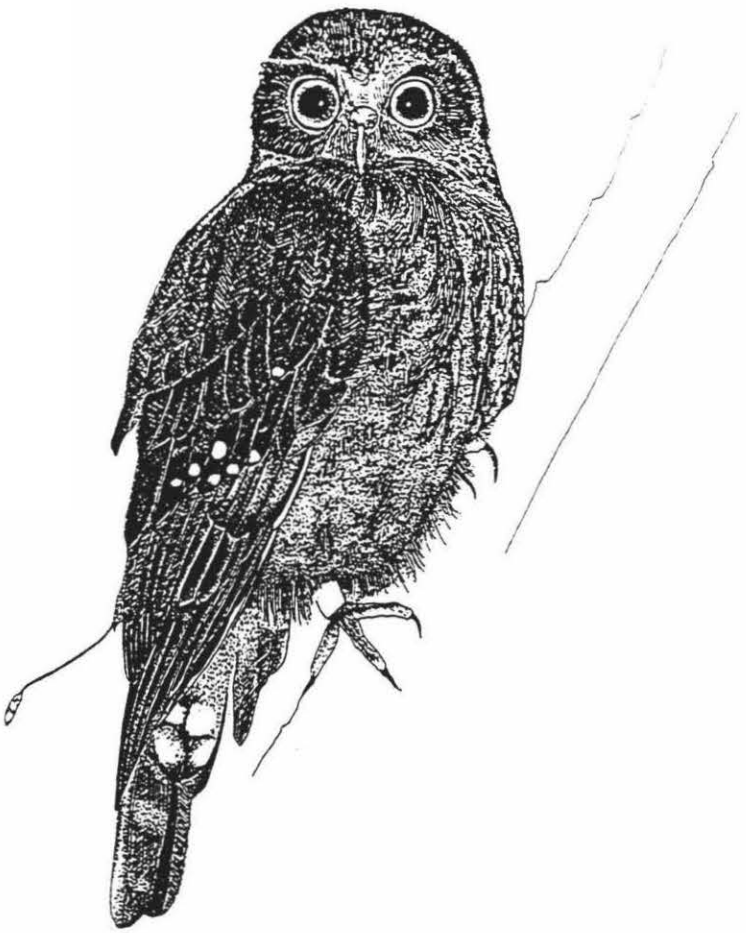
The ecology and breeding biology of morepork, *Ninox novaeseelandiae*, and their risk from secondary poisoning, in New Zealand

by

Brent Mark Stephenson

1998



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Acknowledgments

Mokoia Island belongs to the Ngati Whakaue, Ngati Uenukukopako, Ngati Rangiwewehi and Ngati Rangiteaorere, and is administered by a trust board made up of representatives of these hapu. My research was done with permission of the Trust Board, and aims to contribute to the continuing restoration of Mokoia. I am grateful for support and encouragement from the Trust Board, particularly Bill Kingi, Selwyn Bennett and Mita Mohi.

The idea to study morepork on Mokoia Island and the effects of the poison drop originally came from Paul Jansen, then at the Bay of Plenty Conservancy of the Department of Conservation, and Doug Armstrong from Massey University. I thank them for their ideas and help during the project.

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I have probably missed someone off this rather long list, I thank you too.

Thesis abstract

I studied morepork, *Ninox novaeseelandiae*, on Mokoia Island from November 1995 through to March 1997. Radio telemetry was a technique essential for the study of this species. Methods for the capture of morepork and attachment of radio transmitters were developed during this study. A population estimate of 25 breeding pairs was made for Mokoia.

Thirty-one morepork were captured and transmitters were fitted to 21 of these birds. Both adults and juveniles were radio-tagged successfully. Morphological measurements. a blood sample and plumage descriptions were made at the time of capture. Using the morphological measurements and plumage characteristics the sex of the bird was, in most cases, unable to be determined. However, using the blood sample collected and a DNA based technique, sex could be resolved in all cases.

Before this study, little was known about the ecology and breeding biology of morepork. This thesis reveals that morepork are primarily nocturnal, strictly territorial, and roost during the day amongst foliage. It has also confirmed that morepork are primarily insectivorous, but do prey on mice, *Mus musculus*, and birds. Breeding occurs from September through to January, and nests were located in a variety of locations.

Secondary poisoning has received relatively little investigation, both in New Zealand and world-wide. The growing use of second-generation anticoagulant poisons in New Zealand conservation means that more information is needed. Seventeen radio-tagged morepork were monitored following a poison drop in September 1996, to eradicate mice from Mokoia. I followed 14 birds successfully, and of these, one died due to secondary poisoning, and a further two birds died, probably also as a result of poisoning.

This thesis, therefore, provides information not only on the ecology and breeding biology of a little known species, but also information of use to conservation managers planning future poisoning operations.

Thesis introduction

When looking for a Masters project midway through the final year of my BSc, I approached both Ed Minot and Doug Armstrong, hoping they might be able to help me. Doug had recently been talking with Paul Jansen, then with Department of Conservation in Rotorua, and he had suggested a project studying morepork on Mokoia Island. A mouse eradication was then being planned, and it was unknown what effect this would have on morepork, through the loss of a presumed prey source and/or through secondary poisoning.

I decided this was an interesting problem and started to research morepork and the problem of secondary poisoning. I quickly learnt that there was a dearth of information in both of these areas. Little was known about the basic biology of morepork. Secondary poisoning, while appreciated to be important, had received little research in New Zealand and worldwide. With New Zealand's position in the world-wide conservation movement, I decided that here was something that could potentially be very useful to conservation managers.

The early days of the project were quite demanding due to the fact that almost everything I wanted to do had to be figured out myself with the help of my supervisors - there was almost nothing on which to base our ideas. During the first year of the thesis I managed to meet and correspond with several other people who had studied morepork and other owls, and to these people I am very grateful. However, those first few months involved a very steep learning curve. During this project I have also been lucky enough to learn and utilise a wide range of different skills. The use of transmitters was something I wanted to master, but apart from that I have had an introduction to nocturnal field work, time budget analysis, diet analysis, the use of a home range software package, bird handling and bleeding, the use of cameras and automated set ups at nests, molecular DNA techniques, basic statistics, and hopefully scientific writing skills.

I hope that this thesis, and the scientific papers that have and will be published from it, will provide a substantial base for future study of morepork and secondary poisoning. Each chapter in this thesis has essentially been written as a stand alone scientific paper. Chapters 1, 4 and 5 and parts of 2 and 3 were included, along with management recommendations in a report to the World Wide Fund for Nature.

The contents of the chapters are as follows:

Chapter 1 General introduction to morepork and Mokoia Island

This chapter introduces morepork, outlines what is currently known about its ecology, and discusses its taxonomy and relationship with other *Ninox* owls. As can be seen from this chapter, not much is known about this species, and this thesis represents a major step forward. Mokoia Island, the study site at which this research was conducted, is also outlined in this chapter.

Chapter 2 The ecology of morepork on Mokoia Island

In this rather large chapter I outline the major methodologies used and give a brief overview of the study site. This chapter forms the basis of the ecological work that was conducted during my study and outlines the home ranges, hunting behaviour, roosting and diet information collected. I felt it was better to deal with this material in a single chapter because of its inter-related nature. However, it will be published in several parts. Some of the home range data were presented in a talk at the Ornithological Society of New Zealand's 1998 AGM in Wellington. Although much of this material is not 'traditional' thesis material, I feel it is warranted due to a lack of knowledge of this species, and it does provide the first real insight into the natural history of the species. Much of this information also forms background information to other parts of the thesis.

Chapter 3 ***The breeding biology of morepork on Mokoia Island***

This chapter details the breeding biology of morepork on Mokoia Island. It outlines the nest sites used, describes the eggs and chicks, and presents the first information on morepork chick growth. Differences between the two breeding seasons are also discussed. This chapter will also be submitted for publication.

Chapter 4 ***A review of anticoagulant use with special reference to brodifacoum and secondary poisoning***

This chapter reviews the problem of introduced rodents both in New Zealand and world wide. The use of anticoagulants has been seen as a major step forward in rodent control and eradication. This chapter, however, discusses some of the experiments that have been conducted and shown that the secondary poisoning of avian predators can and does occur with the use of these poisons. Some management implications are discussed in the conclusion. Material from this chapter was presented at the student session of the New Zealand Ecological Society and the Ecological Society of Australia annual meeting in Dunedin 1998. This chapter will also be submitted for publication.

Chapter 5 ***Potential secondary effects of the rodenticide brodifacoum on morepork***

This chapter has really been the key outcome of the study. The project was designed around this chapter, and has since formed the basis of a report to the World Wide Fund for Nature. It details the survival of morepork on Mokoia following the mouse eradication attempt in September 1996. The information in this chapter was presented at both the New Zealand Ecological Society annual meeting in Wellington 1997, and the Ecological consequences of pest management meeting in Christchurch 1998. As part of this conference the material presented will be published in a special issue of the New Zealand Journal of Ecology in 1999.

Chapter 6 Molecular sexing of morepork

Due to the lack of sexual dimorphism of morepork I decided that a better way to sex the birds was needed. For this I turned to a recently developed molecular method for determining the sex of birds, based on DNA polymerase chain reaction. This technique worked well and is outlined in this chapter.

Appendices

Several appendices have been added to this thesis. Appendix one details climate information for the study site. Much of this information was used during the analysis stage of this project and so has been presented as background information.

Appendix two is a paper that is currently in press in the journal *Corrella* (due to be published in the December 1998 issue). This paper outlines the capture, handling, marking and radio-tagging of morepork in New Zealand, along with information added by an Australian colleague, Dr Penny Olsen.

Appendix three consists of two tables, the first detailing all birds caught on Mokoia and fitted with transmitters, and the second all birds caught and just banded. This may be helpful to the reader when the band numbers of birds are refereed to in the text throughout the thesis.

Appendix four is a detailed discussion of morepork moult. This material is the first quantitative work on morepork moult, and it is discussed in relation to other small owls.

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1

General introduction to morepork and Mokoia Island

Morepork

Background

When the Maori first arrived in New Zealand, around 1000 years ago, most of the land was covered in thick temperate rainforest (Gill & Martinson 1991). By the time Europeans arrived, Polynesian fires had helped to replace about one quarter of this forest with tussock, fernland, and shrubs. After almost two centuries of European settlement, 20% of the original forest cover remains (Gill & Martinson 1991). This has lead to major changes in New Zealand's avifauna, with 57 species of New Zealand birds becoming extinct (Gill & Martinson 1991).

New Zealand has, or had, five endemic and two native species of raptor (birds of prey). Three of these species disappeared before European colonisation, the Haast eagle, *Harpagornis moorei*, a fish-eagle, *Ichthyophaga australis*, and a harrier hawk, *Circus eylesi*. Another species, the laughing owl, *Sceloglaux albifacies*, was described by European biologists. However, the last known bird was found dead in South Canterbury in 1914 and this species is now considered extinct (Heather & Robertson 1996a). Only one endemic species is currently extant, the New Zealand falcon, *Falco novaeseelandiae*. Fox (1978) estimated the New Zealand falcon population at between 3,000 and 4,500 pairs. This is probably still a reasonable estimate of the present population.

The two native species of raptor which are found in New Zealand, but also occur in other parts of Australasia are the Australasian harrier, *Circus approximans*, and morepork, *Ninox novaeseelandiae*. The Australasian harrier has adapted well to the large scale habitat change that has been brought about since human arrival, and is probably much more common now than prior to human arrival.

The same may be true for morepork, known more commonly outside New Zealand as boobooks, as bone deposits and midden records of morepork are all within the last 100 years. This perhaps indicates that they were scarce before human settlement of New Zealand (Heather & Robertson 1996b) and may have arrived not long before the Maori. The recent colonisation of morepork could be a possible reason for the decline of the laughing owl. However, exact reasons for the decline of the laughing owl are not well understood.

Maori mythology and European discovery

Morepork were known to the Maori by several names. The general name for both sexes of this bird is *ruru*. Maori sometimes referred to female morepork as *peho* and the male as either *koukou* or *popoia* (Best 1977). The sexes were 'identified' by call, with the male said to have a deeper call than the female. The names *peho* and *koukou* are rendered from the birds' cry (Best 1977).

Morepork were sometimes hunted by the Maori, either being knocked off their perch with a throwing stick or being caught with a slip noose. The hunter would hold a branchlet with one hand, and shake it, and manoeuvre the noose with the other hand. The bird would stare at the shaking branchlet, and would then be noosed over the head (Best 1977). They were eaten occasionally, though not often included in any list of food supplies (Best 1977).

There are also several appearances of morepork in Maori mythology (Best 1977). One of the myths explains how a man named Rongo built the first carved house after acquiring a knowledge of this art from a house in the sky. It was necessary to bury a

tapu offering under the rear wall, and for this purpose Rongo sacrificed Kou-ruru, the personification of the morepork. That is why carved figures now have large, glaring eyes; they are the eyes of Kou-ruru or morepork (Orbell 1996). Another myth featuring morepork describes a great battle between the birds of the land and the sea-birds. During this battle the morepork, who could not fly by day, encouraged the land birds by hooting "*toa koe! toa koe!*" - "thou (art) brave! thou (art) victor!" (Colenso 1878, Colenso 1888, Best 1977).

Morepork were also associated with the night and spirits (Orbell 1996), as is common with owls. Many family groups, perhaps most of them, were thought to have a special relationship with an ancestral spirit, and most of these spirits took the form of a morepork (Orbell 1996). Its presence was usually a warning that someone in the family had died. Morepork would sit in a conspicuous place, knocking on a window or even enter a house (Orbell 1996).

A morepork's call was also considered ominous under certain circumstances. It was considered a bad omen when it was heard as men were discussing a plan of action or from a place associated with the dead, or a crossroads, often meaning that enemies were close at hand (Best 1977, Orbell 1996). The time of day the call was heard also seems to have had some influence on the meaning (Best 1977). When heard late at night it meant a disaster was at hand. However, when heard in the afternoon, it told the village that the population would soon be increased by one.

Morepork first became known to European naturalists in 1773 during Captain Cook's second voyage to New Zealand (Oliver 1974). Johann Reinhold Forster, the official naturalist onboard *The Resolution*, discovered the bird at Queen Charlotte Sound and his subsequent drawing led to Latham's description of 'The New Zealand owl', and to the specific name adopted by Gmelin in 1788 (Oliver 1974).

Early colonists of New Zealand regarded morepork as a threat to the release of 'useful' introduced bird species. Sir Walter Buller, one of New Zealand's early naturalists, wrote at the end of last century

> "I have been informed by Sir George Grey that, of nearly a hundred Diamond-Sparrows which he liberated on the island of Kawau, very few survived the ravages of this little Owl, and that some other importations suffered in like manner. Sir Edward Stafford, who had for many years interested himself in the introduction and acclimatisation of useful birds, has also given evidence against the Morepork on this charge; for he assured me that on one occasion, having turned out a large number of insectivorous birds on his grounds at Wellington, an unusual number of Owls sought to harbour there, and preyed on the little immigrants till scarcely a single one remained." (Turbott 1979)

Morepork were often shot during this period of colonisation for this reason (Turbott 1979). Even introduced birds kept in aviaries were not safe from morepork. Their lacerated bodies were often found in the early morning, after unsuccessful attempts by morepork to pull them through the wire netting (Turbott 1979). However, Buller thought that the crusade against morepork which developed from this was unwise. He realised that morepork also preyed upon rats and mice and insect pests such as moths and beetles and wrote

> "It is a dangerous thing to disturb the balance of nature by violent means; and, in a new country especially, we must be careful that in removing one evil we are not opening the door to an immeasurable greater one. For my own part, I consider the killing of a single Owl a positive injury to the farming industries of the country, and scarely compensated for by the introduction of a score of soft-billed insectivores in its place." (Turbott 1979)

Buller described morepork as being "common in all parts of the country, although not so numerous as it formerly was" (Turbott 1979). However, since Buller's day morepork seem to have coped well with further habitat change. The persecution of this species probably slowed as introductions slowed. The morepork is now looked upon favourably, and most people know its call and regard the bird well (B. Stephenson unpublished data).

Originally a bird of native forest, especially lowland podocarp and hardwood (Imboden 1985), it can now be heard almost anywhere in New Zealand. It is commonly found in the man-made environments and habitats created by farms, pastures, pine plantations and parklands (Oliver 1974, Imboden 1985). However, in some open parts of the South Island morepork seem to have been displaced by the introduced little owl, *Athene noctua*. Its numbers began to decrease in the 1930's which coincides with the increase of the little owl (Turbott 1979). Because of this and the lack of large forests, morepork are not common east of the Southern Alps and are absent from large parts of Canterbury and Otago (Oliver 1974, Imboden 1985).

Taxonomy

Morepork belong to the genus *Ninox* (Family Strigidae), which is represented throughout much of Australasia, the south-west Pacific islands and the Indonesian archipelago (Schodde & Mason 1980). Members of this genus are commonly known outside New Zealand as boobooks, and this species is usually called the Southern boobook in Australia.

This genus is comprised of small, rather similar, hawk owls (Norman et al. in press), a name by which some members are commonly referred. As this name implies, species of this genus are more hawk-like than other owls: some having longer or narrower wings and tails, which give them a hawk-like appearance (Harrison 1973). Harrison (1973) also states that the main difference in appearance of the hawk owls is the reduction in the size of the stiff discs of feathers around the eyes, one of the main distinguishing features of other owls. Following this lack of facial discs, the head appears proportionally smaller and more rounded and the eyes and beak more prominent. Associated with the reduced facial discs are small, symmetrical ear-openings. Strictly nocturnal owls with elaborate facial discs, such as the barn owl, *Tyto alba*, usually also possess specialised asymmetrical ear-openings. These openings enable them to pin-point the position of their prey in conditions where sight cannot be used. In hawk owls the ear-openings are generally symmetrical and associated with the reduced facial disc This indicates that these owls are generally visual predators, rather than locating prey

by sound. This is supported by the observation that boobooks are most active around dusk and dawn and on moonlit nights (Fleay 1968, Olsen et al. 1989). During cloudy weather or on very dark nights they are said to often remain inactive during the middle of the night (Fleay 1968).

These reduced features are far more obvious in the larger Australian hawk owls, namely, the powerful owl, *Ninox strenua*, the rufous owl, *Ninox rufa*, and the barking owl, *Ninox connivens*. In species such as morepork these modifications are to some extent less reduced (Harrison 1973). Short, stiff feathers form a pair of prominent 'eyebrow' ridges of whitish feathers over the eyes, and these owls are more 'typically' owl-like in appearance. However, they do still have a somewhat hawk-like appearance.

The taxonomy of the smaller *Ninox* is largely unresolved and there is still considerable controversy surrounding all forms of the *N. novaeseelandiae* 'complex' (Norman et al. in press). A large number of different morphs occur, and debate centres largely on whether the forms occurring in Australia (*N. n. boobook, N. n. leucopsis, N. n. lurida* etc.) are conspecific with the nominotypical form (*N. n. novaeseelandiae*) from New Zealand (Norman et al. in press). Latham (1801) originally considered all the small *Ninox* as a subspecies of *N. novaeseelandiae*. Mathews (1916) even considered that New Zealand morepork could be broken into two separate subspecies, one in the North Island and one in the South (Mees 1964). This was based on plumage colouration, with the North Island birds being lighter. However, Mees (1964) who performed the most comprehensive revision of this genus to date, failed to detect any differences either in colouration, colour markings or size of North and South Island birds, and classified all New Zealand birds under one name (*N. n. novaeseelandiae*). Mees (1964) also considered there to be at least sixteen races (subspecies) of *N. novaeseelandiae* (Fig. 1). Morepork were considered to be the nominotypical form (*N. n. novaeseelandiae*), with Australian boobooks classified as separate subspecies'. Condon (1975) also classified the group as a complex of subspecies within *N. novaeseelandiae*. Later, Schodde & Mason (1980) separated the complex into two species, one based on the New Zealand morepork (*N. novaeseelandiae*) and the other on the Australian boobook (*N. boobook*).

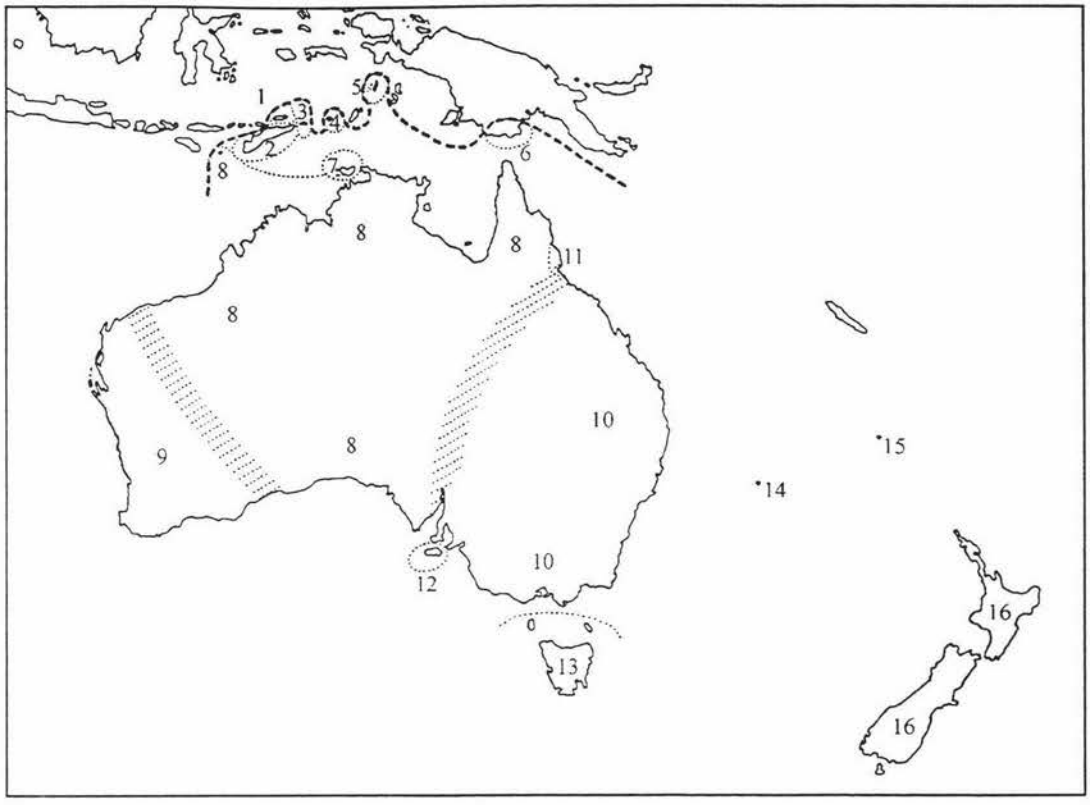

Figure 1. The distribution of *Ninox novaeseelandiae* and its races as described by Mees (1964): 1. *plesseni* 2. *fusca* 3. *moae* 4. *cinnamomina* 5. *remigialis* 6. *pusilla* 7. *melvillensis* 8. *ocellata* 9. *rufigaster* 10. *boobook* 11. *lurida* 12. *halmaturina* 13. *leucopsis* 14. *albaria* 15. *undulata* 16. *novaeseelandiae*.

This was largely on morphological grounds, using wing length to tail ratios, wing formulae and plumage patterning. Schodde & Mason (1980) even considered the Tasmanian boobooks as a subspecies of *N. boobook*, whereas Mathews (1916) originally considered them more closely related to New Zealand morepork. Christidis & Boles (1994) followed the classification of Condon (1975), but recognised the entire *Ninox novaeseelandiae* complex needed a comprehensive revision. Christidis & Boles (1994) suggested that current options ranged from treating each population as a separate species to combining them as one.

Norman et al. (in press) performed the first molecular assessment within the *Ninox* genus. They considered that, using Cytochrome b sequences, the Tasmanian, New

Zealand and Norfolk Island populations of the genus are best treated under the species *N. novaeseelandiae*. It was questioned that with only 0.7% sequence divergence between the Norfolk and the New Zealand forms, that maybe the former should not be treated as a distinct subspecies (Norman et al. in press), as it has been in the past. However, the two forms are readily distinguished by morphology (Norman et al. in press), and sample sizes used during Norman et al.'s (in press) study were small (1 Norfolk Island individual, 1 New Zealand individual), suggesting that taxonomic differentiation may still be warranted. This situation of very little sequence divergence is probably similar among the other forms of boobooks around Australia. Further work is needed in this area, especially for the purpose of conservation as two members of the genus (Sumba boobook, *Ninox rudolfi*, vulnerable; Andaman hawk-owl, *Ninox affinis*, near-threatened) are currently listed in Birds to Watch 2 (Collar et al. 1994).

Throughout this thesis I use the taxonomy of Christidis & Boles (1994) and refer to both New Zealand morepork and Australian boobooks as *Ninox novaeseelandiae*. This is justified in the light of Norman et al.'s (in press) findings. To differentiate between New Zealand morepork and Australian boobooks, I have referred to them as morepork and boobooks respectively.

Current knowledge

In spite of being described as widespread and moderately common (Heather & Robertson 1996b), morepork have received relatively little scientific study in New Zealand. The situation is similar in Australia, with some short notes published in small journals, but very few comprehensive studies. Until relatively recently, most information on morepork was anecdotal or derived from observations or short term study. Several papers have been published in Notornis over the last half-century, consisting mainly of short notes about the birds' diet (Cunningham 1948, Lindsay & Ordish 1964, Saint Girons et al. 1986, Clark 1992) and breeding (Hogg & Skegg 1961, Anderson 1992). A note on calling frequency (O'Donnell 1980), hunting behaviour (Sibson 1989), and general notes (St.Paul 1977) have also been published. These have all been brief, however, and have provided little information on morepork biology.

Imboden (1975) provided the first really qualitative information on this species. In 1973 he attached radio transmitters to two pairs of birds, with home ranges around the then DSIR (Department of Scientific and Industrial Research) Field Station in the Orongorongo Valley. In the early 1970's radio transmitter technology was in its infancy, and the life of these instruments was relatively short. However, he provided an insight into the home range size, activity and roosting behaviour of morepork. Since Imboden's (1975) study there has been little information published on morepork.

