± 0.001
Tetrorea cilipes	0.001 ± 0.001
Curculionidae	0.016 ± 0.006
Ectopsis simplex	0.001 ± 0.001
Other	0.016 ± 0.006
Elateridae	0.255 ± 0.072
Tenebrionidae	0.006 ± 0.004
Lucanidae	0.006 ± 0.003
Parallissofes stewarti	0.005 ± 0.003
Mitophyllus parrianus	0.001 ± 0.001
Staphylinidae	0.068 ± 0.024
Zopheridae	0.001 ± 0.001
Histeridae	0.003 ± 0.003
Other	0.001 ± 0.001
Larvae	0.275 ± 0.093
Diptera	1.026 ± 0.643
Brachycera	0.951 ± 0.649
Culcidae	0.037 ± 0.014
Acroceridae	0.019 ± 0.012
Sciaroidea	0.007 ± 0.007
Stratiomyidae	0.006 ± 0.005
Tipulidae	0.006 ± 0.006
Hymenoptera	1.846 ± 0.723
Apidae	0.011 ± 0.004
Vespidae	0.009 ± 0.005
Pompilidae	0.028 ± 0.007

Formicidae	1.795 ± 0.726
Odonata	0.001 ± 0.001
Hemiptera	0.033 ± 0.017
Pentatomidae	0.030 ± 0.017
Cicadidae	0.002 ± 0.001
Other	0.001 ± 0.001
Orthoptera	2.471 ± 0.981
Anostostomatidae	0.041 ± 0.020
Hemiandrus spp.	0.039 ± 0.018
Hemideina thoracica	0.002 ± 0.001
Raphidophoridae	0.504 ± 0.160
Tettigoniidae	0.002 ± 0.002
Gryllidae	1.924 ± 0.814
Bobilla spp.	0.272 ± 0.124
Teleogryllus commodus	1.652 ± 0.783
Blattodea	0.393 ± 0.141
Collembola	0.188 ± 0.021
Amphipoda	7.805 ± 2.239
Turbellaria	0.054 ± 0.034
Oligochaeta	0.369 ± 0.121
Gastropoda	0.806 ± 0.249
Isopoda	6.232 ± 1.715
Chilopoda	0.067 ± 0.016
Diplopoda	0.395 ± 0.140
Pseudoscorpionidea	0.002 ± 0.001
Acari	0.020 ± 0.012
Phalangida	1.220 ± 0.339
Araneida	1.317 ± 0.285
Zoropsidae	1.068 ± 0.224
Salticidae	0.050 ± 0.016
Thomisidae	0.025 ± 0.012
Dolomedes minor	0.034 ± 0.031
Dysderidae	0.001 ± 0.001
Sidymella spp.	0.005 ± 0.004
Small unknown spp.	0.134 ± 0.043
Lepidoptera	0.037 ± 0.012
Vertebrata	0.022 ± 0.011
Reptilia	0.022 ± 0.011
Cylodina aenea	0.022 ± 0.011

Appendix 2.2a



The monthly mean number of a), beetles b), weta c), spiders and (d), crickets (excluding those <1cm in length) per pitfall site in each of bush, scrub and pasture from August 2007 until April 2008 on Ponui Island.

Appendix 2.2b

The monthly mean number (± s.e.) of beetles, weta, spiders and crickets (excluding those <1cm in length) per pitfall site in each of bush, scrub and pasture from August 2007 until April 2008 on Ponui Island.

		Beetles	**Weta**	**Crickets**	**Spiders**
Bush	Aug	0.24 ± 0.11	0.04 ± 0.03	0	0.36 ± 0.07
	Sep	0.20 ± 0.13	0.12 ± 0.06	0	0.40 ± 0.10
	Oct	0.18 ± 0.07	0.08 ± 0.05	0	0.42 ± 0.08
	Nov	0.40 ± 0.13	0.08 ± 0.04	0.04 ± 0.04	1.04 ± 0.11
	Dec	0.96 ± 0.38	0.34 ± 0.12	0	1.54 ± 0.31
	Feb	0.30 ± 0.12	0.16 ± 0.07	0	0.72 ± 0.15
	Mar	0.20 ± 0.06	0.18 ± 0.11	0	0.90 ± 0.22
	Apr	0.08 ± 0.05	0.04 ± 0.04	0	0.66 ± 0.15
Scrub	Aug	0.08 ± 0.03	0.68 ± 0.21	0	0.66 ± 0.16
	Sep	0.26 ± 0.12	0.48 ± 0.11	0	0.42 ± 0.17
	Oct	0.30 ± 0.13	0.48 ± 0.13	0	0.56 ± 0.10
	Nov	0.62 ± 0.27	0.88 ± 0.23	0.20 ± 0.10	1.60 ± 0.33
	Dec	1.80 ± 0.72	3.80 ± 0.96	0	2.42 ± 0.38
	Feb	0.56 ± 0.39	2.04 ± 0.55	0	1.28 ± 0.29
	Mar	0.26 ± 0.14	1.14 ± 0.19	0	2.06 ± 0.42
	Apr	0.06 ± 0.04	0.28 ± 0.12	0	1.22 ± 0.19
Pasture	Aug	0.48 ± 0.19	0	0	0.12 ± 0.08
	Sep	1.36 ± 0.41	0.04 ± 0.04	0.08 ± 0.08	0.60 ± 0.25
	Oct	1.88 ± 0.63	0.04 ± 0.04	0	1.00 ± 0.28
	Nov	5.40 ± 1.98	0	1.48 ± 0.81	0.68 ± 0.37
	Dec	4.72 ± 0.61	0	30.92 ± 7.67	3.72 ± 1.33
	Feb	2.88 ± 0.50	0	17.20 ± 2.32	1.52 ± 0.51
	Mar	1.60 ± 0.56	0	11.20 ± 2.63	2.76 ± 1.02
	Apr	1.64 ± 1.49	0.06 ± 0.04	4.72 ± 0.54	1.15 ± 0.53

Appendix 2.3

Mean (± s.e.) monthly temperature, dew point and relative humidity (from data logger on Ponui Island), and rainfall on nearby Waiheke Island during the study period.

Month	**Temperature (°C)**	**Dew Point (°C)**	**Relative Humidity (%)**	**Waiheke rainfall (mm)***
August	10.98 ± 0.08	9.95 ± 0.08	93.97 ± 0.42	3.73 ± 8.04
September	11.99 ± 0.09	10.24 ± 0.09	89.47 ± 0.33	1.65 ± 2.72
October	13.10 ± 0.09	11.11 ± 0.09	88.29 ± 0.38	4.76 ± 11.35
November	14.56 ± 0.09	12.11 ± 0.07	85.85 ± 0.40	1.85 ± 3.09
December	17.40 ± 0.08	14.99 ± 0.07	86.33 ± 0.39	2.37 ± 5.71
January	19.58 ± 0.09	16.10 ± 0.08	81.23 ± 0.46	0.62 ± 2.04
February	18.68 ± 0.08	17.74 ± 0.13	95.95 ± 0.67	2.18 ± 7.38
March	18.19 ± 0.07	16.43 ± 0.07	90.09 ± 0.43	1.08 ± 4.23
April	15.89 ± 0.08	14.85 ± 0.13	94.33 ± 0.50	3.02 ± 6.27

*Source: http://clifo.niwa.co.nz.

Appendix 2.4

The total number of invertebrates of each identified taxon caught in interceptor traps on Ponui Island from November 2007 until April 2008.

Taxon	**Number**
Arthropoda	
Coleoptera	297
Scarabaeidae	104
Saphobius spp.	53
Costelytra spp.	1
Odontria xanthosticta	49
Heteronychus arator	1
Cerambycidae	5
Unknown	1
Tetrorea cilipes	1
Prionoplus reticularis	3
Elateridae	51
Conoderus exsul	33
Metablax cinctiger	3
Thoramus wakefieldi	15
Carabidae	4
Laemostenus complanatus	4
Lucanidae	71
Mitophyllus arcuatus	63
Mitophyllus parrianus	8
Curculionidae	2
Tenebrionidae	24
Oedemeridae	6
Anobiidae	30
Araneida	7
Unknown	2
Salticidae	1
Thomisidae	4
Diptera	70
Culcidae	46
Simuliidae	2
Tipulidae	16
Brachycera	4
Stratiomyidae	2
Blattodea	1
Plecoptera	1
Odonata	5
Gastropoda	1
Lepidoptera	1729
Hymenoptera	8
Formicidae	2
Apidae	1
Pompilidae	5
Orthoptera	12
Anostostomatidae	1
Hemideina thoracica	1
Raphidophoridae	9
Gryllidae	2
Hemiptera	17
Acanthosomatidae	2
Ricaniidae	13
Cicadidae	2

Appendix 2.5

The mean number (± s.e.) of each species of large (>100g) bird counted per station during five minute bird counts carried out on Ponui Island between October 2007 and April 2008.

		Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**
Tui	*Prosthemadera novaeseelandiae*	0.25 ± 0.18	1.42 ± 0.26	0.92 ± 0.29	0.67 ± 0.19	0.58 ± 0.26	0.75 ± 0.22	1.42 ± 0.32
Magpie	*Gymnorhina tibicen*	0.17 ± 0.67	0.67 ± 0.45	0.58 ± 0.23	0.83 ± 0.44	0.42 ± 0.19	1.50 ± 0.47	0.50 ± 0.23
Myna	*Acridotheres tristis*	0.08 ± 0.08	0.50 ± 0.23	0.58 ± 0.19	0.50 ± 0.23	1.00 ± 0.33	0.92 ± 0.29	0.92 ± 0.38
New Zealand woodpigeon	*Hemiphaga novaeseelandiae*	0.25 ± 0.18	0.08 ± 0.08	0.42 ± 0.19	0.33 ± 0.22	0.42 ± 0.19	0.17 ± 0.11	0
Australasian harrier	*Circus approximans*	0.50 ± 0.19	0	0.08 ± 0.08	0	0	0	0.08 ± 0.08
Paradise shelduck	*Tadorna variegata*	0	0.42 ± 0.34	0	0	0	0	0.25 ± 0.25
Spur-winged plover	*Vanellus miles*	0.08 ± 0.08	0.08 ± 0.08	0	0	0	0	0.08 ± 0.08
Pukeko	*Porphyrio porphyrio*	0	0	0	0.08 ± 0.08	0	0	0
Eastern rosella	*Platycercus eximius*	0.08 ± 0.08	0	0	0	0	0	0

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Chapter Three: The diet of moreporks (*Ninox novaeseelandiae*) on Ponui Island in relation to availability of their prey

3.0 Abstract

Data were collected on the diet of moreporks (*Ninox novaeseelandiae*) on Ponui Island in the Hauraki Gulf (36°50′S, 175°10′E) from August 2007 until April 2008, and compared with the relative abundance of their prey. Over this period, 226 regurgitated pellets were collected from beneath the daytime roosts of seven radio-tagged moreporks as well as some unmarked birds, and dissected to determine their content. The relative abundance of known morepork prey: invertebrates, birds and mice (*Mus musculus*), was monitored over the same period. On average, 98.2% of prey items in pellets were invertebrates, with weta (Anostostomatidae and Raphidophoridae) and beetles (Coleoptera) being the most frequently recorded taxa. Vertebrate prey (mostly rodents) made up only 1.8% of prey items in pellets on average, but 39.4% of the estimated biomass. There were significant differences between months in the composition of pellets. The mean percentage contribution of beetles, weta, spiders (Araneida) and crickets (Gryllidae) to pellet samples showed a positive relationship with availability as indicated by the percentage contribution of the same taxa to pitfall traps. Additionally, there were spikes in the ocurrence of seasonally abundant taxa in pellet samples including cicadas (Cicadidae) and huhu beetles (*Prionoplus reticularis*). There were also some significant differences between the contents of pellets from bush and scrub roosting birds, with pellets of scrub roosting birds containing more crickets and earwigs (Dermaptera). A peak in the number of rodent prey in pellet samples in April appeared to be related to increased density estimates of ship rats (*Rattus rattus*) as calculated by a concurrent study. This suggests that the impact of rodent control campaigns on moreporks due to secondary poisoning might vary considerably with the season. As moreporks appeared to favour abundant prey sources, they are not likely to threaten persistence of prey populations in most cases, and may have some degree of stabilising influence. The results of the current study suggested high dietary overlap of the morepork with other abundant species on Ponui such as North Island brown kiwi

(*Apteryx mantelli*) and ship rats (as indicated by previous research), such that there is potential competition for invertebrate prey on the island.

3.1 Introduction

3.1.1. The importance of dietary studies

The diet of an organism is important in ecology, as what an animal eats affects the abundance and distribution of both the consumer in question, and its prey (Begon et al., 1996; Pimm, 1982; Polis, 1991). In addition, the diet of a species may overlap with that of others resulting in the potential for competition (Wootton, 1994).

As such, much research involving the construction of food webs showing the trophic interactions between species in a community has been conducted over the past few decades (Paine, 1988; Pimm, 1982; Polis, 1991; Schoener, 1989). Additionally, the dynamics of communities have been investigated in some cases using perturbation experiments such as predator removal to look at the effects on other species (Estes et al., 1989; Krebs et al., 2001; Wootton, 1994).

Based on these types of experiments and analyses, two major theories of community regulation have been formulated 1), that systems are regulated from the bottom up by nutrient flow, as plants are essential to the levels above (White, 1978, 1984) and 2), that systems are regulated from the top down by predators (Hairston et al., 1960; Slobodkin et al., 1967). There are examples of both scenarios in nature (Nystrom et al., 2003; Oksanen et al., 1981; Polis & Winemiller, 1996), and a system may also alternate between the two (Fretwell, 1977; Oksanen, 1988; Oksanen et al., 1981).

Frequently, the study of how a species responds functionally to the abundance of its prey is utilised to assess predator-prey population dynamics (Andersson & Erlinge, 1977; Hanski et al., 1991; Holling, 1959; Korpimaki, 1987; Korpimaki & Norrdahl, 1989, 1991; O’Donoghue et al., 2001; Rohner et al., 2001). See Chapter One for details of the commonly distinguished types of functional response. Predator-prey theory predicts that the number of a given prey type killed by a generalist predator will be density dependent at low densities, having a stabilising influence (Andersson & Erlinge, 1977; Hanski et al., 1991; Holling, 1959; Sinclair et al., 1998). In contrast, the proportion of the prey population removed by a specialist predator is more likely to be inversely density dependent, and thus potentially destabilising (Andersson & Erlinge, 1977; Hanski et al., 1991; Holling, 1959; O'Donoghue et al., 2001; Sinclair et al., 1998).

3.1.2 Factors affecting diet

The physiology of an animal places basic constraints on the type of prey it is able to take – for example, gape size in birds (Begon et al., 1996). However, most animals will feed on a narrower range of prey than they are physically able, and, within this range, show a preference for some types over others (Begon et al., 1996; Stephens & Krebs, 1986).

MacArthur and Pianka (1966) formulated a theory of optimal foraging in which a predator should make foraging decisions in order to maximise its overall mean rate of energy intake. Under this theory, a foraging animal should search until it detects a potential prey item and then decide whether or not to pursue it based on its profitability - the expected energy gain compared to energy expenditure involved in 'handling'(i.e., capturing, subduing and consuming) the prey. This theory predicts that, in general, animals with relatively short handling times in comparison to search times should have broader diets, and predators with long handling times should be specialists (Charnov et al., 1976; MacArthur & Pianka, 1966). Thus, a generalist such as an insectivorous bird is likely to consume more of the abundant species within its preferred range than those that are scarce, as they will be encountered more often (MacArthur & Pianka, 1966; Stephens & Krebs, 1986). However, a range of factors might affect the foraging decisions made by a predator including how efficient it is at recognising different prey types (Erichsen et al., 1980), and how encounter rates affect selectivity (Stephens & Krebs, 1986). For example, bluegill sunfish (*Lepomis macrochirus*) (Werner & Hall, 1974), and great tits (*Parus major*) (Krebs et al., 1977) were observed to prefer large prey types over smaller ones when large prey were frequently encountered, whereas at low encounter rates, they were not selective.

Alternatively, foraging decisions may not be exclusively related to profitability but also to selection of a nutritionally balanced diet (Pulliam, 1975). This is often most obvious in generalist herbivores due to high variation in the nutritional content of plants (Arnold, 1964; Crawley, 1983). The concentration of toxins in different prey types can also influence their relative contribution to the diet (Belovsky, 1981; Bryant & Kuropat, 1980). In addition, there may be a trade-off between optimal foraging and other aspects of fitness (Lima & Dill, 1990; Ydenberg & Houston, 1986). For example, the diet of bottlenose dolphins (*Tursiops aduncus*) was found to vary seasonally according to risk of tiger shark (*Galeocerdo cuvier*) predation, as dolphins avoided highly productive but dangerous habitats when the sharks were abundant in these areas (Heithaus & Dill, 2002). Territorial defence may also affect the efficacy of foraging: The great tit (*Parus major*) defends its territory in the tree tops but feeds largely on the ground, presumably because that is where its preferred prey types are most abundant, therefore there is a trade-off between these two activities (Ydenberg & Houston, 1986).

3.1.3 The importance of dietary studies in New Zealand

In New Zealand, knowledge of the trophic interactions between predator and prey is of particular importance in the context of the impacts of introduced mammalian predators on native wildlife (King, 2005). As such, the ecological importance of these introduced predators is well acknowledged and a number of studies have investigated their diet and their relationships with their prey (e.g. Brown, 1997; Harper, 2005; King, 1983; Murphy et al., 1998; Murphy et al., 2008; Murphy & Dowding, 1995; Shapiro, 2005) as discussed in Chapter One.

However, little research has focused on these aspects of the ecology of native avian predators such as the morepork (*Ninox novaeseelandiae*), Australasian harrier (*Circus approximans*) and weka (*Gallirallus australis*) (see Higgins, 1999 and Marchant and Higgins, 1993 for summaries). Although these species are not likely to have such dramatic impacts on prey species as exotic mammalian predators, they are nonetheless an important constituent of natural systems. In certain situations, the negative impact of their predation on small populations of native species may be great, especially when considered in combination with the effects of mammalian predators. For example, harriers have been recorded as frequent predators at kokako (*Callaeas cinereas*) nests in the Hunua ranges, such that their control may be justified when kokako numbers are very low (Innes & Flux, 1999). Another issue for consideration by conservation managers is that avian predators have been recorded as victims of secondary poisoning during control operations aimed at introduced mammalian predators (e.g. Eason et al., 2002; Ogilvie et al., 1997).

3.1.4 Morepork diet

The morepork is New Zealand’s only extant native owl, and is common throughout much of the country (Higgins, 1999). The boobook owl of Australia is classified under the same species name (Higgins, 1999), although there are differences in biology between the two (Olsen & Moon, 1990). For more information on the biology of moreporks and boobooks see Chapter One.

Although a number of studies have included information on the diet of moreporks or boobooks (see Higgins, 1999 for summary, as well as Haw & Clout, 1999, Haw et al., 2001 and Penck & Queale, 2002), many were based on a small sample size of birds and/or pellets (Anderson, 1992; Baker-Gabb, 1984; Calaby, 1951; Campbell & Rose, 1996; Clark, 1992; Cunningham, 1948; Daniel, 1972; Imboden, 1975; Moon, 2005; Ramsay & Watt, 1971; Rose, 1996), and only a few of the studies were sufficient for assessment of seasonal differences in the diet (Haw & Clout, 1999; Haw et al., 2001; Lindsay & Ordish, 1964; Penck & Queale, 2002; Stephenson, 1998).

These studies indicate that moreporks are primarily insectivorous, although small amounts of vertebrate prey are also consumed (Clark, 1992; Haw & Clout, 1999; Haw et al., 2001; Lindsay & Ordish, 1964; Moon, 2005; Stephenson, 1998). Studies on the Australian boobook have shown a similar dietary composition (Campbell & Rose, 1996; Green et al., 1986; Penck & Queale, 2002; Rose, 1996). Moreporks generally survey an area from high perches, and locate prey using visual and auditory cues. Prey may be taken in flight, from trees, or on the ground (Higgins, 1999).

Beetles (Coleoptera), moths (Lepidoptera) and orthopterans including crickets (Gryllidae) and weta (Anostostomatidae and Raphidophoridae) have been reported as common prey of the morepork (Clark, 1992; Cunningham, 1948; Haw & Clout, 1999; Haw et al., 2001; Imboden, 1975; Lindsay & Ordish, 1964; Saint Girons et al., 1986) and the boobook (Campbell & Rose, 1996; Penck & Queale, 2002; Rose, 1996). However, many other invertebrate taxa are also taken including spiders (Araneida), stick insects (Phasmatidae), millipedes (Diplopoda) centipedes (Chilopoda), cicadas (Cicadidae), and mantids (Mantodea), and there is a considerable amount of variance in the composition of the diet between studies (see Higgins, 1999 for summary, as well as Haw & Clout, 1999, Haw et al., 2001 and Penck & Queale, 2002).

In New Zealand, vertebrate prey includes rodents such as house mice (*Mus musculus*) (Clark, 1992; Lindsay & Ordish, 1964; Stephenson, 1998), ship rats (*Rattus rattus*) (Haw et al., 2001) and kiore (*Rattus exulans*) (Saint Girons et al., 1986), as well as small birds (Aves) (Brown, 1997; Cunningham, 1948; Haw & Clout, 1999; Haw et al., 2001; Hogg & Skegg, 1961), bats (Chiroptera) (Dwyer, 1962; Worthy & Holdaway, 2002) and lizards (Reptilia) (Moon, 2005; Ramsay & Watt, 1971). It appears that vertebrate prey may only be taken by moreporks in large numbers when they are particularly common (Haw et al., 2001; Saint Girons et al., 1986). The Australian boobook also consumes birds, rodents, reptiles and bats, but, in addition may take small marsupials (Marsupiala) (Baker-Gabb, 1984; Campbell & Rose, 1996; Green et al., 1986; Penck & Queale, 2002; Rose, 1996).

Moreporks and boobooks have been observed flushing cicadas from foliage (Stephenson, 1998), attacking birds caught in mist-nets (Imboden, 1975) and catching insects attracted to lights (Ramsay, 1988; Rose, 1973). Thus, they have been described as generalist, opportunistic predators that exploit seasonally abundant prey species (Cunningham, 1948; Green et al., 1986; Haw & Clout, 1999; Haw et al., 2001; Lindsay & Ordish, 1964; Penck & Queale, 2002; Stephenson, 1998).