Mokoia Island

Mokoia Island (38° 05' S Lat.; 176° 17' E Long.) is a small island situated in Lake Rotorua in the North Island of New Zealand (Fig. 2). Lake Rotorua is situated in the caldera of a now extinct rhyolitic volcano and was formed about 150,000 years ago. Mokoia is 135-ha in size and attains a height of 156 m above the lake level (451 m above sea level). It is the largest inland island in New Zealand and the shortest distance to the mainland is 2.1 km.

Mokoia (Fig. 3) has had a long history of human habitation and is highly modified. Most of the island's original vegetation has been succeeded by regenerating secondary forest after clearing, burning and terracing.

Mokoia has for hundreds of years been occupied periodically by members of nearly all the hapu (sub-tribes) around Lake Rotorua. These hapu valued Mokoia both as a defensive site and as a garden (Andrews 1992). Kumera, *Ipomoea batatas*, was the main crop in pre-European days, but in the early 1800s European missionaries introduced a variety of fruit trees, vegetables and other exotics. Many native tree species such as karaka, *Corynocarpus laevigatus*, whau, *Entelea arborescens*, totara, *Podocarpus totara*, puriri, *Vitex lucens*, and kowhai, *Sophora tetraptera*, were introduced by Maori. There are still fruit trees in some parts of the island and other exotics such as pine trees, *Pinus* sp., crested wattle, *Albizia lephanta*, and poplars, *Populus* sp., are scattered around the island.

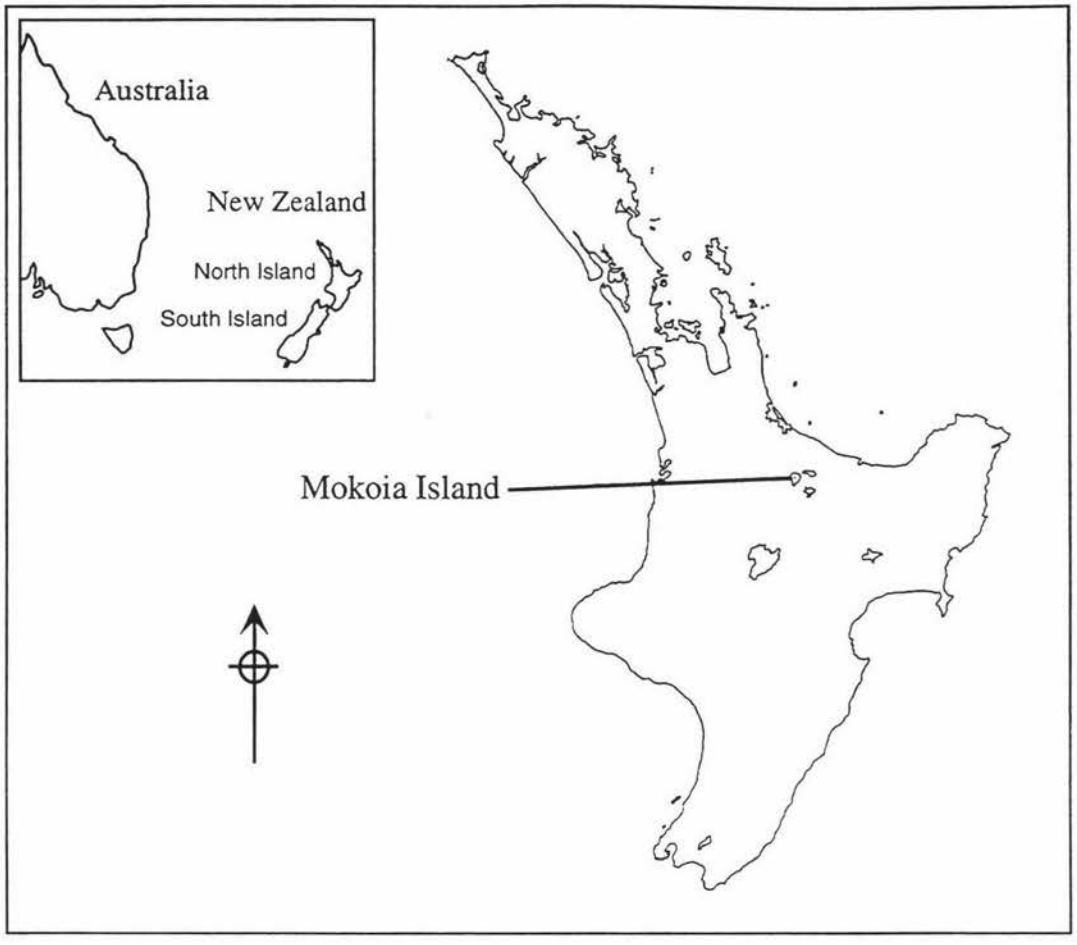

Figure 2. Map of New Zealand and Australia (inset) showing the location of Mokoia Island within the North Island.

During the 1960s Norway rats, *Rattus norvegicus*, were reportedly abundant on Mokoia (Beveridge & Daniel 1965). Cattle, *Bos taurus*, goats, *Capra hircus*, sheep, *Ovis aries*, horses, *Equus caballus*, pigs, *Sus scrofa*, and cats, *Felis catus*, were also later introduced. House mice, *Mus musculus*, also established, but it is not clear when. Possums, *Trichosurus vulpecula*, and mustelids were never introduced. North Island weka, *Gallirallus australis greyii*, were released on the island some time in the 1950s.

Browsing mammals have affected the regeneration of vegetation on Mokoia in such a way that by 1989 the understorey was open with no further regeneration of canopy species taking place.

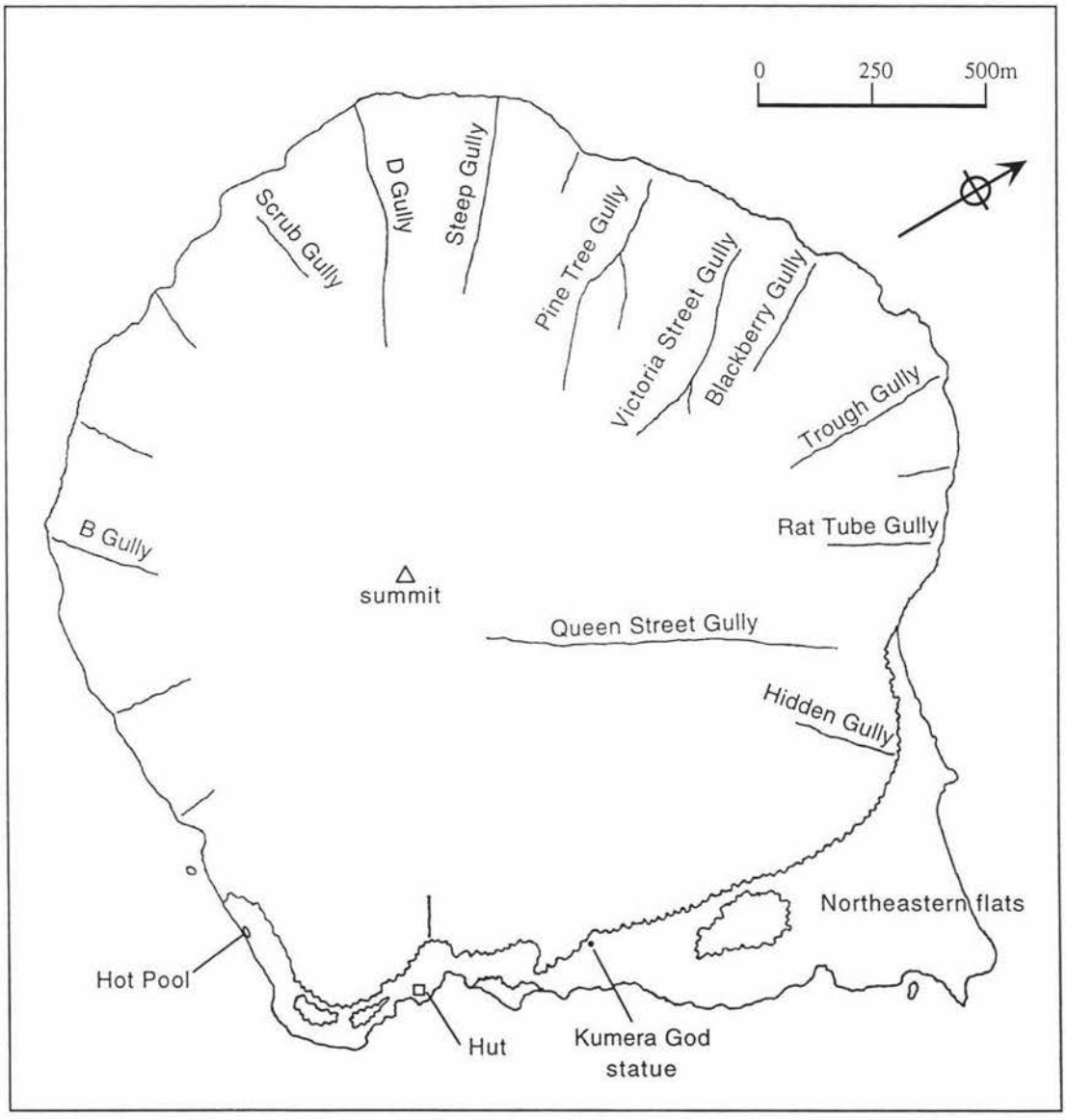

Figure 3. Map of Mokoia Island showing the major gullies radiating down from the summit. The northeastern flats are now predominantly covered in blackberry. The open area around the hut and hot pool is a mown grass area. The rest of the island is covered in regenerating secondary forest.

Cattle, pigs, and cats gradually disappeared and Norway rats, the last remaining sheep and goats were eradicated from the island in 1989–90. The last two horses were helicoptered off the island just before the poison drop in September 1996. The understorey began growing rapidly after the eradication of rats and goats, and is now

extremely thick in most areas. Unfortunately, Norway rats had recolonised in low numbers by the start of this study in late 1995. It is not sure whether they survived in low numbers following the 'eradication' in 1989–90, or if they subsequently recolonised either by boat or swimming from the nearby mainland.

In 1991, North Island robins, *Petroica australis longipes*, were released on the island. North Island saddleback, *Philesturnus carunculatus rufusater*, were transferred in 1992 and have since expanded to a population of around 200 birds. In 1994 stitchbird, *Notiomystis cincta*, were released and currently the population stands at 40–50 birds.

Figure 4. Vegetation on Mokoia is very dense and dominated by mamaku tree ferns (background) especially on the southern side. Introduced weeds such as ragwort, *Senecio jacobaea*, and blackberry can be seen in the foreground and are common around the grassy areas, particularly the northeastern flats. The stone statue in the foreground is the Kumera God.

The vegetation on Mokoia presently consists of regenerating secondary forest species, dominated by mahoe, *Melicytus ramiflorus*, kohuhu, *Pittosporum tenufolium*, five-finger, *Pseudopanax arboreus*, and mamaku tree ferns, *Cyathea medullaris* (Beadel 1990) (Fig. 4). The latter species dominates the canopy on the southern side, while cabbage trees, *Cordyline australis*, are abundant on the northern side (Beadel 1990). In most places the vegetation is very thick, making movement difficult without tracks (Fig. 5). Large areas

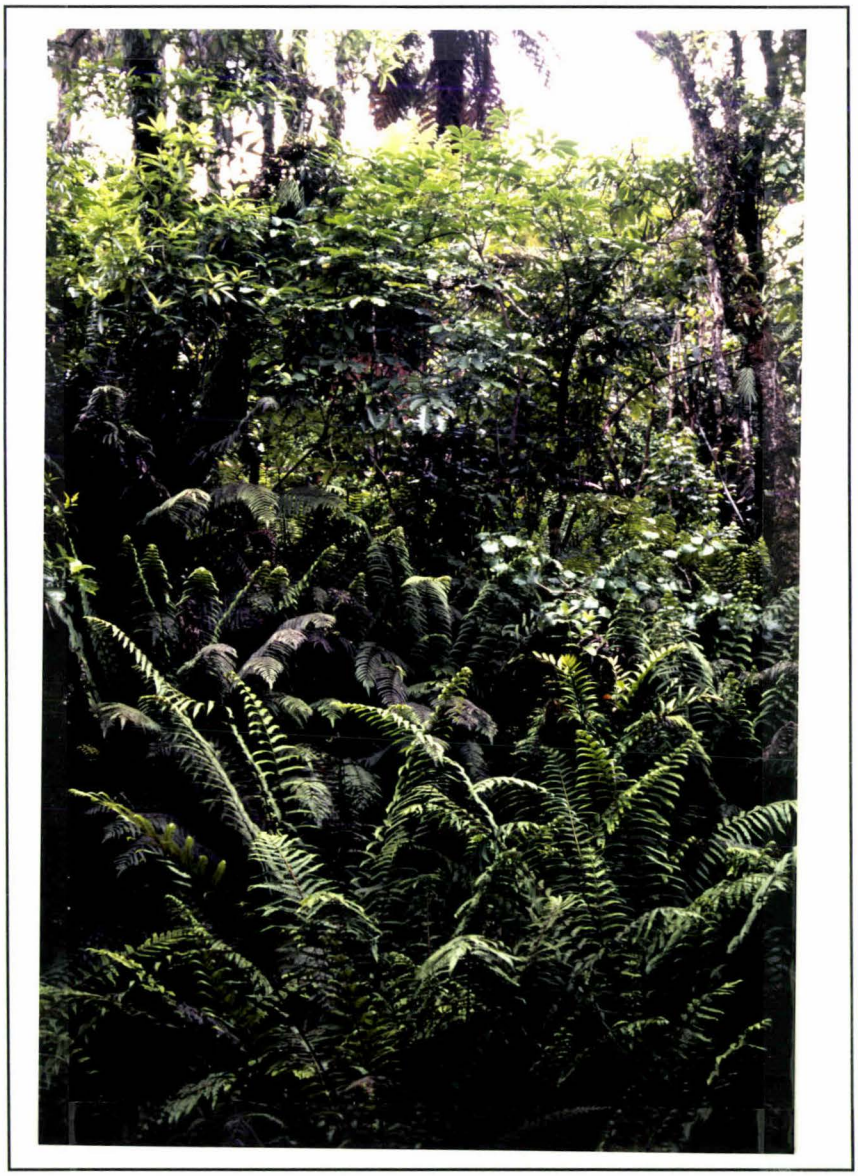

Figure 5. Ferns and a thick sub-canopy make movement without tracks difficult on Mokoia.

of blackberry, *Rubus fruticosus*, cover the northeastern flats. Some grassy areas are also maintained around the Hut and Hot Pool area (see Fig. 3).

Mokoia is Maori owned. It is administered by the Mokoia Island Trust and managed in association with the Department of Conservation (DoC), Bay of Plenty Conservancy.

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2

The ecology of morepork on Mokoia Island

Introduction

The morepork, *Ninox novaeseelandiae*, is a small forest owl native to New Zealand. The *Ninox* genus is made up of a complex group of closely related species and subspecies represented throughout much of Australasia, the south-west Pacific islands and the Indonesian archipelago (Schodde & Mason 1980) (see Chapter 1). Morepork are found throughout forested areas of the North, South and Stewart Islands from sea level to the upper bushline, and on most larger forested offshore islands from the Three Kings to Codfish Island, but absent from the outlying islands (Heather & Robertson 1996). They are commonly found in the man-made environments and habitats created by farms, pastures, pine plantations and parklands (Oliver 1974, Imboden 1985). Despite being described as widespread and moderately common in New Zealand (Heather & Robertson 1996), little is known about the ecology of this species (see Chapter 1 for an overview of work to date). This is probably due to morepork being nocturnal and difficult to locate. However, with the increased life of radio-telemetry devices and the small size of these packages, it is now feasible to attach transmitters to even relatively small birds. This enables nocturnal and secretive species such as morepork to be located easily. This chapter describes the ecology and general habits of morepork on Mokoia Island, based principally on a study using radio-telemetry.

Study site, field work and methods

Study site

All fieldwork was conducted on Mokoia Island (38° 05' S Lat.; 176° 17' E Long.), a 135-ha island situated in Lake Rotorua in the North Island of New Zealand (see Chapter 1 for a full description and maps of the study site). Mokoia attains a height of 156 m above the lake level (451 m above sea level), and is the largest inland island in New Zealand. The shortest distance to the mainland is 2.1 km.

Mokoia has had a long history of human habitation and is highly modified. Most of the island's original vegetation has been succeeded by regenerating secondary forest after clearing, burning and terracing by Maori (Andrews 1992). The vegetation on Mokoia presently consists of regenerating secondary forest species, dominated by mahoe, *Melicytus ramiflorus*, kohuhu, *Pittosporum tenufolium*, five-finger, *Pseudopanax arboreus*, and mamaku tree ferns, *Cyathea medullaris* (Beadel 1990). In most places the vegetation is very thick, making movement difficult without tracks.

Field work timetable

Field work began on 8 November 1995, and started with an intensive four month period during the 1995/96 breeding season. Following this, trips were made to the study site for several days each month until June 1996. In June 1996 and July 1996 several weeks were spent catching additional birds and attaching radio transmitters before an attempt to eradicate mice, *Mus musculus*, from Mokoia Island in September 1996. Following this, several weeks were spent monitoring birds after the poison drop (see Chapter 5). From November 1996 the island was visited for several days each month until March

1997. Weather data were provided by the National Institute of Water and Atmospheric Research Ltd (NIWA) for the duration of the study (see Appendix 1 for full details).

Capture and radio tagging

In November 1995 morepork were captured using a variety of methods, with mistnetting proving the most successful technique (see Appendix 2 for a full account of capture and marking techniques used). At the time of initial capture all birds were fitted with colour bands and a metal number band, morphological data were recorded and a small blood sample was collected. Blood was used to sex birds, due to the limited sexual dimorphism exhibited by morepork (see Chapter 6 for a full description of blood sample collection and molecular sexing techniques).

To determine whether morphological measurements could reliably sex morepork, a discriminant function analysis was conducted using six body measurements. These were: wing length (maximum flattened straightened chord), tail length (from base to tip of tail feathers), head and bill (from upper mandible tip to the indentation formed by the junction of the atlas and occipital), tarsus length (from the proximal end of the tarsometatarsus to the distal end of the first metatarsal of the second digit (owls are zygodactylous - ie. they have two toes forward and two toes back), bill length (from the tip of the upper mandible to end of the culmen, including the cere), bill width (at the cere). The wing measures were taken using a wing rule, to the nearest 0.5 mm. All other measurements were taken to the nearest 0.05 mm with vernier callipers. Birds were weighed using a 300-gram Pesola balance and weighing bags to the nearest one gram. General notes on plumage, moult and colouration were also made at the time of capture. Morepork were usually held for around 40 minutes (if a transmitter was fitted) and were released at the site of capture.

Back-pack style radio transmitters weighing approximately 6.5–7 grams (Fig. 1) were designed for use on morepork. The harness used to attach transmitters had a built in weak-link, designed to break if the bird became entangled by its transmitter or harness (Karl & Clout 1987). Two types of transmitter were used. Firstly, a standard single

stage unit designed to last approximately 10–12.5 months was used. Secondly, four transmitters containing a mercury switch were trialed. These were designed to signal the posture of the bird, and thus infer behaviour when out of sight. The switch was set at approximately 315 degrees from the long axis of the transmitter. When the transmitter was in a vertical position (0 degrees) the transmitter gave a normal signal of 40 pulses per second. However, when the transmitter was at about a 270 degree angle (ie. when the bird was flying) the pulse rate doubled to 80 pulses per second. The transmitters had a shorter life expectancy of around 9–10 months. Transmitters and harnesses were built by Sirtrack Limited (Havelock North, New Zealand).

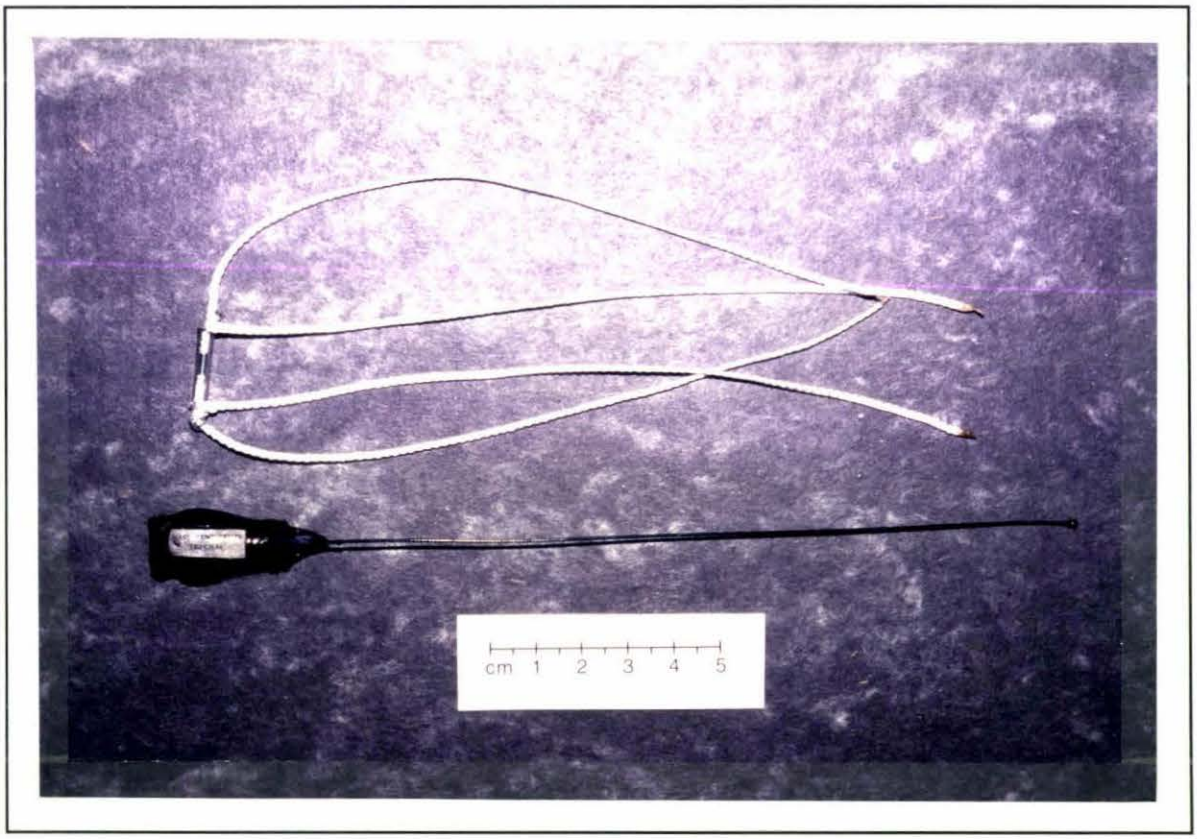

Figure 1. The back-pack style transmitter and harness fitted to morepork on Mokoia Island. The weak-link is situated inside the small plastic tube to the left.

Home range data collection and analysis

Data collection was split into two main sections. Firstly, three pairs of birds which had adjoining territories were radio-tagged (Table 1). These three pairs formed the nucleus of this part of the study and were studied most intensively. Secondly, a further 15 morepork were captured and radio-tagged (Appendix 3) and were monitored less intensively, mainly for data on roost site selection and diet.

Table 1. The three morepork pairs that were studied intensively. Individuals within these pairs are referred to as the Hut male, Hut female, etc.

Bird	Sex	Pair
901	♂	Hut pair
902	♀	"
907	♀	Hot Pool pair
909	♂	"
906	♂	Kumera God pair
910	♀	"

The signals from radio-tagged birds were received using a Telonics TR-4 receiver unit and a three-element hand-held Yagi antenna. Birds from the three intensively studied pairs, including their chicks, were observed leaving and arriving at their roosts at dusk and dawn. Time of departure from the roost was defined as the time at which the bird flew at least one metre from its day perch. Time of arrival at a roost was defined as the time at which the bird jumped to a previously used roosting perch, or the time at which a bird no longer jumped to another branch. Observations were conducted on active birds at night. During these observations birds were followed and kept in sight for as long as possible and a continuous record of everything the bird did was made and timed. This was usually recorded with a hand held microcassette recorder (Olympus Pearlcorder

S927) and later transcribed on to paper. This allowed continuous data collection without losing visual contact of the bird. Behaviour was later broken down into units: perched searching, nocturnal roosting, preening, flying, eating prey, calling, attending chicks and feeding chicks. If visual contact was lost it was often some time before the bird could be visually relocated.

To map the location of roosting and active birds a large area near to, and including, the hut was gridded out at 20 m intervals using a tape measure and compass. This method did not take into account slope of the terrain, but was accurate enough for the purpose of this study.

Data collection

Home range was defined as the area used, traversed, or regularly surrounded by an owl during its normal activities of food-gathering, mating, nesting, caring for young, and seeking shelter (Nicholls & Warner 1972).

Investigation of home range and nocturnal behaviour was conducted on the three main pairs with the bulk of data collected during the initial four months (November 1995 - February 1996). Home range was assessed using three main methods - triangulation, mapping of nocturnal movements (as observed above), and mapping of roost sites.

Triangulation during this study consisted of two observers positioned at stationary points obtaining fixes on birds, using radio telemetry equipment. I always used the TR-4 receiver and three-element hand-held Yagi, while a TR-2 receiver unit and three-element hand-held Yagi antenna was used by the other recorder. Watches were synchronised before triangulation began and hand-held compasses were used to take bearings to each bird's position. Observers were seated at fixed known locations and the positions of two birds were monitored at each sitting. Each observer took simultaneous bearings to the same bird, alternating birds every two and a half minutes. Thus, each bird's location was recorded at five-minute intervals. An estimate of distance to the bird was made at each fix, using signal strength as an indication. Knowledge of the area and the habits of the birds being tracked usually allowed an estimate to be made of the

general location of the bird at each fix. This aided in minimising triangulation error by comparing with the 'triangulated' fix during analysis. When it was difficult to determine the direction of the transmitter signal the data were not used in the analyses.

Statistical analysis

Home range data collected were analysed at several levels. Firstly, all roost locations were analysed separately to give an indication of roost site position within a bird's home range. Secondly, all locations at which a bird was deemed active (from triangulation and observation) were analysed. Thirdly, both were analysed together to determine a birds' home range in the full sense of the definition used in this study.