Haw and Clout (1999) and Haw et al. (2001) looked specifically at seasonal variation in the morepork diet based on the study of 53 stomach samples from throughout New Zealand, and 189 pellet samples from Pureora Forest Park respectively. Both studies found beetles, orthopterans and spiders to be consumed throughout the study period whilst Haw and Clout (1999) found there was a peak in consumption of moths and cicadas in summer, and Haw et al. (2001) noted a peak in stick insect consumption in winter. Lindsay and Ordish (1964) also noted that weta appeared to be a staple of the morepork diet, whilst there was more variation in seasonally abundant taxa such as cicadas (based on analysis of 25 stomach samples). Similarly, Penck and Queale (2002) analysed the gizzard contents of 117 boobooks and found that beetles were frequent prey throughout the year, with increased prevalence of moths during spring, and of mice during autumn. Based on their findings, the authors of these studies, along with several others on morepork diet (Cunningham, 1948; Saint Girons et al., 1986; Stephenson, 1998), have suggested a relationship between the diet and fluctuations in the availability of prey.

However, no study of morepork (or boobook) diet has concurrently measured the relative abundance of its prey. Rather, the suggestion of a functional relationship has been based on circumstantial evidence or general trends in seasonal abundance revealed by spatially or temporally distinct studies. This has the potential to be misleading, as comparisons may have been made between quite different habitats, or the seasonal abundance of prey species may differ substantially between years.

As a common, generalist predator (Higgins, 1999) the morepork is a component of ecosystems throughout the country, and has the potential to interact with many other species, as a predator and a competitor. As such, simultaneous monitoring of morepork diet and prey abundance would help to improve understanding of the bird's feeding behaviour, and its role in communities.

Research of this kind would also help to elucidate the importance of vertebrate prey to the species, and the potential for secondary poisoning. Dead moreporks have been found following rodent poisoning operations using brodifacoum (Eason & Spurr, 1995; Ogilvie et al., 1997; Stephenson et al., 1999; Walker & Elliott, 1997) and 1080 (sodium monofluoroacetate) (Spurr & Powlesland, 1997), presumably as a result of secondary poisoning. Of the birds that were not too decayed to be assayed by Ogilvie et al. (1997) (n=1) and Stephenson et al. (1999) (n=2), all contained brodifacoum residues in their tissues. With this in mind, recent studies on morepork diet in New Zealand have focused on the amount of vertebrate prey included, and the associated risk of secondary poisoning during pest control operations. Stephenson et al. (1999) found that there was a moderate risk to morepork populations on Mokoia Island based on their relatively high consumption rates of mice (which were probably abundant due to the absence of rats), and mortality rates following a poisoning operation. On the other hand, Haw et al. (2001) found that consumption of rodents in Pureora Forest Park was low, despite the fact that they were considered to be fairly abundant throughout the study. This lead to the suggestion that moreporks only eat rodents when they are very abundant (as they may be on some islands), such that the risk of secondary poisoning in mainland forest is probably low. However, they pointed out that their study did not include the period from January to April when rodents may have been more abundant (Haw et al., 2001).

Another point for consideration is that no studies on morepork diet, and only one on the boobook (Baker-Gabb, 1984) have estimated the biomass or calorific value of the vertebrate prey consumed. Instead, prey species in the diet have been measured by either their number or frequency of occurrence in pellets, stomachs or gizzards. For this reason, the importance of vertebrate prey, which could contribute a large amount of biomass to the diet, may have been under-emphasised. There have also been variable suggestions about the role of vertebrate prey in the diet; either that inclusion is purely opportunistic (Haw et al., 2001; Penck & Queale, 2002), or that it is selected for during the breeding season (Imboden, 1985; Schodde & Mason, 1980).

3.1.5 The aims of this study

The aims of the current study are 1), to analyse the diet of the morepork on Ponui Island, and 2), to compare changes in dietary composition with changes in the relative abundance of its key prey groups - invertebrates, birds and rodents (as collected in Chapter Two).

3.2 Methods

3.2.1 Study site

The study site for this project was Ponui Island located in the Hauraki Gulf 30km east of Auckland (36°50′S, 175°10′E; see Chapter One, Fig. 1.1). Ponui Island is 1770ha of which just under a third remains forested with regenerating broadleaf-podocarp forest. The remainder was cleared for agriculture in the early 1900's (Brown, 1979). Additionally, considerable amounts of kauri logging was carried out in the bush around the same time, and many of the ridges were burnt off for grazing such that they are now covered in scrub and regenerating forest (D. Chamberlin, Ponui farmer, pers. comm.).

The research area consisted of four gullies adjacent to each other – Red Stoney Hill (RSH) Gully, Pipe Gully, Straight Gully and Hook Gully (see Chapter One, Fig. 1.1), covering an area of approximately 90ha within a 250ha tract of forest on the southern end of the island. These gullies were chosen for ease of access and representativeness of forest types, along with the fact that previous research (e.g. Latham, 2006; Shapiro, 2005) has been carried out in this area, such that the present study will add to overall knowledge of the site.

3.2.2 Capturing and handling moreporks

Moreporks were very difficult to catch, with several techniques being trialled in July of 2007 including use of 2.6x9m, 38mm and 60mm mesh (Avinet™ Ltd, USA) mist-nets and a bal-chatri trap (40cm diameter) (see Berger & Mueller, 1959). Several lures were also trialled to attract moreporks to mist-nets including 1), use of 'Original Mockingbird™ Audubon bird callers to mimic distressed bird calls 2), broadcasting taped morepork calls 3), placing a life sized stuffed-toy morepork (NativeZ™) close to the net and 4), stationing a juvenile chicken in a cage underneath the net. Mist-nets were opened at dusk with a person nearby making calls using bird callers and/or the tape. During this first catching session (1/7/07-8/7/07), moreporks showed some interest in all of the lures, and two flew into the net but bounced out. Initially, one or two nets were opened at dusk for a period of time between 30 and 90 minutes dependent on the apparent interest from moreporks in the area, based on sightings and call-bouts from nearby. If no moreporks were caught, these nets would be closed and others opened elsewhere, and so on until about 22:00hrs. However, it was noticed that birds seemed to be more receptive earlier in the evening, and made more flights at low altitude. The bal-chatri was trialled with a wild juvenile ship rat inside it, in conjunction with taped calls. Birds showed some interest, but there were no strikes. Accordingly, in subsequent catching sessions, mist-nets only were used. These were opened from dusk until 30 minutes after nightfall, and additionally, at dawn to try and catch birds leaving or returning to their roosting sites. All of the trialled lures were used except for the live chicken and rat as they appeared not to attract more attention than the other methods. In this manner, nine moreporks were captured between August and December 2007 during four week-long mist-netting trips.

Once captured, each bird was fitted with an (E size) metal leg band supplied by the NZ banding office which had a unique number on it, and a ‘backpack’ mounted radio transmitter (Plate 3.1). Transmitters were manufactured by Kiwi Track Ltd (6 Station Rd, Whakatu), and harnesses by Sirtrack Ltd (Goddard Lane, Havelock North). The mass of each transmitter was 4g and the harness 1g. As moreporks are usually between 140 and 240g (Robertson et al., 1983; Stephenson, 1998), the combined mass of the transmitter and the harness was 2-3.6% of the birds’ body mass - below the 4-5% of body mass that has generally been found to cause adverse effects when harness mounted tags are used (Kenward, 2001). The harness included a weak link on the breast designed to break if the bird became entangled.

The following morphometric data were collected; mass to the nearest gram (using a 300g Pesola® spring balance), bill width (at the cere), and tarsus length (from the proximal end of the tarsometatarsus to the distal end of the first metatarsal of the third digit) and width (widest part) to the nearest tenth of a millimetre using Kincrome® vernier calipers, and wing length (maximum flattened straightened cord), using a small tape measure, to the nearest millimetre. In addition, a blood or (loose secondary) feather sample was also collected from each bird for the purpose of molecular sexing. Blood samples (max. 175 µl) were taken by tarsal venipuncture. Each radio-tagged bird was assigned an identification code consisting of the letter M followed by the last digit of its band number (Table 3.3).

Unfortunately, two of the birds (bird M2 caught on 4/8/07 and bird M8 caught on 21/11/07) dropped their transmitters before any data were collected from them. One of these transmitters was found with the harness intact, indicating that perhaps the harness was loose enough for the bird to wriggle free, whilst the other was not recovered as it appeared to be up a tree. The transmitter from another bird, (M4, caught on 7/8/07) was found during October. In this case the weak link appeared to have been bitten by the bird. However, the bird was still able to be located on a regular basis as many of its regular roost sites had been identified, and it continued to roost in the same general area.

Photo by Shane McPherson

Photo by the author

Plate 3.1 a), Placement of the ‘backpack’ transmitter on a morepork prior to trimming of the surplus harness string, and b), a banded morepork in the hand.

3.2.3 Diet of moreporks

Moreporks regurgitate pellets of indigestible material below their daytime roosts (Heather & Robertson, 1995). The diet of moreporks on Ponui Island was assessed by examining the contents of these pellets (see Plates 3.2 and 3.3).

Plate 3.2 Examples of morepork pellets collected on Ponui Island showing variation in shape and size (photo by the author).

Radio-tagged birds were tracked to their roosts during the day, and their pellets collected either in the evening, once the bird had left its roost, or on a subsequent day when the bird was roosting elsewhere, to avoid disturbing the bird. As such, all pellets were thought to be <1 week old. If multiple pellets were present at a roost site only those that appeared to be fresh were collected. Pellets were collected from each radio-tagged bird (as well as some untagged birds whose location was known) each month from August 2007 through to April 2008 with the exception of January 2008. Pellets were stored in plastic containers containing 70% ethanol and labelled with the date of collection and the individual or pair from under whose roost they were collected.

3.2.3.1 Pellet composition

Pellets were examined under a dissecting microscope (Plate 3.3) and, where possible, contents were classified to order or a lower taxonomic level. Pellet contents were identified by comparison with a self-built reference collection made up of pitfall and interceptor trap contents (see Chapter Two) as well as by using reference books (Crowe, 2002; Gillott, 1995; Walker, 2000) and the invertebrate and vertebrate collections held at Auckland Museum.

The content of individual pellets was expressed in three ways; 1), presence or absence of each prey group (a score of either 1 if present or 0 if absent), 2), the minimum number of each prey type where possible 3), an estimation of biomass was made based on this minimum number, (see explanation on pg. 96). If components such as heads, intact elytra, mandibles, chelicerae, pincers or jaws were present, these were used to obtain a minimum number of individuals of each prey type using the method suggested by Calver and Wooller (1982). A head would equate to one animal whereas body parts that come in pairs (e.g. mandibles) were measured, and if a right and left component of the appropriate size were present, these were counted as one individual. Minimum numbers were also estimated based on the total number of legs in cases where they were both easily distinguishable from the legs of other animal types (e.g. huhu beetle, *Prionoplus reticularis*, legs) and adequately intact. If more than one quantifiable body part of a certain prey type was present (e.g. heads and mandibles), that which yielded the higher number was used.

Rodent prey was identified as being a ship rat, a mouse or an unidentified rodent. This classification was based largely on the size of mandibles and teeth, using museum specimens as a reference. In the case of there being only very small rodent bones or bone fragments and/or fur present, the item was classified as an unknown rodent. Additionally, in a number of cases, the mandibles or teeth were of a size such that it could not be reliably determined whether they were from a juvenile ship rat or a mouse - these specimens were also classed as unknown rodents. Identification of birds was based on the presence of feathers, beaks and bones using references from Auckland Museum. Where bone fragments were too small to be reliably identified as bird, rodent or other, they were classified as unknown vertebrate.

Plate 3.3 Contents of one morepork pellet in a Petri dish (photo by the author).

To avoid pseudoreplication, the presence scores and minimum numbers obtained from the analysis of all individual pellets from each pair of birds for a given month were averaged to give a score for that ‘pellet sample’ (i.e. for pair M4/M5 this would include all pellets from either individual). This system was implemented as pellets from members of a pair cannot be considered to be independent. Additionally, moreporks frequently roosted as pairs, such that pellets that could be from either individual made up a large proportion of the data set (Table 3.4). The presence scores, which were initially assigned a value of either 0 or 1, after averaging of pseudoreplicates became a continuum of decimal values between 0 and 1.

Overall monthly scores for 1), the presence of each prey taxon, and 2), the minimum numbers of each taxon per pellet sample were then obtained by combining the monthly scores for each pair as calculated previously, and dividing by the number of pairs sampled. These shall be referred to as 1), mean presence scores and 2), the mean number of each prey taxon per pellet sample, throughout the text. The mean numbers of each taxon per pellet sample were used for all statistical analyses, however, the monthly mean presence scores allowed for a comparison of the trends in occurrence of moths in pellets with other prey types.

An estimate of the biomass that each prey type contributed to the diet was also made, largely for the purpose of comparing the contribution of invertebrate and vertebrate prey to total biomass represented by pellet contents. These values were obtained by multiplying the mean number of each prey taxon per pellet sample in a given month by its estimated biomass. These values shall be referred to as the mean biomass of each taxon per pellet sample. The estimate of bird mass was the mean of the mass of the small birds most frequently counted in the bush on Ponui (see Chapter Two) taken from Heather and Robertson (2005) (Table 3.1). The estimate of mouse mass was taken from Fitzgerald and Karl (1979) (Table 3.2). As many ship rat remains in pellets appeared to be from juveniles, a conservative estimate of 40g was used based on the mass of newly weaned ship rats (Bentley & Taylor, 1965; Hooker & Innes, 1995). The mass used for a rodent of unknown species was the mean of the rat and mouse estimates, and the mass utilised for an unknown vertebrate was the mean of the rat, mouse and bird estimates (Table 3.2).

Some measures of invertebrate mass were obtained from Fitzgerald and Karl (1979), and others were altered slightly according to my estimations. For example, numerous small weta were included in the morepork diet on Ponui (pers. obs.), therefore the estimate of 1.67g was reduced to 1g. In addition, some taxa not included in the study of Fitzgerald and Karl (1979) were added based on my own estimations (Table 3.2).

Table 3.1 Mass of bird species (after Heather & Robertson, 2005) considered most likely to be preyed on by moreporks on Ponui Island.

Bird species		**Mean mass (g)**
Common name	**Scientific name**	
Fantail	*Rhipidura fuliginosa*	8
Silvereye	*Zosterops lateralis*	13
Grey warbler	*Gerygone igata*	6.5
Mean		**9.17**

Table 3.2 Mean mass of various prey types obtained from a study by Fitzgerald and Karl (1979), and the values used in the current study.

Prey Type		**Mass (g)**	
Common name	**Taxon**	**Fitzgerald and Karl (1979)**	**Current Study**
Beetle	Coleoptera	0.50	0.50
Weta	Anostostomatidae & Raphidophoridae	1.67	1.00
Cicada	Cicadidae	0.68	0.68
Spider	Araneida	0.50	0.65
Cricket	Gryllidae	no value	0.60
Shore earwig	*Anisolabus littorea*	no value	0.50
Cockroach	Blattodea	no value	0.30
Centipede	Chilopoda	no value	0.25
Millipede	Diplopoda	no value	0.25
Mouse	*Mus musculus*	15.5	15.50
Juvenile ship rat	*Rattus rattus*	no value	40.00*
Unknown rodent	Unknown Rodentia	no value	27.25
Unknown vertebrate	Unknown Vertebrata	no value	21.56

*****Based on the mass of newly weaned ship rats (Bentley & Taylor, 1965; Hooker & Innes, 1995).

In order to assess changes in the relative contribution of each taxon to pellet samples from month to month, the mean numbers of each different prey taxon per pellet sample were summed for a given month, and the percentage that each contributed to the total calculated. These values will be referred to as the mean percentage contribution of each taxon to pellet samples. The mean biomass of each taxon per pellet sample was converted to a percentage in the same way, and will be referred to as the biomass weighted mean percentage contribution to pellet samples.

Finally, summary statistics for pellet sample contents over the study period were obtained by averaging the monthly mean number and mean biomass of each taxon per pellet sample, summing the different prey taxa, and calculating the percentage that each contributed to the total. Monthly presence scores were also averaged to give a mean value for the entire study period.

3.2.3.2 Statistical analysis of pellet data

Standardised one way ANOSIM tests were carried out in PRIMER v5.2 (Clarke & Gorley, 2002) to compare the proportional composition of pellet samples between 1), pairs of birds and 2), months. An nMDS plot was also produced to provide a visual representation of the similarity between pellet samples**.** See Chapter Two for details of these statistical analyses**.**

In order to look at trends in each key prey taxon separately, univariate analyses were carried out in the package SPSS 15.0 (SPSS Inc., 2006). The data were not normally distributed and homoscedastic according to the Kolmogorov-Smirnov and Levene's tests respectively. Therefore, Kruskal-Wallis one-way analysis of variance tests were used to assess differences in the numbers of each of weta, beetles, spiders, cicadas, crickets and vertebrate prey (as an aggregate) in pellet samples between months. Unless otherwise stated, the level of significance for all statistical analyses was taken as α = 0.05.

3.2.3.3 Difference between birds that roosted in bush and those that roosted in scrub

Each pair of moreporks that was included in the dietary study (n =6) roosted in habitat classed broadly either as 'bush' or 'scrub' (Table 3.4; see Chapter Four for details of roost sites). The overall mean number and mean biomass of each taxon per pellet sample was calculated for bush and scrub roosting birds separately to provide a comparison. The overall mean presence scores for moths were also calculated for bush and scrub roosting birds separately for the same purpose. Differences in the mean number of each taxon in pellet samples of bush and scrub roosting birds were analysed using Mann-Whitney U tests. Additionally, the total number of prey items per pellet sample, and the total biomass of prey per pellet sample (all taxa combined) were also compared between bush and scrub roosting birds using Mann-Whitney U tests.

3.2.3.4 Relationship between pellet contents and prey availability

For the taxa that were regularly recorded in both pellets and pitfall traps (beetles, weta, spiders and crickets), the monthly mean number per pellet sample of each was compared with the mean number of the same taxon caught per pitfall site (see Chapter Two). This allowed for an assessment of whether moreporks responded functionally to relative abundance of their prey. The data did not meet the assumptions of Pearson's correlation of being normally distributed with equal variances, and could not be transformed to meet these assumptions. Therefore, Spearman's rank order correlation (Spearman's rho) was used.

The monthly mean percentage contribution of each of the abovementioned prey taxa to 1), pellet samples and 2), pitfall catch were also compared using Spearman's rho (monthly mean percentage contribution of each taxon to pitfall catch was calculated in the same way as for pellet samples). This allowed for investigation of whether moreporks responded to the availability of each taxon in relation to the total prey base.

It must be noted that carrying out multiple tests may increase the chance of a Type I error. Additionally, it should be considered that the data for each month may be autocorrelated to some degree due to the close temporal proximity, and the fact that pellets were repeatedly collected from the same birds. Accordingly, the results of the Spearman's correlations - particularly any that are only marginally significant, should be interpreted cautiously.

The monthly mean presence scores for moths, and the monthly mean percentage contribution to pellet samples of mice and birds were compared with relative abundance of these taxa using descriptive statistics and graphs, as sufficient data were not available to carry out other types of statistical analyses.

3.3 Results

3.3.1 Morepork morphometrics

Morphometrics, band numbers, and sex if known of radio-tagged moreporks are presented in Table 3.3.

Table 3.3 Measurements taken from captured moreporks on Ponui Island.

Band number	**Bird ID***	**Date caught**	**Mass (g)**	**Tarsus length (mm)**	**Bill width (mm)**	**Cord length (mm)**	**Sex**
E200501	M1	3/8/07	173	43.6	12.2	185	?**
E200502	M2	4/8/07	153	41.4	10.1	200	?**
E200503	M3	5/8/07	187	43.2	8.4	200	?**
E200504	M4	7/8/07	198	44.6	10.2	195	?**
E200505	M5	7/8/07	172	42.6	8.2	190	?**
E200506	M6	7/9/07	158	43.4	9.8	210	?**
E200507	M7	21/11/07	197	44.6	9.7	190	♀
E200508	M8	21/11/07	168	41.7	9.9	198	?**
E200509	M9	17/12/07	149	38.2	7.8	195	♂
Mean ± s.e.	n/a	n/a	172.78 ± 6.04	42.59 ± 0.66	9.59 ± 0.44	195.89 ± 2.43	n/a

*****These ID codes will be used to refer to the birds throughout the thesis. Additionally, M10/M11 will refer to an untagged pair in pipe gully and M12 to the untagged mate of bird M7.

**Blood samples were taken from these birds for the purpose of molecular sexing, however, for an unknown reason this was unsuccessful. Molecular sexing using feathers was successfully used for the other two birds.

3.3.2 Pellet contents over the period of the study

In total, 2696 individual prey items were identified in 226 pellets collected from at least 10 different birds. Collecting effort was approximately equal each month. However, not all birds entered the study at the same time (Table 3.3) and pellets weren't collected from all radio-tagged birds every month, such that the total number of pellets collected each month was variable (Table 3.4). It was not possible to confirm that untagged birds such as pair M10/M11 were always the same individuals. However, for the purposes of the dietary study it was assumed that this was the case.

Table 3.4 Monthly number of pellets found under the roosts of morepork individuals or pairs on Ponui Island between August 2007 and April 2008. Next to each pair the letter in brackets indicates whether that pair roosted in (b), bush habitat or (s), scrub habitat. Note that no data were collected during January of 2008.

Bird	**Month**								
	Aug	**Sep**	**Oct**	**Nov**	**Dec**	**Feb**	**Mar**	**Apr**	**Total**
M1	0	2	2	3	3	8	9	15	42
M2*	0	0	0	0	0	0	0	0	0
M1/M2 (s)	0	0	2	2	0	0	0	0	4
M3	1	2	3	0	1	8	5	4	24
M6	0	0	0	2	1	1	1	5	10
M3/M6 (b)	2	2	10	2	4	0	0	2	22
M4	1	0	3	0	4	2	5	3	18
M5	1	0	2	0	7	3	3	4	20
M4/M5 (s)	2	3	8	4	2	0	0	9	28
M10/M11 (b)	1	2	2	1	0	0	0	1	7
M7	0	0	0	0	3	7	4	4	18
M7/M12 (b)	0	0	0	0	4	4	3	0	11
M9	0	0	0	0	2	1	2	6	11
M9/M6 (s)	0	0	0	0	0	5	6	0	11
TOTAL	**8**	**11**	**32**	**14**	**31**	**39**	**38**	**53**	**226**

*This bird lost its transmitter in Sep/Oct therefore it was only sighted when roosting with M1. Note that bird M6 roosted with two different individuals – M3 and M9.

The majority of prey items in pellet samples were invertebrates (Table 3.5). Weta (Anostostomatidae and Raphidophoridae) made the largest mean percentage contribution to pellet samples over the study period, followed by Coleoptera, particularly scarab beetles (Scarabaeidae), but also longhorn beetles (Cerambycidae), weevils (Curculionidae), click beetles (Elateridae) and stag beetles (Lucanidae) (Table 3.5).

Spiders (Araneida) also made a substantial mean percentage contribution to pellet samples, followed by cicadas (Cicadidae) and crickets (Gryllidae) (Table 3.5). Although the number of moths (Lepidoptera) in each pellet could not be quantified, the mean presence score of 0.70 ± 0.08 suggested that this was also an important prey type. Other invertebrate prey included shore earwigs (*Anisolabus littorea*), as well as centipedes (Chilopoda) and millipedes (Diplopoda) although their mean percentage contribution was very small (Table 3.5).

The mean percentage contribution of vertebrate prey was also small, however, the biomass weighted mean percentage contribution was far greater (Table 3.5). Of the 57 individual vertebrate prey items identified in pellets, 20 were classed as unknown vertebrate, 15 as unknown rodent, 13 as ship rats (*Rattus rattus*), 4 as mice (*Mus musculus*) and 5 as birds (Aves).

Table 3.5 The overall mean percentage contribution to pellet samples (Percentage), the overall biomass weighted mean percentage contribution to pellet samples (Percentage biomass) and the overall mean presence scores (Presence) (± s.e.) for each taxon identified in a sample of morepork pellets collected on Ponui Island between August 2007 and April 2008.

Prey Item	**Percentage**[1]	**Percentage biomass**[1]	**Presence**
Arthropoda	98.2	60.6	
Coleoptera	32.9	13.4	0.77 ± 0.08
Unknown	3.2	*	*
Scarabaeidae	21.7	*	*
Unknown	6.3	*	*
Costelytra spp.	2.4	*	*
Stethaspis spp.	0.7	*	*
Odontria xanthosticta	11.5	*	*
Heteronychus arator	0.8	*	*
Cerambycidae	6.7	*	*
Unknown	0.5	*	*
Xuthodes punctipennis	1.2	*	*
Oemona hirta	0.7	*	*
Tetrorea cilipes	2.4	*	*
Prionoplus reticularis	2	*	*
Elateridae	0.6	*	*
Lucanidae	0.2	*	*
Curculionidae	0.4	*	*
Orthoptera	47.9	*	*
Anostostomatidae & Raphidophoridae	44.8	36.5	0.97 ± 0.01
Unknown	40.9	*	*
Hemideina thoracica	3.9	*	*
Gryllidae	3.1	1.5	0.10 ± 0.03
Araneida	10.2	5.4	0.47 ± 0.09
Dermaptera		*	*
Labiduridae	1.3	0.5	0.08 ± 0.03
Hemiptera	5.7	*	*
Cicadidae	5.7	3.2	0.31 ± 0.12
Chilopoda	0.02	*	*
Diplopoda	0.01	*	*
Blattodea	0.1	*	*
Lepidoptera	n/a	n/a	0.70 ± 0.07
Vertebrata	1.8	39.4	0.24 ± 0.08
Unknown	1	16.7	0.12 ± 0.07
Rodentia	0.7	22.1	0.11 ± 0.05
Unknown	0.3	7.3	0.04 ± 0.02
Rattus rattus	0.4	14.3	0.06 ± 0.03
Mus musculus	0.04	0.5	0.01 ± 0.01
Aves	0.1	0.7	0.01 ± 0.01

*Presence scores and percentage biomass estimates were calculated only for the main taxa of interest for comparative purposes.

[1] These values were obtained from the overall mean number or biomass of each taxon per pellet sample converted to a percentage of the sum of all taxa for clarity of presentation. The original mean values ± s.e. are presented in Appendix 3.1.

3.3.3 Monthly differences in pellet composition

There was a significant difference in the overall proportional composition of pellet samples between pairs of birds (one way ANOSIM (standardised); Global R = 0.132, p = 0.024). However, the difference was very small, therefore, data from all pairs were combined to look at monthly differences. There was a significant monthly difference in the proportional composition of pellet samples (one way ANOSIM (standardised); Global R = 0.303, p = 0.001). Although the difference was highly significant, the low Global R value indicated a high degree of overlap between months. In general, there was greater similarity between consecutive months in pellet composition than between those further apart in time (Fig. 3.1). The stress value of 0.16 indicated a moderate level of accuracy of the 2d representation of the true dimensionality of the data (Fig. 3.1).

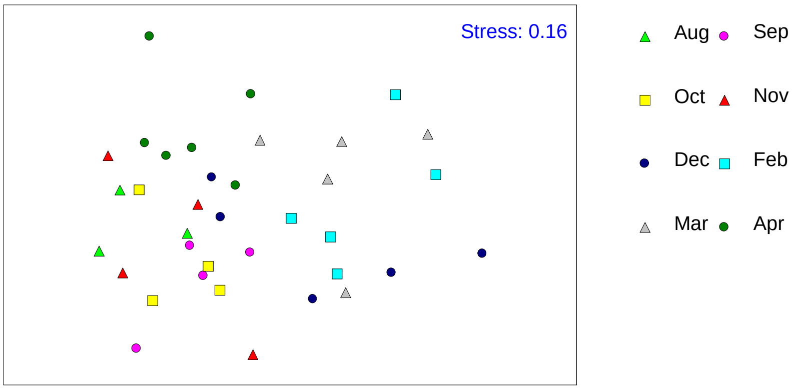
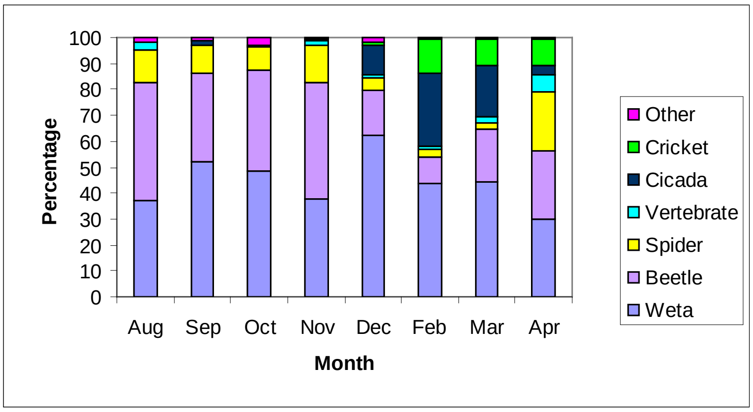
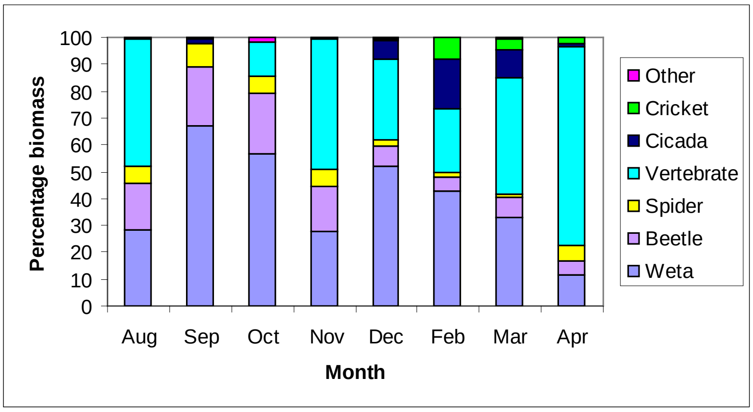


Fig 3.1 nMDS plot showing the relative similarity of morepork pellet sample contents between months.

The mean percentage contribution of beetles to pellet samples was higher during the period from August to November than from December to April (Fig. 3.2a). Similarly, the mean percentage contribution of spiders was reduced during the period from December to March (Fig 3.2a). On the other hand, the mean percentage contribution of cicadas and crickets was much higher during the warmer months, peaking in February (Fig. 3.2a). The mean percentage contribution of weta was not highly variable, but was greatest in December and lowest in April (Fig. 3.2a). The mean percentage contribution of vertebrate prey was small throughout the study, but was highest in April (Fig. 3.2a). When the biomass weighted mean percentage contribution of each taxon was calculated, the same general trends could be seen, but the contribution of vertebrate prey was emphasised, as was that of weta when compared with other invertebrate prey (Fig. 3.2b).



a



b

Fig. 3.2 a), Mean monthly percentage contribution and b), biomass weighted percentage contribution of each taxon to pellet samples taken from moreporks on Ponui Island between August 2007 and April 2008. The category of Other includes millipedes, centipedes, cockroaches and earwigs.

There were also clear trends in the mean percentage contribution to pellet samples of particular beetle species, for example, huhu beetles peaked during November and December, whereas the mean percentage contribution of mumu/tanguru (*Stethaspis* spp.) beetles was greatest during December and February (see Appendix 3.2).

3.3.4 Trends in the monthly mean number of prey per pellet sample

The mean monthly number of beetles and weta per pellet sample was high relative to other taxa throughout much of the study, but was noticeably higher during the first three months than during the latter part of the study (Fig. 3.3). Similarly, the mean number of spiders per pellet sample was lower during the period from December to March than at other times (Fig. 3.3). Conversely, cicadas and crickets were prevalent only during the warmer months (Fig. 3.3). The mean number of vertebrate prey per pellet sample was low throughout the study period, but highest in August and April (Fig. 3.3). As small numbers of vertebrate prey were present relative to invertebrate prey, they are presented as an aggregate of all taxa in Fig. 3.3. However, most that could be reliably identified were rodent prey, particularly ship rats (Appendix 3.3). Some of these were identified as adults, however, many were juveniles, particularly in March and April (Appendix 3.3). Additionally, many prey items were classified as 'unidentified rodent' in April due to a lack of certainty regarding the distinction between mice and juvenile ship rats based on the size of dental features (Appendix 3.3). Kruskal-Wallis tests showed significant differences in the mean number of beetles, spiders, cicadas and vertebrates in pellet samples between months (all Kruskal-Wallis tests, d.f. = 7, $p \leq 0.05$), and a near significant difference for weta (Kruskal-Wallis, d.f. = 7, p = 0.073). There was no significant difference between months for crickets (Kruskal-Wallis, d.f. = 7, p = 0.118), which was probably due to the relatively low numbers overall, and high variability between pellet samples in the number of crickets counted.

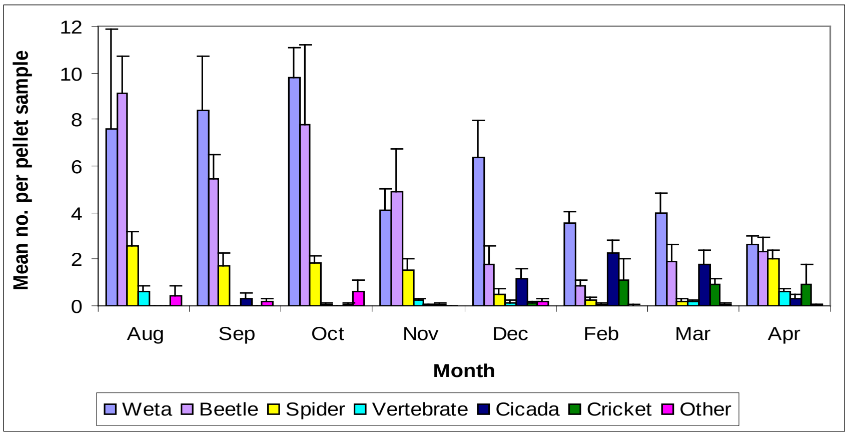


Fig. 3.3 Mean monthly number of prey taxa (+ s.e.) per pellet sample collected from Ponui Island moreporks between August 2007 and April 2008.

3.3.5 Trends in the monthly mean presence score for each taxon

The same general trends were apparent in the mean presence scores for each taxon from month to month (Fig. 3.4) as for the mean number per pellet sample (Fig. 3.3) above. However, Fig. 3.4 allows for comparison of moths with other taxa. We can see that the mean presence scores for moths were quite high throughout much of the study period, but were greatest in February and March (Fig. 3.4).

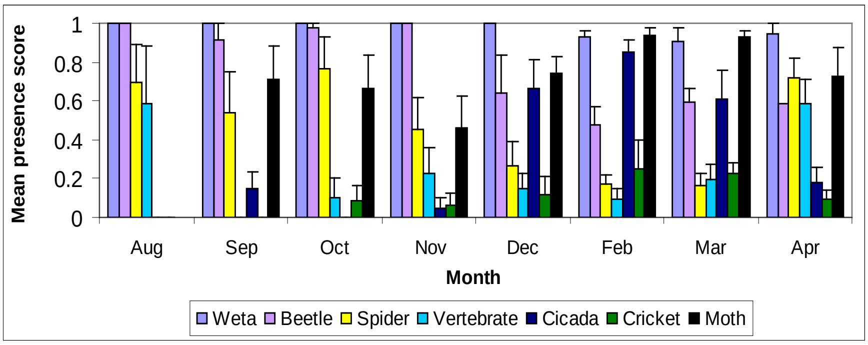


Fig. 3.4 Mean monthly presence scores (+ s.e.) for each taxon occurring in pellets collected from Ponui Island moreporks from August 2007 until April 2008.

3.3.6 Differences between bush and scrub roosting moreporks

The mean total number of prey items per pellet sample was slightly higher for birds that roosted in bush than those in scrub (Table 3.6) although this difference was not significant (Mann-Whitney U test, $p = 0.216$). The mean total biomass of prey per pellet sample was very similar for bush and scrub roosting birds (Table 3.6) (Mann-Whitney U test, $p = 0.788$).

The mean number of crickets (Mann-Whitney U test, $Z = 2.525$, $p = 0.012$) and earwigs (Mann-Whitney U test, $Z = 2.729$, $p = 0.006$) per pellet sample was significantly higher for scrub roosting birds than those that roosted in bush (Table 3.6). The mean number of vertebrates per pellet sample was also higher for scrub roosting birds (Table 3.6), although this difference was not significant (Mann-Whitney U test, $p = 0.168$). The mean numbers of weta and beetles per pellet sample were higher for bush roosting birds (Table 3.6) although these differences were not significant (both Mann-Whitney U tests, $p > 0.05$). There was little difference between the mean number of spiders or cicadas per pellet sample of bush and scrub roosting birds (Table 3.6) (both Mann-Whitney U tests, $p > 0.7$).

Table 3.6 The mean number and mean biomass (± s.e.) per pellet sample of each main prey taxon for moreporks that roosted in bush and scrub on Ponui Island between August 2007 and April 2008.

	Mean number		**Mean biomass (g)**	
Taxon	**Bush**	**Scrub**	**Bush**	**Scrub**
Weta	6.91 ± 1.19	4.63 ± 0.74	6.91 ± 1.19	4.63 ± 0.74
Earwig	0	0.39 ± 0.18	0	0.20 ± 0.09
Beetle	5.37 ± 1.37	3.20 ± 0.92	2.69 ± 0.68	1.60 ± 0.46
Spider	1.16 ± 0.29	1.57 ± 0.46	0.76 ± 0.19	1.02 ± 0.30
Vertebrate	0.18 ± 0.09	0.30 ± 0.09	4.79 ± 2.91	7.67 ± 2.06
Cicada	0.80 ± 0.38	0.69 ± 0.31	0.55 ± 0.26	0.47 ± 0.21
Cricket	0.07 ± 0.05	0.65 ± 0.30	0.04 ± 0.03	0.39 ± 0.18
Other	0	0.03 ± 0.03	0	0.01 ± 0.01
TOTAL	**14.50 ± 2.21**	**11.47 ±1.55**	**15.72 ± 2.87**	**15.98 ± 2.31**

When the mean biomass per pellet sample was calculated for each prey type, the contribution of weta and beetles to the samples collected from bush roosting birds was emphasised, as was the large contribution of vertebrate prey to those from scrub roosting birds (Table 3.6).

A comparison was also made between the overall mean presence scores for moths of pellet samples from bush and scrub roosting birds. There was little difference, with a mean presence score of 0.70 ± 0.07 in bush and 0.72 ± 0.06 in scrub.

3.3.7 Relationship between pellet contents and relative abundance of prey

This section compares the monthly content of morepork pellet samples with data obtained on the relative abundance of prey taxa (see Chapter Two for details of how these data were collected and analysed).

3.3.7.1 Relationship between the mean percentage contribution of taxa to pellets and pitfalls

The relationship between the mean percentage contribution of beetles, weta, spiders and crickets to pitfall traps and morepork pellet samples was analysed for investigation of whether moreporks responded to the availability of a given taxon in relation to alternative prey. The pitfall data for all habitats (bush, scrub and pasture) were combined for these correlations, as birds had the opportunity to forage in all of these habitats. Pitfalls in each habitat also showed the same general trends in abundance of prey types between months, although the amplitude of the changes was not uniform (Chapter Two; Appendices 2.2a and 2.2b).

There was a significant positive relationship between the mean percentage contribution of crickets to pitfalls and pellet samples (Spearman’s rho; $r_s = 0.849$, $p = 0.008$) (Fig. 3.5). There was also a positive relationship (although not significant) between the mean percentage contribution of beetles to pitfalls and pellet samples (Spearman’s rho; $r_s = 0.619$, $p = 0.102$) (Fig. 3.5). There was no significant relationship for weta (Spearman's rho; $r_s = 0.310$, $p = 0.456$), or spiders (Spearman's rho; $r_s = 0.238$, $p = 0.570$). Although a statistically significant relationship was found only for crickets, the graphs below (Fig. 3.5) indicate similar fluctuations from month to month in the mean percentage contribution of each taxon to both pitfalls and pellet samples much of the time. The statistical significance of these correlations must be interpreted cautiously due to the possible effects of multiple tests, and potential autocorrelation of samples between months.

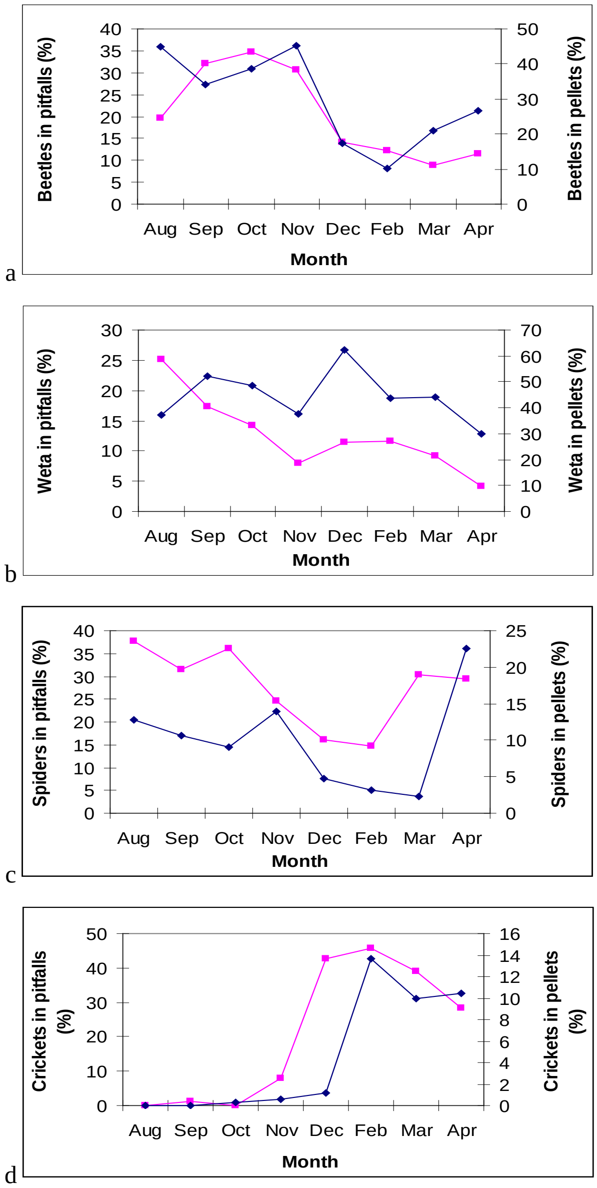


Fig. 3.5 The monthly mean percentage contribution of a), beetles b), weta, c), spiders and d), crickets to morepork pellet samples (blue line) plotted next to the monthly mean percentage contribution to pitfalls (pink line) between August 2007 and April 2008 on Ponui Island.

3.3.7.2 Relationship between the mean number of prey taxa per pellet sample and per pitfall site

The relationship between the monthly mean number of each prey taxon per pellet sample and per pitfall site was also investigated as an approximation of the functional response. There was a significant negative relationship between the mean number of spiders per pellet sample and per pitfall site (Spearman's rho; $r_s = -0.786$, $p = 0.021$) (Fig. 3.6), and a significant positive relationship between the mean number of crickets per pellet sample and the mean number per pitfall site (Spearman's rho; $r_s = 0.752$, $p = 0.032$) (Fig. 3.6). However, there was no significant relationship for beetles (Spearman's rho; $r_s = -0.571$, $p = 0.139$) (Fig. 3.6) or weta (Spearman's rho; $r_s = -0.190$, $p = 0.651$) (Fig. 3.6). Scatterplots were produced, however, the low number of data points ($n = 8$) and high variability meant that they did not provide much indication of the shape of the functional response. Thus, the mean number of each of the abovementioned prey taxa per pellet sample is plotted next to the mean number per pitfall site over the period of the study (Fig. 3.6), and scatterplots of the same data are provided in Appendix 3.4. The statistical significance of these correlations must be interpreted cautiously due to the possible effects of multiple tests, and potential autocorrelation of samples between months.