Before acceptance for analysis, data points derived from triangulations were scrutinised for outliers. This was conducted based on the known range of the equipment, the angle between intersecting bearings and field notes on signal strength and the estimated location of the bird. Due to the small home ranges of these birds we were usually less than 250–300 m away. Thus, triangulation error was kept to a minimum by using these methods and the need for other error estimation techniques (eg. placing transmitters in known locations) were not seen as worthwhile. Independence of data points was not tested for before calculating ranges. However, I used White & Garrott's (1990) rule of thumb that two locations can be considered statistically independent if enough time has elapsed for the animal to move from one end of its home range to the other. Morepork were considered to be highly mobile and could cover several hundred metres within several seconds. Thus, independence was considered to have been achieved if data points were at least 10 seconds apart.

Home range analyses were performed using WildTrak v.1.20 (I.A. Todd 1996, Department of Zoology, University of Oxford, U.K.). Triangulation bearings were converted to co-ordinates using the bearing converter which is part of the WildTrak package. Several methods of non-parametric data analysis were used to estimate home ranges, as outlined by Todd (1996). The minimum convex polygon (MCP) method (Mohr 1947) is the most popular method currently used to provide estimates of an animal's home range (Harris et al. 1990). The minimum area polygon is constructed by

connecting the outer locations to form a convex polygon and then calculating the area of this polygon (White & Garrott 1990). The advantage of this technique is that it is the only method which is strictly comparable between studies (Harris et al. 1990). It is for this reason that MCPs were calculated. However, it is thought to be less suitable biologically as a descriptive statistic because the technique estimates total area utilised, not the area utilised in normal movements (White & Garrott 1990). Therefore, any rare movements of an animal outside of its normal home range increases the estimate calculated.

One approach to correcting this problem is to remove the outliers before the home range polygon is calculated, making the home range estimates more biologically meaningful (White & Garrott 1990). The usual level considered is the 95% or 90% area polygon. Thus, in keeping with the definition used, 95% areas of birds' home range are considered estimates of true home range. This is calculated by excluding the 5% of data points furthest from the arithmetic mean centre of the MCP home range. Overlap areas between birds and home range size comparisons were calculated using home ranges derived from this latter method of analysis. Core areas of adult birds were also assessed by determining 50% areas for active and roosting ranges separately (that is the outermost 50% of data points were excluded from the analysis). This gives an idea of the size of the area that is utilised most intensively by the birds. Differences between home range sizes were tested using Mann-Whitney tests. Home ranges were also tested to determine whether their utilisation was random. That is, whether the birds were using parts of their home range more than would be expected from a random distribution. If birds were using their home ranges randomly the actual core areas (50% areas) should be the same as expected core areas. That is, 53% of the home ranges (95% areas). To test for significant differences between actual and expected core areas (50% areas), Wilcoxon tests of all adult birds' roosting and active ranges were used.

Roost site selection and roosting behaviour

Roost sites of all birds were located by walking in on transmitter signals. Roost sites of untagged birds were also found by searching. The position of a roost was sometimes given away by the presence of 'white-wash' below the roost (Fig. 2). This 'white-wash' was usually only found below well used roosts and consisted of a build up of the uric acid-rich white part of the bird's faeces. All roost sites were described using a variety of characteristics (Table 2). Position of the roost sites of the three main pairs, including their fledglings (and later as juveniles) were plotted onto a map using locations derived from the grid points. Observations of roosting behaviour were conducted during the day. Most birds appeared undisturbed by the presence of an observer and could be watched from less than 10 m away.

Figure 2. Characteristic 'white-wash' found beneath morepork roosts. This is usually only found beneath well used roosts.

Table 2. Roost site characteristics and other related data recorded following location of a roosting adult bird.

Roost site characteristics described
Height above ground (m)
Roost tree species
Roost cover index (1–4)
Perch diameter (cm)
Leg perched on
Distance to bird's mate (if known)
Distance to bird's chicks (if known)
Species mobbing (if any)
Weather conditions

Roosting range and statistical analysis

Only adult roost sites were used for analysis as juveniles were found to use 'unusual' roost sites and were more active during the day.

Roost sites were plotted on a map and roosting range calculated using the home range analysis methods as above. This indicated where roost sites were positioned in a bird's home range and whether these sites provide an accurate estimate of a birds' home range.

Weather data were analysed and daily averages of wind speed, ambient temperature and rain were used in investigating roost site selection. These weather variables may have had an effect on roost site characteristics morepork selected. A principal component analysis using SYSTAT 5.2.1 (1990–92 Systat Inc.) was conducted using the daily means of these three weather variables. Wind direction was not analysed in relation to roost site choice because wind direction frequently changed during the day. Weather variables such as ambient temperature, rainfall and wind speed probably gave a better indication of the weather for the entire day.

Vocalisations

A Sony TCD-D8 Digital Audio Tape recorder and Sennheiser MKH815T shotgun microphone were used to make recordings of morepork calls on Mokoia. Calls were transferred to an Apple Macintosh G3 and the software package Canary v. 1.2.1 (The Cornell Bioacoustics Workstation) was used to analyse calls and produce sonagrams.

Diet analysis

Several methods were used to assess the diet of morepork on Mokoia. Pellets were collected from below any morepork roosts located. Only complete pellets were collected and analysed. Pellets are small packages of indigestible material (eg. insect exoskeleton, bones, feathers) which are regurgitated by owls. Using these pellets, an accurate indication of the bird's diet can be gained (Southern 1970). Spreading sheets below frequently used roosts aided in the collection of complete pellets, as pellets consisting entirely of invertebrate remains often shattered. Pellets were stored in alcohol following collection and were later sorted under a binocular microscope. Prey remains were categorised as bird, mouse or invertebrate. During direct observations of the birds, prey species were identified where possible and categorised as unidentified flying invertebrate, unidentified invertebrate, beetle, cicada, moth, or mouse. Prey remains were identified or collected during nest inspections (analysed and discussed in Chapter 3).

Throughout this chapter most morepork are referred to by the last three digits of their NZ Wildlife Service bands. However, some birds are referred to by their colour band combinations (eg. g/w, w/w, w/y).

Minitab 8.21 (1993 Minitab Inc.) was used to conduct statistical analyses, unless otherwise indicated. The 95% confidence level was used for all statistical tests.

Results

A total of 31 birds was captured, measured, and banded (adults: 14 ♂♂, 11 ♀♀) (juveniles: 3 ♂♂, 3 ♀♀) (Appendix 3). Of these 21 were fitted with transmitters. A population estimate of 25 pairs was made for Mokoia.

Transmitters weighed an average of 3.5–3.7 % of an adult owl's body weight (range=3.0–4.5%, n=15). The attachment of transmitters using a weak-link harness appeared to have little effect on most birds (see Appendix 2). Signals from transmitters were able to be detected at a range of up to 300–400 m in the forest during dry conditions. In wet conditions or when the birds roosted down in gullies detection distance was less.

Morepork on Mokoia were found to be extremely tame, often allowing an approach to within 2–3m before flying away, both at night and during the day while roosting. During observations at night birds often landed only metres away. Thus observer presence was assumed to have little effect on their behaviour. However, it may have affected the behaviour of prey species, such as mice and passerines.

Plumage and morphology

Adult plumage

Plumage colouration and patterning was found to be extremely variable among birds on Mokoia.

The following description of adult morepork plumage is taken from Imboden (1985), and demonstrates the birds' highly variable plumage.

> "Head, back, scapulars and wing coverts brownish grey to dusky brown. Sometimes white to cinnamon brown flecks or radiating stripes on head, neck - forming collar - and back. Flecks on wing coverts and scapulars often large. Primaries dark brownish grey with obscure pale bars and 4 or 5 white to fawn flecks on outer web. Secondaries and tail feathers like primaries but without flecks. Facial disc greyish white with prominent white or cinnamon brows. Underside dark chocolate brown to deep rufous with white, buff or umber flecks, sometimes numerous and forming stripes. Large white flecks on underwing give distinct black-and-white striped pattern when wings open. Underwing coverts pale yellow brown to dark rufous. Undertail coverts from dull white with dark brown spots to rufous brown with white spots. Tarsus feathered, rufous to pale yellow brown. Toes yellow or yellow-brown; claws dark. Iris bright yellow. Bill varies from dark brown with white or yellow ridge on upper mandible to mainly yellow with dark cutting edges."

Colouration of birds on Mokoia Island fitted this description. Figure 3 demonstrates the variation in plumage colouration and patterning found on Mokoia. Birds varied from red-brown through to grey-brown, with varying amounts of spotting or streaking on the breast, belly, wings and back. This spotting or streaking also varied in colour from crisp white to creamy fawn. It did not appear to be related to sex. Both male and female morepork were found to exhibit the various plumage colours and patterns. However, it could not be ascertained if colouration was related to age. The colour of soft parts (ie. cere, talons) also varied among individuals, from green-yellow to bright yellow. Eye colour varied, from a dull yellow to bright yellow.

Immature plumage

In boobooks, first year immature birds are said to be distinguished from adults in that they are usually paler with more spots and streaks, with the upperparts being light or dark brown and the mantle spotted (Schodde & Mason 1980, Olsen 1994). They are also said to have a more distinct facial disc than adults and the crown is usually whitish.

a

b

c

Figure 3. Examples of plumage colouration and patterning of morepork on Mokoia Island. Note the extent of the 'eyebrows': (a) Hut female (902), notice the worn breast and belly plumage indicative of an incubating or brooding female morepork, (b) Kumera God female (910), also showing slightly worn belly feathers from incubation and brooding, (c) unbanded female (left) and the male g/w (right).

On Mokoia immature morepork appeared to have a less distinct disc than adults, but have similar plumage.

Moult

Moult in adult *Ninox novaeseelandiae* has not been described before. Morepork were found to moult on Mokoia following the breeding season (September - January), from December through to March (for a full description of morepork moult see Appendix 4). Morepork moulted their body feathers, followed by their primaries and tail feathers, annually.

Sexual differences in morphology and plumage

When seen in the field the sexes are very similar in appearance. Fleay (1968) also noted this with boobooks.

> "The females of these examples of the southern mainland race (*N. n. boobook*) appeared slightly larger and sturdier than males, but the plumage of the sexes was much alike, and each individual bird was characterised by a different mottling and varied fulvous striations of the under-surface. In other words, the great variation characterising individuals among Boobook owls, which has given rise to endless confusion, puzzled me even in those early days. Also, following the summer moult each owl donned mottling which appeared to me not precisely that of the previous season." (Fleay 1968)

Male and female morepork were indistinguishable in the field. There appeared to be no difference in plumage or colouration of bare parts, and size differences were impossible to detect, even when a known pair roosted beside each other. Captured birds also showed no noticeable differences in plumage.

The morphological data collected from all adult birds captured on Mokoia is shown in Table 3. Female morepork were significantly longer in wing length (Mann-Whitney test: $W=165.5$, $n=10+14$, $P<0.05$) and bill width (Mann-Whitney test: $W=162.0$, $n=10+14$, $P<0.05$). Females also weighed significantly more than males (Mann-Whitney test:

W=165.0, n=11+12, P<0.05). However, weight and all other measurements showed large amounts of overlap, as can be seen in Figure 4. It appears that weight can be used to determine the sex of a bird at the extremes of the scale. That is, a bird weighing more

Table 3. Morphological data collected from adult male and female morepork captured live on Mokoia Island. Significance of morphological differences between the sexes were analysed using Mann-Whitney tests.

Measurement	Sex	$\bar{x}$	sd	range	n
Wing length (mm)	Female	198.70	5.67	191.00–206.00	10
	Male	192.75	4.41	183.00–200.00	14
		W=165.5	P<0.05 *		
Tail length (mm)	Female	116.60	7.17	102.50–124.80	10
	Male	115.50	5.63	108.50–128.90	13
		W=131.5	P>0.05		
Head and bill (mm)	Female	49.43	1.64	47.20–52.50	10
	Male	49.23	1.24	47.00–51.50	14
		W=129.0	P>0.05		
Tarsus length (mm)	Female	37.22	1.25	35.00–38.90	10
	Male	38.22	0.80	37.20–39.90	14
		W=93.5	P>0.05		
Bill length (mm)	Female	21.69	0.86	20.20–23.50	10
	Male	21.34	0.76	19.70–22.50	14
		W=137.5	P>0.05		
Bill width (mm)	Female	9.48	1.10	8.45–11.90	10
	Male	8.84	0.29	8.30–9.40	14
		W=162.0	P<0.05 *		
Weight (grams)	Female	192.09	19.96	171.00–237.00	11
	Male	176.75	16.03	155.00–211.00	12
		W=165.0	P<0.05 *		

* Indicates significance at 95% CI

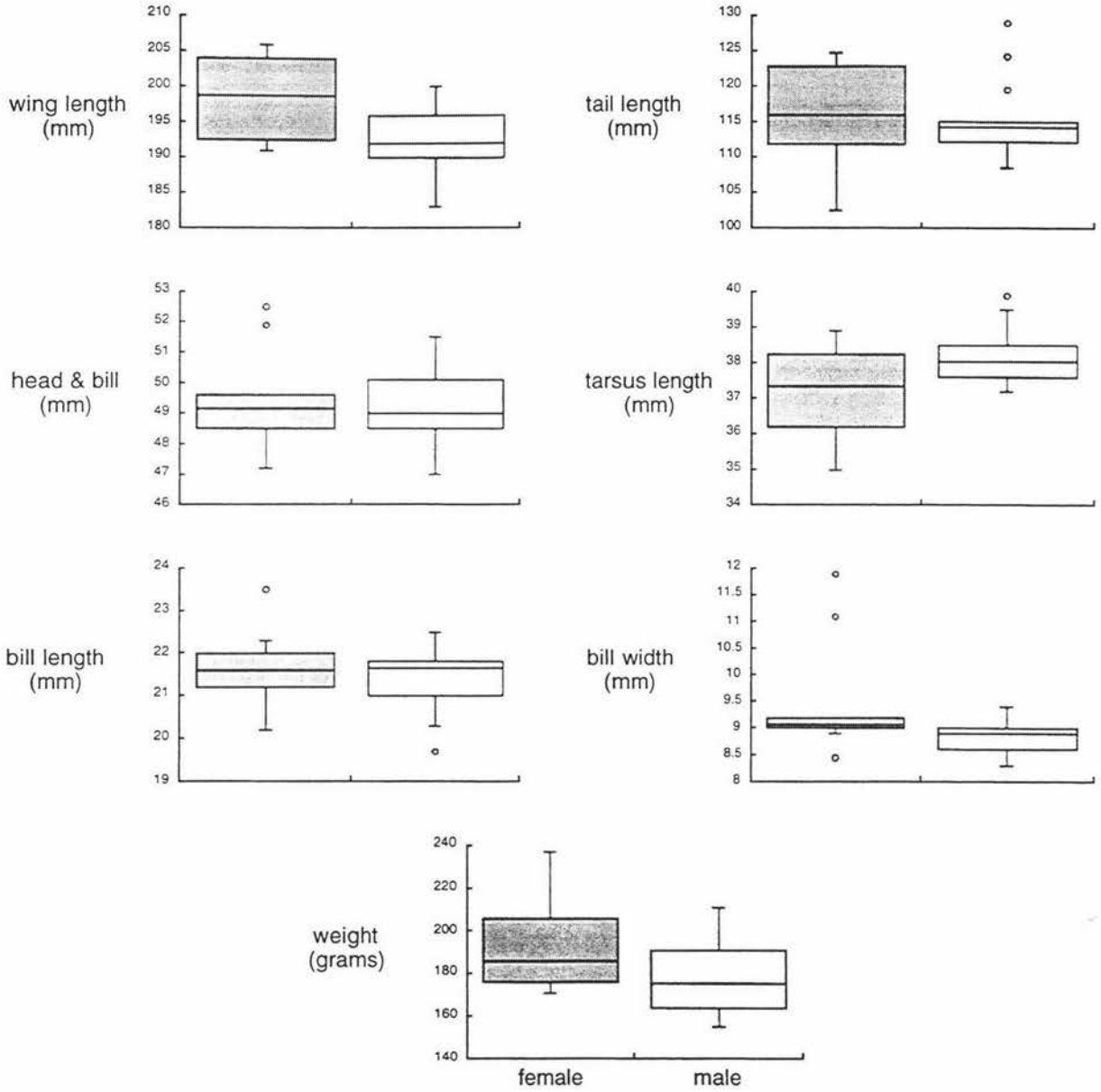

Figure 4. Morphological data collected from adult female (dark shading) and adult male (light shading) morepork captured live on Mokoia Island. The central line of the plot signifies the median, with the two ends of the box indicating the upper and lower quartiles. The lines extending out from the box show the maximum and minimum values, with circles representing outliers. It can be seen that there is a large degree of overlap in most measurements, making it difficult to determine the sex of an unknown morepork captured on Mokoia.

than 212 grams is probably a female and less than 170 grams is probably a male. This will mean, however, that most birds cannot be sexed. This uncertainty in differentiating the sexes of morepork was also reflected in the discriminant function analysis results, which showed that morepork could not be reliably sexed.

The sex ratio of morepork on Mokoia was difficult to investigate. This is due to the fact that non-territorial birds probably do not react to taped calls and therefore are extremely difficult to detect. Thus, the detectable sex ratio will always be even with a secretive monogamous species such as morepork.

Home range use and territoriality

The hut female (902) was not included in the home range analysis as she died on 21 December 1995, and too few data points had been collected. The majority of active data points of the other five adults were collected during the initial study period from November 1995 to February 1996. At this stage all birds either had attempted to breed (907 & 909) or were still caring for young (901, 906 & 910). The majority of roost data points were also collected during this same period, although, roost locations were observed over a longer period. The duration of the tracking period for each bird is shown in Table 4.

Home ranges (95% areas), core areas (50% areas) and MCPs (100% areas) using active, roosting and combined location data are shown in Table 4. Data on home ranges were also calculated for three juvenile birds, two (912 & 913) from the Hut pair (901 & 902) and one (911) from the Kumera God pair (906 & 910) (Table 5). The duration of tracking for these juveniles varied, with 912 dying around 26 December 1995. However, the other two juveniles provided longer tracking periods (Table 5).

Home range estimates

Home ranges (using active and roosting locations) of the five adult morepork were

Table 4. Sizes of adult morepork home ranges (= 95% areas), core areas (= 50% areas) and MCPs (= 100% areas) for the three levels at which home range sizes were calculated.

owl	sex	tracking period	duration of tracking period (days)	no. of active locations	no. of roost locations	area (ha)							
						home range area			core area		MCP		
						active	roost	combined	active	roost	active	roost	combined
907	f	14/12/95 - 02/10/96	292	159	40	4.08	1.49	4.08	0.64	0.24	4.38	1.97	4.75
909	m	08/12/95 - 20/09/96	294	129	54	3.30	1.83	4.60	0.69	0.39	4.75	2.59	5.16
901	m	19/10/95 - 02/02/97	470	945	122	3.01	0.97	3.46	0.42	0.39	5.92	1.04	5.92
906	m	14/11/95 - 03/02/97	446	186	91	2.76	1.07	2.97	0.77	0.13	4.00	1.61	4.45
910	f	05/12/95 - 01/02/97	392	281	98	1.83	0.19	1.72	0.62	0.13	3.92	2.79	6.71
		Mean all birds				3.00	1.11	3.37	0.63	0.26	4.60	2.00	5.40
		Mean male				3.02	1.29	3.68	0.63	0.30	4.89	1.75	5.18
		Mean female				2.96	0.84	2.90	0.63	0.19	4.15	2.38	5.73

Table 5. Sizes of juvenile morepork home ranges (= 95% areas), core areas (= 50% areas) and MCPs (= 100% areas) for the three levels at which home range sizes were calculated.

						area (ha)							
						home range area			core area		MCP		
owl	sex	tracking period	duration of tracking period (days)	no. of active locations	no. of roost locations	active	roost	combined	active	roost	active	roost	combined
912	m	08/12/95 - 21/12/95	14	-	23	-	0.04	-	-	0.002	-	0.04	-
913	m	08/12/95 - 18/06/96	192	586	71	2.00	1.60	2.00	0.31	0.14	5.94	4.93	9.56
911	f	15/12/95 - 24/02/96	71	152	53	1.08	0.36	1.59	0.03	0.11	1.95	0.63	2.69
		Mean all birds				1.54	0.67	1.80	0.17	0.084	3.95	1.87	6.13

relatively small (Table 4), varying from 1.72–4.60 ha ($\bar{x}$=3.37 ha, sd=1.11, n=5). The home ranges of combined data for the three males ($\bar{x}$=3.68 ha, sd=0.84) were on average 27% larger than those of the two females ($\bar{x}$=2.90 ha, sd=1.67). However, this difference was not statistically significant (Mann-Whitney test: W=5.0, n=3+2, NS). MCP estimates are also shown in Table 4. The home ranges of pair partners overlapped to a large extent ($\bar{x}$=81%, sd=18%, range=56–97%, n=4) whereas there was very little overlap with neighbours ($\bar{x}$=0.2%, sd=0.3%, range=0–0.7%, n=8) (Fig. 5) (Table 6).

Home ranges of pairs (using both active and roosting locations for each bird of the pair) were also calculated. The Hot pool pair (907 & 909) had a combined home range of 5.40 ha and the Kumera God pair (906 & 910) had a home range of 7.88 ha.

Mean distance from the range centre to the furthest polygon corner of individual adult home ranges was 139 m (sd=27, range=106–168, n=5). There was no significant difference in this distance between males and females (Mann-Whitney test: W=10.0, n=3+2, NS). Thus, on average the furthest distance a morepork could fly, from one end of its home range to the other, was less than 277 m. Furthermore, distance between home range centres of neighbours was on average 244.6 m (sd=0.82, range=243.6–245.3,

Table 6. Overlap matrix showing the percentage overlap of adjacent adult morepork home ranges . Range areas in rows are overlapped by range areas in columns. Note that overlaps have been calculated from home ranges of both active and roosting ranges combined. Figures in bold are overlaps between pair partners. X signifies non-neighbouring individuals.

owl	901	907	909	906	910
901	-	0.00	0.74	0.00	0.00
907	0.00	-	**90.91**	X	X
909	0.55	**80.65**	-	X	X
906	0.00	X	X	-	**56.42**
910	0.00	X	X	**97.36**	-

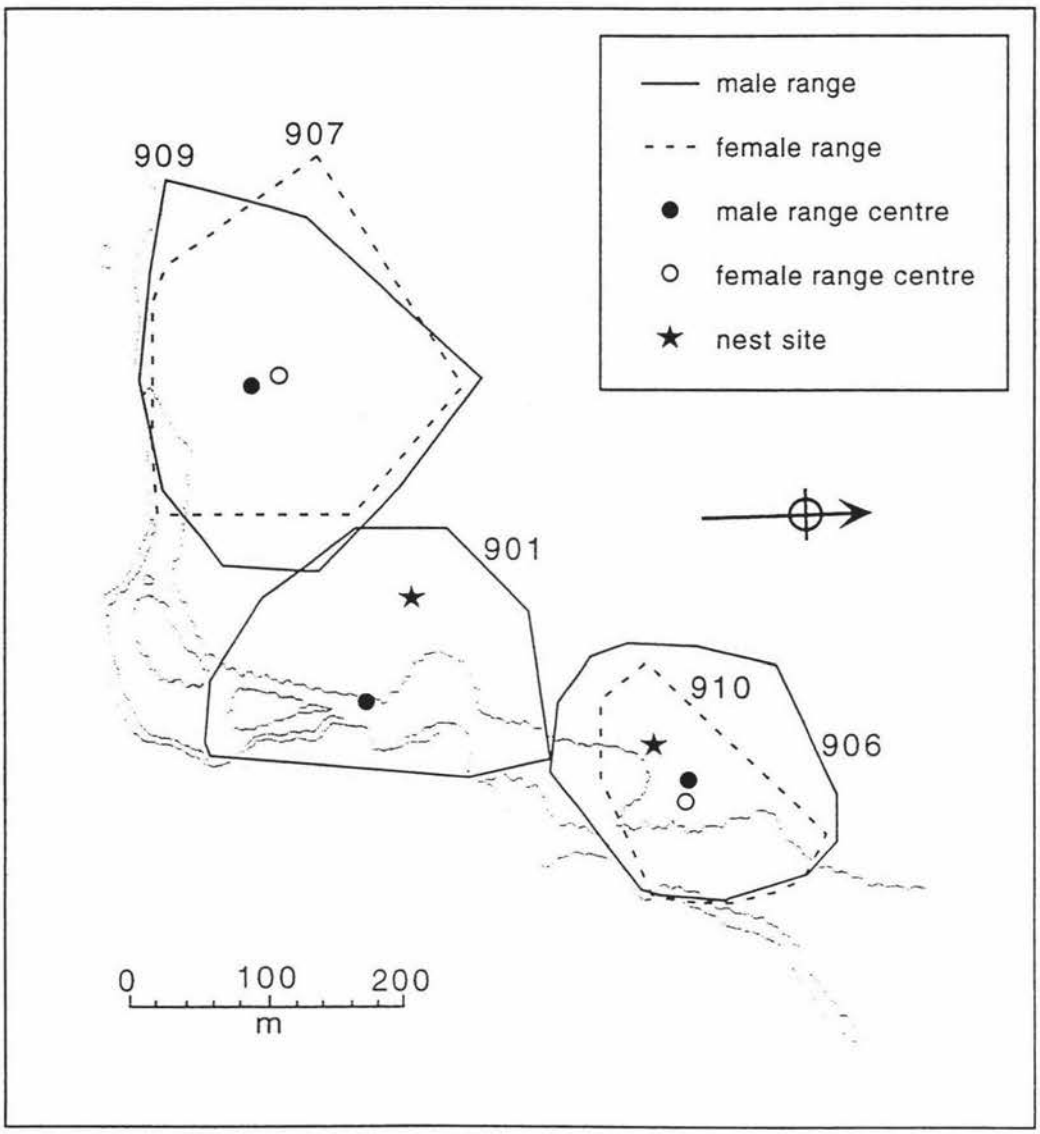

Figure 5. Nest locations and individual home ranges (95% areas) of the five adult morepork intensively studied. Home ranges are overlaid upon a map of the area.

n=4), and between members of the same pair was 17.2 m (sd=4.2, range=14.2–20.2, n=2).

The 1995/96 nest sites of the Hut pair (901 & 902) and the Kumera God pair (906 & 910) were plotted on their calculated home ranges (Fig. 5). Nest sites were positioned near the middle of the birds' home ranges, and were situated 200 m apart. Both nests were also situated at least 60 m from the nearest polygon corner. The Hot Pool pair (907 & 909) may have attempted to breed, but by the time this pair was captured and radio-tagged they were not attending a nest or young.