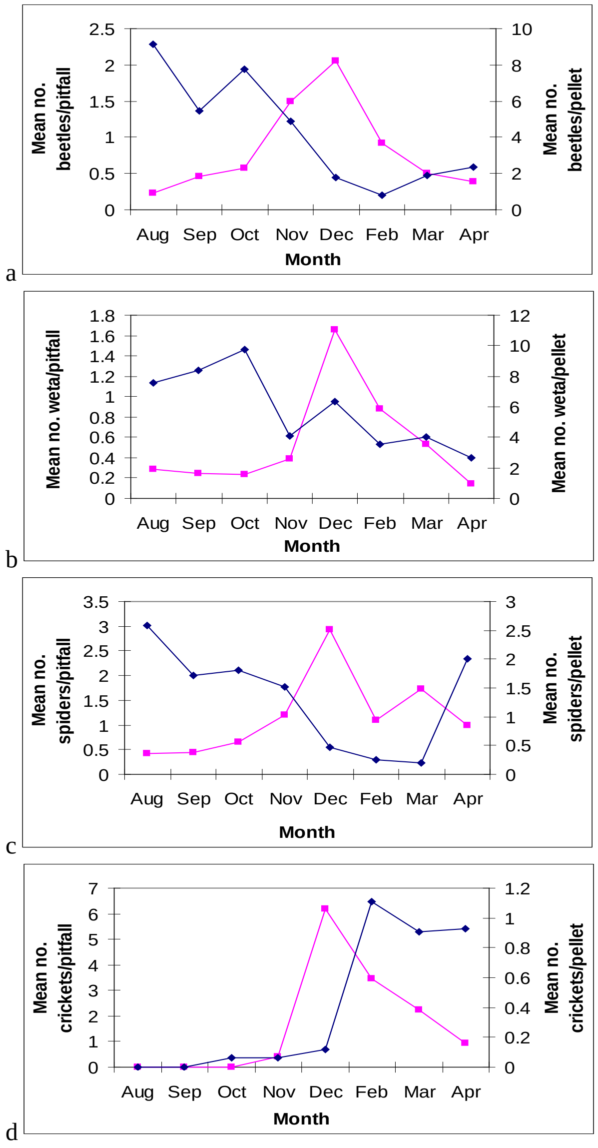


Fig. 3.6 (a-d) The monthly mean number of a), beetles b), weta c), spiders and d) crickets per morepork pellet sample (blue line) plotted next to mean number per pitfall site (pink line) between August 2007 and Arpil 2008 on Ponui Island.

3.3.7.3 Comparison of relative abundance and occurrence in pellets of other prey groups

Moths

There were not sufficient data to test for a relationship between relative abundance of moths and their occurrence in pellets. However, the percentage of interceptor catch made up of moths and the mean presence score for moths in pellets both peaked in February and then declined (Fig. 3.7) suggesting a positive relationship.

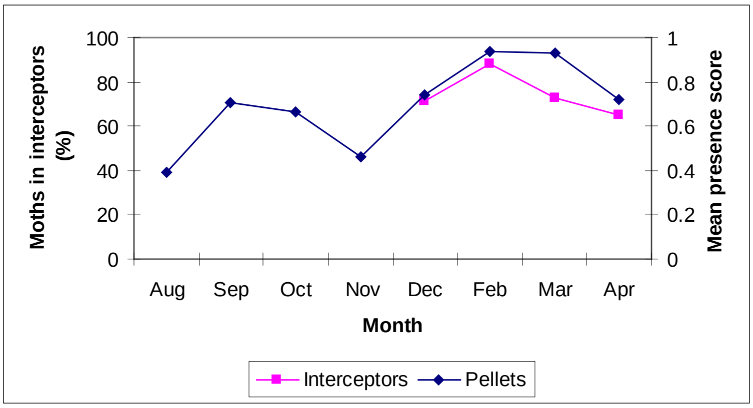


Fig. 3.7 The percentage of interceptor catch made up of moths (pink line), and mean presence scores for moths in morepork pellets (blue line) on Ponui Island between August 2007 and April 2008.

Vertebrate prey

Mice were identified in only a small number (4) of pellets (all during April), and none were caught during trapping surveys. Therefore, it was not possible to determine whether there was a relationship between the two. Similarly, although counts of small birds during 5MBCs were highest in November and December, very small numbers of prey items were identified as birds (1 in October, 1 in March and 3 in April), thus there was not a clear relationship between the two based on these data. Small numbers of ship rats were present in pellets in October, November, March and April. Additionally, unknown rodents and unknown vertebrates were found every month except September, with numbers being highest in August and April (Appendix 3.3). The relative abundance of ship rats was not monitored as part of the present study, however, in the discussion these trends will be compared with estimates of ship rat density carried out during a concurrent study.

3.4 Discussion

3.4.1 Morepork morphometrics

The mean mass of moreporks on Ponui of 172.78g was very similar to the mean value obtained by Robertson et al. (1983) in the Orongorongo Valley, and also to those of Stephenson (1998) for Mokoia Island moreporks, although perhaps slightly lighter (see Appendix 3.5). Mass of captured birds on Mokoia ranged from 155g to 237g, whereas Ponui birds ranged from 149 to 198g. This could be a random effect of a small sample size in the current study, or Mokoia birds may actually have been heavier on average, possibly due to higher resource availability, or lower stress levels in the absence of all mammalian predators besides mice.

There were no notable differences between the other morphometrics taken for Ponui birds and the equivalent measures taken by Stephenson (1998) and Robertson et al. (1983) (see Appendix 3.5 for a comparison of their morphometrics with those from the current study).

It was not possible to compare morphometrics between the sexes in the current study as the sex of only two out of nine birds was known. These birds were sexed using feather samples, whereas analysis of blood samples from the other seven birds was not successful. The reason for this was not clear, with contamination of the samples being one possibility. However, as moreporks were difficult to take blood from due to their small tarsial veins (pers. obs.), collection of a feather sample may be an easier and less invasive technique for sexing moreporks.

3.4.2 Morepork diet on Ponui Island

Moreporks on Ponui Island showed a generalised diet, including large numbers of invertebrate prey, particularly weta and beetles, and small numbers of vertebrates including rats, mice and birds. There was seasonal variation in the diet, which appeared to be related to the relative availability of prey types within the morepork’s acceptable range.

3.4.2.1 Dietary composition

The prevalence of prey groups such as weta, beetles and moths was consistent with the findings of other studies on the morepork (Clark, 1992; Cunningham, 1948; Haw & Clout, 1999; Haw et al., 2001; Imboden, 1975; Lindsay & Ordish, 1964; Stephenson,

1998) and the boobook (Campbell & Rose, 1996; Green et al., 1986; Penck & Queale, 2002; Rose, 1996). The inclusion of weta, beetles and spiders in the diet of Ponui moreporks throughout the study period, with peaks in occurrence of seasonal taxa such as moths and cicadas was also similar to seasonal trends noted in previous studies (Haw & Clout, 1999; Haw et al., 2001; Lindsay & Ordish, 1964). The generalised diet of moreporks is probably facilitated to a certain extent by the relatively low handling times associated with invertebrate prey (Charnov et al., 1976; MacArthur & Pianka, 1966). As such, when an invertebrate prey item is encountered, even if it is not the most profitable prey type, it is likely to result in some energy gain and thus be consumed. However, there is likely to be some degree of preference for larger invertebrate prey items, particularly if encounter rates are high (Charnov et al., 1976; MacArthur & Pianka, 1966; Schoener, 1979). For example, in the present study, moreporks tended to take prey items >1cm in length (pers. obs.), as also noted by Haw and Clout (1999), with many large hunting spiders, weta and large beetle species such as huhu being recorded. How discriminate the bird is may also depend on dietary considerations besides energy content including nutrient and toxin profiles of a prey taxon (Belovsky, 1981; Pulliam, 1975; Schoener, 1979).

Although there was some variation in the mean number of weta per pellet sample, and the mean percentage contribution to pellet samples between months, this variation was not great, and weta appeared as a core component of the morepork diet on Ponui. Although weta are known to be common prey of the morepork (Haw et al., 2001; Lindsay & Ordish, 1964), a comparison with the results of previous quantitative studies (Table 3.7) indicates that the prevalence of weta was particularly high in the diet of Ponui moreporks. An animal is said to exhibit a preference for a prey type if the proportion in the diet is greater than the proportion it makes up of the available prey base (Begon et al., 1996). During the present study, invertebrate availability was monitored using measures of relative abundance (pitfall and interceptor traps) that may have been biased towards certain taxa (Henderson, 2003; Lang, 2000; Luff, 1975; see Chapter Two). Therefore, it is not possible to conclude that there is a preference for weta over other invertebrate prey, however, it seems likely that they are being selected by Ponui moreporks based on their size as well as their availability.

Haw et al. (2001) conducted the only other detailed study of morepork diet in New Zealand based on pellet analysis to date. At their study site in Pureora Forest Park, they found beetles to make up a similarly large proportion of the diet to orthopterans (largely weta) in the present study. The composition of the beetle component of the diet was similar to that of Ponui moreporks, with scarab and longhorn beetles comprising the majority. Weta and spiders also made up a considerable proportion of the diet of moreporks in Pureora, in common with the present study. In contrast, a large number of stick insects (Phasmatodea) were recorded by Haw et al. (2001) (Table 3.7), suggesting that this prey type was abundant at Pureora during their study.

In common with previous studies of morepork diet, the numbers of vertebrate prey in pellets of Ponui moreporks were low in comparison with invertebrate prey (Table 3.7). The apparent paucity of birds in the diet of Ponui moreporks may be related to the handling time associated with avian prey. Small passerines are fast and highly manoeuvrable, and as such, may often be difficult to catch. Additionally, potential avian prey of moreporks are diurnal, so that moreporks may only have small windows of opportunity at dusk and dawn in which to catch them. Moreporks are thought to rely heavily on sound and motion when hunting (Higgins, 1999), such that sleeping animals may be very difficult for them to detect. Numbers of birds consumed were also low in most previous studies of morepork diet (Clark, 1992; Haw & Clout, 1999; Haw et al., 2001; Lindsay & Ordish, 1964), although higher than in the present study. Noticeably more birds, particularly house sparrows (*Passer domesticus*) were taken in the suburban study of Cunningham (1948), possibly due to high densities of exotic birds. There were also bird remains in a relatively high proportion of samples on Mokoia Island (Stephenson, 1998). This is likely due to greater availability of birds in the absence of most mammalian predators, and is in accordance with observations of high predation rates on small birds on other offshore islands such as Tiritiri Matangi, where such prey are abundant, and mammalian predators are controlled (D. Van Winkel, Massey University, pers. comm.).

The prevalence of rodent prey in the present study, particularly ship rats, was higher than that of avian prey although still low in comparison with the mean percentage contribution of invertebrate prey. However, the biomass weighted percentage contribution of confirmed rodent prey (22.1%) was substantial, giving some idea of its potential caloric importance in the diet, even when apparently very low numbers of individuals were taken.

The seeming reluctance of moreporks to take rodent prey despite the high energetic return expected may be related to the large size of adult ship rats. Shapiro (2005) recorded a mean mass (± s.d.) of 139.78 ± 33.59g for males (n = 59) and 126.02 ± 33.71 for females (n = 42) on Ponui Island. These figures are close to the mean mass of moreporks (± s.d.) obtained in the current study (172.78 ± 18.12g). As such, although there was some evidence of adult ship rats in the diet of Ponui moreporks (Appendix 3.3), it may be that they are not often hunted due to the expenditure of time and energy involved. Additionally, their size and aggression may result in risk of injury to the morepork. Conversely, juveniles may be easier to catch due to their smaller size, and possible naiveté to predators. However, chase time could still be a deterrent, for example, Daniel (1972) observed a morepork unsuccessfully hunting a juvenile ship rat for over 90 minutes in the Orongorongo Valley. This suggests that, when density is low, the return from capturing rodents may not be worth the energy expenditure involved in the chase, whereas at high densities, more initial ‘strikes’ may result in success. Mice were present in a relatively high percentage of pellets on Mokoia Island (Stephenson, 1998; see Table 3.7), which could be related to the absence of rats or other mammalian predators, resulting in high densities of mice (e.g. Brown et al., 1996). Additionally, mice may be easier prey to catch than rats owing to their smaller size and reduced aggression. Very few vertebrate remains were confirmed as belonging to mice in the current study, although it is possible that some of the remains classed as unidentified rodents or vertebrates were mice. However, in light of the low availability of mice in the bush on Ponui Island as indicated by live trapping (see Chapter Two) and the high densities of ship rats (Morgan et al., unpubl. data), it is likely that most were ship rats.

It has been noted that morepork parents appear to provide their young with more vertebrate prey than they themselves consume (Chambers et al., 1955; Stephenson, 1998) with Moon (2005) having made the observation that the first prey item brought to the nest in the evening is often a vertebrate.

If parent birds can only carry one prey item at a time, they may save energy by consuming invertebrate prey at the point of capture, and bringing larger prey items back to the nest (Orians & Pearson, 1979). Finding a large prey item early in the night to feed young may also provide parent birds with more time to forage for themselves. However, the diet of juvenile moreporks has been based largely on the remains found in nests, rather than observations of feeding behaviour (Chambers et al., 1955; Hogg & Skegg, 1961; Stephenson, 1998). These studies are likely to be biased towards representation of vertebrate prey, the remains of which may persist in the nest for longer than those of invertebrates (Marti, 1987). As no nests were located during the study on Ponui (Chapter Four), it was not possible to investigate the amount of vertebrate prey brought to the nest in relation to how much was consumed by adults.

Table 3.7 The percentage (% no.) of the diet that was made up of different prey types or the percentage of samples in which they were present (%p) for different studies of the morepork diet in New Zealand, using either stomach samples or pellets. The location of the study, number of birds sampled if relevant, and the time of year the study was carried out are detailed below the table.

Reference	**Form of Data**	**Pellet(p)/Stomach(s) no. in parentheses**	**Coleoptera**	**Orthoptera**	**Blattodea**	**Lepidoptera**	**Araneida**	**Phasmatodea**	**Hemiptera**	**Invertebrate (other/unknown)**	**Aves**	***Rattus.* spp.**	***Mus musculus***	**Vertebrate (other/unknown)**
Clark 1992[1]	% no.	s (19)	14	13	4	60.5	3.5	0.01	0	0	1.5	0	2.5	0
Cunningham, 1948[2]	% no.	p (30)	5	0	0	84.5	4	0	0	0	5.5	0	1	0
Lindsay & Ordish, 1964[3]	% no	s (25)	19.7	18.2	1.5	53.2	2.7	1.2	2.0	1	0.25	0	0.25	0
Haw et al., 2001[4]	% no.	p (187)	48.6	11.8	0	0.3	9.7	25.6	1	2.2	0.3	0.1	0	0.2
Haw & Clout, 1999[5]	% no.	s (75)	34.6	18.2	2.3	32.2	5.9	2.2	0.8	2	1.7	0	0.1	0
Stephenson,1998[6]	% p	p (56)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	98.2*	14.3	0	28.6	0
Current Study[7]	% no.	p (226)	32.9	47.9	0.1	n/a	10.2	0	5.7	0.03	0.1	0.4	0.04	1.3
Current Study[8]	% p	p (226)	77.4	98.0	1.7	69.5	47.1	0	31.1	0	1.2	5.8	0.5	16.6

[1]: Taranaki, around human habitation, outside known breeding season [2]: Masterton (urban), one bird, all seasons [3]: North island, all seasons [4]: Pureora forest, 13 birds (5 each month), May -Dec [5]: New Zealand, various locations, all seasons [6]: Mokoia Island, unknown no. birds, all seasons *frequency of invertebrate types not stated, but sample known to contain Coleoptera, Orthoptera and Lepidoptera , [7,8]: Ponui Island, at least 10 birds, August – April. Note that % p in this case is the mean presence score multiplied by 100 for ease of comparison, and % no. is the mean percentage contribution.

Some frogs (*Litoria* spp.) and lizards (Reptilia) are present on Ponui Island (pers.obs.), including the copper skink (*Cyclodina aenea*), that was recorded in pitfall traps (Chapter Two). However, there was no evidence of inclusion of any reptile or amphibian prey in the diet of moreporks during the period of the present study. This is in accordance with a lack of such prey in the other quantitative dietary studies listed in Table 3.7. Although lizards have been recorded as prey at morepork nests (Chambers et al., 1955; Moon, 2005; Ramsay & Watt, 1971), they appear not to be taken commonly. This may be related in part to the fact that a number of lizard species are diurnal (Gill & Whitaker, 1996; Towns, 1999) and hence difficult to detect. However, many others are either crepuscular or nocturnal (Gill & Whitaker, 1996; Towns, 1999), suggesting another reason, such as lack of palatability and/or limited availability.

The composition of the Australian boobook's diet also appears to be similar to that of the Ponui Island morepork, consisting largely of invertebrates, particularly large beetles (Calaby, 1951; Campbell & Rose, 1996; Penck & Queale, 2002; Rose, 1996) as well as orthopterans (Baker-Gabb, 1984; Campbell & Rose, 1996; Penck & Queale, 2002; Rose, 1996) and spiders (Green et al., 1986; Penck & Queale, 2002; Rose, 1996).

However, it would appear that boobooks consume a greater variety of vertebrate prey including reptiles and marsupials (Campbell & Rose, 1996; Green et al., 1986; Rose, 1996; see Appendix 3.6). Ostensibly, this is a product of availability, with there being a greater range of mammals in the size range accessible to moreporks in Australia, including antechinus' (*Antechinus* spp.) and pygmy possums (Burramyidae). See Appendix 3.6 for a summary of quantitative studies of the boobook diet.

3.4.2.2 Limitations of pellet analysis

The advantages of using pellet analysis to study owl diet include that it is possible to collect a large sample with relatively little expense and disturbance of the study animals. Pellet analysis also facilitates investigation of seasonal and yearly trends using the same birds (Marti, 1987).

However, there are also problems and sources of bias associated with pellet analysis. The most obvious is that pellets consist only of the least digestible body parts (Marti, 1987), therefore, soft bodied and smaller prey are likely to be under-represented (Hill & Lill, 1998; Southern, 1969; Stephenson, 1998). For example, Hill and Lill (1998) found more invertebrate prey in stomach samples than in pellets of Christmas Island hawk owls (*Ninox natalis*), particularly moths.

Studies of morepork diet using pellets also tend to suggest a much lower prevalence of moths in the diet than those using stomach samples (Table 3.7). Whereas moths in the gut may be quantified, in pellets, they are often only recognisable by the presence or absence of wing scales. This technique was used in the current study and suggested a significant contribution of moths to morepork diet, which increased over the warmer months. However, it is likely that a more accurate representation of the composition of the morepork diet would have been obtained if it were possible to quantify the number of moths in pellets.

It is also possible that other, relatively soft bodied prey such as mantids, larvae, or worms were included in the diet of moreporks on Ponui although they were not apparent in pellets. The presence of such prey in the diet could be ascertained by direct observation of feeding behaviour, although it may be difficult to quantify. For example, Stephenson (1998) noted the absence of caterpillars in morepork pellet samples, although they were observed to prey on them during his study.

Another potential source of bias is that it is unknown whether the hard parts of certain prey types are more likely to be regurgitated than others, or whether moreporks could be avoiding the hard body parts of certain prey. Such factors could have affected the overall proportions of different prey taxa that were assumed to be consumed by moreporks on Ponui. However, these should be relatively constant sources of bias, and, as such, should not have had a large effect on seasonal trends for each prey type in the present study, or comparison with the results of other studies using pellet analysis.

Use of stomach or gizzard samples may reduce such sources of error, particularly in assessment of the soft bodied prey consumed (Marti, 1987). However, one concern with the use of this technique is that the contents of the stomach at the time of death may not be representative of the diet in general (Clark, 1982). In addition, the obvious disadvantage to using stomach samples is that each individual may be sampled only once. Thus, for the purposes of the current study, which looked at changes in the diet over time in a specific location, pellet collection was the appropriate method.

3.4.2.3 Roosting habitat and diet

Significantly more crickets were recorded in pellet samples of scrub roosting birds than bush roosting birds. This was likely because these birds roosted closer to the pasture (Chapter Four; Fig. 4.1), where relative abundance of crickets was much higher as indicated by pitfall sampling (Chapter Two). Additionally, all pellets containing black beetles (*Heteronychus arator*), the majority of which were also caught in pasture pitfalls, were collected from scrub roosting birds, indicating pasture foraging sessions during which birds would have fed largely on the ground.

No shore earwigs were caught in pitfall traps, such that it is not known whether their relative abundance was higher in bush or scrub. However, all specimens recorded in pellets were from scrub roosting birds, with the majority being consumed by pair M4/M5. This may be indicative of a localised source of earwigs in the pair's territory.

Pitfall traps indicated higher overall invertebrate availability in scrub habitat than bush, although this was not reflected in the diet of the moreporks. On average, there were fewer prey items per pellet sample of scrub roosting birds, although this difference was not statistically significant. The discrepancy between pitfall and pellet samples in the two habitats may be related to the potential for under-representation of certain taxa in pitfalls, such as tree weta and flying beetles (Chapter Two), which may be more abundant in bush habitat. The mean total biomass per pellet sample was very similar for bush and scrub roosting birds, therefore, another explanation for the scrub birds taking fewer items could be the fact that they appeared to take slightly more vertebrate prey. This would theoretically provide more calories, resulting in consumption of less prey items being necessary. All of the confirmed mouse bones were found in pellets of scrub roosting birds such that, as for crickets, it seems likely that they were obtained from the pasture nearby: Availability of mice in the bush appeared to be low (see Chapter Two) whereas mice are regularly sighted in the pasture (D. Chamberlin, Ponui farmer, pers. comm.).

Naturally, the suggestion that there were differences in the diet of moreporks related to the vegetation that characterised their roosting area relies on the assumption that they spent more time feeding in that habitat than in the alternative. This wasn’t necessarily the case, as the ‘roosting territory’ (the area containing all known roosts of a given pair) may be smaller than its home range (e.g. Stephenson, 1998). However, based on the home range sizes for pairs of 3.5 -7.88ha estimated by Stephenson (1998) and Imboden (1975), along with the fact that ‘roosting territories’(Chapter Four; Fig. 4.1) were located in fairly large and continuous sections of vegetation of the given category (pers. obs.), it seems reasonably likely that the above assumption was met.

3.4.2.4 The relationship between the mean percentage contribution of invertebrate taxa to pitfalls and pellets

The mean percentage contribution to pellet samples of weta, beetles, spiders and crickets each month showed similar trends over the period of the study to the percentage contribution of the same taxa to pitfalls. This suggested a positive relationship between the proportion that each made up of the available prey base and its prevalence in the diet, although a significant positive correlation was found only for crickets.

Trends in the mean percentage contribution of other taxa to pellet samples also supported this idea. For example, there was a notable increase in the contribution of cicadas over the warmer months. Although this could not be compared to availability, as very few cicadas were caught in pitfall or interceptor traps, this is the time of year when cicadas are generally more abundant (Moeed & Meads, 1983; Walker, 2000). There were also peaks in the mean percentage contribution of particular beetle species to pellet sample contents. For example, huhu beetles peaked in November and December, and *Stethaspis* spp. in December and February. Although these species were not frequently caught in pitfall or interceptor traps, the spikes in consumption coincided with normal dates for the emergence of the short-lived adult forms of these beetle species (Crowe, 2002). Similarly**,** there were not sufficient data to analyse the relationship between occurrence in the diet and availability of moths. However, the data obtained did suggest that moreporks were responding positively to increased availability, as relative abundance and consumption both appeared to be higher in summer.

These trends are probably related to the rate at which a given prey type was encountered relative to other kinds (Holling, 1959; MacArthur & Pianka, 1966; Stephens & Krebs, 1986). As already mentioned, a generalist predator with low handling times might be expected to take a large proportion of the acceptable prey items encountered, resulting in a positive relationship with availability (Charnov et al., 1976; MacArthur & Pianka, 1966).

However, there are factors besides relative abundance that might influence foraging behaviour, and thus explain the lack of a significant correlation in some cases. For example, certain prey types are likely to be more profitable and as such, preferred over other kinds. At high encounter rates of these prey taxa, consumption of other types may not be worthwhile, resulting in unclear relationships between availability and consumption (Schoener, 1971; Stephens & Krebs, 1986). The apparent relationship between availability and consumption might also be affected by other unknown factors such as the strength of stimulus from each prey type (e.g. its visual or auditory ‘conspicuousness’) (Holling, 1959).

Alternatively, requirements for certain nutrients (Pulliam, 1975), or the concentration of toxins in prey (Belovsky, 1978; Bryant & Kuropat, 1980) might result in partial preferences for prey types that are not the most profitable or the most attractive, in order to obtain a balanced diet. Such requirements might preclude a large increase in consumption of a prey taxon such as weta, that consistently makes up a large portion of the diet, when its availability increases.

Finally, trade-offs between foraging and other activities may influence foraging strategy and success (Lima & Dill, 1990; Stephens & Krebs, 1986; Ydenberg & Houston, 1986). For example, in the present study, although the numbers of crickets in pellet samples increased noticeably over the summer, the mean percentage contribution to pellet sample contents remained low in comparison with other prey types such as beetles and weta. It is possible that this is related in part to the need to feed on the bush-pasture edge to obtain this prey type: The consumption of readily available crickets might be a trade off with time spent in territorial defence, as an individual must retain a territory and a mate in order to breed.

3.4.2.5 The relationship between the mean numbers of invertebrate prey taxa per pellet sample and per pitfall site

In the current study, the relationship between the mean number of each prey taxon per pellet sample and the mean number per pitfall site was utilised as the best available approximation of the functional response of moreporks to weta, beetles, spiders and crickets.

When the mean number of each taxon per pellet sample was plotted next to the mean number per pitfall site, the relationship was not very clear, except in the case of spiders, but was largely a negative one; when relative abundance of each was high, consumption was low. This was likely due to the fact that although the relative abundance of beetles, for example, increased in summer, so too did that of other taxa (e.g. weta and spiders, along with seasonally prolific species such as crickets and cicadas), resulting in lower abundance in relation to the total prey base. On the other hand, both availability and consumption of crickets showed a dramatic increase over the warmer months such that the trend in the mean number per pellet sample was much the same as for the change in mean percentage contribution. Scatter-plots were produced in an attempt to look at the shape of the functional response, however, these plots were relatively uninformative and it was not possible to determine the type of response based on them.

Many studies of functional response focus on the change in one prey type only without considering the abundance of alternative prey, and the percentage of the total prey base that the prey of interest makes up (Boutin, 1995). However, it is clear that, in the case of a generalist predator with a broad prey base, the response to any one prey type will be affected by the availability, profitability and palatability of many others. Thus, it is likely that the shape of the functional response will not be as simple, or easy to detect, as in the case of more specialised predators.

Methodological factors may also have had some influence on the apparent relationship between availability and inclusion in the diet in the present study. Potential confounding factors include the biases associated with the use of pitfall and interceptor traps discussed in Chapter Two. These include the influence of body size, and activity levels on the likelihood of pitfall capture (e.g. Baars, 1979; Lang, 2000), and the effect of variable attraction to light or weather conditions on interceptor catch (Henderson,

2003) (see Chapter Two). Additionally, an equal number of pellets were not collected each month, with notably fewer during the first half of the study, making the results for these months less robust.

3.4.2.6 Relationship between availability and consumption of vertebrate prey

Very few bird remains were found in morepork pellets over the study period such that it was not possible to determine a relationship with availability. However, there was a notable peak in the contribution of rodents to pellet contents during April, coinciding with an increase in ship rat density in the area (Morgan et al., unpubl. data). Additionally, January to April is the time of year when rodent populations are expected to increase due to seasonality of breeding (King, 2005), and most rodent specimens in April were classed as juvenile rats, or small unidentified rodents (Appendix 3.3). These findings suggest that moreporks are responding to increased availability of rodent prey. As adult ship rats are relatively abundant on Ponui throughout the year (Latham, 2006; Morgan et al., unpubl. data; Shapiro, 2005), it is likely that the availability of ship rats to moreporks is affected by the size of the prey, as previously discussed, as well as their density. The mean number of vertebrate prey per pellet sample was also noticeably higher in August than in other months, (although results for this month were based on a small number of pellets, and as such, were less robust). Similarly, Stephenson (1998) collected only a small number (n = 4) of morepork pellets during winter on Mokoia Island, but noted that vertebrate prey made up a larger proportion of pellet contents (by volume) than during the other seasons. This could be related to reduced availability of invertebrate prey during the colder months as indicated by reduced pitfall catch in the current study (Chapter Two), or increased abundance of young rats subsequent to the breeding season (Innes et al., 2001).

In some owl species, including spotted owlets (*Athene brama*) (Pande et al., 2007) and spotted owls (*Strix occidentalis*) (Smith et al., 1999; White, 1996), there is a positive relationship between breeding success and the amount of large vertebrate prey in the breeding season diet. In the present study, there was a small peak in the contribution of vertebrate prey to the diet in November. If the radio-tagged birds had been breeding, this would likely have coincided with them having dependent young. However, the most noticeable increase in rodent predation by moreporks coincided with increased rodent density (Morgan et al., unpubl. data). Accordingly, it is most likely that consumption of rodents on Ponui simply reflected their availability rather than being specifically related to breeding. Of course, it is likely that increased consumption of vertebrate prey prior to breeding would improve body condition and increase energy available for breeding if this prey were easily accessible. For example, Chambers et al. (1955) noted that both moreporks and kiore (which were found as prey in numerous morepork nests), appeared to be more abundant on Lady Alice Island than on Hen Island suggesting a link between the two. Further study would be required to assess whether there is a correlation between the amount of vertebrate prey taken and breeding success in moreporks.

3.4.3 Application of results

3.4.3.1 The impact of moreporks on their prey

In the present study, it was not possible to determine the shape of the functional response of moreporks to their prey. However, a recurrent theme was emergent in that the prevalence of a given prey type in the morepork diet seemed to be positively related to the percentage it made up of the available prey base.

Prey switching occurs when the proportion of a given prey type in the diet is disproportionately large when the species is abundant relative to other prey, and disproportionately small when the species is rare (Murdoch 1969). A predator that displays prey switching has a potentially stabilising influence on populations of its prey (Murdoch, 1969). Switching is commonly associated with generalist predators, and is thought to be a causative factor in producing the type III functional response (Andersson & Erlinge, 1977; Erlinge, 1987; Erlinge et al., 1983; Hanski et al., 1991).

However, in order to prove that a ‘switch’ has occurred, it is necessary to know the exact proportion that each prey group makes up of the available prey base in addition to the proportion that each prey taxon makes up of the diet when all are equally common (i.e. the predator’s innate preference) (Murdoch, 1969). As such, in the present study, it was not clear whether moreporks were ‘switching’ to abundant prey, or simply consuming each taxon in relation to its availability due to rates of chance encounter. Nevertheless, the trends observed, along with the diversity of the morepork diet suggest that moreporks are unlikely to take large numbers of uncommon prey species or have a destabilising effect on prey populations (Andersson & Erlinge, 1977; Erlinge, 1987; Erlinge et al., 1983; Hanski et al., 1991).

Accordingly, moreporks are not expected to be of concern for the conservation of native fauna in most instances, although they have been recorded taking uncommon bird species such as hihi (*Notiomystis cincta*) (I.C. Castro, pers. comm.), saddlebacks (*Philesturnus carunculatus*) (Anderson, 1992) and robins (*Petroica australis*) (Brown, 1997; Brown et al., 1998) from time to time. However, the impact a predator has on its prey may be influenced by the spatial distribution of the prey species (Stephens & Krebs, 1986). For example, if a prey species occurs in dense clusters, predation on a prey 'patch' could have a greater than expected impact. Moreporks have been observed foraging in such an opportunistic manner. For example Brown et al. (1998) observed two robin nests to be preyed on by moreporks, with each nest being visited multiple times (presumably by the same bird) in order to remove all of the chicks. Additionally, moreporks are known to flush cicadas from foliage (Stephenson, 1998) and hawk moths around lights (Ramsay, 1988). Moreover, there was evidence of 'bingeing' behaviour by birds in the present study, for example, individual pellets were collected that contained large numbers of crickets (up to 37) and little else. Large numbers of a particular species in individual boobook pellets have also been noted (Green et al., 1986; Penck & Queale, 2002). Opportunistic foraging on a localised source of an abundant prey type is likely to have either a negligible or some degree of stabilising influence. However, if numbers of a particular species are perilously low, then any degree of opportunistic predation will represent removal of a large proportion of the population.

Additionally, when the available range of prey is reduced, the effects of morepork predation will be less diffuse. For example, in the present study the mean numbers of weta, beetles and spiders per pellet sample appeared to be negatively related to the mean number in pitfall traps, probably due to a reduction in the available range of invertebrate prey over the winter. Accordingly, the influence of morepork predation on these taxa may be greater than on those that are prevalent only during the spring and summer. However, moreporks preyed on a range of taxa throughout the study period, and may have favoured the more abundant species within the broad taxonomic categories of weta, beetle and spider.

The total impact of a population of predators on its prey is determined not only by its dietary response to prey abundance, but also its numerical response (Holling, 1959; Solomon, 1949). However, the morepork is a resident territorial species, and has a relatively slow breeding rate (Higgins, 1999). Therefore, a rapid numerical response to increased availability of prey is not expected. This suggests that, even if moreporks show a preference for abundant prey types, the rates of increase of their invertebrate and rodent prey species will be too great for morepork predation alone to have a regulatory effect (Holling, 1959). Nonetheless, in all cases, when predation by moreporks is combined with other factors – for example predation by other species, then it may be contributing to regulation of prey populations, or at least dampening fluctuations in abundance (Holling, 1959).

3.4.3.2 Implications for the success of moreporks

In addition to having a potentially stabilising influence in communities, the feeding strategy of moreporks indicates that they are less likely to suffer from severe prey shortages than more specialised predators (Newton, 1979; Sinclair, 2003). The diversity of the morepork's diet, and its opportunism, may be important factors in its continued success in New Zealand. However, it is still a possibility that food is limited in certain circumstances and affects their survival or breeding ability. As seen in the current study, the range of invertebrate prey available to moreporks appears to be reduced during the winter, and invertebrate activity in general is thought to be depressed during the colder months (Moeed & Meads, 1985, 1987a, 1987b). Therefore, the resources available to moreporks over this time may be an important predictor of breeding success the following spring. Weather conditions might influence the overall availability of such prey (Moeed & Meads, 1985, 1987a, 1987b). On Ponui Island, competition could be another factor influencing the availability of prey to moreporks: Research has indicated that high densities of kiwi (Miles & Castro, 2000) and rats (Latham, 2006; Morgan et al., unpubl. data; Shapiro, 2005) are present on Ponui, and that they prey on many of the same invertebrate taxa as moreporks (Shapiro, 2005).

3.4.3.3 The risk of secondary poisoning following mammalian pest control operations

The inclusion of rodent prey in the diet of moreporks has implications for the risk of secondary poisoning during pest control operations. It has been suggested, based on opportunistic observations and call count surveys, that morepork populations are not adversely affected by poison drops over the short to medium term (Eason & Spurr, 1995; Empson & Miskelly, 1999; Fraser & Hauber, 2008; Taylor & Thomas, 1993), and may appear to increase (Fraser & Hauber, 2008). However, dead moreporks have been found following brodifacoum drops with residues of this poison in their tissues (Ogilvie et al., 1997; Stephenson et al., 1999). Additionally, Stephenson and Minot (2006) recorded reduced breeding success following a brodifacoum drop on Mokoia Island. As brodifacoum can persist in organs and tissues for at least six months (Eason et al., 2002), this could have been due to sublethal effects on breeding success. It is possible that the rates of secondary poisoning on Mokoia Island were higher than in other locations due to increased availability of mice in the absence of other mammalian predators. As previously discussed, mice may be more accessible to moreporks as prey than larger rodents, as suggested by their presence in a relatively high percentage of pellets on Mokoia Island (Stephenson, 1998; Table 3.7).

Moreporks are not known to scavenge dead carcasses, which would increase their exposure to secondary poisoning (Stephenson et al., 1999). However, another factor that could affect the risk of poisoning for moreporks would be a pre-mortality change in behaviour that increased the likelihood of capture. For example, the blood trails, sluggishness and increased diurnal activity seen in Norway rats (*Rattus norvegicus*) that had ingested brodifacoum (Cox & Smith, 1992). Encouragingly, Hooker and Innes (1995) noted no behavioural changes in brodifacoum poisoned ship rats prior to death, with most dying inside their dens.

During the current study, vertebrate prey, most of which was thought to be rodent prey, made up a small proportion of the morepork diet. However, moreporks appeared to respond to increased availability of rodent prey by including greater numbers in their diet. These results indicate that the amount of rodent prey consumed by moreporks, and the associated risk of secondary poisoning, may vary considerably according to the abundance of different rodent species in a given area, and the time of year that the poisoning operation is conducted.

3.5 Conclusions and recommendations for further research

In summary, these results support the suggestion that there are seasonal differences in the morepork diet related to availability of their prey (Cunningham, 1948; Haw & Clout, 1999; Haw et al., 2001; Lindsay & Ordish, 1964; Stephenson, 1998). Although the shape of the functional response of moreporks to different taxa could not be determined, data obtained were suggestive of a relationship between proportional availability and prevalence in the diet.

As none of the radio-tagged birds bred in the current study (Chapter Four), it was not possible to assess whether there was a relationship between consumption of vertebrate prey and breeding success. However, there was a peak in consumption of rodent prey that appeared to be in response to increased availability, indicating that the risk of morepork mortality associated with rodent poisoning operations may vary substantially. Observation of prey items brought to morepork nests in combination with study of the diet of adult birds might suggest whether juveniles are preferentially fed with certain prey, and whether the diet of individual birds, (e.g. the proportion of vertebrate prey in the diet), appears to be related to breeding success.

The tendency of moreporks to prey on abundant food sources suggests that morepork predation in itself is unlikely to depress prey populations to low levels or have a destabilising influence. In some cases it may even have a stabilising influence on prey fluctuations, particularly when considered in conjunction with predation by other species. Comparison of the results of the present study with those from a study of rats and kiwi on Ponui Island (Shapiro, 2005) suggested considerable dietary overlap and thus the potential for competition.

Knowledge of the morepork’s diet and its relationship with prey species could be improved by future research involving analysis of pellet contents in combination with direct observations on morepork feeding behaviour using infrared cameras. Observations might reveal predation on taxa that are not apparent in pellets, and allow for some degree of calibration of the results of pellet analysis. Additionally, such research might reveal interesting aspects of morepork behaviour including their apparent response to changes in abundance, differences between the feeding behaviour of individuals, and the intensity with which moreporks exploit particular prey patches or ‘hotspots’.

Appendix 3.1

The overall mean number (Number) and mean biomass (Biomass) (± s.e.) per pellet sample of each taxon identified in morepork pellets collected on Ponui Island between August 2007 and April 2008.

Taxon	Number	Biomass (g)
Arthropoda	12.72 ± 1.80	9.63 ± 1.31**Error! Not a valid link.**
Coleoptera	4.27 ± 1.08	2.13 ± 0.54
Unknown	0.42 ± 0.10	*
Scarabaeidae	2.81 ± 0.89	*
Unknown	0.81 ± 0.32	*
Costelytra spp.	0.31 ± 0.27	*
Stethaspis spp.	0.09 ± 0.04	*
Odontria xanthosticta	1.48 ± 0.53	*
Heteronychus arator	0.11 ± 0.07	*
Cerambycidae	0.87 ± 0.21	*
Unknown	0.06 ± 0.01	*
Xuthodes punctipennis	0.15 ± 0.05	*
Oemona hirta	0.08 ± 0.04	*
Tetrorea cilipes	0.31 ± 0.15	*
Prionoplus reticularis	0.26 ± 0.13	*
Elateridae	0.08 ± 0.06	*
Lucanidae	0.03 ± 0.02	*
Curculionidae	0.06 ± 0.02	*
Orthoptera	6.20 ± 0.79	*
Anostostomatidae & Raphidophoridae	5.80 ± 0.92	5.80 ± 0.92
Unknown	5.20 ± 0.92	*
Hemideina thoracica	0.50 ± 0.09	*
Gryllidae	0.40 ± 0.17	0.24 ± 0.10
Araneida	1.32 ± 0.32	0.86 ± 0.20
Dermaptera	0.17 ± 0.07	*
Labiduridae	0.17 ± 0.07	0.09 ± 0.04
Hemiptera	0.74 ± 0.31	*
Cicadidae	0.74 ± 0.31	0.50 ± 0.21
Chilopoda	0.003 ± 0.003	*
Diplopoda	0.001 ± 0.001	*
Blattodea	0.01 ± 0.01	*
Lepidoptera	n/a	n/a
Vertebrata	0.24 ± 0.08	6.27 ± 2.08
Unknown	0.12 ± 0.07	2.66 ± 1.45
Rodentia	0.10 ± 0.05	*
Unknown	0.04 ± 0.02	1.16 ± 0.55
Rattus rattus	0.06 ± 0.03	2.27 ± 1.17
Mus musculus	0.01 ± 0.01	0.08 ± 0.08
Aves	0.01 ± 0.01	0.11 ± 0.05

*Biomass estimates were calculated only for the main taxa of interest for comparative purposes.

Appendix 3.2

The mean percentage contribution of different taxa of scarab and longhorn beetles identified in pellet samples of moreporks on Ponui Island between August 2007 and April 2008.

Taxon	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Feb**	**Mar**	**Apr**
Odontria xanthosticta	3.89	2.15	3.09	1.11	0.11	0.12	0.28	0.70
Costelytra spp.	0.00	0.00	2.13	0.06	0.16	0.05	0.03	0.00
Stethaspis spp.	0.00	0.12	0.00	0.00	0.32	0.17	0.09	0.00
Heteronychus arator	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.42
Prionoplus reticularis	0.00	0.08	0.27	1.07	0.42	0.13	0.02	0.00
Tetrorea cilipes	1.18	0.60	0.06	0.12	0.10	0.11	0.07	0.17
Oemona hirta	0.08	0.00	0.32	0.06	0.11	0.02	0.00	0.07
Xuthodes punctipennis	0.40	0.12	0.12	0.29	0.06	0.00	0.03	0.16

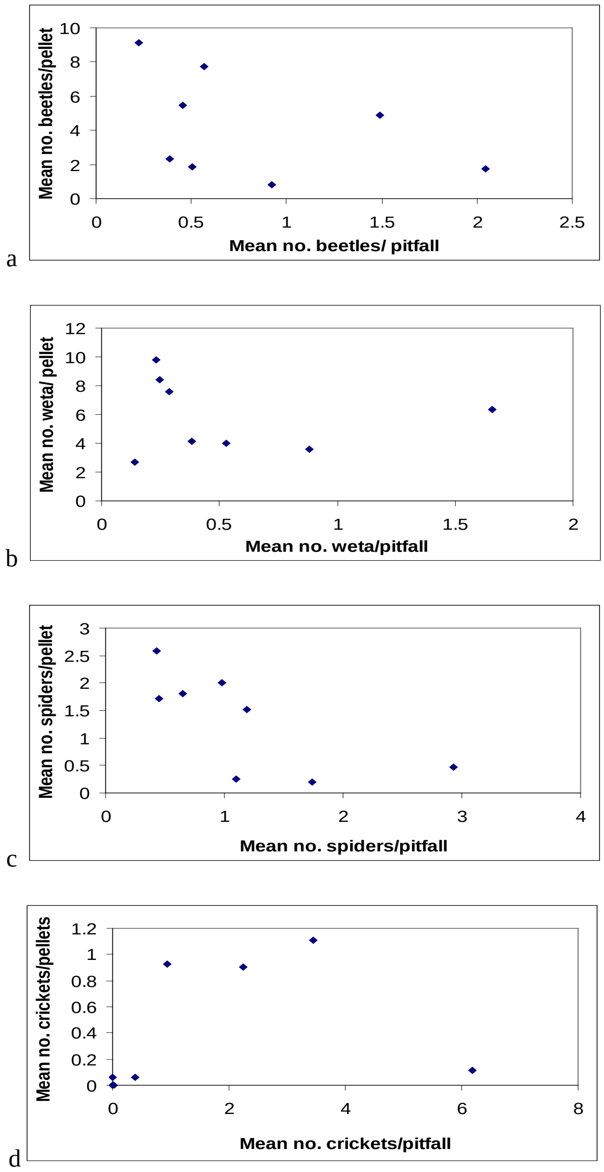
Appendix 3.3

The mean number of each vertebrate prey taxon per morepork pellet sample collected on Ponui Island between August 2007 and April 2008. The actual number of specimens identified is included in parentheses. If the approximate size of the ship rats or unidentified rodents could be determined this is denoted by an asterisk, and details are provided below the table.