A comparison of the overlap between active home ranges and roosting home ranges of each adult was conducted. Results of this analysis are shown in Table 7. It was found that 0–56% of the roosting range lay outside of a bird's active range. This suggests that estimates of home range taken from roosting locations alone would severely underestimate a bird's true home range.

Table 7. A comparison of the overlap between active home ranges and roosting home ranges for each adult morepork.

		home range estimate (95% areas)	
owl	area of overlap (ha)	active area %	roosting area %
901	0.7806	25.9	80.5
907	1.4850	36.4	100.0
909	0.8119	24.6	44.3
906	0.7297	26.4	68.5
910	0.1892	10.3	99.6

Core area use

Active and roosting core areas of birds, other than mated pairs, did not overlap. It was found that although there were large differences between the actual core areas (50%

areas) and the expected core areas, the differences were not significant (active: $P<0.059$; roosting: $P<0.059$). The Wilcoxon test, however, is a conservative, non-parametric test. The results yielded from this test therefore suggest that these differences are close to significant. Because the data are non-normal and because of the small sample size, the use of another less conservative measure would be inappropriate. If the differences were significant, it would mean that birds were not using their home ranges randomly, but were spending more time in certain areas.

Adult dispersal and range expansion

Morepork on Mokoia appeared to be relatively sedentary throughout the duration of this study. Of the six individuals that were intensively studied, one died during the summer of 1995/96 (902) and another died following the poison drop (907) (see Chapter 5). However, the remaining four birds were still occupying the same home ranges in the 1996/97 breeding season as they were in the 1995/96 breeding season.

A mated pair and five single radio-tagged morepork were also located over both breeding seasons (1995/96 & 1996/97). These birds had home ranges scattered around the island. Of these birds, four appeared to use the same home range in both the 1995/96 and 1996/97 breeding seasons. Another pair which did not have transmitters, and so were not located on a regular basis, were also seen during the 1996/97 season in the same area as they had been in the previous season.

Despite this generally sedentary nature, three dispersal/expansion events of adult morepork were recorded (Fig. 6). The first occurred between 8 August 1996 and 20 September 1996 when the female from Trough Gully (905), whose mate was unbanded, was found in a different area. She was located approximately 700–1000 m from where she nested in the 1995/96 breeding season and was with an unbanded male. There was no way to tell if this male was her previous mate.

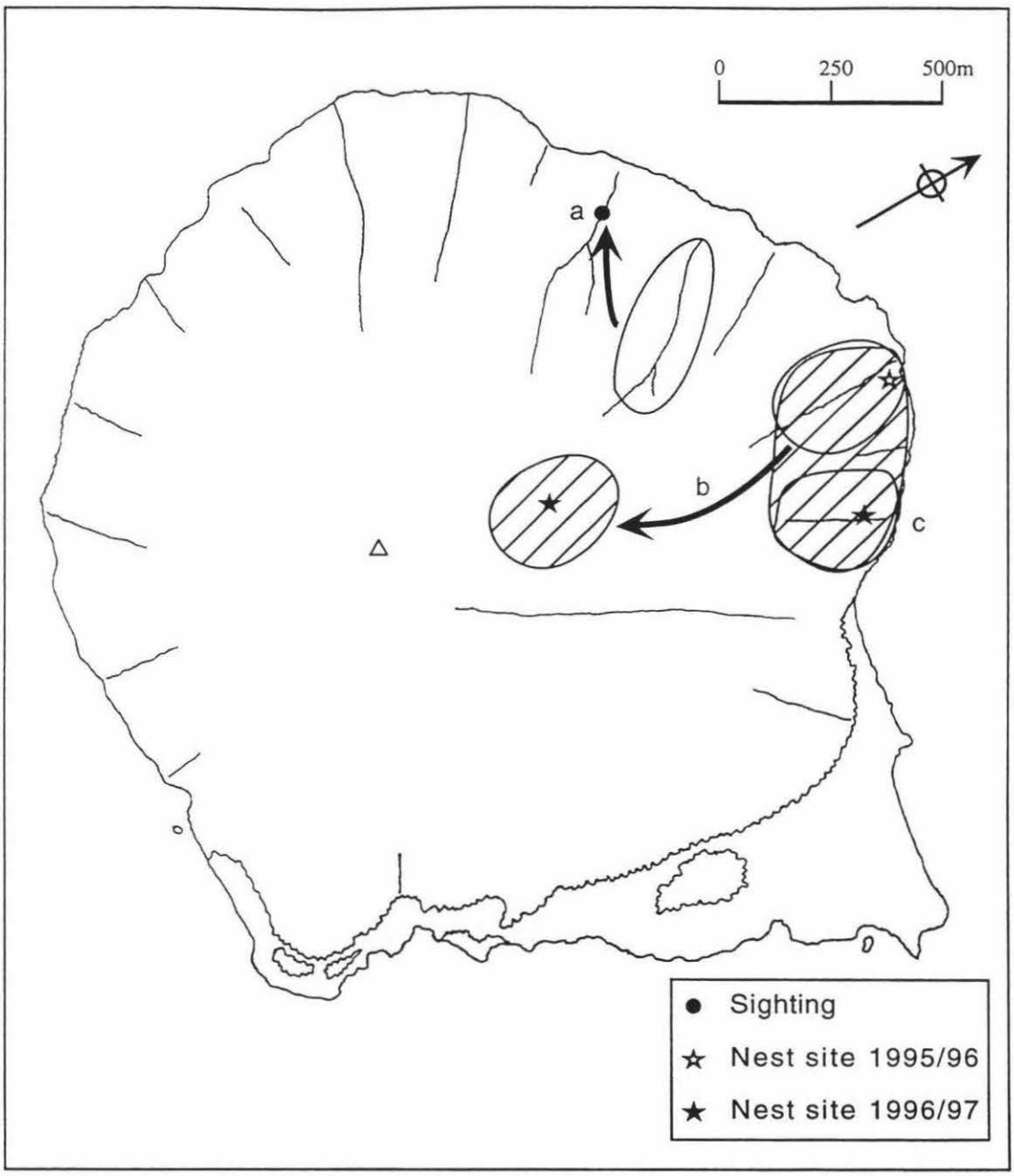

Figure 6. Map of Mokoia showing dispersal/expansion events of adult morepork. Shaded areas indicate approximate home ranges in the 1995/96 breeding season and hatched areas indicated approximate home ranges to which they moved. The new home range of 928, indicated by (a), was unknown as this bird was observed at only the one location. The pair which occupied range (c) in 1995/96 (914 & 918) expanded their home range to include the home range of (b) (905 and unbanded male) in the 1996/97 season. 905 moved home range, but the identification of her mate was not possible as he was not banded.

In the second instance, the pair which had occupied Rat Tube Gully in the 1995/96 breeding season (914 & 918) were seen at the base of Trough Gully on 20 September 1996. Thus they had expanded their home range to include the 1995/96 home range of 905 and her mate. They were seen in both Rat Tube Gully and Trough Gully throughout the 1996/97 breeding season, and attempted to nest in Rat Tube Gully. A possible reason for these movements could have been the death of 905's mate and her subsequent eviction from her home range by the neighbouring Rat Tube Gully pair. Or, both 905 and her mate could have been ousted by the Rat Tube Gully pair for some reason. This movement could also be considered expansion of home range rather than true dispersal.

The third event involved a radio-tagged male (925) from Victoria Street Gully. His normal roosting range was within this gully during the winter and summer of 1996. During the 1997/98 breeding season he was seen in the adjacent Pine Tree Gully using the same roost on a number of occasions. This is approximately 250 m from Victoria Street Gully. In October 1996 Department of Conservation staff found a dead morepork following a poison drop conducted on the island in September 1996, in Pine Tree Gully, near where 925 was subsequently seen roosting (see Chapter 5). Thus, this expansion event may have been caused by the availability of a home range resulting from the death of a morepork following the poison drop. Again, this may be just an expansion of the birds previous home range.

Diurnal behaviour and roost site analyses

Diurnal behaviour

Although morepork are primarily nocturnal, adult morepork were sometimes active during the day. Day time sightings of morepork were analysed to investigate the frequency of this diurnal activity. All sightings of active birds between one hour following sunrise and one hour before sunset were excluded. This reduced the chance of classifying a bird that was going to roost late, or had left its roost early, as this would not strictly have been diurnal activity. This is a reasonable assumption based on

observations of adult morepork arriving and departing from roosts during December-February 1995/96.

I analysed 741 day time sightings and classified behaviour broadly as roosting or active. Roosting birds were recorded on 713 occasions (96.2%), with active birds being recorded 28 times (3.8%). During the 28 times that birds were recorded as active, they were usually exhibiting hunting behaviour, that is turning their heads rapidly looking intently at moving objects with eyes wide open and making short flights. They tended not to stay at perches for as long as when hunting at night.

Roost site characteristics

I analysed the site characteristics of 788 morepork roosts. Each roosting episode was analysed, regardless of whether the roost site had been used before, as birds often chose a different perch or roosted at a slightly different height even if the same roost was used more than once. Analysing roosts using this method may mean the statistics have been affected by pseudoreplication. Thus, caution should be taken when interpreting these results. Not all roost site descriptions contained data for all measures.

Mean roost height was 4.3 m from the ground (sd=2.1, range=0.5–17.0, n=644) (Fig. 7). Birds usually perched on smaller branches, not close to the trunks of the roost tree. This was indicated by analysis of perch diameter ($\bar{x}$=2.4 cm, sd=2.1, range=0.5–15.0, n=401).

Morepork were found to roost in a variety of tree species (Table 8), with kawakawa used most commonly. The relative use of tree species was probably associated with the availability of these species on Mokoia. However, kawakawa seemed to be used at a higher rate than its availability. This is may be because kawakawa provides compact and continuous cover.

The amount of cover was measured and analysed for 652 roosts (Fig. 8). Cover was estimated and given an index of 1–4: 1 being excellent all round cover, 2 being good all

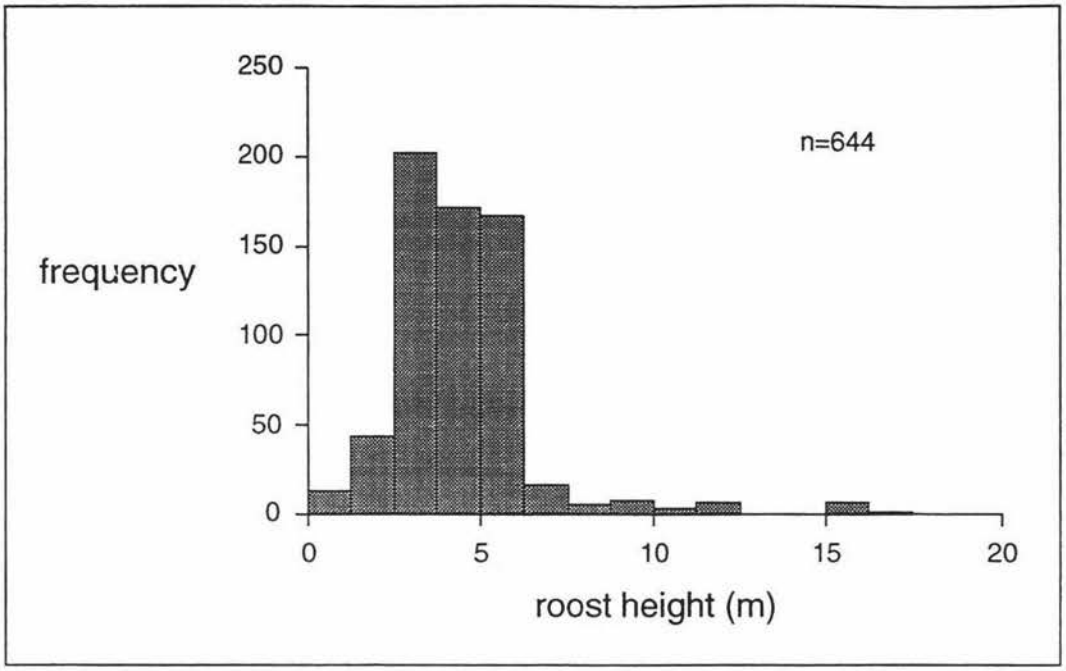

Figure 7. Morepork roost heights recorded on Mokoia Island. Mean roost height was 4.3 m.

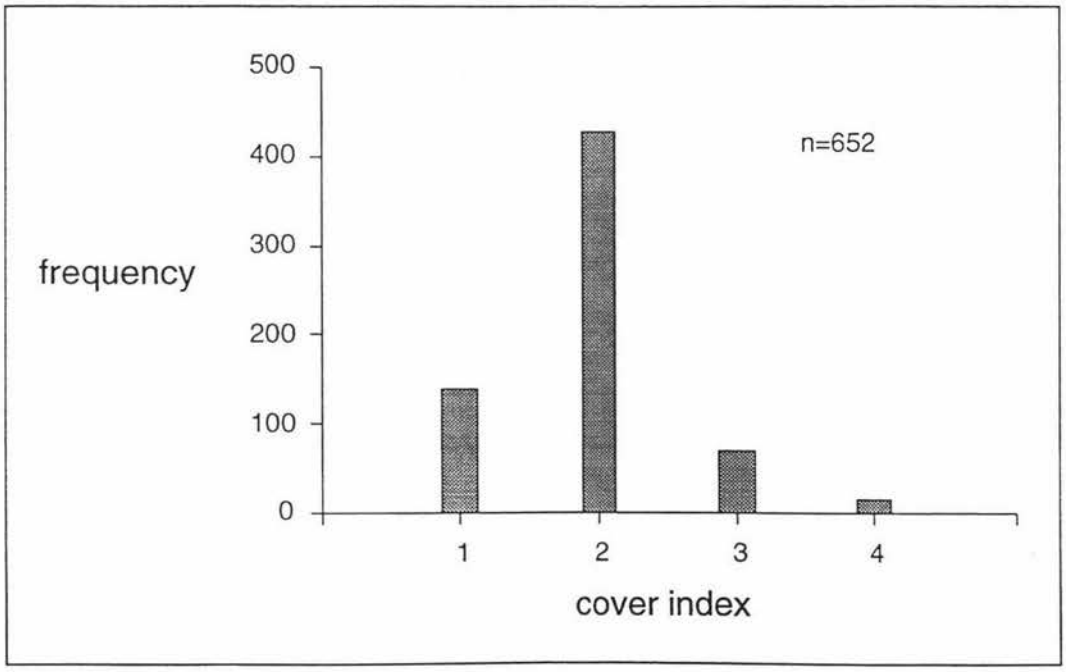

Figure 8. Cover index of morepork roosts found on Mokoia Island. 1 indicates excellent all round cover, 2 good all round cover, 3 fair cover, but lacking in some areas, and 4 poor all round cover.

Table 8. Tree species used as roost sites by adult morepork on Mokoia Island, with the total number of roosts located in each species.

Roost tree species	Scientific name	no. of roosts	%
Kawakawa	*Macropiper excelsum*	228	36.1
Wheki	*Dicksonia squarrosa*	76	12.0
Rangiora	*Brachyglottis repanda*	60	9.5
Mahoe	*Melicytus ramiflorus*	52	8.2
Pate	*Schefflera digitata*	51	8.1
Kohekohe	*Dysoxylum spectabile*	43	6.8
Mamaku	*Cyathea medullaris*	32	5.1
Silver fern	*Cyathea dealbata*	31	4.9
Karaka	*Corynocarpus laevigatus*	30	4.8
Fern	*Blechnum spp.*	6	1.0
Whau	*Entelea arborescens*	5	0.8
Cabbage tree	*Cordyline australis*	5	0.8
Robinia	*Robinia spp.*	4	0.6
Pittosporum	*Pittosporum eugenoides*	3	0.5
Five-finger	*Pseudopanax arboreus*	3	0.5
Fuschia	*Fuchsia excorticata*	1	0.2
Climbing rata	*Metrosideros sp.*	1	0.2
Total		631	100

round cover, 3 being fair cover but lacking in some areas, (eg. above or around the roost), and 4 being poor all round cover (ie. exposed). Analysis showed that 21.5% of roosts were class 1, 65.6% class 2, 10.6% class 3, and 2.3% class 4. Thus, birds usually used well covered roost sites, and very rarely used completely exposed roosts.

Birds tended to use roosts with less cover when it was raining (One-way Analysis of Variance: $F_{2,646}$=6.94, P<0.001). This is related to the fact that tree species used as roosts when it was raining were species such as karaka, *Corynocarpus laevigatus*, mamaku, and kohekohe, *Dysoxylum spectabile*, which have a more open interior, and offer less cover, but have a thicker canopy layer. There were similar relationships with temperature and wind in that birds tended to use more exposed perches as the temperature increased (One-way Analysis of Variance: $F_{2,646}$=3.99, P<0.002) and more exposed perches in higher winds (One-way Analysis of Variance: $F_{2,646}$=3.97, P<0.002).

Roost sites seemed to have some generally favourable attributes. Birds were sometimes found roosting on the same perch used by another bird months earlier. This was even found to occur amongst birds from different pairs. When the female 905 left her home range in Trough Gully and moved to the north of Queen Street Gully (see dispersal above), the Rat Tube pair (914 & 918) were found to use several of the same roosts that 905 and her unbanded mate had used in the previous breeding season.

The number of roosts used by individual morepork seemed to vary widely, with some birds' having new roosts almost everyday, and others using the same roost or the same series of roosts for prolonged periods. This may be at least partially related to the bird's stage of breeding. Birds which had newly fledged chicks, or juveniles that had been fledged for only a month or so (1995/96: 901, 906 & 910) tended to roost in the same area each day. However, other birds with a failed breeding attempt (1995/96: 907 & 909) used a large number of roosts that were often more than 50 m apart.

Roost arrival and departure

The arrival and departure of adult morepork from their day roosts generally coincided with sunrise and sunset respectively (Fig. 9). The average time that morepork arrived at their roosts was 12.25 minutes after sunrise (sd=20.27, range=15.07 before–63.00 after, n=28). The average time that morepork left their roosts was 12.65 minutes before sunset (sd=18.70, range=59.28 before–08.58 after, n=19).

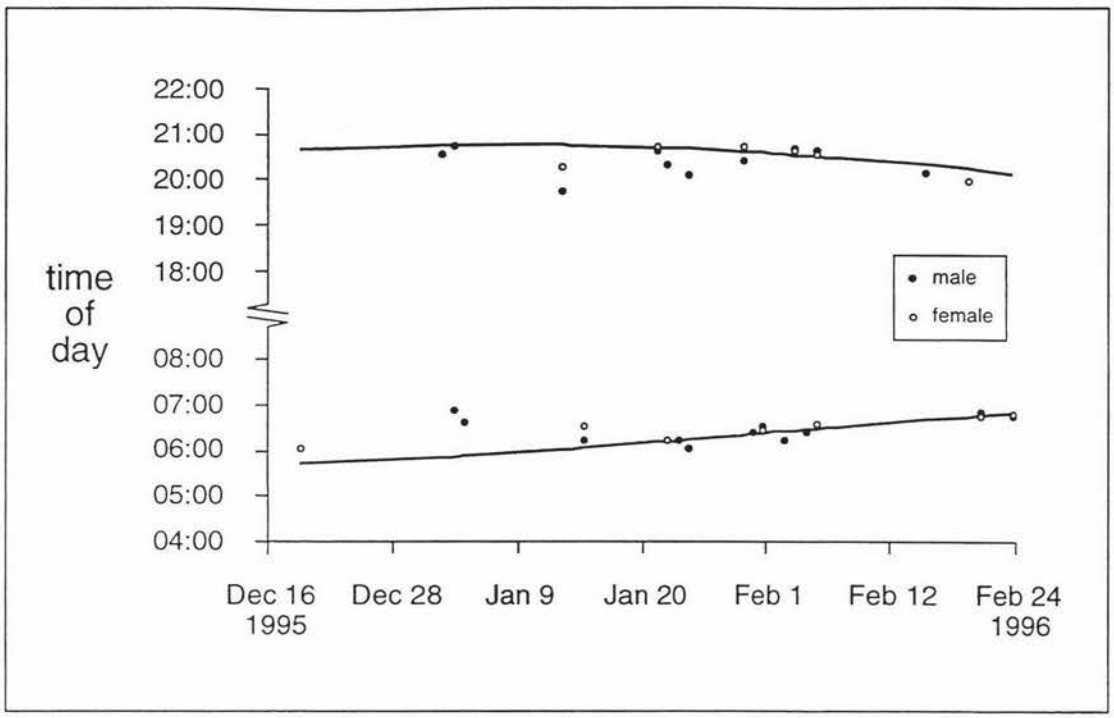

Figure 9. Roost arrival and departure times of adult morepork on Mokoia Island, shown in relation to sunset and sunrise. Shaded areas indicate night.

Birds tend to arrive at their roosts later in the morning, and leave their roosts earlier in the evening, during mid-summer when night length is shorter (Fig. 9). This may just be an artefact of the limited sample size, or could actually be a real phenomena. At this time (December and January, when night length is at its minimum) the birds included in this analysis also had fledglings to feed. Thus, adult morepork may have been spending more time actively hunting in order to be able to catch enough prey for themselves and their offspring.

Distance between roosting pair mates

On average it was found that morepork roosted 30.7 m from their mates (sd=47.92, range=0.05–200.0, n=455) (Fig. 10). This was an average over all roosting birds and the time of year effect was not analysed separately. Birds rarely shared the same roost (ie.

the same branch) except during the early breeding stage before the female started laying and incubating eggs (see Chapter 3). However 55% of roosts were within 10 m of their mates' roosts. The Kumera God pair (906 & 910) spent most of January and February roosting within 6 m of each other when their chick was still dependent and roosting with them. Most other birds, however, roosted separately and usually some distance apart. Thus, the results were probably biased by this pair. Another bias which may also have affected these results was the fact that untagged mates roosting close to their radio-tagged mates would have been easier to find than when they roosted further away. Therefore, mean roost distances between mates reported here may be shorter due to sampling errors.

Behaviour at roosts

Once a bird arrived at a roost in the morning, it usually spent the whole day at this roost. Roosting birds were checked twice during the same day on 72 occasions. Birds were found at the same roost (on the second check as they had been previously that day) 49 times (68.1%). On 11 (15.2%) occasions the bird had moved less than 10 m, usually only several metres to another perch in the same roost tree. However, on 12 occasions (16.7%) the bird had moved more than 10 m to another roost.

While at day roosts, morepork were observed to spend most time perched with eyes closed. They usually perched on one leg with the other tucked up into the belly feathers. Periods of sleep rarely lasted longer than an hour, and were interrupted by brief periods of preening or actively looking about. The birds preened plumage and feet, stretched their wings and tail, and sometimes shook the entire plumage. These preening bouts did not usually cover extensive areas of the plumage, except just after birds returned to roost in the morning, or especially in the evening just prior to leaving their roosts. Birds usually preened for about half an hour at this time.

Morepork were sometimes seen to stretch their heads up and open their bills in a yawning action. The behaviour was usually performed on warm days. On one day in particular the Kumera God female (910) performed this behaviour 31 times in just over

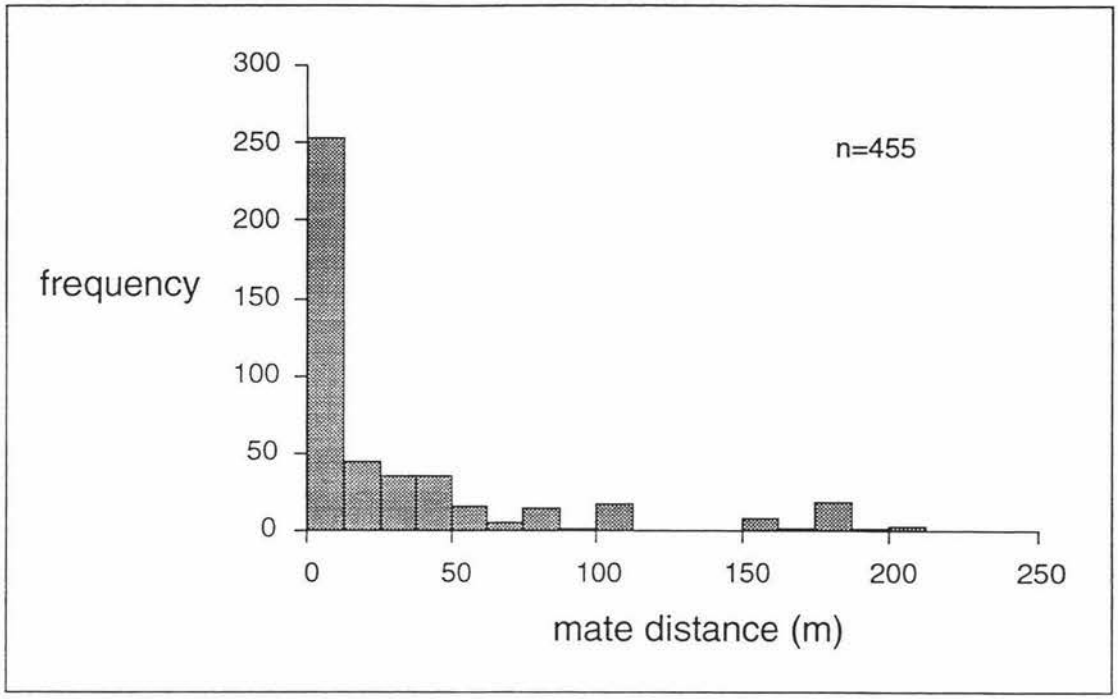

Figure 10. Frequency histogram of the distance from a roosting bird to its mate, if the location of its mate was known. Mean distance was 30.7 m.

five minutes. This was a particularly hot day with a maximum temperature of 24° C. This behaviour may help morepork to lose heat and lower their body temperature.

Allopreening between pair mates was very rare and was observed only once. This is probably related to the fact that pair members do not usually roost together. Allopreening between chicks and adults, however, was observed on several occasions when chicks were still dependent on the adults and roosting with them (less than one month after fledging). At these times chicks would nuzzle up to the male or female and nibble the breast feathers of the adult. The adult would sometimes reciprocate and would preen around the face of the chick. The chick would then do the same. Sometimes the chick gave the *chitter* call (see vocalisations below) when being allopreened by the adult. This seemed to be a sign of 'excitement' on behalf of the

chick. Adult-chick allopreening episodes did not last longer than five minutes and were usually terminated by the adult when it moved away from the chick.

Pellets were only recovered from below roosts. Birds were not seen to regurgitate pellets at night when active, but may have done so. Pellets appeared to be regurgitated at roosts in the late afternoon, but the actual process was never observed. Freshly ejected pellets were found beneath roosts between 1500h–1900h in the summer of 1995/96.

Mobbing of roosting morepork by passerines

During investigation of the 788 roost sites, mobbing by passerines was observed at 27 of the sites (3.4%). A total of 51 birds, from nine species, was recorded mobbing morepork (Table 9). The most commonly recorded mobbing species were fantails (n=12) with thrushes being recorded as a mobbing species only once. Mobbing birds usually perched up to 30 cm from the morepork and alarm called. However, tui were sometimes more bold. During pre-departure observations of the Hut male (901) and his fledgling (913) at their roost, a tui started to mob (913 had been fledged about 20 days). The tui was calling and kept hitting branches just above the roost. The male did not seem 'uncomfortable'. The juvenile, however, spread its wings several times in an attempt to confront the tui. After several minutes the juvenile hopped to another branch, the tui attacked him, and they flew off with the tui chasing. The juvenile had flown about eight metres when it was knocked out of the air by the tui and they rolled around on the ground for several seconds, before the juvenile flew off. The tui gave chase again, but was not seen to physically attack. Although tui were not the most frequent mobbers, they were the most aggressive.

When being mobbed adult morepork tended just to tuck their bills down into their breast feathers and stay at their perch, usually with partly closed eyes. This behaviour was also common when an observer first arrived at a roost. Morepork have bright yellow irides and when their eye lids are open, as when active, they are very bright. With their eyelids partly closed only the pupil is visible and it looks as if their eyes are closed. Morepork may use this behaviour to make themselves less conspicuous. Juvenile

morepork would quite often stare at the mobbing birds and wobble their heads from side to side, but apart from the incident described above, physical contact was not observed.

Morepork were mobbed after they had left their roosts in the evening and before roosting in the morning. During one mobbing session two thrushes, *Turdus philomelos*, were nearly hitting an adult male (901) that was perched ready to begin its nights hunting. The morepork seemed to ignore the thrushes. It flew off after several minutes.

Table 9. Bird species recorded mobbing roosting adult morepork, number of times each species was recorded and the number of individuals recorded mobbing from a total of 27 mobbing episodes.

Species	Scientific name	no. of mobbing occurrences	total no. individuals recorded mobbing
Fantail	*Rhipidura fuliginosa*	12	22
Silvereye	*Zosterops lateralis*	10	20
Saddleback	*Philesturnus carunculatus*	9	16
Chaffinch	*Fringilla coelebs*	7	8
Stitchbird	*Notiomystis cincta*	4	10
Robin	*Petroica australis*	4	6
Blackbird	*Turdus merula*	4	5
Tui	*Prosthemadera novaeseelandiae*	3	8
Thrush	*Turdus philomelos*	1	2
Total		54	97

Vocalisations

Calls given by morepork were classified into seven types. All types of call were given by both sexes, but some appeared to be given by one sex more than the other. There was a large variation in the pitch of calls given and this was possibly associated with the sex of the calling bird. However, after considerable time spent listening to certain individuals calling, it was still not possible to distinguish individuals, or the sex of the calling bird as has been described in other studies of owls (Forsman et al. 1984, Galeotti & Pavan 1991, Appleby & Redpath 1997, Hill & Lill 1998c).

More-pork call (location call)

This was the most common call heard, the common name 'morepork' being derived from it. It consisted of a clear double noted call, with approximately 68 milliseconds between the two notes (Fig. 11). The second note of the call is slightly lower in pitch than the first note. Each *more-pork* is repeated a variable number of times, from only a single call up to 30 or more calls, spaced approximately 2–10 seconds apart. Both sexes were found to use this call on Mokoia, although males appeared to use it far more frequently. It was used in a variety of situations and seemed to function primarily as a territorial challenge, although it may also have alternative functions such as a general location call between paired birds and a pair bonding call. On several occasions two birds were heard calling together in the middle of a pair's home range. In these instances it was more than likely both members of the pair were calling to each other or 'duetting'. It was also used by adults near fledged chicks and probably functioned as a location call in this situation. A more subdued version of this call was sometimes given when birds arrived at roosts or near their mates.

This call was usually first heard around sunset, and there appeared to be peaks of calling within several hours after and before sunset and sunrise, respectively. Calls, however, were not restricted to these periods, and birds actively called at all times during the night. This call was heard during the day on rare occasions, usually in the late afternoon.

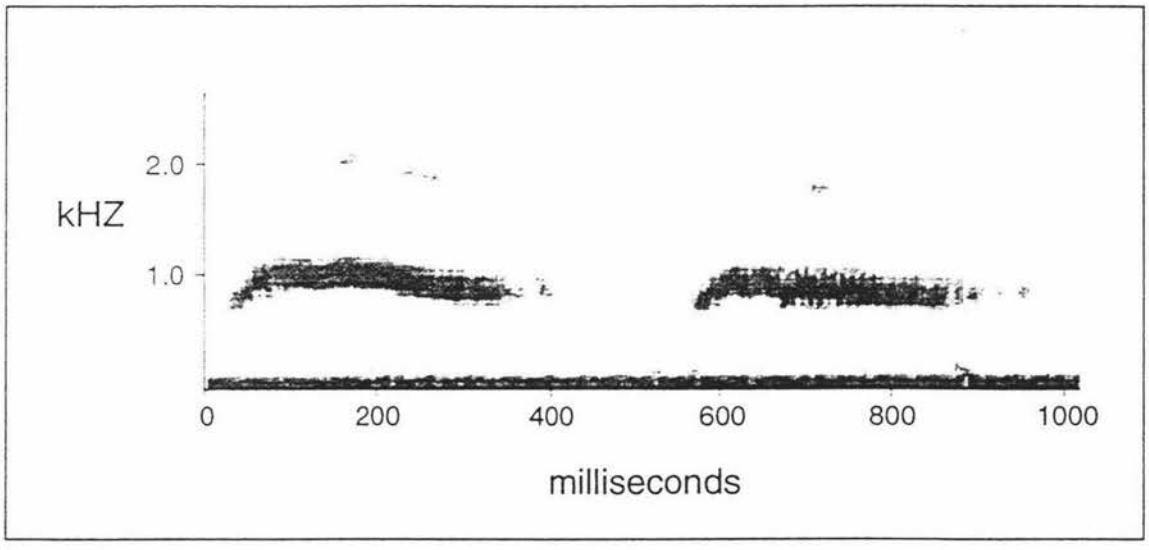

Figure 11. Sonagram of a *more-pork* call recorded on Mokoia Island.

When used as a territorial call, the calling bird was usually positioned on or near the edge of its home range. Therefore, it was assumed to be defending its home range as a territory. When calling the bird would lean slightly forward, its throat would bulge and its head extend upwards with each syllable of the *more-pork* call. The call was made with the bill open. Sometimes a neighbouring bird would react and start *more-porking* from a distance and then move in towards the 'boundary' ('duelling'). A dispute would sometimes occur (see *more* call below) or the birds would appear to give up and stop calling.

Morepork commonly responded to taped versions of this call (see Appendix 2 for details). Responses, however, were variable. When a bird approached to within 5–30 m it usually called back. Both male and female birds approached the calls, and both sexes were captured in mistnets using this technique to call birds in. When a bird approached the taped calls and perched nearby, it would assume an 'aggressive' posture with wings slightly outstretched and drooped at its sides, and body feathers slightly fluffed up. On several occasions both birds of a pair approached to within 5–10 m and called together in response to the 'intruder'. They often continued to call long after the taped calls had stopped.

Factors associated with calling frequency were not investigated. However, there were nights on which this call could be heard all over the island, and other nights on which this call was hardly given. It did not seem that weather alone influenced the frequency of this call. Morepork were heard using this call on several very wet and windy nights, and were often heard calling during light rain. Under clear weather conditions this call often carried over 500 m. Other factors such as stage of breeding, moon phase and position of the moon in the sky could also be important factors involved with calling activity, although the call was heard at any time of the year on Mokoia.

More call (agitated location call)

This call appeared to be given in situations of apparent sexual or aggressive 'excitement'. It generally consisted of a series of deep *more* calls repeated rapidly in a *more-more-more* type call. This call was also given at any time of the year.

This call was usually given following a period of normal territorial *more-pork* calling. It appeared that for some reason a neighbouring bird would approach the *more-porking* bird, and as a result both birds would enter what I termed a 'confrontation'. This confrontation consisted of both birds perched from 5–30 m apart. The site of these disputes usually coincided with my estimates of home range boundaries. Often birds would use this call continuously for several minutes, sometimes adding *more-porks* and *more-more-porks* or other variants of the normal *more-pork* call. I observed both male and female morepork using this call in this manner.

An example of this situation occurred on 13 January 1996 at 2120h. I found the Hut male (901) and the Hot Pool female (907) calling on their home range boundary. They were about 7 m apart, facing each other. The female bird was doing the *more* call and was sitting with wings partly outstretched and drooped at her sides. The male bird was also sitting with wings half outstretched and almost in a crouching position, with his head out mainly doing the *more-pork* call. At 212h the Hot Pool male (909) was about 100 m away. However, at 2122h he had moved closer and did several *purr* calls (see below) from about 45 m away. At no stage did he join the confrontation. The two birds carried on with the confrontation until 2123, when the Hot Pool female flew down towards her mate, and the Hut male flew off.

This call was also given singly when leaving the roost in the evenings, particularly by the male when the female was nearby, and in this situation may have been a sexual call. It was also given singly by females and males at other stages, possibly when their mates were nearby. The Hut male (901) was seen chasing his juvenile (913) and giving this call 59 days after the chick had fledged. This was probably an aggressive display by the male encouraging the chick to leave his home range.

Purr call (contact call)

This is usually a soft trilling call, lasting about 1 second in length. It was frequently heard. However, its function was hard to determine. Both males and females used this call. Females often did purr calls when near or on the nest, and so it may be used by the female to solicit food or co-operation from the males. However, males also used this call, even when their mates were not around. It was sometimes used when chicks were nearby or giving the *chitter* call. Thus it may act as a contact call with them or as a call to let the young know that the adult has food. This call was mainly given during the breeding season, although it was also heard during winter.

The *purr* call was sometimes given at a higher pitch, and this was termed the *shrill-purr*. However, the significance of this call was not detected.

Peow call (series location call)

This is an unusual call and usually consisted of a series of 2–11 high-pitched yells, although it was often given singly. It was phoneticised as *peow-peow-peow*. It possibly functioned as a long distance contact call, as it was quite often given as the bird flew long distances between feeding areas. However, the Hut male (901), who did not have a mate for the later stage of the 1995/96 breeding season, still gave this call frequently. This call was not frequently heard at the start of the breeding season or during the winter, but mainly from December to April.

Pew call (alarm call)

The *pew* call is similar to the *peow* call. It was not repeated, however, and was not as loud. It was usually given when the bird was frightened or alarmed. For example, the Hut male (901) was sitting on a branch above the canopy hawking flying invertebrates when one of his chicks flew up behind him and knocked him off his perch. The male gave the *pew* call. Adult birds sometimes gave a similar call when being handled.

Chitter (chick alarm call)

The *chitter* call appeared to be the chick and juvenile form of the adult *pew* alarm call. This call consisted of a rapid series of high-pitched chittering notes. It was given when the chick was being handled or sometimes when being roughed up by the adult. Quiet *chitter* calls were also given during allopreening between adults and chicks and may have been a sign of 'excitement' rather than alarm. When a taped *chitter* call was played, adult morepork often responded strongly by approaching closely and *purr* calling. Thus, this call can be used to lure adults into mistnets (see Appendix 2). Adult morepork even respond to this call in winter and when they hadn't even produced chicks in the previous breeding season.

Juvenile begging call

This call was given almost constantly by older chicks in the nest and for up to about three weeks after fledging. It consisted of a shrill cricket like trill, that gradually deepened and became more raspy as the chicks grew older. Between three to five weeks

after fledging the chicks only called when an adult was in sight. By five weeks the call had deepened from the trill to a raspy *purr* call, and by about seven weeks they rarely called. This was the only call regularly made by chicks. It was often audible up to 50 m away, especially if the chick was high up in trees. When still in the nest the call was not audible for much more than 20 m.

Hunting behaviour and nocturnal activity

Morepork actively hunted as soon as they left their day roosts. The period between leaving the roost and darkness was usually characterised by short flights from perch to perch within the forest. While perched the bird rapidly moved its head, looking in the direction of sounds and movement. They did not usually leave the cover of forest until it was nearly dark. During these early forays the birds were relatively easy to follow as there was still enough light to see them and they usually flew less than 10 m at a time.

Quantifying nocturnal activity

Morepork can be classified as sit-and-wait predators (as opposed to pursuers), but are very active while hunting. The transmitters that contained the activity switches unfortunately did not operate as well as hoped. The angle that I had the switches set at was too great, and a 'flying' signal was often given when the birds moved, even when perched. Thus, I could not accurately differentiate between flying and perching as hoped. Observation was the only method used to assess nocturnal behaviour. Just over nine hours of nocturnal observations were conducted on three adult morepork (the Kumera God pair (906 & 910) and the Hut male (901)). Although most of their time was spent actively searching for prey, time was also spent in other behaviours (Table 10). Perched searching was distinguished from nocturnal roosting by the rapid, jerking head movements of the bird and the birds usually wide-eyed appearance whilst searching.

To quantify the hunting behaviour of adult morepork, I recorded flight distances between perches and time spent searching for prey while perched (perched searching).

Perched searching times were usually short, being one minute or less 76% of the time ($\bar{x}$=01.02, sd=02.02, range=0.02–21.28 n=411) (Fig. 12a). Flight distances were more difficult to measure and nearly six and a half hours of observation on the Hut male (901) were used in the analysis. Flight distances between hunting perches were also usually short, with 63% being 5 m or less ($\bar{x}$=14.2, sd=21.6, range=0.2-104.0, n=184) (Fig. 12b).

Table 10. Nocturnal activity of three adult morepork collected from 9 hours 12 minutes of observations on Mokoia Island. The observations of the male 901 are split into two months, as his chick (913) was still dependent in the first month, but was independent by the second month. The Kumera God pair had a chick (911) which was dependent for the duration of observations. Figures shown are percentages.

	Bird under observation			
Activity	901 (month 1)	901 (month 2)	906	910
perched searching	76.8	62.1	88.5	75.8
nocturnal roosting	1.6	0.0	4.1	4.1
preening	0.8	25.0	5.9	11.3
flying	9.3	1.3	0.3	0.5
eating prey	3.8	5.1	0.0	6.5
calling	0.1	6.5	1.2	1.7
attending chicks	3.8	0.0	0.0	0.0
feeding chicks	3.8	0.0	0.0	0.1
Total observation time (hrs)	3.85	2.55	1.08	1.68

Behaviour while hunting and hunting techniques

When actively hunting, morepork would perch, sometimes with wings slightly drooped out from the body, with eyes wide open and rapidly move their heads and look in the direction of forest sounds. They used two main techniques for catching prey. Firstly

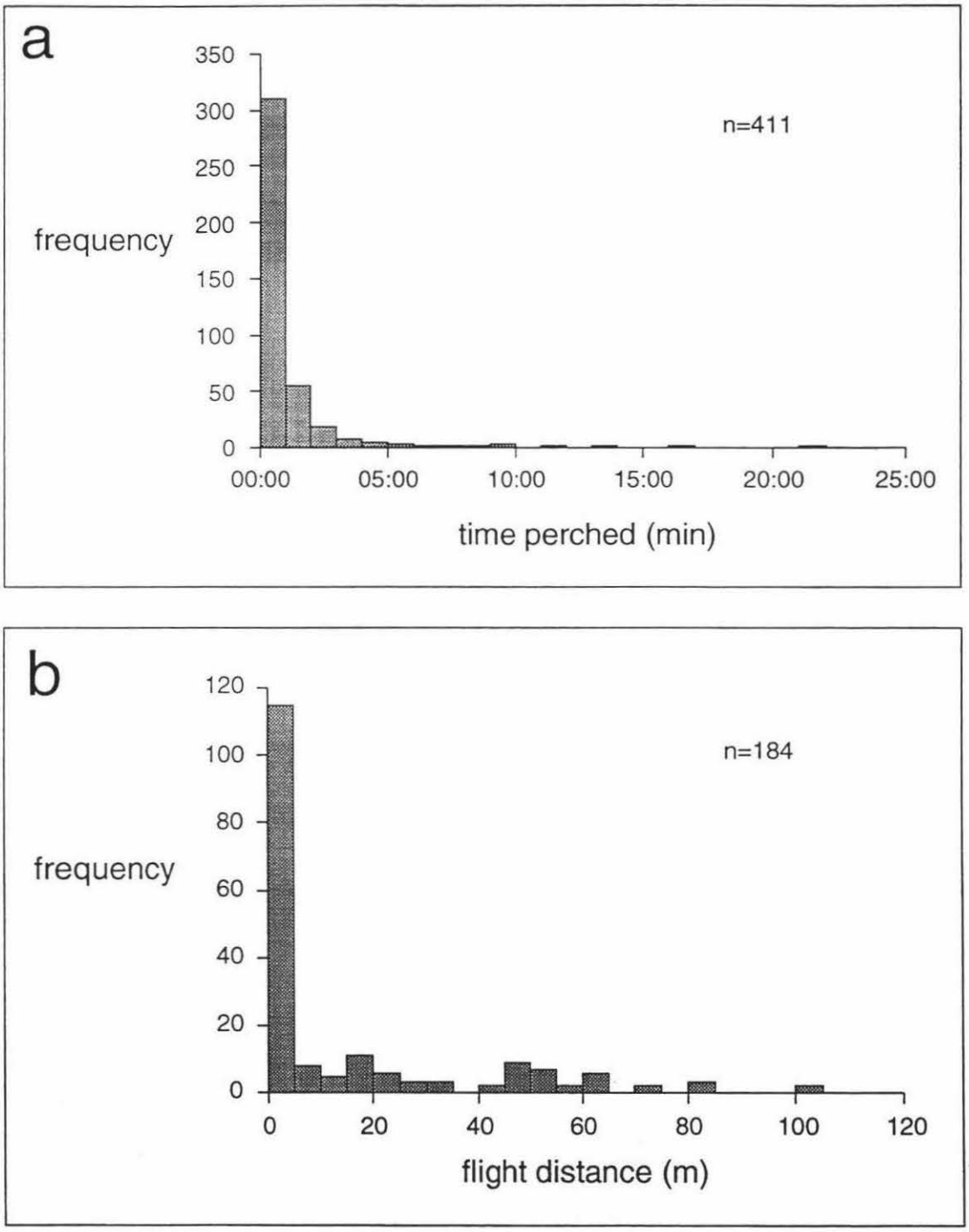

Figure 12. Foraging behaviour of adult morepork described by distribution of (a) perched searching times and (b) flight distances recorded during hunting bouts. Perch times are taken from 9 hours 12 minutes of observations of three adults, and flight distances were taken from 6 hours 24 minutes of observations of the Hut male (901) on 14 nights.

they would sit on a perch within the forest and survey the branches and forest floor around them. This was termed perch hunting. Secondly, morepork would sit on an exposed perch, often above the canopy or in a tree on the forest edge, and make flights out of the forest to catch flying prey, often returning to the same perch. This was termed hawking.

While perch hunting, birds were targeting larger prey such as mice, weta, and large beetles. During the period before darkness in the evening, and before full light in the morning, birds would also be potential prey. At night, roosting passerines may also have been taken by morepork using this technique. The usual method of prey capture when employing this technique was to swoop down from the perch, often gliding, and pounce on top of the prey, grasping it with the talons. If the prey was on a branch or tree trunk the bird would fly past it and grab it with its talons. On several occasions morepork were seen to leave their perch and fly out of sight, to be seen several minutes later, with a dead mouse. Morepork were not seen capturing mice or birds, but they were seen catching a variety of insects.

When hawking, morepork surveyed leaves and branches around them but were mostly watching for flying insects, such as moths and beetles. They also used this technique to capture cicadas, which were very abundant on Mokoia during the 1995/96 breeding season. Morepork would perch looking into the foliage, then flutter into the leaves after cicadas or pluck them off the branches as they flew. Morepork have exceptional eyesight, and on several occasions were seen to fly from a prominent perch out over the forest canopy to catch something in midair up to 100 m away. The prey in these cases were assumed to be large flying moths. Most hawking flights were short. Observations of the Hut male (901) revealed that 83 % of hawking attempts were at a distance of 20 m or less ($\bar{x}$=14.9, sd=17.5, range=1–100, n=191) (Fig. 13). Morepork generally captured prey with their talons. On several occasions the Hut male (901) returned to his perch with two moths in his talons, and this corresponds with observations of morepork catching prey in midair, then swerving and catching another prey item. Morepork also captured flying prey such as small moths in their bill, and had usually swallowed or were swallowing the prey by the time they returned to their perch.

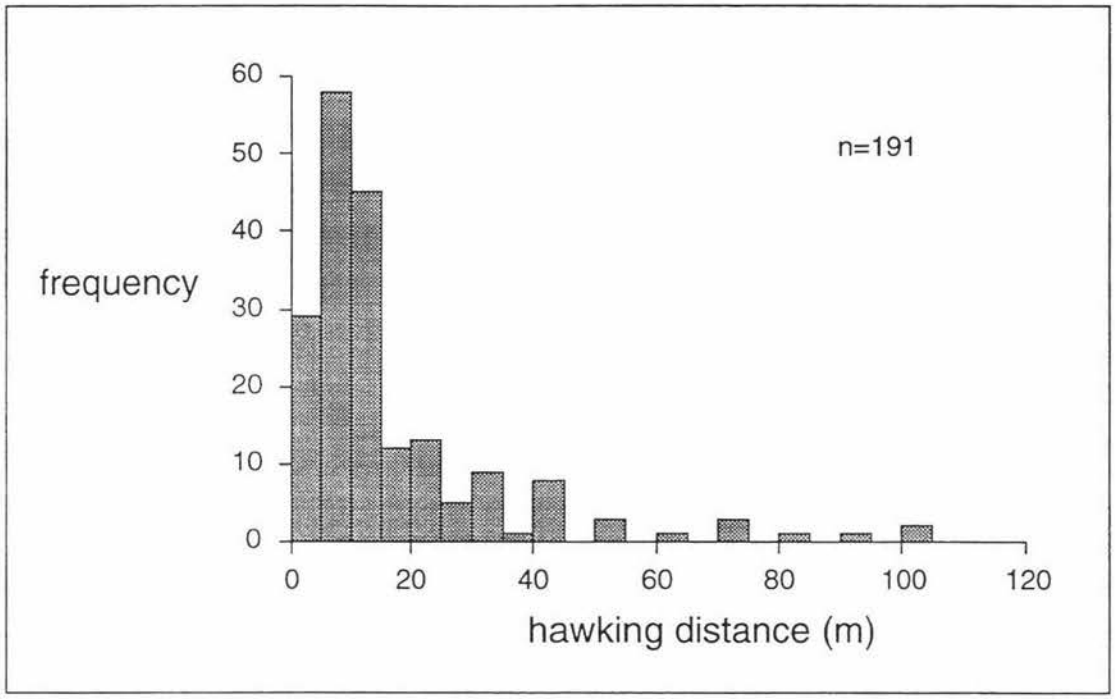

Figure 13. Frequency of flight distances made whilst hawking for prey. Taken from 6 hours 24 minutes of observations of the Hut male (901) on 14 nights. Mean hawking distance was 14.9 m.

For both of these hunting techniques, morepork spent most of their time perched at the same location (within 20 m or so). This meant that individual morepork had certain 'hotspots' from which they spent a large amount of time hunting. This was also suggested by the home range and core area use as investigated above.

Diet

Pellets

A total of 56 pellets was collected from below morepork roosts. Pellets were not as easy to collect as was first hoped. This was mainly because morepork often used

different roosts. Thus, collection sheets could not be placed below roosts and examined daily. Also, when morepork roosted too high, the pellets tended to disintegrate upon impact with the ground or hit branches and shatter on the way down. They were also difficult to locate amongst the leaf litter and ferns beneath roosts.

Of the 56 pellets collected and analysed, 55 (98.2%) contained invertebrate remains, 16 (28.6%) contained mouse remains (bones or fur), and eight (14.3%) contained bird remains (small pieces of bone or feather). The one pellet that did not contain invertebrate remains was made up entirely of bird feathers, probably those of a North Island robin. Pellets were sorted and prey items analysed by volume. Prey volumes were then collated into months and average monthly percentages (of volume) were obtained (Fig. 14).