	Aug	**Sep**	**Oct**	**Nov**	**Dec**	**Feb**	**Mar**	**Apr**
Bird	0	0	0.02 ± 0.01 (1)	0	0	0	0.04 ± 0.04 (1)	0.03 ± 0.03 (3)
Mouse	0	0	0	0	0	0	0	0.04 ± 0.03 (4)
Rat	0	0	0.04 ± 0.03 (2)*	0.11 ± 0.05 (2)*	0	0	0.07 ± 0.05 (3)*	0.23 ± 0.16 (6)*
Unknown rodent	0	0	0	0.05 ± 0.04 (1)	0.08 ± 0.06 (2)	0	0.04 ± 0.04 (2)	0.16 ± 0.06 (10)*
Unknown vertebrate	0.58 ± 0.30 (4)	0	0.02 ± 0.01 (1)	0.06 ± 0.05 (1)	0.07 ± 0.07 (2)	0.09 ± 0.06 (3)	0.04 ± 0.04 (2)	0.12 ± 0.05 (7)
TOTAL	**0.58 ± 0.30 (4)**	**0**	**0.08 ± 0.06 (4)**	**0.23 ± 0.10 (4)**	**0.15 ± 0.08 (4)**	**0.09 ± 0.06 (3)**	**0.20 ± 0.07 (8)**	**0.59 ± 0.12 (30)**

*In October both ship rats were adults. In November both ship rats were adults. In March 2 ship rats were juveniles and one was an adult. In April, 4 ship rats were juveniles and 2 were adults. 6 of the unknown rodents in April were classed as such due to the small size of teeth and mandibles making it difficult to distinguish between mice and juvenile rats.

Appendix 3.4



Mean monthly number of a), beetles b), weta c), spiders and d) crickets per pellet sample vs. the mean number per pitfall site.

Appendix 3.5

Comparison of morphometric data collected for moreporks during the present study with equivalent measures taken during other studies.

Measurement	**Study**	**sex**	**n**	$\bar{x}$	**s.d.**
Tarsus length[1] (mm)	Robertson et al. (1983)	n/a	45	40.00	2.66
	Current study	n/a	9	42.59	1.99
Wing length[2] (mm)	Stephenson (1998)	♀	10	198.70	5.67
		♂	14	192.75	4.41
	Current study	n/a	9	195.89	7.30
Bill width[3] (mm)	Stephenson (1998)	♀	10	9.48	1.10
		♂	14	8.84	0.29
	Current study	n/a	9	9.59	1.33
Mass (g)	Robertson et al. (1983)	n/a	60	174.14	14.32
	Stephenson (1998)	♀	11	192.09	19.96
		♂	12	176.75	16.03
	Current study	n/a	9	172.78	18.12

[1] From the proximal end of the tarsometatarsus to the distal end of the first metatarsal of the 3rd digit.

[2] Maximum flattened straightened cord.

[3] At the cere.

Appendix 3.6

The numeric percentage (% no.) or percent biomass (% b) of the diet that was made up of different prey types, or the percentage of samples in which they were present (% p) for different studies of the boobook diet in Australia using stomach, gizzard or pellet samples. Where known, the location of the study, time of year it was carried out, and number of birds or roost sites sampled (if relevant) are listed below the table.

Reference	Form of Data	Pellet(p)/Stomach(s) /Gizzard (g) Number in parentheses	Coleoptera	Orthoptera	Blattodea	Lepidoptera	Araneida	Phasmatodea	Hemiptera	Arthropod (other/unknown)	Aves	Rodentia	Mammal (unknown)	Marsupial	Reptile & Amphibian	Chiroptera
Campbell & Rose, 1996[1]	% no.	p (17)	77.67	18.3	0	0	0	0	0	1.67	0	2	0	2	0	0
Rose, 1996[2]	% p	s (20)	65	60	20	75	35	15	0	5	5	10	0	0	0	0
Rose, 1996[3]	% p	p (12)*	92	33	8	42	17	8	8	16	42	58	8	25	17	25
Calaby, 1951[4]	% no.	p (10)	60	0	0	0	6.67	0	0	20	6.67	6.67	0	0	0	0
Baker-Gabb, 1984/1985[5]	% no.	p (?)	7.9	44.9	0	0	3.2	0	0	9.6	0.6	33.8	0	0	0	0
Baker-Gabb, 1984/1985[6]	% b	p (?)	0	13.3	0	0	0	0	0	6.1	2.8	77.8	0	0	0	0
Green et al., 1986[7]	% p	p (89)	0	0	0	0	61	0	0	100[a]	17	8	0	0	18	0
Penck & Queale, 2002[8]	% no.	g (117)	40.8	11.3	0	29.6	9	0	0	4.8	1.2	0	2.9	0	0.4	0
Rose, 1973[9]	% p	s (5)	60	0	20	100	20	0	0	0	0	20	0	0	0	0

[1] NSW , Autumn/Winter, vertebrate estimated as being 72% of biomass
[2] NSW roadkill
[3] Various sites *12 refers to number of pellet collections (of small numbers of pellets) at different locations and roost sites
[4] Victoria, near a farm house, 1 bird
[5,6] Taken from Baker-Gabb (1984) and the supplement to this paper (Baker-Gabb, 1985) Werribee, autumn & winter, 6 roost sites
[7] Tasmania, 3 birds [a] all pellets contained insects most of which were beetles
[8] Throughout South Australia, all seasons
Near Sydney, 1 bird collected in March, 1 in April, 3 in unknown month

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Chapter Four: Roost site characteristics and breeding success of moreporks (*Ninox novaeseelandiae*) on Ponui Island

4.0 Abstract

Data were collected on the location and characteristics of roost sites of seven radio-tagged moreporks (*Ninox novaeseelandiae*) and at least two unmarked moreporks between August 2007 and April 2008 on Ponui Island (Hauraki Gulf, New Zealand). Moreporks were also monitored in order to record details of their breeding behaviour and recruitment rates. Roost trees were found by locating radio-tagged moreporks during the day. For each known roost tree (n=90) the following information was recorded: 1), the morepork(s) that roosted there 2), tree species 3), diameter at breast height (DBH) 4), perch height and diameter 5), tree height and canopy height and 6), estimated percent cover immediately around, above and below the perch. In addition, the number and DBH of woody poles, and the percent cover at four height tiers were recorded within a 2m radius of each roost tree. For comparative purposes, twenty-five control trees (and the vegetation within a 2m radius) were randomly selected within the roosting areas of the monitored birds, and the equivalent measurements taken. Moreporks roosted at a mean height of 3.97m, generally choosing smaller secondary branches on which to perch. The mean percent cover provided by foliage directly above the perch (84%) was significantly higher than that surrounding (31%) and below (15%). The majority of measured characters did not differ significantly between roost and control sites, although foliar cover provided at the 4-6m height tier was greater in roost than control sites. The majority of roost trees were tree coprosma (*Coprosma arborea*) or silver ferns (*Cyathea dealbata*), with these species being used more frequently than would be expected based on their availability. These data suggested that overhead cover provided by the roost tree and surrounding vegetation was the most important characteristic influencing selection of roost-sites by moreporks. This may be an adaptation for avoidance of avian predators and/or mobbing passerines, or there may be thermoregulatory benefits. No radiotagged birds bred successfully during the 2007-08 breeding season, and few juvenile birds were sighted in the study area. Possible

explanations for the apparently low breeding success include intraspecific competition for territories or nest sites, interspecific competition for food, or predation.

4.1 Introduction

4.1.1 Habitat and roost selection

Habitat selection by an animal may be influenced by a broad range of factors including competition and food limitation (Cody & Diamond, 1975; Lack, 1954; MacArthur, 1958, 1972), risk of predation (Martin, 1993; Werner & Hall, 1988), availability of breeding areas (Martin, 1993), proximity to waterways , exposure to the elements (North et al., 2000) or distance from human settlement (Vegvari & Tar, 2002).

Selection for particular characteristics may apply to an animal's habitat as a whole (MacArthur, 1972; Martin, 1993; May & Gutierrez, 2002), as well as to finer scale components such as roost and nest sites in the case of birds (Barrows, 1981; Byholm & Nikula, 2007; Hendrichsen et al., 2006; Jaako et al., 2005). Roost-site selection is of importance, as any energetic cost associated with a poorly selected site may reduce the amount of energy available for other activities such as foraging and reproduction (Kerth et al., 2001; Walsberg, 1986). Thus, roost site selection may be influenced by many factors such as predation risk, competition, ectoparasitism and microclimate (Kerth et al., 2001; Kortner & Geiser, 1999). In particular, many nocturnal birds of prey appear to select roost sites to minimise predation risk, by roosting under dense foliar cover, using colour camouflage, or roosting inside cavities (Duguay et al., 1997; Fisher et al., 2004; Ganey et al., 1997; Hill & Lill, 1998; Swengel & Swengel, 1992).

Roost site characteristics that reduce the risk of detection by predators may also assist in the avoidance of mobbers. Mobbing is a widespread anti-predator behaviour in animals (Curio, 1978), including birds (Bildstein, 1982; Francis et al., 1989; Hurd, 1996; McLean et al., 1986; Pavey & Smyth, 1998; Stone & Trost, 1991), which involves gathering around a predator, making loud vocalisations and conspicuous visual displays, sometimes also striking the predator (Francis et al., 1989; Pavey & Smyth, 1998). Potential costs associated with being the victim of mobbing include increased stress levels, energy expenditure in deterring mobbers, being driven from the roost site, or increased risk of detection by larger predators (Curio, 1978; Flasskamp, 1994; McLean et al., 1986; Pettifor, 1990; Slagsvold, 1982b). Therefore, it is adaptive for target species to avoid mobbers as well as predators, by roosting in a cryptic position (Hendrichsen et al., 2006; Pavey & Smyth, 1998; Sunde et al., 2003).

For a number of owl species, the microclimate associated with a roost site also appears to be an important factor. For example, roost sites are often selected that maximise or minimise heat loss, depending on the ambient temperature and the owl's thermoregulatory requirements (Barrows, 1981; Duguay et al., 1997; Fisher et al., 2004; Ganey & Dick, 1995; Hayward et al., 1993; Hill & Lill, 1998; Kortner & Geiser, 1999; Swengel & Swengel, 1992). This reduces the need for physiological regulation of temperature through mechanisms such as shivering, or evaporative cooling of moist tissues, which incur a metabolic cost (Coulombe, 1970; Newton, 1998).

4.1.2 Habitat and roost sites of moreporks (*Ninox novaeseelandiae*)

Moreporks and boobooks are found in most habitats with trees, from the coast (including offshore islands), to the treeline, in New Zealand and Australia respectively (Higgins, 1999). The morepork is reportedly most abundant in native forests, although it is also found in scrub, forest fragments, farmland, exotic plantations and in urban areas, provided there is sufficient vegetation (Higgins, 1999).

Although members of the *N. novaeseelandiae* species complex have adapted relatively well to habitat change, they are not immune to the effects of deforestation. For example, the Norfolk Island boobook (*Ninox novaeseelandiae undulata*) declined to the brink of extinction, with just one female remaining (Olsen et al., 1989), following habitat destruction and introduction of exotic species (Norman et al., 1998). This involved selective logging of large mature trees from remnant forest, reducing the availability of nest-hollows (Olsen, 1996b; Olsen et al., 1989).

In New Zealand, moreporks have decreased in open parts of the South Island, and populations are also said to have declined around Tauranga, Kawerau, Lake Taupo, Masterton and Stewart Island (see Higgins, 1999 for summary). Additionally, in Australia, boobook populations are thought to have declined in many areas (see Higgins, 1999 for summary). Most declines are thought to be due to habitat destruction. However, in some cases, it has been speculated that other factors, such as competition for nest sites (e.g. from common starlings, *Sturnus vulgaris* or possums, *Trichosurus vulpecula*), or predation by rats (*Rattus* spp.) and cats (*Felis catus*) are at least partly responsible (see Higgins, 1999 for summary).

Very few studies have been conducted on morepork roost sites in New Zealand. Imboden (1975) carried out a brief observational study on the roosts of two morepork pairs in the Orongorongo Valley, Wellington over a six week period, and Stephenson (1998) analysed 788 roosting episodes (some in the same tree) by approximately 21 birds on Mokoia Island, Bay of Plenty, between November 1995 and March 1997. All roost sites recorded during these two studies were on tree branches or in the tops of tree ferns (Imboden, 1975; Stephenson, 1998). Both Imboden (1975) and Stephenson (1998) noted that good overhead cover appeared to be a consistent feature of roost sites, although in some cases the interior of the roost was quite open, leaving the bird relatively exposed from the sides or below. Moreporks were recorded roosting in a variety of tree species by Imboden (1975) and Stephenson (1998). However, Stephenson (1998) noted that moreporks appeared to show a preference for kawakawa (*Macropiper excelsum*). It was hypothesised that this was due to it providing good all-round cover. Furthermore, Stephenson (1998) found that roost sites with less all-round cover were used significantly more often when it was raining, and suggested this was due to the use of tree species with reduced interior cover, but a thicker canopy.

Both Imboden (1975) and Stephenson (1998) noted that moreporks seem to prefer roosts with certain characteristics. However, only Stephenson (1998) systematically measured roost site characteristics, and neither study compared roost sites with controls, therefore it is difficult to say whether roosts are selected based on these properties.

4.1.3 Nest selection and breeding success

Selection of a nest site is of great importance for birds, as its characteristics can influence reproductive success (Martin, 1993). Factors influencing suitability of nest sites might include microhabitat and predation risk as for roost sites, as well as structural aspects such as size and propensity to flooding (Li & Martin, 1991; Radford & Du Plessis, 2003; Severinghaus, 2007). Factors minimising predation risk may be amongst the most important for nest selection, as nest predation has been recorded as the most prevalent cause of nest losses across a variety of bird species in different habitats and locations (Hanski et al., 1996; Martins, 1992; Ricklefs, 1969). Such factors may include nest concealment (Byholm & Nikula, 2007; Hoover & Brittingham, 1998;

Jaako et al., 2005) or depth and height off the ground of a nesting cavity (Severinghaus, 2007).

In some cases, inability to secure a nest due to low availability might prevent some birds from breeding, particularly in the case of secondary cavity nesters (Both & Visser, 2003; Holt & Martin, 1997; Loeb & Hooper, 1997; Village, 1983). In addition to such intraspecific competition for nest sites, other competitive or social factors such as death or divorce of a mate (Bruinzeel, 2007; Catry et al., 1998; Jenkins & Jackman, 1993), inability to secure a breeding territory (Bruinzeel, 2007; Grainger Hunt, 1998; Newton, 1988), or direct behavioural interference from conspecifics (Bruinzeel, 2007; Catry et al., 1998; Harris & Wanless, 1995; Jenkins & Jackman, 1993) might also reduce breeding success, or result in intermittent breeding. Often, such constraints on an individual may be the result of competitive inferiority (Catry et al., 1998; Harris & Wanless, 1995). Alternatively, reduced investment in breeding may be the result of an adaptive decision by an individual (Lack, 1954; Williams, 1966). Investment in a particular breeding attempt should be balanced against the effect it has on the individual’s lifetime breeding potential (Williams, 1966). Accordingly, a relatively long-lived bird with a small clutch size is likely to reduce investment in a given breeding attempt if this will improve body condition and survival through to the next breeding attempt (Curio, 1988; Williams, 1966). This trade off between breeding effort and parental fitness might be affected by factors such as food availability (Crawford & Dyer, 1995; Rohner, 1996; Southern, 1970; White, 1996), weather (through direct impacts on fitness or indirectly through the effect on prey availability) (Crawford & Dyer, 1995; Kalmbach et al., 2001; North et al., 2000; Village, 1990), or predation (Armstrong & Robertson, 1988; Fernandez & Reboreda, 2000). For example, in species such as the great horned owl (*Bubo virginianus*) and Tengmalm’s owl (*Aegolius funereus*) whose main prey undergoes cyclic fluctuations in Canada and Northern Europe respectively, a strong positive relationship between food availability and breeding success has been shown (Korpimaki, 1985; Rohner, 1996), with reproduction of populations sometimes ceasing altogether when prey species are most scarce (Rohner, 1996).

In general, factors that can reduce breeding success, such as interference competition (Bretagnolle et al., 2008; Jenkins & Jackman, 1993; López-Sepulcre & Kokko, 2005;

Louch, 1956), or resource depletion (Charnov et al., 1976; Sutherland, 1996), are more likely to occur during periods of high population density (Andrewartha & Birch, 1954; Lack, 1954; Newton, 1998). A negative relationship between population density and breeding has been shown in a number of raptor species, most often due to occupation of low quality territories by subordinate individuals, or behavioural interference (Bretagnolle et al., 2008; Carreté et al., 2006; Ferrer, 1993; Mougeot et al., 2002). For example, breeding success of the Spanish imperial eagle (*Aquila heliaca*) is reduced at high densities, due to occupation of territories with lower food availability (Ferrer, 1993). Additionally, increased territorial intrusions and 'floaters' (individuals without territories) appear to be the key cause of density dependence in Pyrenean bearded vultures (*Gypaetus barbatus*) and ospreys (*Pandion haliaetus*) (Bretagnolle et al., 2008; Carreté et al., 2006; Mougeot et al., 2002).

4.1.4 Breeding and nest site selection in moreporks

The morepork's breeding season is from September to February (Higgins, 1999). Nest sites are reportedly most often in tree hollows (see Higgins, 1999 for summary). However, alternatives include clusters of epiphytes (Moon, 2005), deep tree-forks (Imboden, 1985), nest-boxes (Hogg & Skegg, 1961), and sheltered sites or cavities on or near the ground, particularly in areas where mammalian predators are absent, or present only in small numbers (Anderson, 1992; Ramsay & Watt, 1971; Stephenson & Minot, 2006).

Basic information on clutch size, incubation time, and time to fledging in moreporks has been gained largely from opportunistic observation of nests (Chambers et al., 1955; Hogg & Skegg, 1961; Moon, 2005). However, only one study (Stephenson & Minot, 2006) has presented quantitative data on morepork breeding success. In that study, a fledging rate of 0.9 chicks per breeding pair (n=10) was recorded in the 1995/1996 breeding season, and 0.125 chicks per breeding pair (n=8) the following year after a brodifacoum poison drop. These success rates did not include morepork individuals or pairs that were not thought to have attempted to breed (Stephenson & Minot, 2006).

4.1.5 The aims of this study

The primary aims of this chapter are to 1), describe roost sites of moreporks on Ponui Island, and 2), determine whether roost selection by moreporks is indiscriminate, or whether certain roost site characteristics are favoured, through comparison with control sites. The secondary aim is to record information on nest sites, breeding behaviour and breeding success of radio-tagged moreporks and their mates during the 2007-08 breeding season.

4.2 Methods

4.2.1 Study site

The study site for this project was Ponui Island located in the Hauraki Gulf 30km east of Auckland (36°50′S, 175°10′E) (Chapter One; Fig. 1.1). The island is 1770ha of which just under a third remains forested with regenerating podocarp/broadleaf forest. The rest was cleared for agriculture in the early 1900's. In addition, many of the ridges in the main stand of bush on the southern end of the island were burnt off to graze cattle around the same time, and thus are made up of regenerating scrub (D. Chamberlin, Ponui farmer, pers. comm.). The study area (approx. 90ha) is situated within a continuous tract of broadleaf/kauri forest covering approximately 250ha of the southern end of the island (Chapter One; Fig. 1.1), and is bordered by pastureland. As the bush is not fenced off, it is freely accessible to stock (sheep, *Ovis aries*, and cows, *Bos taurus*), resulting in an open understorey with reduced numbers of palatable plants in the browse layer, and soil compaction in some areas (D. Chamberlin, Ponui farmer, pers. comm.). There are high densities of ship rats (*Rattus rattus*) (Shapiro, 2005) on the island as well as feral cats but no known mustelid (*Mustela erminea, M. nivalis* or *M. furo*) populations, and no possums (*Trichosurus vulpecula*). There are also high densities of North Island brown kiwi (*Apteryx mantelli*) (Miles & Castro, 2000), following a translocation of 14 individuals in 1964.

4.2.2 Study species

The morepork or ruru is a small owl which is widespread and common throughout much of New Zealand, including offshore islands (Higgins, 1999). Although considered typical of native bush habitat, moreporks may also be found in exotic forest as well as in suburban gardens and parks (Higgins, 1999). See Chapter One for more information on the basic biology and ecology of the morepork.

4.2.3 Collection of roosting data

Roost sites were located by radio-tracking seven radio-tagged birds during the day from August 2007 until April 2008. For details of how birds were captured and radio-tagged see Chapter Three. Two of the radio-tagged birds had untagged mates whose roosts were also included in the study. In my analyses it was assumed that these birds were always the same two individuals although this could not be confirmed. Each of the study birds was given an identification name consisting of the letter M followed by a number. The five pairs followed consisted of the following combinations of birds: M4/M5, M3/M6, M7/M12, M9/M6 and M1/M2. Bird M1 was largely observed to roost on its own, but sometimes roosted with an untagged bird assumed to be M2. M2 was captured in the same place as M1 and was radio-tagged, but dropped the transmitter shortly afterwards. M12 was the untagged mate of bird M7. Bird M6 was included in two pairs as it swapped roosting territories and mates for a period of the study.

4.2.4 Roost site characteristics

For each different roost tree identified, several measurements were taken: 1), Perch height (m), tree height (m) and height of the canopy above the roost tree (m) were estimated visually, with the aid of a 3m long wooden pole marked at 30cm intervals to improve accuracy 2), circumference at breast height of the trunk was measured using a soft tape measure and then converted to diameter at breast height (DBH)(cm) 3), perch diameter (cm) was estimated visually based on physical measurements of branches at accessible height 4), a visual estimate was made of the percent cover provided directly below and above the perch, and in a 2m radius around the roost tree. The percent cover directly below the perch was obtained by standing directly underneath it and estimating the percent of the bird that would have been obstructed from view (measurements were taken when the bird was not present). The percent cover above was obtained from the same position based on the amount of sky visible overhead in a 15cm radius from the midline of where the bird’s body would have been. The cover around the perch was estimated by taking a starting point 2m from the perch and estimating the percent of the bird that would be obstructed from view from that side; this measure was repeated 90°, 180° and 270° from the starting point, and the mean of the four estimates was calculated. Additionally, the species of the roost tree was recorded.

Data were also collected on the vegetation within a 2m radius of the roost tree (this area is referred to as the roost site) in order to characterise the habitat. For each roost site, the number and species of poles in five categories of DBH (<5, 5-10, 10-20, 20-30 and 30+ cm) was recorded. A pole was classed as anything with a woody trunk >1m high.

The composition of vegetation at four different height tiers (<1, 1-4, 4-6 and >6m) was also recorded. For each tier, a visual estimation was made of the percent cover provided by all vegetation. This estimate was obtained by dividing the area in a 2m radius around the roost tree into quarters, estimating the cover for each, and taking the mean of these estimates. Each tier was assessed separately as a percent out of 100, such that the sum of the estimates for all tiers at a given roost site may be more than 100. All estimates were made from ground level by the same observer.