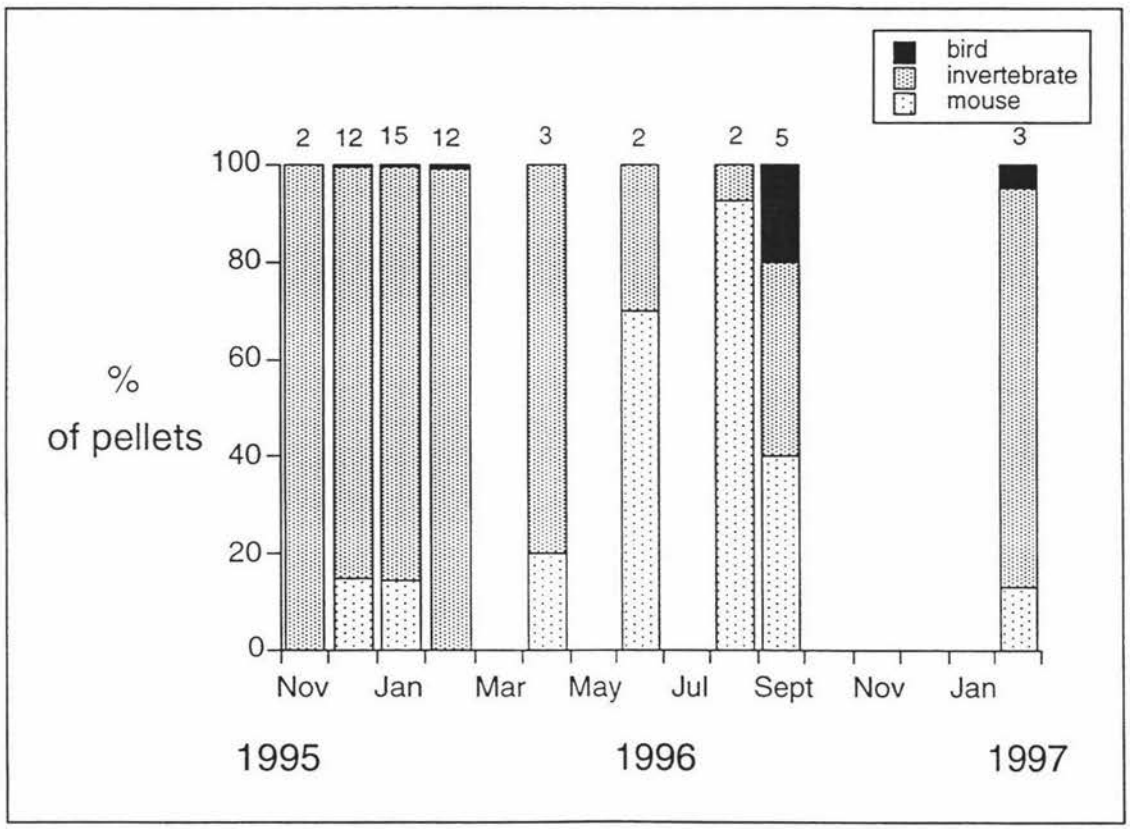

Figure 14. Percentage volume of prey remains contained in morepork pellets collected from below roosts on Mokoia Island. Columns contain the average prey remains of all pellets collected during each month. The number at the top of each column is the number of pellets analysed for that month.

Invertebrate remains were difficult to identify. However, weta formed a major component of the birds diet and were represented in the pellets by pieces of exoskeleton, complete eggs from female weta and their large mandibles. These were easily sorted from pellets and up to 7 sets of mandibles were found in some pellets. Other characteristic invertebrate remains were beetle elytra (wing cases) and head capsules and pieces of cicada exoskeleton. The scales from the wings of moths were also frequently found, as were tangled masses of insect trachea.

Seasonal changes occurred in the diet of morepork on Mokoia (Fig. 14). Although morepork primarily ate invertebrates, mice and birds were also found in pellets in most months. This was especially true during winter when there is a large increase in the percentage volume of mice and birds in pellets.

Prey determined from observations

During observations of the intensively studied pairs in January and February 1996, prey items were identified. All items being eaten by adults, or fed to juveniles by adults were analysed. Of 144 items identified only 5% were mice, thus 95% of the prey items observed to be eaten at this time consisted of invertebrate prey (Table 11). Thus, observations support the fact that morepork are primarily insectivorous.

The method of eating prey differed between prey types. Small invertebrates, such as moths and beetles were usually handled for a very short duration, in which time the wings of moths were sometimes removed. Otherwise, these smaller prey items were brought up towards the beak with the leg and swallowed whole. The Hut female (902) was kept in captivity for several days, allowing her handling of wetas to be observed. The wetas were dropped into her cage live and she would pounce on them with her talons. She always held them in her right foot and would always remove only one of the large spiny back legs before picking them up in her bill and swallowing them whole. It would take approximately 30 seconds for her to consume a large weta. Morepork were observed eating mice on several occasions. The mouse was always held to a branch using their talons and pieces of flesh ripped off by tearing upwards with the bill. The

Table 11. Prey items eaten by adult morepork or fed to juveniles by adult morepork.

Prey item	No. observed being eaten	Percentage
Unidentified flying invertebrate	43	29.9
Unidentified invertebrate	4	3.0
Beetle	2	1.0
Cicada	3	2.0
Moth	85	59.1
Mouse	7	5.0
Total	144	100.0

wings and tail were frequently used to keep the bird's balance. It appeared that bones, internal organs, feathers, and fur were all consumed, except for maybe the intestines which were found discarded in the captive female's cage on several occasions.

Food caching

Morepork were seen to cache prey during the day, and at night following capture of large prey items (ie. mice). Caching sites were usually flat branches or a broken branch stump at least three metres off the ground. It is not known whether morepork returned to these sites to retrieve cached food, but on two occasions when the site was checked the following day the prey had gone. Prey was also commonly cached in the nest during incubation and chick rearing (see Chapter 3). Morepork were never seen to eat at their roosts and were not seen to cache prey at their roosts.

Discussion

The use of transmitters was essential. The back-pack transmitter and harness used in this study appeared to have little effect on the behaviour of morepork. However, one bird (g/w) did die due to getting its transmitter aerial caught. Transmitters have been used on many owls and several studies have assessed their impact (see Paton et al. 1991, Taylor 1991, Foster et al. 1992). Paton et al. (1991) suggested that researchers working with spotted owls, *Strix occidentalis*, should avoid using back-pack mounted radio transmitters due to decreases in nesting success and increases in mortality. However, both Taylor (1991) and Foster et al. (1992) suggested that transmitters were unlikely to negatively affect survival or breeding potential when fitted correctly. The death of one morepork in this study, highlights that accidents can happen and no transmitter attachment method is infallible. However, the study of a silent flying nocturnal species is almost impossible without the use of transmitters.

Plumage and morphology

Reliable differences in plumage or morphology of male and female morepork were not noted on Mokoia. From the morphological data analysed only wing length, bill width and weight showed significant differences between males and females. Females exhibited larger values for all of these measures. Morepork, therefore, exhibit a limited degree of reversed sexual dimorphism (ie. females are larger Norberg 1987) that is found in most other owls (McGillivray 1987). However, all these measures exhibited a large degree of overlap, and only birds at the extreme of each measure would be able to be sexed confidently. Even discriminant function analysis showed that reliably sexing individuals was not possible. This situation seems to differ quite markedly from boobooks in Australia which appear to be more easily sexed based on morphology.

Comparisons with Australian boobooks

Schodde & Mason (1980) state that boobook females resemble males, except for their slightly larger size, richer tone to the brown of the back, and slightly darker and more streaked ventral surface. Schodde & Mason (1980) also state that male boobooks weigh 170–298 grams and females weigh 194–360 grams, suggesting a lesser degree of overlap. This overlap also appears to be related to the geographic location within Australia, in that females from the west approach the size of males in the east. Thus, in any one place in Australia there is likely to be even less overlap, with sexes distinguishable based on morphology alone in most cases.

In New Zealand, female morepork are also said to be slightly larger than males (Mees 1964, Imboden 1985). Imboden (1985) probably based this on Australian experiences. Both Imboden (1975) and Robertson et al. (1983) must have found difficulty with assigning sex, as no mention of the sex of birds captured was made in their studies. This study shows little support for distinguishable sexual dimorphisms in morepork.

As has been outlined in Chapter 1, the taxonomy of the smaller *Ninox* owls is unresolved. However, one factor that has been used in the past to advocate the separation of Australian boobooks and New Zealand morepork, apart from the obvious size distinctions, are tail to wing ratios. Schodde & Mason (1980) suggest morepork have a disproportionately longer tail (tail/wing ratio 65%), compared with boobooks (tail/wing ratio 58–59%). However, using measurements taken from adult morepork on Mokoia, the tail to wing length ratio is 58.7% for females and 59.7% for males. Thus, these data show that morepork have the same tail to wing ratios as boobooks. This issue needs to be resolved.

Morepork home range estimates in comparison with other owls

The sizes of home ranges recorded on Mokoia (individual $\bar{x}$=3.37 ha, pair ranges 5.40 and 7.88 ha) are comparable to other home range sizes reported for morepork and boobooks. The two pairs of morepork fitted with transmitters in the Orongorongo Valley near Wellington, New Zealand, had home ranges of approximately 3.5 and 5.3

hectares (minimum size) (Imboden 1975). These sizes are very similar to those calculated on Mokoia. The very similar Christmas Island hawk-owl, *Ninox natalis*, was found to have minimum home range estimates of between 5.5–10.6 ha (Hill & Lill 1998a). Home range estimates were still increasing even for the bird that was tracked the longest (Hill & Lill 1998a). In Australia, boobooks have been described as having territories estimated at 4–10 ha (Olsen 1994) and from 8 ha (varying according to habitat) (Schodde & Mason 1980). However, Olsen & Trost (1998) report a single radio-tagged male defending an area of about 100 ha. Another colour banded male was seen over some 50 ha. Olsen & Trost (1998) considered estimates of home range between 4 and 10 ha far too low.

It has been hypothesised that home range size should be positively correlated with body size in raptors (Schoener 1968). This prompted me to do a literature search of owl studies in which birds had been radio-tagged and had home ranges estimated. In total, 26 studies were examined and compared with the results of this study (Table 12). The duration of some of these studies questions the accuracy of home range estimates. Only individual MCP estimates of home range were used. In some cases the weight of female owls was not presented along with the home range estimate, so mean female weights have been derived from another source as indicated. These data show a very weak positive correlation between home range size and mean female weight (Fig. 15). However, there is a lot of variation and several interesting outliers. In particular, one of the smallest owls, the Boreal owl, *Aegolius funereus*, was shown to have the largest home range estimate of 2048.0 hectares. Compare this with the largest owls examined, the great horned owl, *Bubo virginianus*, and the snowy owl, *Nyctea scaniaca*, which had estimated home ranges of 212.6 and 494.1 hectares respectively. Perhaps more interesting is the fact that the same species, the spotted owl has quite different mean home range estimates from seven different studies.

Factors such as length of the study, timing of the study (ie. breeding or non-breeding season), and sample size may all confound home range estimates. Also, home range in some of these species may not equal defended territory size. The relationship suggested by Schoener (1968), however, does not appear to hold true for owls. Benn & Kemp

Table 12. A comparison of home range sizes for members of the Families Strigidae and Tytonidae. Unless otherwise indicated the home range sizes listed are individual averages. In some cases the mean female weight was not presented, so mean female weights have been derived from another source, as indicated. No. corresponds with points plotted in Fig. 15.

Species	No.	Mean female weight (grams)	Home range size (ha)	Reference
Pygmy owl	1	63	176.5	(Kullberg 1995)
Glaucidium passerinum				
Saw-whet owl	2	75	112.3 [1]	(Forbes & Warner 1974)
Aegolius acadicus				
Boreal owl	3	167 [2]	2048.0	(Hayward et al. 1993)
Aegolius funereus				
Burrowing owl	4	151 [3]	241.0	(Haug & Oliphant 1990)
Speotyto cunicularia				
Christmas Island hawk-owl	5	153 [4]	8.8	(Hill & Lill 1998a)
Ninox natalis				
Screech owl	6	184 [5]	134.0	(Hegdal & Colvin 1988)
Otus asio				
Morepork	7	192 [6]	4.5 [7]	(Imboden 1975)
Ninox novaeseelandiae				
Morepork	*	192	5.4	This study
Ninox novaeseelandiae				
Boobook	8	253	37.2	(Olsen & Bartos 1997)
Ninox novaeseelandiae				
Boobook	9	316 [8]	100.00	(Olsen & Trost 1998)
Ninox novaeseelandiae				
Mottled owl	10	336	21.7 [9]	(Gerhardt et al. 1994b)
Ciccaba virgata				
Tawny owl	11	478	16.0	(Southern 1970)
Strix aluco				
Barn owl	12	490 [3]	717.0	(Hegdal & Blaskiewicz 1984)
Tyto alba				
Black-and-white owl	13	536	261.6 [10]	(Gerhardt et al. 1994b)
Ciccaba nigrolineata				
Tawny owl	14	570	117.5	(Nilsson 1978)
Strix aluco				
Spotted owl	15	637 [3]	1177.0	(Forsman et al. 1984)
Strix occidentalis caurina				

Spotted owl	16	637 [3]	648.0	(Ganey & Balda 1989)
S. o. lucida				
Spotted owl	17	637 [3]	1580.0	(Carey et al. 1990)
S o. caurina				
Spotted owl	18	637 [3]	1180.0	(Call et al. 1992)
S. o. occidentalis				
Spotted owl	19	637 [3]	742.0	(Zwank et al. 1994)
S. o. lucida				
Spotted owl	20	637 [3]	1580.0	(Willey 1995)
S. o. lucida				
Spotted owl	21	667	412.9	(Solis & Gutierrez 1990)
S. o. caurina				
Barred owl	22	801 [3]	228.7	(Nicholls & Warner 1972)
Strix varia				
Barred owl	23	801 [3]	567.8	(Hegdal & Colvin 1988)
Strix varia				
Masked owl	24	835	1178 [11]	(Kavanagh & Murray 1996)
Tyto novaehollandiae				
Great horned owl	25	1510	212.6	(Craighead & Craighead 1956)
Bubo virginianus				
Snowy owl	26	1920	494.1	(Watson 1957)
Nyctea scaniaca				

1 - only one unsexed bird's home range analysed
2 - weight taken from Hayward & Hayward (1991)
3 - weight taken from Earhart & Johnson (1970)
4 - weight taken from Olsen & Stokes (1989)
5 - weight of *O. a. naevius* taken from Earhart & Johnson (197[illegible]
6 - weight taken from present study
7 - pair home range's analysed
8 - weight taken from Higgins (in prep.)
9 - only male home range's analysed
10 - only one male's home range analysed
11 - only one female weighed and home range analysed

(1995) suggested that home range size of Dickinson's kestrel, *Falco dickinsoni*, was possibly correlated to some factor other than body size when compared to home range sizes of other *Falco* species. Forsman et al. (1984) suggested that the home range estimates derived from their study on spotted owls did not support this theory. Ganey

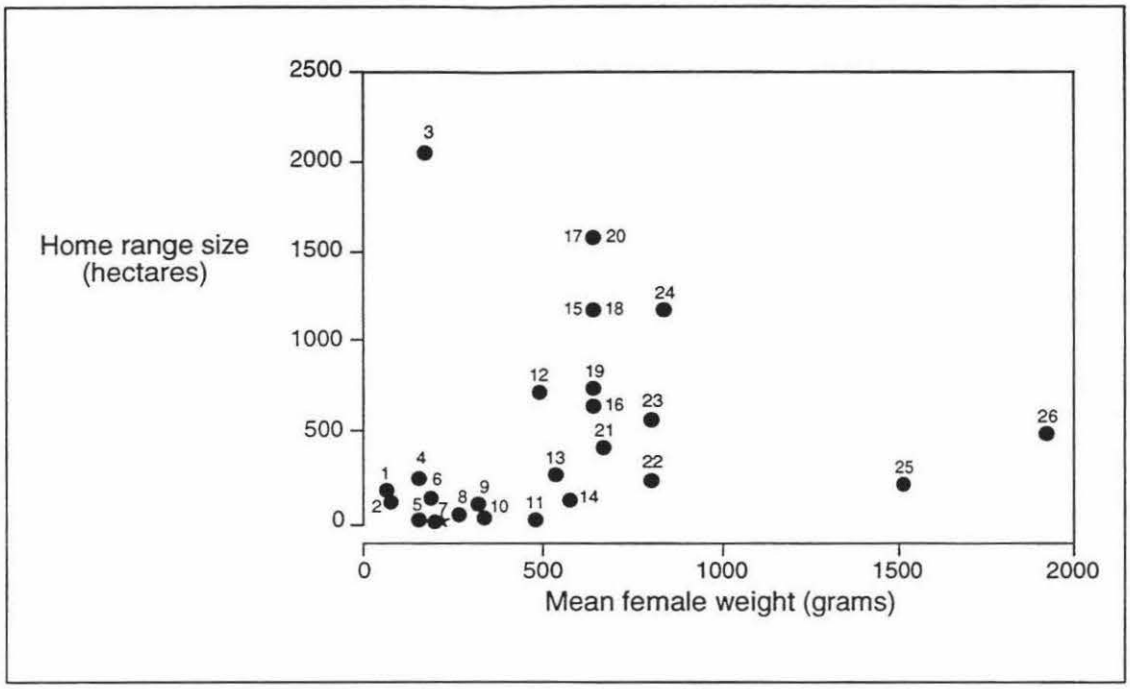

Figure 15. Home ranges determined from 26 studies of 16 species, plotted against mean female weight. The present study is indicated by the star. Numbers refer to the study number in Table 12.

& Balda (1989) came to a similar conclusion with their work on spotted owls. The relationship between raptor body size and home range size is not consistent because it may be confounded by factors such as geographic location, seasonal conditions, habitat quality, differences in the types of prey utilised and prey availability. Work with tawny owls, *Strix aluco*, has shown that male home range size varies according to two measures of habitat fragmentation: patch isolation and patch size (Redpath 1995). Factors such as the availability of nesting cavities may also be important for owls, many of which are cavity nesters. Additionally, the occurrence of competitors may influence home range. Many of the Northern Hemisphere owl species occur sympatrically and may at certain times of the year compete for the same prey. This may impose limits on home range size where overlap occurs.

From this exercise it can be seen that the small *Ninox* have relatively small home ranges when compared with other owls. This suggests that there is a complex link between

home range size and body size in these raptors. Differences in this case may be due to the relative lack of competitors or the forested habitats (and the prey species/availability associated with these forests) in which *Ninox* are generally found. Hill & Lill (1998a) in their study of the Christmas Island hawk-owl suggested that secondary vegetation may provide important foraging sites, because at times it may support larger numbers of some large insects and introduced rodents, than does neighbouring primary forest, and has higher light levels in the understorey than primary forest. The secondary forest on Mokoia is probably very similar. New Zealand morepork have no avian competitors, but boobooks do have some potential competitors in parts of their range. Compared with the forested areas in New Zealand in which morepork have been studied to date, much of Australia can be considered arid. Thus the, home range size of morepork could be expected to be smaller than that of a boobooks home range.

Home range characteristics and use

Morepork on Mokoia share home range characteristics with several other species of owl, but also differ in some areas. The size of individual home ranges did not differ significantly between the sexes, although male home ranges were 27% larger than those of females. This appears similar to that of spotted owls in a study by Ganey & Balda (1989) who found no significant difference between male and female home range size. However, Redpath (1995) discovered that male tawny owls had significantly larger home ranges than females. Conversely, Solis & Gutierrez (1990), found that male spotted owls had significantly smaller home ranges than females, but that there was a great deal of variation among individuals. This suggests that there are some differences between and within species, but more work is required before some sort of trend becomes evident.

Overlap in home ranges between partners of morepork pairs was on average quite large ($\bar{x}$=81%). This shows that the male and female of a pair generally share the same home range, but may have areas where only one or the other visits. This high degree of overlap has been found in several studies on spotted owls (eg. 72–92% (Carey et al. 1990), $\bar{x}$=62.4% (Solis & Gutierrez 1990), 47–63% (Call et al. 1992), $\bar{x}$=66% (Ganey & Balda 1989)) and is probably widespread amongst owls.

Overlap between neighbouring morepork was very slight, with home ranges being almost exclusive (except for pair partners). Furthermore, none of the five adult morepork were found (either active or roosting) inside the estimated home range of another radio-tagged morepork. Boreal owls (>50% overlap) and burrowing owls, *Speotyto cunicularia* (4.8–59% overlap) seem to show considerable overlap in male home range (Haug & Oliphant 1990, Hayward et al. 1993). However, most other owl species appear to have fairly exclusive home ranges.

If all or part of a home range is defended against other individuals of the same species, the guarded area is called a territory (Odum & Kuenzler 1955). The vocalisations of morepork appear to function not only as contact calls between mates, but also to serve as territorial advertisements to neighbouring pairs. Both male and female morepork were recorded calling on home range boundaries, and were observed in aggressive encounters with neighbouring birds on these boundaries. Thus, the vocalisations and aggressive interactions that were commonly observed between neighbouring pairs were probably territory defence behaviours. Vocalisations and aggressive encounters were noted throughout the year, suggesting the morepork are territorial year round. Defence of the entire home range as exclusive territories has been reported for many other species of owls (eg. barred owls, *Strix varia* (Nicholls & Fuller 1987), mottled owls, *Ciccaba virgata* (Gerhardt et al. 1994b), tawny owls (Southern 1970, Hirons et al. 1984), spotted owls (Forsman et al. 1984) and Ural owls, *Strix uralensis* (Lundberg 1981)).

The comparison of roosting ranges with active ranges revealed quite an interesting result. Morepork roosted over a much smaller area than their active range. This means that if home ranges were calculated on roosting locations alone, and did not analyse nocturnal locations the home range would be greatly underestimated. This may be true for other species of owls and has been noted in saw-whet owls, *Aegolius acadicus* (Forbes & Warner 1974). However, Imboden (1975) stated that morepork roosts appeared to be distributed rather evenly over a bird's calculated home range.

Use of territories by morepork was similar to that found in several other owl studies. Core area analysis showed that morepork favoured certain parts of their home range, both while roosting and while active, and spent more time in these areas than would be

expected from random (uniform) use. Although, these differences were not statistically significant due to the conservative nature of the test used (Wilcoxon test), morepork spent more time in certain areas. Both spotted owls, Ural owls and boobooks have been shown to favour certain parts of their home range (Lundberg 1981, Ganey & Balda 1989, Willey 1995, Olsen & Bartos 1997). These favoured areas probably relate to favourite hunting perches, areas close to roost sites, and during the breeding season the area around the nest.

Dispersal

From this study it appears that morepork are generally sedentary. However, some movement of adults did occur during the study, and dispersal events may be more common on the mainland. No migration to the mainland was recorded during this study. However it is expected that some dispersal does occur. Tawny owls have been shown to be highly sedentary (Southern 1970, Hirons et al. 1984). Ural owls are also highly sedentary, defending the same home range even though no breeding occurs over successive years (Lundberg 1981). Spotted owls have been described as generally sedentary, but dispersal of adults and especially juveniles does occur (Gutierrez et al. 1996). The study of morepork in the Orongorongo Valley showed that in each of the two territories one bird was present for more than five years (Imboden 1975). However, during seven years of mist-netting 20 different morepork passed through the two territories. Some of them were caught only once, and may have been juveniles, but others were caught up to 15 times. This suggests that the location of Mokoia was responsible for the low dispersal and highly territorial nature of morepork, and that on the mainland home ranges are not defended as rigorously and ownership may change regularly. More work needs to be carried out on the mainland to investigate this more closely. In Australia it has been suggested that boobooks are territorial when breeding, but often seem to wander when not (Schodde & Mason 1980). This seems to be based mostly on anecdotal evidence of unmarked birds. Olsen & Trost (1998) suggested that female boobooks near Canberra eventually disappeared following the breeding season. However, these birds did not have transmitters and may just have been hard to locate at this time of year.

Roosts and roosting behaviour

In general morepork on Mokoia were nocturnal, roosting by day. However, some occurrences of diurnal activity did occur. Morepork are generally considered nocturnal, not leaving their roosts unless disturbed (Imboden 1985). However, boobooks are sometimes active by day (Fleay 1968). Fleay (1968) also states "I have watched New Zealand 'moreporks' hunting in late afternoon". Spotted owls are also occasionally active during the day, but in most cases appear to be active due to an opportunistic response to prey located from their roosts (Sovern et al. 1994). The reason for diurnal activity in morepork is not known.

Morepork frequently changed roosts and seemed to return to a number of favourite roosts. This has been noted in both morepork (Imboden 1975) and the Christmas Island hawk-owl (Hill & Lill 1998b). During the breeding season, and especially when 'guarding' fledged juveniles, morepork used the same roost for prolonged periods.

Morepork tended to select sheltered roosts within the vegetation, usually within the thick sub-canopy layer. Morepork were only ever found to roost amongst foliage and were not recorded roosting in hollows or on the ground. This differs from boobooks which are noted as roosting in hollows and on the ground (Schodde & Mason 1980, Olsen 1994, Olsen & Trost 1998). This is possibly due to a lack of cavities and the fact that on Mokoia there are a large number of potential foliage sites within the secondary forest. However, there appeared to be something favourable about roost sites morepork chose. Roosts were usually associated with good all round cover, and birds were usually concealed not only by the roost tree, but also by surrounding foliage. Surrounding foliage often consisted of tree fern fronds, which provide camouflage. Concealment and cover were probably far more important than height. Studies on other small owls have also demonstrated this (eg. saw-whet owls, *Aegolius acadicus* (Swengel & Swengel 1992)). However, due to the vegetation on Mokoia, these two factors are probably interrelated. Both Christmas Island hawk-owls and morepork in the Orongorongo valley tended to choose sites with good all round cover, with overhead cover being particularly important (Imboden 1975, Hill & Lill 1998b). Analysis also suggested morepork were selecting roosts based on weather, with rain causing birds to roost in more exposed

roosts. This could be because birds chose roost trees that had a better canopy layer, and so let less rain through. However, these trees usually had a more open interior, giving the birds less concealment. Birds also used more exposed roosts in high wind or high temperature. This is similar to spotted owls, which choose lower roosts during high temperatures, and higher roosts when it was cold, raining or snowing (Forsman et al. 1984). Thus, thermoregulation appears to play a part in roost site selection. However, the fact that different morepork were found roosting on the same roost at different times suggests that these roosts have some favourable quality.

Morepork rarely shared the same roost as their mate, except during the early stages of breeding before the female begins incubation and whilst 'guarding' newly fledged juveniles (see Chapter 3). This has been noted before with morepork (Imboden 1975, D. Mudge pers comm.) and boobooks (Schodde & Mason 1980, Olsen & Trost 1998) and seems to be natural pair bonding behaviour. Even though morepork did not commonly roost together, they were often (55% of the time) within 10 m of their mates.

Although roosts generally provided good cover and concealment, morepork were often harassed or mobbed by passerines during the day. Species recorded mobbing morepork on Mokoia are similar to those recorded mobbing morepork elsewhere in New Zealand (Cunningham 1948, Chambers et al. 1955, St.Paul 1977, Anon. 1985). It is interesting to note that silvereyes, *Zosterops lateralis*, were one of most frequently recorded species mobbing morepork on Mokoia. Hill & Lill (1998b) noted Christmas Island white-eyes, *Zosterops natalis*, mobbing the Christmas Island hawk-owl when roosting. While being mobbed, morepork tended to ignore the mobbers and remained motionless.

Vocalisations

All owls tend to have a similar series of calls (eg. spotted owl, tawny owl, short-eared owl, *Asio flammeus* (Southern 1970, Clark 1975, Forsman et al. 1984)). Morepork on Mokoia Island had seven different calls. Ten different calls have been recorded for *Ninox novaeseelandiae* (boobooks and morepork) (Higgins in prep.).

The *more-pork* location call is similar to that of the boobook, but does differ in pitch and structure of the call. Each note of the call rises in pitch to start with and then drops off as each syllable ends. This differs to boobook calls which don't have the same rise and fall within each syllable (pers obs.). However, the function of this call appears to be similar to that of the boobook's call and both sexes gave this call. The call's main function appears to be that of territorial advertisement and defence. A secondary function of this call could be communication between members of pairs. This is supported by the observations noted on Mokoia, and has been suggested in spotted owls (Ganey 1990).

Hunting behaviour and nocturnal activity

This is the first study to have tried to quantify the behaviour of *Ninox novaeseelandiae*, that is either the morepork or boobook. It is unfortunate that the posture sensing transmitters used during this study to monitor activity of the birds were relatively unsuccessful. With some experimentation the correct angle at which to position the mercury switch could be determined. Having the mercury switch set along the long axis of the transmitter would probably allow differentiation of perching and flying and could potentially be a very valuable technique in assessing behaviour of birds even when out of sight.

The activity budget analysis conducted showed that at night birds spent most of their time perched searching for prey. It is interesting to note that in the second month of analysis, 901 spent a quarter of his time preening. This may have been because at this time he was moulting heavily and was assisting with the moult of old feathers and preening the new ones. Morepork activity budgets were characterised by short perch times and short flights. This is similar to the findings of Hayward et al. (1993) who found that flight distances and perch times of Boreal owls were generally short. More data need to be collected to further investigate morepork activity budgets at different times of the year. It must be remembered that the data presented here were collected only in summer.

Morepork on Mokoia were sit-and-wait predators, similar to most other forest dwelling species of owls (Norberg 1987). Their use of two different hunting techniques is interesting. Small *Ninox* have previously been noted to hawk insects (Fleay 1968, Imboden 1975, Olsen & Bartos 1997) and use the sit-and-wait technique (Imboden 1975, Hill & Lill 1998b). This distinction between the two hunting techniques has not been made before. Using these two techniques, the birds are clearly focussing on different prey types. Distances flown to capture prey whilst hawking were generally less than 20 m, However, several flights of over 100 m were made. This highlights the incredible eyesight of this species.

Diet

The use of pellets to determine the diet of owls is widespread (eg. Southern 1969, Southern 1970, Nilsson 1981, Gerhardt et al. 1994a, Pavey et al. 1994, Pavey 1995, Holt & Leroux 1996, Kavanagh 1996, Kavanagh & Murray 1996, Hill & Lill 1998b). The reliability of pellet analysis has been discussed before (Southern 1969). It was found that 15–60% of small mammals in tawny owl's diet were not represented in pellets collected. Nevertheless, this method should give an insight into the species being preyed upon and their frequency of occurrence. The Mokoia population would need to be studied over several years to fully understand the changes that occur throughout the year.

Analysis of both pellets and hunting observations show that as previously suggested, morepork are primarily insectivorous (Cunningham 1948, Lindsay & Ordish 1964, Imboden 1975). However, the data presented also show that at certain times of the year, particularly during winter, vertebrate prey such as mice and birds are important. This is probably due to a diet switch during these periods induced by climatic variables. That is, during winter months invertebrates are far less abundant and so alternative prey items are easier to obtain. Similar seasonal variation in prey species has been recorded in other species of owls, particularly tawny owls (Nilsson 1984, Godfrey 1985) and the long-eared owl, *Asio otus* (Nilsson 1984).

Some prey items may be under-represented in morepork pellets (or even absent). Morepork are known to prey upon small caterpillars (from observations on Mokoia and examination of roadkill stomach contents). However, no caterpillar remains were found in pellets. This suggests that in order to reliably assess this species' diet more than just pellet analysis needs to be conducted.

Morepork on Mokoia seemed to be able to home in on abundant prey sources. For example, whilse pohutukawa trees, *Metrosideros excelsa*, were flowering in December and January, morepork were often found hawking moths from around the flowers. Similarly, later in the summer when cicadas had increased to huge numbers, morepork could be seen hunting for these noisy insects. Opportunistic utilisation of abundant prey sources has been noted before in owls (eg boobooks and mice (Schodde & Mason 1980), flammulated owls, *Otus flammeolus*, and katydids (Powers et al. 1996)).

Some disparity between prey recorded in pellets and prey delivered to the nest has been noted in other studies of owl diet (eg. tawny owls (Southern 1969)). Southern (1969) attributed this disparity to the fact that adult tawny owls were feeding their chicks with larger prey, and consuming smaller rodents themselves. He came to the conclusion that the safest way to determine the diet of tawny owls was to combine pellet data with that collected from nocturnal nest observations and remains found in nests during inspection. Comparisons of pellet, hunting observations and nest remains have not been conducted in this chapter. However, prey remains found in nests are discussed in Chapter 3. From this it can be seen that most remains found in nests were in fact vertebrate (mice or birds), so it appears that this disparity does occur in morepork also.

Conclusions

1. The use of transmitters was found to be both safe and essential for the study of morepork. Transmitters appeared to have no effect on birds carrying them, except for one bird which became entangled and died (see Appendix 2). Development of an

effective posture sensing transmitter would be of great use in further studies of morepork.

2. The sexes of all morepork on Mokoia could not be distinguished, either by observation or in the hand. The use of plumage and morphological measurements to sex morepork was inaccurate and only molecular sexing was reliable (see Chapter 6).

3. Morepork pairs on Mokoia had small essentially exclusive home ranges. They called around these home range boundaries, and this was interpreted as territorial defence. Confrontations with neighbouring birds were commonly witnessed along these boundaries. Both males and females appeared to defend the territory. Dispersal of adults was detected, but in general morepork appeared sedentary.

4. Morepork generally roosted in trees during the day. However, they were sometimes seen actively hunting. Roost sites appeared to have some favourable characteristics, and use of sites appeared to be loosely related to weather.

5. Morepork were usually quite vocal and a number of different calls were recorded on Mokoia. These calls are similar to those given by boobooks in Australia, and a similar range of calls are given by other owls.

6. Two distinct hunting techniques were employed by morepork on Mokoia, sit-and-wait hunting and hawking. Prey types captured were related to the mode of hunting, with larger terrestrial prey items generally caught using the sit-and-wait technique, and flying invertebrates caught using the hawking approach.

7. Diet, as assessed using pellet analysis and observations of hunting behaviour showed that morepork are predominantly insectivorous. Mice and birds, however, were found to be important prey, and some seasonal variation occurred.

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3

The breeding biology of morepork on Mokoia Island

Introduction

Of all the aspects of morepork, *Ninox novaeseelandiae*, ecology, the breeding biology is probably the most studied. This is partly because nest sites are often reused, and so once found can be checked annually. Also, as morepork are hard to locate and follow, having a site to which a morepork returns makes studying them a lot easier. However, there is still a lack of in-depth knowledge about most aspects of this species' breeding biology. To date most information appears to have come from the 26 nest record cards from the Ornithological Society of New Zealand's Nest Record Card Scheme, which date back to 1927, and a handful of short papers which outline nests discovered on offshore islands (Chambers et al. 1955, Ramsay & Watt 1971, Anderson 1992). These papers, and a short note on a pair of morepork using a nestbox at King's College (Hogg & Skegg 1961) seem to have formed the basis of published information on morepork breeding biology.

Imboden (1985) states that morepork start the breeding season with an increase in calling activity in the second half of August (*more-pork* call). However, O'Donnell (1980) found the main peak in calling frequency in April, with a smaller peak in August. O'Donnell's (1980) observation suggests that calling may have functions other than mate attraction (see Chapter 2). Mating has been recorded on 1 September, with egg laying beginning in early October and reaching a peak in November (Imboden 1985). Nest sites are most commonly in tree-hollows, but also in thick clusters of epiphytes, cabbage trees, *Cordyline australis*, piles of pine needles in tree-forks and caves (Imboden 1985).

Morepork have also been recorded nesting in nestboxes, on the ground (Anderson 1992), and in burrows in riverbanks and beneath rocks (Ramsay & Watt 1971).

The nest itself has been described as merely a depression formed in the material found at the site (Imboden 1985). The normal clutch is two, dull white, almost spherical eggs. The second egg follows about two days after the first, and incubation starts with the laying of the first egg (Imboden 1985). Thus the eggs hatch asynchronously. Length of incubation is stated by Imboden (1985) as being about 30–31 days. However, Heather & Robertson (1996) suggest 20–30 days. Both authors (Imboden (1985) & Heather & Robertson (1996)) state that only the female incubates, and is fed by the male on the nest. However, only unbanded birds have been observed and as shown in Chapter 2 & 6 sexing of morepork can be inaccurate using external morphology alone. Thus, the assumption that females alone incubate may be tenuous. The chicks fledge after about 34 days (Imboden 1985) (35 days in Heather & Robertson (1996)). Thus, the breeding biology of morepork is not well understood and has been pieced together from anecdotal observations of unmarked and unsexed birds.

This chapter describes the breeding biology of morepork on Mokoia Island studied over two breeding seasons (1995/96 and 1996/97) and discusses the nesting habits, chick development and breeding success of this species.

Methods

Morepork breeding biology was investigated on Mokoia using several methods (see Chapter 1 for a full account of the study site and Chapter 2 for a description of methodology used). Likely areas and trees with cavities were searched for nests. However, this method was found to be both labour intensive and inefficient. Known historical nest sites were checked to determine whether they were occupied. Also, as part of another project saddleback, *Philesturnus carunculatus*, nestboxes were checked every 2 weeks and two morepork nests were discovered in these boxes.

In the 1995/96 breeding season, I attempted to capture female morepork that might have been incubating eggs or brooding. Transmitters were attached to these birds and the incubating or brooding bird located the next day. Also, females that were still carrying functional transmitters in the 1996/97 breeding season facilitated location of nest sites.

Once nests were discovered they were checked on a regular basis. Nest sites were described and several characteristics were recorded, including nest tree species, height of nest above ground and the dimensions of the cavity. Eggs were measured where possible, and measurements and weights of chicks were recorded at one nest (Trough Gully nest 1995/96). Date of hatching and chick fledging were monitored and prey remains in nests were recorded during nest inspections. Fledging chicks were also weighed and measured at the Kumera God nest (1995/96) and at the Hut nest (1995/96). I measure breeding success as the number of chicks fledging from the nest. Determining the survival of chicks past fledging would have required all chicks to be fitted with radio-transmitters. This was not possible due to a limited number of transmitters.

An automatic monitoring system was set up at the Trough gully nest in the 1995/96 breeding season to investigate the timing of visits to the nest by the adults and to identify prey being delivered. As this nest was positioned less than a metre off the ground in a large mahoe, *Melicytis ramiflorus*, it was in an easy location to set up this system. A Super 8 video camera was connected to a large flashgun and wired to a photo-electric beam which was positioned across one of the nest entrances. As a bird arrived at the nest it broke the photo-electric beam and a single frame was taken of the bird in flight. A small clock was positioned in the background so that the time of each frame was known. The camera was run on five nights starting when the chick was 26 days old (06/12/95) and the last night's film captured the chick fledging from the nest (19/12/95). The film was developed at the end of the breeding season and a binocular microscope used to view the film. An attempt was made to identify each prey item and the timing of visits recorded.

Results

During the 1995/96 breeding season nine breeding pairs were monitored (Fig. 1), and in the 1996/97 season eight pairs were monitored (Fig. 2). Thus a total of 17 breeding attempts were monitored. Only one of the nests was used over consecutive breeding seasons (Kumera God nest). In both seasons several pairs whose nests were not located were deemed to have failed to breed because no chicks were seen with either adult near the end of the breeding season (January). At this time adults which had bred successfully roosted close to their dependent young. Thus the absence of chicks was taken to indicate a failed breeding attempt.

Nest site description

Eleven nesting sites were found over the two breeding seasons (Table 1, 2). Of these 11 nests one was in a hollow in a cabbage tree, one was in a mahoe tree hollow (Fig. 3a), and one in a hole in a dirt bank. Two nests were in saddleback nestboxes, two in the broken tops of mamaku tree ferns, *Cyathea dealbata*, two in piles of mamaku tree fern fronds in the forks of mamakus (Fig. 3b) and two on the ground at the base of mamakus (Fig 3c, d).

Dimensions of the cavity and the size of the entrance to the cavity varied greatly. All except the cabbage tree nest at Hut in 1995/96, had entrances of 20 cm diameter or less. The cabbage tree nest had a large open top of approximately 45 cm by 50 cm. Internal dimensions of the nest cavities also varied greatly. The two nests in mamaku tree ferns had maximum internal diameters of 20 cm. In both cases the nest was at least 30 cm below the entrance, and the nest in D Gully was 1.5 m down from the entrance. The adults were frequently heard scrambling their way down into the nest and back out again when feeding the chick. Cavity size of other nest sites was larger, up to 45 cm by 45 cm.

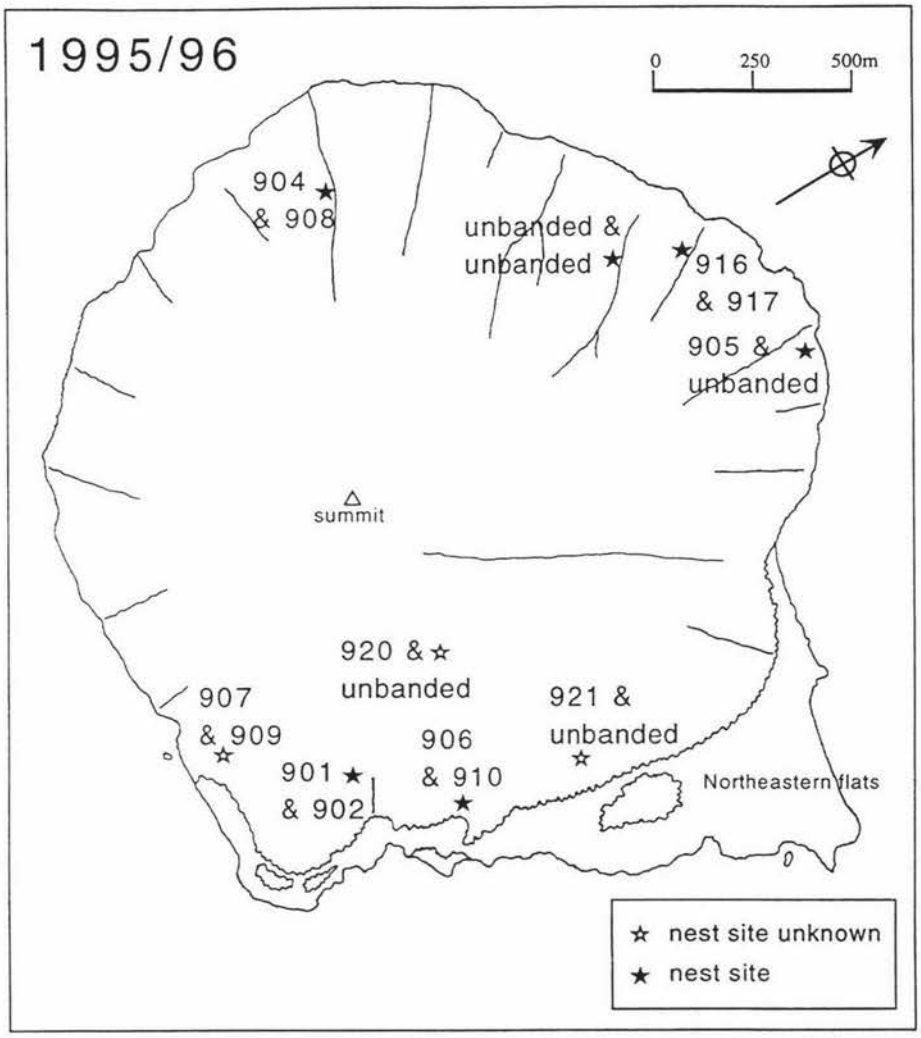

Figure 1. Morepork nest sites or areas in which breeding attempts were discovered in the first breeding season (1995/96).

Table 1. Nesting pairs monitored during the 1995/96 breeding season, showing the nest site they used.

male	female	nest site
901	902	cabbage tree
906	910	broken off mamaku
908	904	broken off mamaku
unbanded	unbanded	saddleback nestbox
917	916	base of mamaku
unbanded	905	mahoe

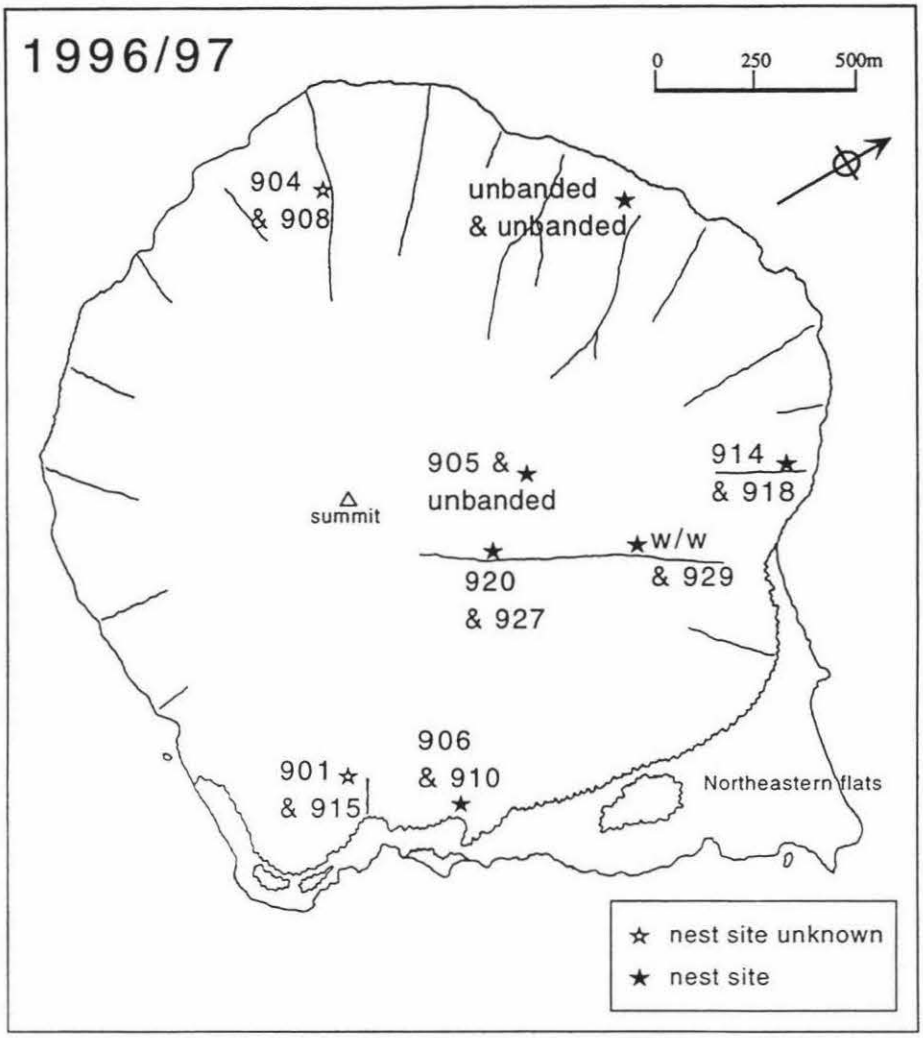

Figure 2. Morepork nest sites or areas in which breeding attempts were discovered in the second breeding season (1996/97).

Table 2. Nesting pairs monitored during the 1996/97 breeding season, showing the nest site they used.

male	female	nest site
906	910	broken off mamaku
920	927	mamaku fork
unbanded	905	mamaku fork
w/w	929	base of mamaku
914	918	dirt bank
unbanded	unbanded	saddleback nestbox

Figure 3. Morepork nest sites used on Mokoia: (a) at the base of a mamaku tree fern beneath the fronds, (b) at the base of a mamaku with very little cover (behind the fronds to the left of the trunk), (c) in a mahoe tree, (d) in mamaku tree fern fronds between two mamaku trunks (centre of the picture.

Mean height of the nest above ground for the 11 nest sites was 1.9 m. However, morepork did not seem to be choosing nest sites at certain heights, and indeed did not appear to be particularly fussy about choosing nest sites. As long as the location provided shelter, then it was a potential nest site. The choice of a nest on the ground and in a broken mamaku tree fern reflects the fact that suitable tree cavities are uncommon on Mokoia. However, this does not appear to present a problem. Morepork on Mokoia seem to be fairly adaptable when it comes to choosing nest sites. The absence of mammalian predators on Mokoia means that they are not open to predation as they would be on the mainland.

The nests consisted of a scrape in the base of the cavity or on the ground (Fig. 4). There appeared to be no added materials, just what was already at the site. Usually this consisted of leaf litter and wood dust type material.

Figure 4. The nest scrape and single egg of w/w & 929, on the ground at the base of a mamaku tree fern, in Queen Street Gully.

Timing of breeding

On Mokoia, morepork pairs began roosting together in late September 1996. This appeared to be characteristic behaviour associated with the start of breeding and probably strengthened the pair bond. Following this, the females would disappear and were assumed to be occupying the nest site or incubating eggs.

1995/96 breeding season

The saddleback nestbox used by the unbanded male & female in Victoria Street Gully, was empty on 30 September. However, on 18 October the unbanded female was incubating one egg in this nestbox. On 17 October 1995 the Trough Gully female (905) was found incubating eggs in the mahoe cavity and the first egg hatched on 10 November 1995. It is assumed the second egg hatched the next day (asynchronous hatching) as more egg shell was seen in the nest cavity. Thus, it appeared that egg laying began on Mokoia around the beginning of October.

The first chicks to fledge were the two male chicks (912 & 913) from the cabbage tree nest of the Hut pair (901 & 902). They fledged on 8 December, suggesting they hatched around 1 November (the chick from Trough gully fledged after 39 days in the nest). The last chicks to fledge were the two found near Kumera God (922 & unbanded). They must have fledged around 10 January. The chick from the nest in D Gully died of unknown causes, but would have fledged in mid to late January had it survived. Thus, fledging dates for morepork were between early December and mid January.

1996/97 breeding season

Morepork pairs were found roosting together in late September. The nest in the saddleback nestbox near Pine Tree Gully was discovered on 20 October with two eggs being incubated by the unbanded female. In late October w/w & unbanded's nest in Queen Street was found. Thus, morepork again seemed to start egg laying at around the beginning of October.

Due to the failure of most of the nests this season, fledging dates were not determined. Similarities in laying dates, however, suggest a similar series of events would have taken place had chicks survived. A fledged chick was seen near the Kumera God nest on 1 February, and had probably fledged about a month previously.

Camera monitoring of the Trough Gully nest

The monitoring camera produced pictures of fairly low resolution. However, all identifiable prey delivered to the nest were invertebrates, mainly large weta, *Hemideina* spp. Due to there being two nest entrances it was not possible to determine whether all visits were captured on film. I suspect that some visits were missed so the results could not be analysed in full. However, it did appear that the male (unbanded) visited the nest twice as often as the female (905). The number of visits per hour peaked in the two hours following sunset and there was then a steady rate of visits throughout the night. There was a maximum of six visits recorded in the first hour after dark (some visits may have been missed) and there were usually two or three visits for each hour afterwards. There did not appear to be a second peak just before sunrise. Mean number of visits to the nest each night was 16.2 (range=10–27). Number of visits per night did not seem to correspond with development of the chick.

Egg description

Nine morepork eggs from seven nests were measured, and three of these were weighed. The age of the eggs at weighing was not known, but they were not fresh. The eggs had an average length of 39.0 mm (sd=1.4, range=36.3–41.1, n=9) and an average width of 32.9 mm (sd=1.3, range=31.2–35.2, n=9). The weight of the three eggs averaged 22.5 grams (sd=1.6, range=21.0–24.1). The eggs had a dull white chalky appearance and the shell was quite textured (Fig. 4).

The total number of eggs laid was known for nine nests (from both breeding seasons). Of these, four nests had one egg, four nests had two eggs, and one nest had three eggs.

Chick description

The chicks at Trough Gully (1995/96) were not seen until 22 November, when the oldest chick was 12 days old. This is because the female sat very tightly, even when being observed through the nest entrance. On 22 November 1995 both chicks were weighed and measured. At this stage the older chick weighed 66 grams and its eyes were wide open. The younger chick weighed 56 grams, was quite a bit smaller, and its eyes were still partly closed. From this it seems their eyes open around day 11. On 25 November the smaller chick was found dead and mostly eaten, probably by the older chick. The cause of death is unknown, but it may have been killed by the older chick. The older chick was weighed and measured regularly through to fledging (Fig. 5).

The chicks started off with light coloured down, and this gradually gave way to darker grey down by the time the chick was 15 days old. At about 17 days old feathers were starting to come through the down, and the dark grey down was giving way to a brown coloured fluff. The talons were stronger, and the bristles around its beak were emerging. At 18 days old the wing feathers were starting to grow rapidly. At age 25 days the chick clacked its bill when removed from the nest, and the feathers were emerging from the brown down. White spots on feathers on its back and secondaries were noticeable. It still had traces of light grey down on the back half of its head and brown fluff on the sides of its head. The rest of the body was still covered in traces of brown and dark grey down. The talons were noticeably stronger. On 8 December 1995, when the chick was 28 days old, the light grey down had almost gone and the body was still covered in the dark grey down. However, there was no down around the eyes and beak, just feathers still in pin. This gave the chick the appearance of wearing a ski-mask. By 30 days old its tail feathers had emerged from the pins about 1 cm. The chick gradually became more feathered, losing the dark grey down until, the time it fledged (19 December) when it was well feathered. At fledging it still had quite a bit of dark down on the breast, around the head and on its back. The growth of the chick's head and bill and tarsus was gradual with no sudden growth spurts.