In order to investigate whether roost sites were randomly selected, or had certain characteristics that were preferred by moreporks, surveys of randomly selected trees, and the vegetation in the surrounding 2m radius were conducted to act as 'controls' (note that there is a possibility that moreporks roosted in these sites, although they weren't observed to do so. However, the purpose of the control sites was to determine whether known sites differed from a random selection). The area containing all of the roost trees of a given pair is referred to as the 'roosting territory'(note that this is an arbitrary term – certain parts of this area may never have been used by the birds for roosting, and, additionally, birds may have roosted in areas not recorded during the course of the study. No assumptions are made about the size of the exclusive territory or active home range of birds based on the location of mapped roost sites). Within each roosting territory (n=5) five known roost trees were randomly chosen. From each of these a compass bearing was selected and followed for 10-30m (exact bearings and distances were chosen at random). This range of distances was selected so that the control roost site would be a reasonable distance from the known roost site but not so far that it was likely to be outside the area frequented by the bird(s). From this point, the nearest tree >2m high and of >3cm DBH (these minimum measurements were used as smaller trees or shrubs were unlikely to be used as roosts; see results) in the given direction was chosen as the control roost tree. If the random coordinates led to the pasture, or the randomly selected tree was within the 2m radius of another known or control roost tree, the next set of data points was used. For each control roost site, the same data were collected as for the known roost sites (with the exception of those measures that applied to the specific perch location).

Each site was coded according to whether it was a known roost or control site, and which morepork pair's roosting territory it was recorded in (see Fig. 4.1). Coordinates of each site were taken using a hand held Garmin^{TM} GPS unit.

4.2.5 Collection of breeding data

During the breeding season (September to February; Higgins, 1999) radio-tagged birds were located with the intention of making observations on nest site characteristics, breeding and recruitment rates and juvenile survival. During monthly trips, birds were located at their diurnal roosts in order to determine whether they inhabited a potential nest site that would warrant further monitoring. Within each roosting territory a visual survey was carried out to search for potential nest sites such as tree cavities and clusters of epiphytes. In addition, roosting areas of known birds were searched for juvenile birds.

4.2.6 Data analysis

All statistical analyses were carried out using the program SPSS v.15.0 (SPSS Inc., 2006) with the level of significance taken as $\alpha = 0.05$ unless otherwise indicated. In order to compare the characteristics of roost and control sites, the measurements taken for all roost sites and all control sites for each roosting territory were averaged to improve independence. The data were not normally distributed with homogeneous variances (according to the Kolmogorov-Smirnov and Levene's tests respectively), and some data were not continuous. Therefore, percent cover and number of poles at each tier, DBH, tree height and canopy height were compared between known and control sites using non-parametric Wilcoxon signed ranks tests. Wilcoxon signed ranks tests were also used to compare the cover directly above known perches with that below and around.

To investigate whether certain species of trees were favoured by moreporks for roosting, the proportion of roost trees of a particular species were compared with available proportions (estimated using the species composition of tiers >1m in height in the control sites, excluding non-woody species recorded such as grasses and vines) of that species using one-tailed binomial tests. The vegetation in each roosting territory was classed broadly either as 'bush' or 'scrub': As the species composition differed greatly between the two classes of vegetation (Table 4.4), binomial tests were carried out for roost trees in each of these habitats separately. The null hypothesis was that there was no difference between available proportions and the proportion used as roost trees. The alternative hypothesis was that the proportion of a species used for roosting was either greater than or less than its availability, based on the direction of the apparent difference between available and observed proportions.

4.3 Results

4.3.1 Roosts

4.3.1.1 Roost location and number

During the study period, known roost sites of radio-tagged moreporks and their mates were located in clusters, with many roost trees situated within 2-50m of each other (Fig. 4.1). The roosting territories did not overlap, although the peripheral roost sites of some were quite close together (Fig. 4.1). Between 8 and 23 distinct roost trees were identified for each monitored pair (Fig. 4.1).

4.3.1.2 Interaction with other bird species

Only one instance of interspecific interaction between moreporks and other birds was witnessed despite roost sites being repeatedly visited in order to collect pellets. This interaction consisted of individual M1 being harassed by a male blackbird (*Turdus merula*) on 3/8/07 shortly before it left its roost in the evening.

4.3.1.3 Roost tree characteristics

Mean values of morepork roost and control tree characteristics are presented in Table 4.1. There were no significant differences in DBH, tree height, or canopy height of roost trees and control trees (Wilcoxon signed ranks test; $p > 0.05$). The cover directly above known perches was significantly higher than that present around (Wilcoxon signed ranks test; $Z = 2.023$, $p = 0.043$) and below (Wilcoxon signed ranks test, $Z = 2.023$, $p = 0.043$; Table 4.1).

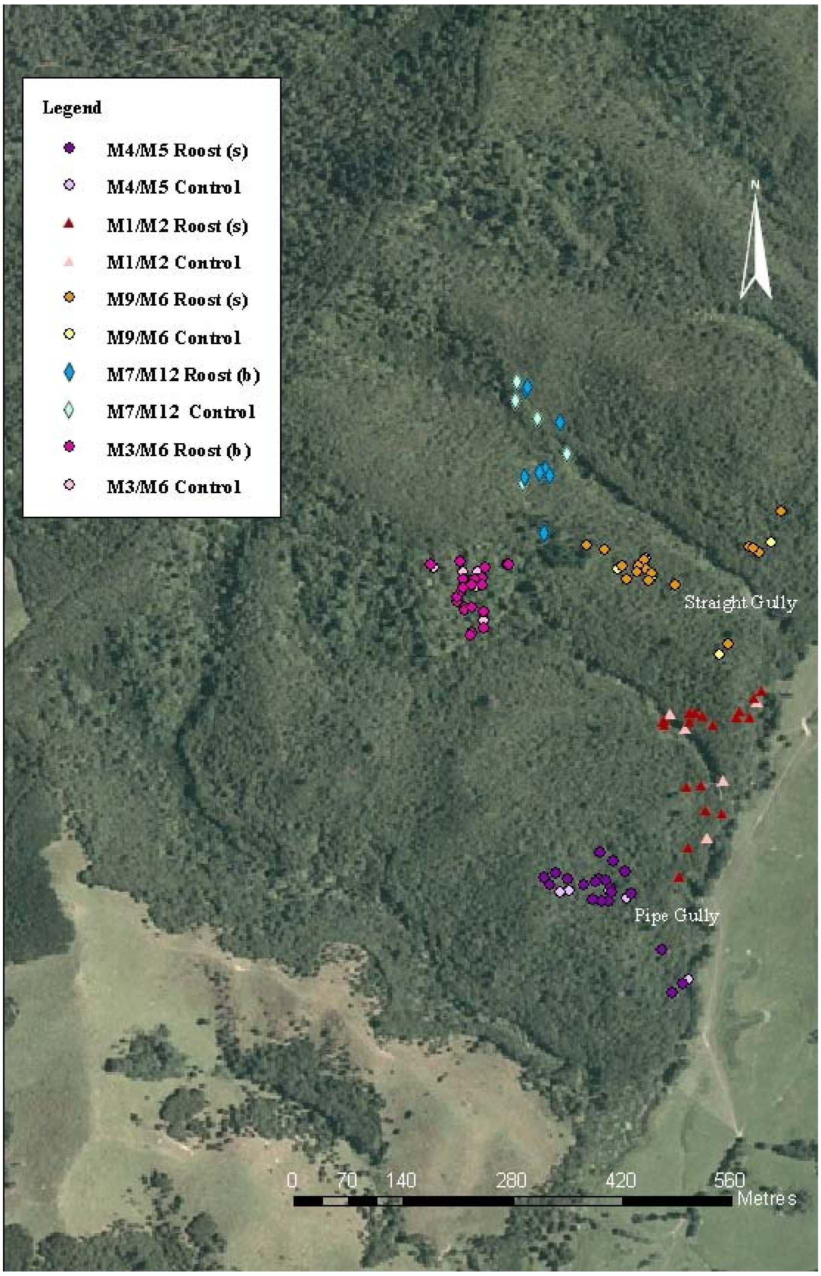

Fig. 4.1 The location of known morepork roost sites (‘roosting territories’) and control sites on Ponui Island for each monitored pair. Aerial photo sourced from Google™Earth. Points plotted using ESRI®ArcMap™ 9.1.

Table 4.1 Characteristics of morepork roost trees and control trees on Ponui Island. Data are presented as mean ± s.e.

Measure	Roost tree	Control tree
DBH (cm)	11.12 ± 1.16	10.47 ± 1.55
Perch height (m)	3.97 ± 0.29	n/a*
Tree height (m)	5.68 ± 0.34	6.49 ± 0.39
Canopy height above tree (m)	10.09 ± 0.58	11.12 ± 0.74
Perch diameter (cm)	3.23 ± 0.58	n/a*
Cover directly above perch (%)	84.08 ± 2.30	n/a*
Cover around perch (%)	30.72 ± 3.80	n/a*
Cover directly below perch (%)	15.31 ± 1.95	n/a*

*****Measures pertaining to the specific perch cannot be taken at random roost sites where no bird has been observed.

Some roost trees showed a large departure from the mean values shown in Table 4.1. For example, one of the trees frequently observed to be used by M3 on a thick puriri (*Vitex lucens*) branch (perch diameter = 17cm), surrounded by hanging epiphytes. This tree had a DBH of 41cm, and the percent cover directly below, around and above the perch were estimated as 100%, 90% and 100% respectively. The following photos were taken with and without flash, illustrating how well the bird was camouflaged. The blue arrow indicates the position of the bird’s head.

Plate 4.1: Individual M3 roosting on a puriri branch surrounded by the hanging leaves of an epiphyte. The photo on the right was taken with flash and that on the left without, to emphasise the high concealment of the bird (photos by the author).

4.3.1.4 Roost site characteristics

Woody poles counted in roost and control sites

The mean number of poles in each category of DBH was remarkably similar between roost and control sites (Table 4.2; all Wilcoxon signed ranks tests; p >0.05).

Table 4.2 Number of woody poles in five categories of DBH (cm) at roost and control sites of moreporks on Ponui Island. Data are presented as mean ± s.e.

	Number of poles				
	<5cm	**5-10cm**	**10-20cm**	**20-30cm**	**30+cm**
Roost	6.42 ± 1.80	2.91 ± 0.62	1.88 ± 0.31	0.40 ± 0.11	0.22 ± 0.03
Control	7.68 ± 1.40	3.68 ± 0.42	1.88 ± 0.76	0.36 ± 0.18	0.20 ± 0.06

Percent cover at four height tiers in roost and control sites

The estimated cover was significantly higher for control plots than for roost plots at the lowest tier (Table 4.3; Wilcoxon signed ranks test; Z = 2.023, p= 0.043). At all other tiers, the difference between control and roost sites was not significant (Table 4.3; all Wilcoxon signed ranks tests; p >0.05). However, the tendency was for cover to be higher in roost sites than control sites with this difference being near significant for the 4-6m category (Table 4.3; Wilcoxon signed ranks test; Z = 1.753, p= 0.080).

Table 4.3 Estimated cover at four height tiers for roost and control sites of moreporks on Ponui Island. Data are presented as mean ± s.e.

	Percent cover at each tier			
	<1m	**1-4m**	**4-6m**	**>6m**
Roost	18.62 ± 2.34	33.98 ± 5.10	38.19 ± 5.45	30.32 ± 4.55
Control	29.04 ± 3.95	24.96 ± 4.04	21.32 ± 3.13	27.28 ± 5.87

4.3.1.5 Selection of roost tree species

In scrubby habitat, the majority of roost trees were tree coprosma (*Coprosma arborea*) (73%; Table 4.4), whereas in bush the most frequently used species of tree was the silver fern (*Cyathea dealbata*) (45%; Table 4.4). Smaller numbers of other tree species were also used (Table 4.4).

When the proportion that a species of roost tree made up of all roost trees was compared with available proportions (from the composition of vegetation in control sites), tree coprosma were used significantly more than their availability in scrub habitat (Binomial test, n = 59, $p \leq 0.001$; Table 4.4) whereas in bush they were used less than their availability (Binomial test, n = 31, p = 0.005; Table 4.4). Silver ferns appeared to be used according to their availability in scrub habitat (Binomial test, n = 31, p = 0.295; Table 4.4) whereas in bush habitat they were used significantly more than their availability (Binomial test, n = 31, $p \leq 0.001$; Table 4.4). Other trees taken as an aggregate were used according to their availability in bush habitat (Binomial test, n = 31, p = 0.319; Table 4.4) and less than their availability in scrub (Binomial test, n = 59, p = 0.001; Table 4.4).

Table 4.4 The observed proportions of roost trees in scrub and bush vegetation compared with the expected proportions based on the composition of vegetation in control sites. All species used as roost trees are listed, and additional species in control sites are combined as 'other'. p values are shown for binomial tests for tree coprosma, silver fern and all other species as an aggregate.

Tree species		**Proportion of roost trees**		**Proportion of trees in control sites**		**p Value**	
Common name	**Latin name**	**Scrub**	**Bush**	**Scrub**	**Bush**	**Scrub (n = 59)**	**Bush (n = 31)**
Tree coprosma	*Coprosma arborea*	0.73	0.10	0.49	0.31	≤ 0.001	0.005
Silver fern	*Cyathea dealbata*	0.05	0.45	0.08	0.18	0.295	≤ 0.001
Kanuka	*Kunzea ericoides*	0.03	0	0.08	0.08		
Pine	*Pinus radiata*	0.02	0	0	0		
Prickly mingimingi	*Cyathodes juniperina*	0.02	0	0.10	0		
Kamahi	*Weinmannia racemosa*	0.02	0	0	0.02		
Celery pine	*Phyllocladus trichomanoides*	0.08	0.03	0.01	0.08		
Mamaku	*Cyathea medullaris*	0.05	0	0	0		
Toru	*Toronia toru*	0	0.03	0	0		
Tawa	*Beilschmiedia tawa*	0	0.03	0	0.02		
Olearia	*Olearia spp.*	0	0.03	0.04	0.02		
Taraire	*Beilschmiedia tarairi*	0	0.03	0	0		
Puriri	*Vitex lucens*	0	0.06	0	0		
Kohekohe	*Dysoxylum spectabile*	0	0.03	0	0		
Rata	*Metrosideros* spp.	0	0.03	0	0.02		
White maire	*Nestegis lanceolata*	0	0.03	0.01	0.01		
Kohuhu	*Pittosporum tenuifolium*	0	0.03	0	0.02		
Hangehange	*Geniostoma rupestre var. ligustrifolium*	0	0.03	0.01	0.01		
Dead tree	n/a	0	0.06	0	0		
Other	n/a	0	0	0.18	0.23		
Total – tree coprosma and silver fern*	n/a	0.22	0.45	0.43	0.51	0.001	0.319

* The observed and expected proportions for all tree species besides tree coprosma and silver fern.

4.3.2 Breeding

None of the radio-tagged birds included in the current study bred successfully during the 2007-08 breeding season (September to February). When radio-tagged birds were located during the day over this period, they were always found in open roosting sites on branches, rather than potential nesting sites such as tree hollows, or clumps of epiphytes. No juvenile birds were sighted in the roosting territories of study birds and, furthermore, none of the radio-tagged birds were seen feeding young. Pair M4/M5 appeared to have produced eggs in mid-November, however, these were located on the ground (Plate 4.2) (one intact and one broken) in the open, nearby to the pair's habitual roost (approx. 2m). No evidence of an attempt to disguise the eggs or incubate them was observed. Tree cavities and epiphytes (which may have been potential nesting sites) were located within the roosting area of pairs M3/M6 and M7/M12 but not those of M9/M6, M4/M5 or M1/M2.

Plate 4.2 An intact egg found near a habitual roost of pair M4/M5 on the ground in an exposed position.

In addition, only three juvenile moreporks were seen or heard in the study area (90ha) by myself (pers. obs.) or other researchers on the island (I. C. Castro, pers. comm.), suggesting that breeding success of moreporks in general on Ponui Island may have been low in the 2007-08 breeding season.

One instance of copulation was witnessed on 7/9/07. This involved a pair of unmarked birds in Pipe Gully. As the birds were not radio-tagged it is not known whether this pair bred successfully, however no juveniles were sighted or heard begging in the area. During this interaction, the birds flew back and forth calling to each other then alighted on the same branch. One bird mounted the other, flapping its wings. The episode ended with a high pitched squeal from one of the birds.

4.4 Discussion

In the present study it was noted that morepork roost sites had greater overhead cover than control sites, and tree coprosma and silver fern were used as roost trees more often than would be expected based on their estimated availability in scrub and bush habitat respectively. No radio-tagged birds were observed to incubate eggs, or fledge young, and breeding success appeared to be low throughout the study area.

4.4.1 Roost site characteristics

The apparent importance of overhead cover at a roost site has been noted during many studies on owls and other nocturnal birds of prey, including the eastern screech-owl, (*Otus asio*) (Duguay et al., 1997), the common nighthawk, (*Chordeiles minor*) (Fisher et al., 2004), tawny frogmouths, (*Podergus strigoides*) (Kortner & Geiser, 1999), northern saw-whet owls, (*Aegolius acadicus*) (Swengel & Swengel, 1992), spotted owls, (*Strix occidentalis*) (Barrows, 1981; Ganey et al., 1997) and Christmas Island hawk owls, (*Ninox natalis*) (Hill & Lill, 1998). Overhead cover also appeared to be a key factor in roost site selection for moreporks in the present study, in accordance with the suggestions of Stephenson (1998) and Imboden (1975).

Morepork perches in the current study had much greater cover overhead than that surrounding or below, and there was greater cover at the 4-6m tier in roost sites than in control sites. The increased cover at this tier corresponded with a mean perch height of 3.97m, suggesting that moreporks were selecting perches at the height that provided the greatest foliar cover overhead. Similarly, Swengel and Swengel (1992) found that, in northern saw-whet owls, the height of the perch varied with roost tree species, and how far from the base of the tree its foliage began, indicating that foliar cover was more important than perch height in itself.

Moreporks, like several other owl species (Duguay et al., 1997; Hill & Lill, 1998; Swengel & Swengel, 1992) may select roost sites with increased foliar cover in order to reduce visual, chemical and auditory cues to their predators (Martin, 1993). Foliar cover may not afford much protection against exotic mammalian predators such as rats and cats that are terrestrial/arboreal and hunt using olfactory as well as visual stimuli (Brown, 1997; King, 2005). However, it may reduce predation by other raptors. For example, Australasian harriers (*Circus approximans*) are aerial hunters that rely largely on visual cues, and have been suspected of preying on morepork fledglings (Stephenson & Minot, 2006). In addition, they have been observed as predators at nests of forest birds including kokako (*Callaeas cinereas*) (Innes et al., 1999). New Zealand falcons (*Falco novaeseelandiae*) have not been recorded as taking moreporks, however, are well adapted to the forest, and frequently prey on nestlings, and birds as large as ducks (*Anas* spp.) and white faced herons (*Ardea novaehollandiae*) (see Marchant & Higgins, 1993 for summary). Moreover, reduced conspicuousness to predators may have had a greater impact on morepork survival in the past, when other large raptors such as Eyle's harrier (*Circus eylesi*) were extant (Worthy & Holdaway, 2002).

Mobbing might be another factor influencing selection of a well concealed roost site. Only one instance of interspecific aggression towards a morepork was observed on Ponui Island during the study period involving a male blackbird (*Turdus merula*). Additionally, few bird remains were found in the pellets of Ponui Island moreporks (Chapter Three), suggesting that morepork predation may not represent much of a threat to small birds on the island. However, avoidance of mobbing may be an adaptation to conditions where mobbing is more frequent. For example, Stephenson (1998) noted relatively high rates of mobbing on Mokoia Island where all mammals except mice (*Mus musculus*) had been eradicated. It can be expected that the abundance and species richness of small native passerines on Mokoia, and in other areas where mammalian predators have been controlled or eradicated are closer to those with which the morepork evolved than those on Ponui.

Although overhead cover appeared to be the most important characteristic of roost sites on Ponui, moreporks also tended to roost in positions with a reasonable degree of surrounding foliage. In addition, even small amounts of foliage provided good camouflage due to the moreporks' cryptic colouration. Study birds were often difficult to detect even with radio-transmitters attached. As such, the avoidance of exposed branches for roosting may aid in minimisation of mobbing, however, this does not entirely explain the apparent preference for overhead cover.

The microclimate provided by a particular roost site may be an influential factor in its selection, as suggested in the case of several other nocturnal bird species (Barrows, 1981; Duguay et al., 1997; Hayward et al., 1993; Kortner & Geiser, 1999). For example, the tawny frogmouth appears to select roost sites to maximise sun exposure (Kortner & Geiser, 1999), and eastern screech owls roost in man-made boxes or cavities, which offer greater protection against the cold, more often during the winter than summer (Duguay et al., 1997). Selection of sheltered, sub-canopy roost sites by moreporks might provide protection from the elements in a number of ways. For example, Barrows (1981) found that the combination of a dense canopy and north facing slopes created a microclimate 1-6 °C cooler in spotted owl roosting sites than in more open areas. Hayward et al. (1993) also found that roosting sites of boreal owls were cooler due to canopy cover. Alternatively, a more open roost site might be advantageous in certain circumstances as it would allow for convective heat loss due to wind exposure (Barrows, 1981; Walsberg, 1986). Selection of a roost site with an appropriate ambient temperature can be of importance for the fitness of a bird, as compensatory mechanisms for dealing with heat stress (or cold) may have energetic costs. For example, when an owl commences panting and/or fluttering of the gular region of the oesophagus, this indicates high heat levels and increased energy expenditure (Bartholomew et al., 1968; Calder & King, 1974; Coulombe, 1970). Stephenson (1998) observed moreporks to repeatedly perform a ‘yawning’ behaviour on warm days on Mokoia Island, indicating that overheating may be a problem for moreporks at times. This would provide some rationale for selection of high cover on Ponui Island during summer. As well as providing a cool microclimate in summer, overhead cover may protect the bird from rainfall throughout the year as suggested by Stephenson (1998) in the case of the morepork, and Hill and Lill (1998) for the Christmas Island hawk owl, a small owl in the same genus.

The findings of Hill and Lill (1998) regarding the roost sites of Christmas Island hawk owls were also similar to those of Stephenson (1998), and the current study on moreporks in that the birds roosted in the sub-canopy with ample overhead cover, but little foliage beneath the perch. Hill and Lill (1998) suggested that having a clear area below the perch could be an advantage in terms of providing an easy escape route if the bird was threatened. When moreporks were flushed during the day on Ponui (by the observer), they would often swoop down and fly lower to the ground before flying back up into another roost tree some distance away. Hence it might be speculated that the generally low levels of vegetation in the tiers beneath the perch allowed for ease of escape as hypothesised in the case of the Christmas Island hawk owl. An alternative explanation may be that a clear area below the roost allows for better prey surveillance, or airflow for convective heat loss (Walsberg, 1986). Considering the reduced density of foliage in the browse layer on Ponui, the trend for reduced foliage beneath the perch might also be coincidental.

The mean perch height in the present study of 3.97m was remarkably similar to the mean height of 4.3m recorded by Stephenson (1998) on Mokoia Island. This similarity could be largely a product of this being the most likely height at which to find good cover in both study sites. Vegetation on Mokoia is characterised by young regenerating bush (Perrott & Armstrong, 2000) as is the bush on Ponui, particularly in scrubby areas. Thus the sub-canopy may generally be at a similar level. Although there are many taller trees in areas of mature bush on Ponui (pers. obs.), the mean height of the roost tree and the associated perch were similar for bush and scrub roosting birds. Many of these taller trees appeared as if they would provide as much visual camouflage to moreporks as the roost trees selected, such that other factors, for example, more sheltered conditions, may have explained why lower perches were generally selected.

Relatively small branches were selected by moreporks as perches in the current study, the mean diameter of which was 3.2cm. Similarly narrow perches with a mean diameter of 2.4cm were recorded for moreporks on Mokoia Island (Stephenson, 1998). Moreporks might gain better cover from foliage amongst smaller branches of a tree than on larger branches closer to the trunk, potentially explaining this result.

The species of tree selected by moreporks for roosting appeared not to be random. For example, even though tree coprosma and silver fern are abundant on Ponui (this study), they appeared to be selected more often than their availability would suggest. It may be that these tree species provide good overhead cover more frequently than other common species on Ponui. Similarly, on Mokoia Island, Stephenson (1998) suggested that kawakawa was the most common roost tree species as it provided a high degree of cover to roosting moreporks. Tree ferns were also observed to be used frequently on Mokoia, with three types combined (silver fern, mamaku and wheki, *Dicksonia squarrosa*) making up 22% of roost trees (Stephenson, 1998). Similarly, in the Orongorongo Valley in beech and rata-podocarp forest, a range of roost tree species were used by moreporks, but all were characterised by a high level of cover, particularly from above (Imboden, 1975). However, as previously discussed, choice of a roost tree on Ponui appeared not to be based solely on the trees' properties but also on the surrounding vegetation in the roost site. Often a large portion of the cover provided at the tiers around and above the morepork perch was from surrounding trees. For example, two perches were dead trees that provided no foliar cover at all, but were protected by overhanging vegetation from neighbouring plants.

4.4.2 Breeding

The current study involved a small sample size of radio-tagged birds and few data on morepork recruitment or breeding success are available for comparison (but see Stephenson & Minot, 2006). As such, it is difficult to say whether or not the production of no known nestlings by the three pairs regularly sighted together over the breeding season (M4/M5, M3/M6 and M7/M12) and two other birds (M1 and M9) was representative of low breeding success. However, it is suggestive of this when considered in combination with the paucity of juveniles recorded in the study, particularly as their 'trilling' call may be heard from up to 50m away (Stephenson, 1998). If 0.9 young had been fledged per breeding pair as recorded by Stephenson and Minot (2006) in 1995/1996, it would be expected that more juveniles be apparent. The fledging rate of 0.125 chicks per pair recorded by Stephenson and Minot (2006) in the following breeding season (1996/1997) probably represented low success as it was considered likely that recruitment rates were affected by brodifacoum poisoning in this case.

It was of interest that although the monitored pairs roosted together often in the present study (pers.obs.), which was one of the criteria used by Stephenson (1998) to classify a breeding pair, none was found to have established a nest site. Female boobooks have been reported to occupy the nest site only a couple of days before laying (Olsen, 1996a). Therefore, it is a possibility that radio-tagged birds established nests which subsequently failed for some reason during one of the two week periods between researcher visits to the island, or, in the case of pair M7/M12 and bird M9, before they became part of the study in November and December respectively.

The reasons for the apparently low breeding success of Ponui Island moreporks in the current study are not known, and an individual bird may be influenced by a wide range of factors including age (Cam & Monnat, 2000; Curio, 1983; Laaksonen et al., 2002; Martin, 1995), predation (Byholm & Nikula, 2007; Ghalambor & Martin, 2001; Martin, 1993), or a lack of sufficient resources such as food (Korpimaki, 1985; Southern, 1970; White, 1996), a territory (Bretagnolle et al., 2008; Bruinzeel, 2007; Jenkins & Jackman, 1993; Newton & Marquiss, 1991; Southern, 1970), or a mate (Bowman & Bird, 1986; Catry et al., 1998; Crawford & Dyer, 1995; Jenkins & Jackman, 1993; Newton, 1992). However, some possibilities are discussed below.

Predation is one factor that might reduce breeding success of moreporks on Ponui Island. Ship rats have been recorded in high densities on Ponui (Latham, 2006; Shapiro, 2005), inclusive of the period of the present study (Morgan et al., unpubl. data). Ship rats frequently prey on small birds and their eggs (Atkinson, 1978; Brown et al., 1998; Innes et al., 1999; Morgan et al., 2006; Mudge, 2002), with morepork eggs being within the size range they are known to be capable of taking (Atkinson, 1978). Additionally, cats (Harper, 2005; Morgan et al., 2006; Sanders & Maloney, 2002) and Australasian harriers (Innes et al., 1999; Morgan et al., 2006; Sanders & Maloney, 2002) are also predators of birds and eggs that could affect moreporks on Ponui Island.

A shortage of suitable nest sites is another factor that could influence morepork breeding on Ponui. There are substantial areas of scrubby, regenerating vegetation on the island containing few large mature trees and associated potential nest sites such as cavities, deep tree forks and perching epiphytes. Moreporks are not obligate cavity nesters, and show some flexibility in the type of nest site they use (Higgins, 1999). However, the risk of predation may be a factor influencing nest site selection, and investment in a given breeding attempt (Lack, 1954; Lima & Dill, 1990; Martin, 1993; Sergio et al., 2003; Tome et al., 2004). Although moreporks have been seen to nest on the ground, this generally occurs in areas that are free of all or most mammalian predators (Anderson, 1992; R. Seaton, ecologist, pers. comm.; Ramsay & Watt, 1971; Stephenson & Minot, 2006) and/or that may lack mature trees suitable for nesting (Anderson, 1992; Imboden, 1985; R. Seaton, pers. comm.; Stephenson, 1998). Similarly, buzzards (*Buteo buteo*) and kestrels (*Falco tinnunculus*) both nest on the ground only on islands lacking mammalian predators (Newton, 1979).

The pair (M4/M5) that was observed to make a failed breeding attempt (with eggs found on the ground) roosted in a scrubby area containing no obvious sites for a nest. There are numerous possible explanations for this observation, however, lack of a suitable nest site is one scenario that could result in desertion of the eggs or vulnerability to predation (Ghalambor & Martin, 2001; Martin, 1993; Slagsvold, 1982a; Tome et al., 2004). Interestingly, the two birds that were not regularly seen to be roosting with a mate over the breeding season (M9 and M1) also roosted in scrubby areas, further suggesting that this habitat may be less suitable for moreporks than mature bush. Perhaps the birds that secure high quality breeding territories (e.g. with more or better potential nest sites) are superior competitors and more easily attract a mate. The occupation of sub-optimal breeding habitats by subordinate or young individuals has been suggested in several raptor species (Bruinzeel, 2007; Carreté et al., 2006; Ferrer et al., 2006; Korpimaki, 1988).

A link has also been made between prey availability and the breeding success of numerous owl species (Korpimaki, 1992; North et al., 2000; Rohner, 1996; Sasvari & Hegyi, 2002; Smith et al., 1999; Southern, 1970; Ward et al., 1998). For example, Southern (1970) carried out a 12 year study of between 17 and 30 territorial pairs of tawny owls (*Strix aluco*) in a given area, and found rates of breeding success to be positively related to availability of rodent prey. During a year of particularly low rodent densities, no owls attempted to breed. Similarly, during the low phase of the snowshoe hare (*Lepus americanus*) cycle in Canada, none of 25 monitored pairs of territorial great horned owls bred (Rohner, 1996). On Ponui Island there are high densities of kiwi (Miles & Castro, 2000) and ship rats (Latham, 2006; Shapiro, 2005) that prey on many of the same invertebrate species as moreporks (Shapiro, 2005) creating the potential for competition. In addition, other invertebrate predators are also present on the island including other forest birds and cats. As such, although moreporks have a generalised diet (see Chapter Three), which is likely to buffer them somewhat against prey shortages, competition for invertebrate prey might contribute to reduced availability and an associated reduction in breeding success.

Intraspecific competition could also have a significant impact on recruitment of moreporks if densities are high on Ponui, resulting in, for example, more birds being excluded from high quality territories, or increased pressure on food resources (Newton, 1998).

4.5 Conclusions and recommendations for further research

Overhead cover seemed to be the most important feature of roost site selection by moreporks on Ponui Island. The reasons for this preference were not known, although possible explanations include avoidance of predation and mobbers, and the microclimate provided. Moreover, the observed characteristics of roost sites may have resulted from a combination of such influences (Hill & Lill, 1998; May & Gutierrez, 2002; Svardson, 1949). A more detailed study involving a greater number of birds, and measuring a wider range of roost site variables, including microclimatic conditions would be required to further investigate the factors influencing roost site selection. In addition, observation of the roosting birds to determine rates of behaviours such as panting, and disturbance due to mobbing, may help to determine whether certain roost site features provide an energetic advantage.

During the present study, each distinct roost tree was marked the first time it was seen to be used by a radio-tagged bird or its mate, however, formal records of the bird ID and date were not taken each subsequent time that the same roost was used. Collection of such data would allow for conclusions to be drawn on the characteristics of intensely used roosts, and seasonal patterns in roost use relative to weather conditions.

Breeding success of moreporks on Ponui Island appeared to be low in the 2007-08 breeding season although few data on recruitment in moreporks are available for comparison. Possible reasons for this include competition with or predation by other species on Ponui, particularly ship rats, or a lack of suitable breeding habitat. Naturally, in a given breeding season, a range of factors might combine to result in low breeding rates.

Clearly, more work on morepork productivity is required, in order to 1), provide an indication of ‘normal’ rates of breeding success, and 2), investigate the factors influencing success. Ideally, such research would involve a large sample of moreporks monitored over several breeding seasons with concurrent monitoring of potentially influential variables such as prey availability, weather and the abundance of predators. Estimation of population density at different sites and between years would also allow for investigation of whether home range size is adjusted to resource availability, and whether breeding appears to be density dependent. Finally, comparison of the characteristics of habitat and nest sites between territories of different moreporks in relation to breeding success may indicate whether factors such as canopy cover or nest exposure influence morepork productivity.

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Chapter Five: General discussion

Ponui Island moreporks (*Ninox novaeseelandiae*) showed a generalised diet in the current study, which included a range of invertebrate prey and smaller amounts of vertebrate prey. The importance of prey species that are available throughout the year, particularly weta (Anostostomatidae and Raphidophoridae), in the diet of Ponui moreporks was clear. Additionally, an estimation of biomass represented by the different taxa in pellets emphasised the fact that even when very small numbers of vertebrate prey are taken by moreporks, their calorific contribution to the diet may be large.

The suggestion that moreporks adjust their diet according to seasonal availability of their prey (Haw & Clout, 1999; Haw et al., 2001; Lindsay & Ordish, 1964; Stephenson, 1998) was confirmed by the results of the present study. The proportion of a given prey taxon in the diet appeared to be related to the proportion that it made up of the available prey base, and there were peaks in consumption of seasonally abundant taxa such as cicadas (Cicadidae), crickets (Gryllidae) and huhu beetles (*Prionoplus reticularis*).

These aspects of the morepork's feeding behaviour imply that morepork predation is not likely to have a detrimental impact on prey populations in most circumstances, and may have some degree of stabilising influence, particularly when considered in combination with predation by other species (Andersson & Erlinge, 1977; Erlinge, 1987; Hanski et al., 1991; Holling, 1959). This influence may be enhanced by the territoriality (Imboden, 1975; Stephenson, 1998) and conservative breeding (e.g. Stephenson & Minot, 2006) shown by moreporks, as major fluctuations in population size are not likely to occur over the short-term in response to prey availability (Erlinge, 1987).

However, moreporks do prey on uncommon native species from time to time (Anderson, 1992; Brown, 1997; I.C. Castro, pers.comm.) and, as such, they may have detrimental impacts on very small populations of such species. As mentioned in Chapter Three, knowledge of the relationship between moreporks and their prey could be improved by combining further study of the diet through pellet analysis with direct observations of feeding behaviour.

The opportunistic feeding behaviour of moreporks means that the exact composition of their diet may vary considerably with location. Even within the present study, there were some significant differences between pellets of scrub and bush roosting birds that could have been a product of the amount of time spent foraging in that habitat. The ability of moreporks to adjust their diet to availability is surely a factor in their continued abundance throughout much of the country, inclusive of some highly modified landscapes.

As mentioned above, moreporks are territorial (Imboden, 1975; Stephenson, 1998), a factor which might promote stable densities and reduce pressure on resources (Newton, 1998). However, territorial owls sometimes show large fluctuations in breeding rates in relation to food supply, although densities of adult birds remain relatively stable, as exemplified by tawny owls (*Strix aluco*) in the United Kingdom (Southern, 1970) and great horned owls (*Bubo virginianus*) in Canada (Rohner, 1996).

In the current study, morepork breeding rates appeared to be low, and it was hypothesised that interspecific competition for food could be a contributory factor. Competition, and an associated reduction in fitness for some or all of the parties involved, occurs as a result of a shared requirement for a limited resource (Begon et al., 1996).

The scope of the present study did not include analysis of the diet of other species on Ponui Island, therefore a direct comparison between the diet of the morepork and its potential competitors cannot be made. However, Shapiro (2005) looked at the diet of North Island brown kiwi (*Apteryx mantelli*) and ship rats (*Rattus rattus*) (whilst monitoring prey availability) on Ponui in 2004/2005. His study showed that rat diet reflected seasonal abundance, and that weta were frequently consumed throughout the study, along with spiders (Araneida) and scarab beetles (Scarabaeidae), suggesting a high degree of overlap with the morepork diet. Shapiro (2005) also found the kiwi diet to include weta, scarab beetles and larvae, and spiders, along with other soil dwelling organisms, implying that they may also compete with morepork, although to a lesser extent than ship rats.

Dietary overlap in itself, however, does not represent proof of competition, as it could simply be indicative of the exploitation of abundant food resources by generalist predators. Thus, the question is whether availability of invertebrate prey is a limiting factor on Ponui.

Ship rats were observed to be at very high densities throughout the period of the current study (Morgan et al., unpubl. data) as well as during those of Shapiro (2005) and Latham (2006). This is in accordance with the idea that island populations of rodents often reach higher densities than those on the mainland (Adler & Levins, 1994; Gliwicz, 1980). The pressure on resources can be higher in insular systems than on the mainland due to reduced dispersal (Krebs et al., 1969; Tamarin, 1978). For example, experiments on rodent populations in fenced areas have recorded abnormally inflated rodent densities, with food supplies within the area sometimes being exhausted, emphasising the potential impact of insular rodent populations (Boonstra & Krebs, 1977; Krebs et al., 1969; Louch, 1956). Accordingly, the magnitude of resource use by ship rats due to their sheer numbers could be creating an environment of competition for invertebrate prey on Ponui Island. Furthermore, densities of kiwi are also high on Ponui (Miles & Castro, 2000). However, Shapiro (2005) found that kiwi chicks on Ponui had low growth rates compared to chicks on the mainland, and suggested that this could be influenced by competition with rats. As such, it seems feasible that this could also be a factor contributing to the apparently low breeding success of moreporks on Ponui during the 2007-08 breeding season. Additionally, other known invertebrate predators including passerines (Heather & Robertson, 2005), and (to a lesser degree) cats (*Felis catus*) (e.g. Fitzgerald & Karl, 1979; Harper, 2005), are also present on Ponui Island, such that availability of invertebrate prey could be an important limiting factor in this system.

The possibility of resource limitation does not imply that predation is not also a key determinant of ecosystem structure and function. The Ponui system is like many in New Zealand in that the abundance and diversity of native species present is probably limited by the presence of introduced mammalian predators (Bell & Merton, 2002; Craig et al., 2000; Daugherty et al., 1990). The fact that kiwi have proliferated so greatly on Ponui may be due to the absence of stoats (*Mustela erminea*), which appear to be the main predator of juvenile kiwi (McLennan et al., 2004; McLennan et al., 1996), and possums (*Trichosurus vulpecula*), that can prey on kiwi eggs (McLennan et al., 1996). Ship rats are unable to open or remove kiwi eggs due to their large size McLennan et al., 2004). However, they have been observed as predators at the nests of a number of smaller bird species (Brown, 1997; Innes et al., 1999; Morgan et al., 2006), and morepork eggs fall within the size range that they are known to be capable of taking (Atkinson, 1978). The ship rat is a generalist predator (Daniel, 1973; Innes, 1979; Shapiro, 2005), a factor which, as previously mentioned, is often associated with the promotion of stability (e.g. Andersson & Erlinge, 1977; Hanski et al., 1991). However, this relationship may not hold in the case of an introduced predator in an insular system (Sinclair et al., 1998). Exotic predators can be highly successful in these conditions when they are released from their natural control agents (Colautti et al., 2004) and presented with naïve prey (Carlquist, 1974; Whittaker & Fernandez-Palacios, 2007; Worthy & Holdaway, 2002). Accordingly, predation by invasive species is often inversely density dependent, and of an unsustainable magnitude (Sinclair, 2003; Sinclair et al., 1998), particularly in the case of a generalist whose success isn’t linked to that of one key prey species (Sinclair, 2003; Sinclair et al., 1998). In addition to the ubiquitous ship rats, predation by harriers (*Circus approximans*) (e.g. Innes et al., 1999; Morgan et al., 2006) and cats (e.g. Fitzgerald & Karl, 1979; Morgan et al., 2006) may also have an impact on the success of moreporks and other bird species on Ponui.

Interestingly, Fraser and Hauber (2008) recorded significantly higher morepork call rates in Ark in the Park (an area of the Waitakere ranges, Auckland, where brodifacoum poisoning targeting mammalian predators had been ongoing for three years), than in matched sites outside the park. If call rates are a correlate of abundance as expected, these findings support the suggestion that mammalian predators are detrimental to moreporks due to predation on eggs or nestlings and/or their effects on prey availability (Fraser & Hauber, 2008).

The apparent benefits to moreporks in Ark in the Park from predator control (Fraser & Hauber, 2008) occurred despite the fact that some mortality (Ogilvie et al., 1997; Stephenson et al., 1999; Walker & Elliott, 1997), and reduced breeding success (Stephenson et al., 1999) of moreporks has been attributed to secondary poisoning following brodifacoum operations. This is most likely to be as a result of consumption of poisoned rodents (Eason et al., 2002; Ogilvie et al., 1997; Stephenson et al., 1999), however, there is a possibility that ingestion of contaminated invertebrates could also be a factor (Bowie & Ross, 2006; Ogilvie et al., 1997).

Haw et al. (2001) found very few rodents in the diet of moreporks in Pureora forest and thus suggested that the hypothetical risk to moreporks from secondary poisoning was low in that location, and probably also at most other mainland sites. This may be a reasonable assumption due to the tendency for higher rodent densities on islands than on the mainland (Adler & Levins, 1994). However, it is possible that Haw et al. (2001) would have found more rodent remains in pellets if their study had included the period from January to April when rodents, particularly juveniles, are generally more abundant (King, 2005). Accordingly, in the current study, there was a significant increase in the amount of rodent prey (including juvenile ship rats) in morepork pellets during April. This appeared to be related to higher density of ship rats (Morgan et al., unpubl. data), and was probably influenced by the greater accessibility of small juveniles as prey compared with adults. These findings emphasise that the risk of poisoning will vary according to the density of different rodent species and alternative prey in a given area, which will be affected by the time of year. Decisions on whether to carry out poisoning, the type of poison used, at what frequency and time of year are a balance between the benefits of pest control and the potential for negative impacts on native species. The complexity of these issues highlights the importance of a whole ecosystem approach to conservation management.

Naturally, there are alternative explanations for low breeding rates in Ponui moreporks besides competition for food or the impact of predation. In the present study, some of the radio-tagged birds were observed to roost only in scrubby habitat that lacked obvious potential nest sites. Although it is recognised that the areas observed to be roosted in weren’t necessarily equivalent to the entire home range of a given bird, there are substantial areas of regenerating forest on Ponui which might be suboptimal habitat for moreporks. As such, although moreporks have adapted relatively well to modified landscapes throughout much of New Zealand, it could be that certain areas in which adult moreporks are present are not suitable for breeding, and thus represent sink populations.

Numerous factors may affect the productivity of moreporks including nest availability, predation, competition, and poisoning operations as discussed above. Study of morepork populations over multiple breeding seasons would be required to determine whether success varies in relation to such factors.

Additionally, moreporks may have minimum habitat requirements besides those most obviously related to breeding success (i.e. food and nest availability as discussed above). In the present study, roost site selection was non-random, appearing to be associated with high overhead cover. Potential explanations for this include protection from predation or mobbing, and microclimatic conditions, although further work would be required to determine whether this is the case. Accordingly, there may be a minimum degree of vegetative cover or structural complexity associated with the inhabitation of an area by moreporks. For example, it is likely that their absence from the Canterbury Plains, and relatively low abundance in some other open parts of the South Island is due to a lack of suitable habitat as suggested by Stephenson (1998).

In summary, the study of morepork ecology is of importance in terms of their interactions with other species, including threatened natives, in addition to the fact that this species is of intrinsic value as our only extant native owl. Although moreporks are currently common and widespread (Higgins, 1999), it is necessary to have baseline data on their ecology in order to detect any changes in abundance or distribution in the future and to determine the likely causes.

In addition, many questions were raised during this thesis about the importance of resource limitation and competition, and predation as regulatory factors in the Ponui Island ecosystem. Such questions highlight the need for further research into the influence of these factors (both on Ponui Island and in general), including an experimental approach.

5.1 References

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