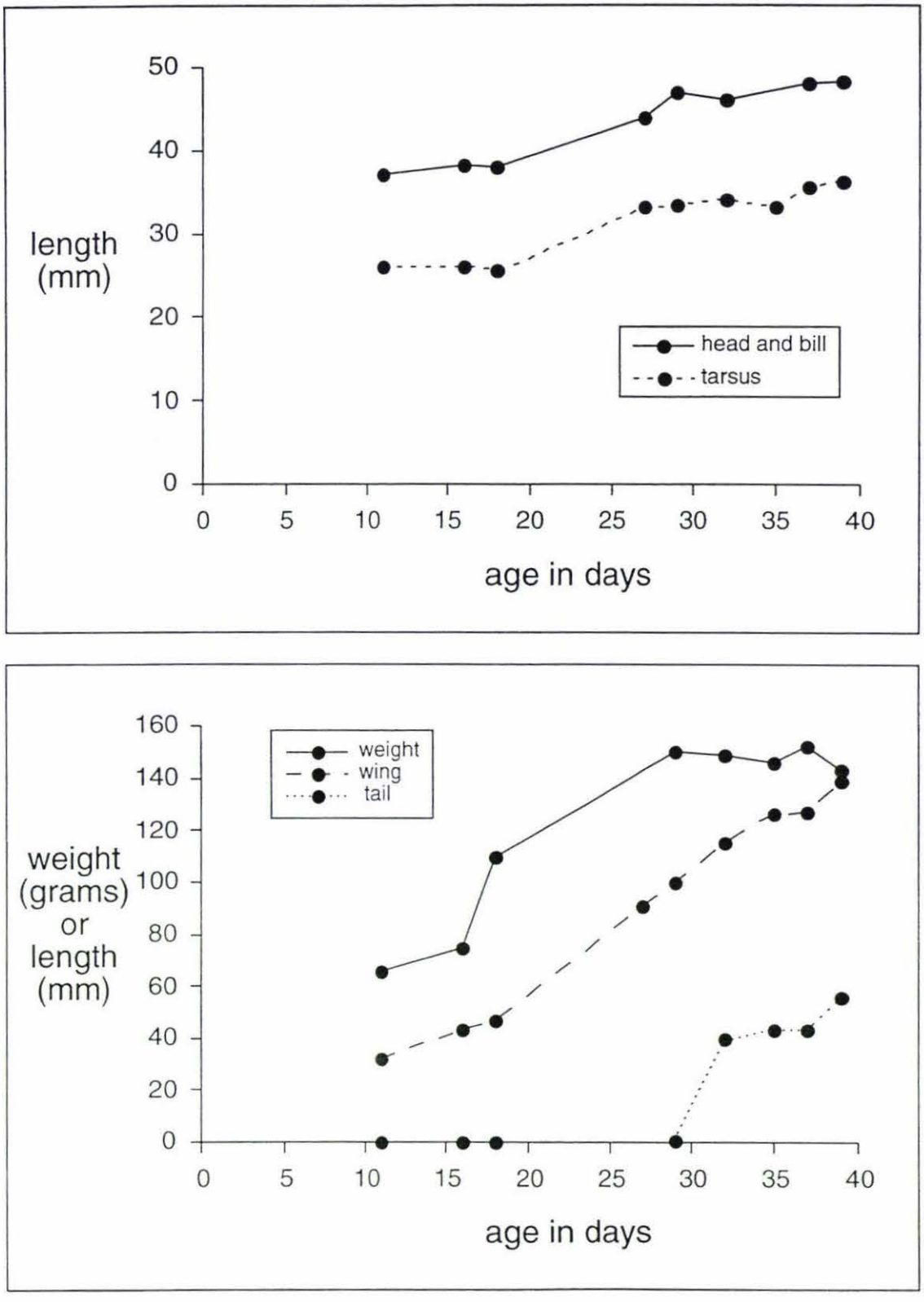

Figure 5. Weights and measurements of the chick from the Trough Gully nest in 1995/96. This chick ate its younger sibling when 15 days old. This and the increased food from then on probably accounts for the steep increase in weight over the next few days.

The two chicks (912 & 913) from the Hut nest followed a similar pattern of growth (they were found when about 10 days old). When discovered there was a noticeable size difference. However, by the time they fledged the size difference was less noticeable (both were male) (Fig. 6). Three days before they fledged the older chick was 16 grams heavier (Table 3).

Six chicks were weighed the day they fledged, or within about one week of fledging. Mean weight of these chicks was 164 grams (range=143–178, sd=12.6).

Table 3. Weights of six chicks three days before they fledged (912 & 913), on the day they fledged (Trough & 911) or about one week after they fledged (915 & 919).

chick	sex	weight (grams)
912	♂	162
913	♂	178
Trough nest	?	143
911	♀	160
915	♀	168
919	♀	175

Female morepork were found to stop brooding the chicks 10 days (Kumera God nest) and 5 days (Hut nest) before fledging. The Trough female (905) stopped brooding 7 days before the chicks fledged. During this time the females could be found roosting close to the nest, usually within 5–10 m.

Figure 6. The chicks (912 & 913) from the Hut pair's (901 & 902) cabbage tree nest four days after they fledged.

Prey remains found in nests

Eight prey remains were found from six nest inspections at the Trough gully and Hut nests in the 1995/96 breeding season. All prey remains were found in the nest during the chick stage. The prey items were made up of five mice, *Mus musculus*, two birds, and one weta. The mice all had their heads and internal organs removed. During one late afternoon nest inspection at the Trough gully nest the chick was eating one of these mice. The two bird remains found were a uropygeal gland with some tail feathers from a small passerine (probably a robin, *Petroica australis*) and the legs and tail, along with a large amount of feathers, from a thrush, *Turdus philomelos*. The thrush was very fresh and had been caught around sunrise that day.

Several visits were seen at the Hut nest in 1995/96 during observations of birds in the evening. The Hut female (902) arrived near the nest with a large female weta in her bill, and not long after the Hut male (901) arrived with a freshly killed mouse in his bill.

Breeding success 1995/96

From nine breeding pairs that were monitored, nine chicks are known to have fledged. Thus, a fledging rate of one chick per breeding pair was attained in the 1995/96 breeding season.

At least three chicks died within one month of fledging (unbanded Trough Gully chick, 912 & 919). A further two other chicks were not seen later than one month after fledging (two unbanded). One died about seven months after fledging (913) (Fig. 8d), two were known to have survived at least nine months after fledging (911 & 922), and one was known to have survived and attempted to breed in the 1995/96 breeding season (915).

The cause of mortality was unknown for most of these. The weather between 20 December and 1 January was cold and wet, and may have been a contributor to the death of two of the chicks which died over this period (912 and the Trough Gully chick). However, the transmitter of 919 from the Blackberry Gully nest was found in the nest of an Australasian harrier, *Circus approximans*, about 10 days after the chick fledged. The harrier probably saw the young morepork roosting and killed it rather than scavenged it. The chick 913 from the Hut nest may also have been killed by a harrier, as its bones were located in a place suggestive of harrier predation, and the remains appeared similar to those of 919.

Breeding success 1996/97

Out of eight breeding pairs that were monitored, one chick fledged. The survival of this chick is not known past about one month from fledging. Thus, a fledging rate of 0.13 chicks per breeding pair was attained in the 1996/97 breeding season.

Statistical analysis of breeding success

A Fisher exact test was conducted on the breeding success data between the two years. This was performed on the basis that a successful nest fledged at least one chick. Thus, in the 1995/96 breeding season six nests were successful and three unsuccessful, and in the 1996/97 breeding season one was successful and seven were unsuccessful. It was found that breeding success between the two years was significantly different (Fisher exact test, two-tailed, $P<0.05$). These statistics may have been biased due to differences in sampling. In the first breeding season (1995/96) nests were located later in the season and so failed nests may have been missed. Therefore, the results of this test should be treated with caution.

Juvenile dispersal

After the chicks fledged the female usually roosted within 1 m of the chicks. The male was also usually close by. This distance gradually grew as the chicks became older and more independent (Fig. 7). Fledglings tended to explore their natal territory, and then gradually the neighbouring territories. However, dispersal of the chicks from their natal territory varied among individuals. I monitored dispersal of three individuals that were radio-tagged and one un-tagged individual that survived longer than one month post fledging. The Kumera God chick (911) fledged on 16 December 1995 and was seen in her natal territory until 24 February 1996 (Fig 8a). On 30 March 1996 she was discovered around the other side of the island in Scrub gully roosting near a male bird

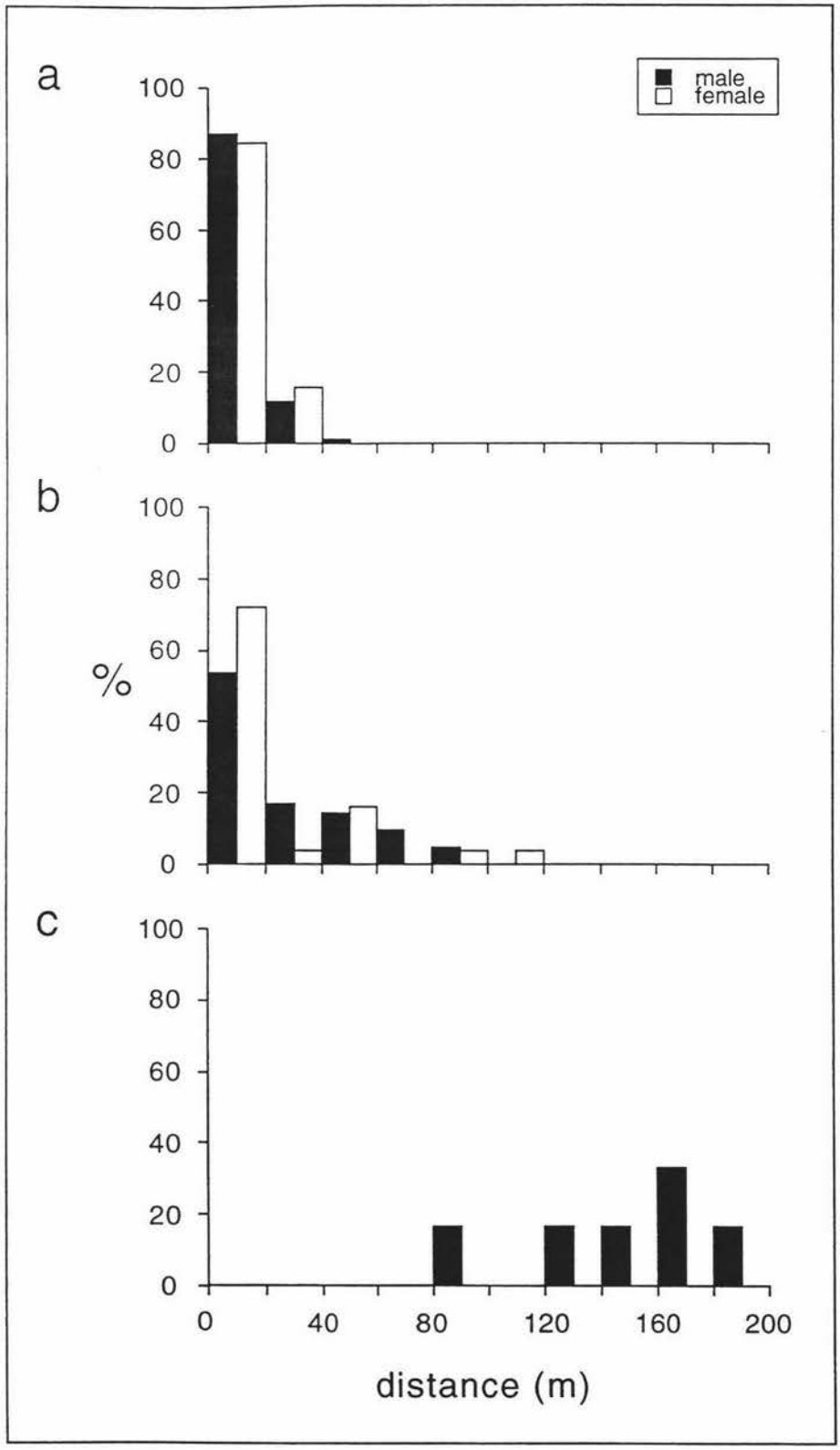

Figure 7. Percentage of chick roosts at distance classes from the roosting male and female adults for (a) the first month after fledging, (b) the second month after fledging, and (c) the third month after fledging. Percentages for (a) are derived from three chicks, (b) from two chicks and (c) from one chick.

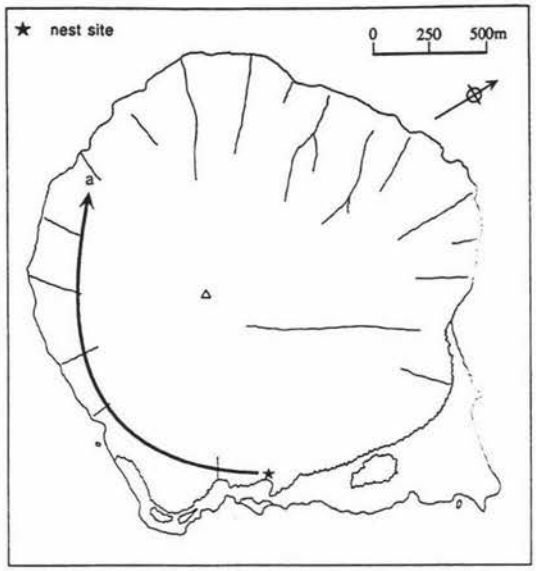

Figure 8a. Dispersal of the Kumera God chick (911) from her nest in 1995/96. She left the nest area by March and was found in a gully on the other side of the island with a male bird. Presumably they had paired up as they were found roosting near each other on several occasions.

(w/y). They were found roosting together on several occasions and I suspect they had paired up. The Kumera God chick was last located on 1 October 1996 in the same area when her transmitter expired.

The Camp gully chick (922) fledged along with its sibling sometime in early January 1996. It stayed in its natal territory until 21 February 1996 when it was seen in a nearby patch of bush (Fig 8b). He was mostly found roosting in this patch of bush through to 16 May 1996 with occasional 'exploratory' movements outside of the area. He was seen in the Hut area on 17-18 June 1996, well outside his natal territory. On 19 July and 8 August he was again seen roosting in the bush patch, but on 26 September he was found roosting around towards Queen Street gully. He continued to roost in this area until 1 October 1996 when his transmitter expired.

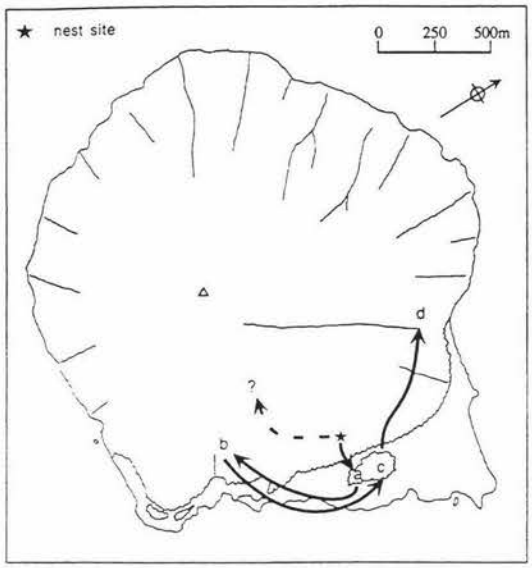

Figure 8b. Dispersal of the two chicks from the Camp gully nest in 1995/96. Only one chick (922) was banded and fitted with a transmitter (represented by solid line). This chick spent up until March in his natal area before moving into the bush patch (a). He was then found roosting in the Hut area (b) in May, before being seen back in the bush island (c) through to September. In late September he started to move around towards Queen Street gully (d) where his transmitter failed in early October. 922's sibling was unable to be located after the end of January and it is unsure whether this bird survived.

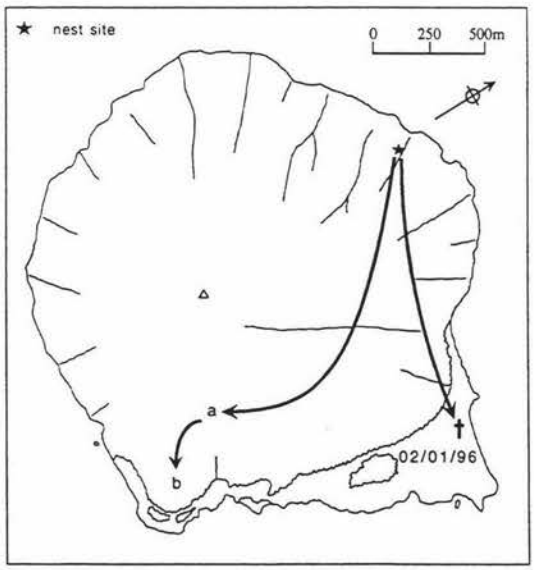

Figure 8c. These two female siblings (915 & 919) were captured about a week after fledging at the end of December, and 919 was fitted with a transmitter. 919 was subsequently found dead in a harrier's nest four days later. 915 was located near the Hut in mid May and then relocated roosting with the Hut male (901) in September 1996.

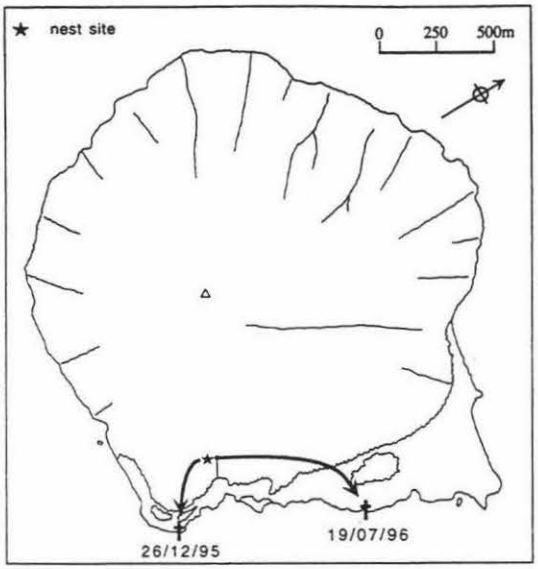

Figure 8d. These two chicks (912 & 913) fledged in mid December 1995 and the smaller chick (912) disappeared on 26 December. Feathers were found but the cause of death was unknown. The larger chick (913) stayed near his natal territory and made some exploratory movements into neighbouring areas. However, he was found dead on 19 July 1996, possibly as the result of harrier predation.

The Blackberry Gully chick (915) fledged in late December 1995 along with her sibling (919). She was last seen in Blackberry Gully on 30 December 1995 (Fig 8c). On 15 May 1996 she was discovered in the Hut male's (901) territory, and then again on 18 June 1996. From this time on she was found in various parts of the hut male's territory and they were seen roosting together in late September 1996. It appears that they attempted to breed, but the attempt was unsuccessful.

The Hut chick (913) fledged along with his younger sibling on 8 December 1995. He stayed in his natal territory right through until he was found dead on 19 July 1996 (Fig 8d). His death was possibly a result of harrier predation. During this time he did make 'exploratory' movements outside of his natal territory. However, he continued to return and roost in his natal territory until his death.

It is interesting to note that although the sample size is rather small, the two males (913 & 922) appeared to stay within or near their natal territories for much longer than the

two females (911 & 919). Both the females dispersed quite quickly to the other side of the island.

Discussion

This study presents the first quantitative data on morepork breeding biology. The data collected during this study support Imboden (1985) in that egg laying started in early October. The range of nest sites used were similar to those found in other studies (Hogg & Skegg 1961, Ramsay & Watt 1971, Imboden 1985, Anderson 1992). The clutch sizes and the asynchronous hatching found on Mokoia were also similar to those suggested elsewhere (Imboden 1985, Heather & Robertson 1996).

However, the incubation duration of 20–30 days given by Heather & Robertson (1996) is not supported by the data collected on Mokoia. Duration of incubation at the Trough Gully nest was at least 24 days in the 1995/96 breeding season and likely closer to 30. Thus the 30–31 days given by Imboden (1985) appears more accurate. Schodde & Mason (1980) give an incubation period of 31 days for boobooks, and this seems fairly consistent with these findings. The suggestion that only the female incubates was supported by this study, and only females were observed brooding as well. Sole incubation by the female has been found in other species of owl (eg. mottled owls, *Ciccaba virgata* (Gerhardt et al. 1994a) and Ural owls, *Strix uralensis* (Lundberg 1981)), and Fleay (1968) also discovered this in boobooks. Male morepork were quite capable of feeding and caring for fledged young, as the Hut male (901) proved when his mate (902) died shortly after the chicks fledged.

Time to fledging on Mokoia was 39 days for the Trough Gully chick, and the other chicks monitored appeared to be similar. Thus, morepork chicks appeared to spend 39–40 days in the nest before fledging. This is substantiated by personal communications with D. Mudge, who also suggested a fledging duration in Waikane of 40 days. This is longer than that suggested by both Imboden (1985) (34 days) and Heather & Robertson

(1996) (c.35 days). Schodde & Mason (1980) give estimates of 5–6 weeks and Olsen & Trost (1998) 6 weeks for boobooks, and again this is fairly consistent.

The cause of death of most morepork chicks during this study was unknown. However, the younger chick from the 1995/96 season Trough Gully nest probably died as a result of siblicide. This is a common phenomena in many owls and hawks (Mock 1985). Bad weather may also have played a part in the mortality incurred in late December 1995.

The use of an automated camera system at the nest proved to be useful. However, the set up used during this project could be improved. This set up would be best suited to a nest with only one entrance, allowing all visits to be recorded. The use of a camera with better resolution would also enable all prey items to be identified accurately and allow classification of invertebrates. Despite the problems encountered some useful information was derived from this part of the study. The finding that the male visited the nest twice as often as the female supports Imboden's (1985) statement that the male feeds the female on the nest, but shows that the female also delivers prey to the nest once the chick has reached a certain stage (the camera was not operated at the nest until the chick was well over half grown). The fact that all prey delivered to the nest was invertebrate was also interesting, when compared to prey remains found in nests. There could be three possible reasons for this disparity. Firstly, vertebrate prey are not commonly delivered to the nest, in which case the limited number of nights in which the camera was used was not enough to capture vertebrates being delivered. Secondly, the delivery of vertebrate prey was missed on the camera. Finally, the identification of prey items being delivered was inaccurate due to the resolution of the film. The second reason is the most likely due to the presence of several vertebrate prey items found in this nest and the fact that some visits are known to have been missed by the camera.

The number of visits to the nest during the night was also of interest. Even though not all visits were captured, the pattern should still be the same. The peak in the first few hours following sunset was to be expected. However the continuous visits during the night with no peak at sunrise was not expected. Also the number of visits per hour is on the whole extremely low. Compared with the flammulated owl, *Otus flammeolus*, in which McCallum et al. (1995) recorded a mean number of 81 visits per night, the 16.2

visits per night recorded during this study is very low. Size of prey may have something to do with it, and the use of a camera with better resolution would enable estimates of biomass delivered to be made. David Mudge has developed a very good system using a video camera which provides very good resolution and enables all visits to be monitored. The use of such a system would be of great value in gathering more information on nesting activity.

The analysis of prey remains at the nest also shows a disparity between the prey recorded in pellets and those captured during observations, in that no vertebrate prey was recorded. This is similar to the disparity found in other species of owls (eg. mottled owls (Gerhardt et al. 1994a), tawny owls, *Strix aluco* (Southern 1969)). This disparity may well be due to adults preferentially feeding nestlings vertebrate prey.

Comparison of breeding success between 1995/96 and 1996/97

The significant difference between breeding success in the 1995/96 and 1996/97 breeding seasons may be a result of the brodifacoum poison drop that occurred in September 1995 (see Chapter 5). This could have been brought about by lack of prey due to the decrease in mouse numbers following the poisoning operation (see Chapter 5) or may be due to a sub-lethal affect of the poison itself. Alternatively, the drop in breeding success in the 1996/97 breeding season could be due to weather or other natural fluctuations. Therefore, there is a need for further research to determine the natural extent of annual fluctuations in morepork breeding success due to differences in climate and prey densities.

Juvenile survival and dispersal

Survival of the morepork fledging on Mokoia appeared to be quite low. Causes of death following fledging were unknown in most cases. However, two juveniles (913 & 919) possibly died as the result of predation by harriers. Starvation and bad weather are possible contributing factors to the deaths of the other birds. This high level of

mortality in the first year of life appears to be common among owls, with high levels of mortality being recorded in spotted owls, *Strix occidentalis* (Willey 1995), Ural owls, (Lundberg 1981), tawny owls (Southern 1970) and Eastern screech-owls, *Otus asio* (Belthoff & Ritchison 1989). It is probably associated with the highly territorial nature of many of these species and the fact that young owls have to 'learn' to catch prey which may require some degree of skill. The high density of morepork on Mokoia may further affect juvenile dispersal and the ability of a juvenile to find a vacant home range. This could also lessen survival.

Dispersal of the juveniles in this study, although from a limited number of individuals, does provide some interesting information. Juveniles generally stayed within their natal territories for the first two to three months. During the first month or so they roosted near the male and female and were fed by them. They then gradually roosted further and further away, but still within their natal territory. In Australia, juvenile boobooks are fed by their parents for a month or so after fledging and may remain in the parents' territory until the following autumn (Schodde & Mason 1980). Olsen & Trost (1998) found a female boobook stopped feeding the chicks 2–4 weeks after fledging, after which they started to follow the male and camp out with him. I found no evidence of 'camping out' with the male. However, a dependency period of about a month is consistent. Thus, morepork appear to be similar to boobooks and also to other owls (eg. mottled owls (Gerhardt et al. 1994b), tawny owls (Southern et al. 1954) and Eastern screech-owls (Belthoff & Ritchison 1989)) and raptors (eg. common buzzards, *Buteo buteo* (Tyack et al. 1998) and ferruginous hawks, *Buteo regalis* (Konrad & Gilmer 1986)) which have similar patterns.

It also appears that juvenile female morepork dispersed earlier and further than males. That is, they left their natal territories earlier than the two males and moved to the other side of the island where they quickly paired up with 'batchelor' males. This fits with the general thoughts on dispersal in birds, in that females are generally the dispersing sex (Greenwood 1980).

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4

A review of anticoagulant use with special reference to brodifacoum and secondary poisoning

Introduction

Rodents and their effects on New Zealand

Since the beginning of human occupation in New Zealand, animals have been introduced either deliberately or accidentally to the mainland and offshore islands (Veitch & Bell 1990). Most of the accidental liberations have been small rodents and invertebrates. Three rat species have colonised New Zealand, the ship or black rat, *Rattus rattus*, the Norway rat, *Rattus norvegicus*, and the kiore, *Rattus exulans*. The effect of the three rat species on the island biotas they have invaded has been severe (Buckle & Fenn 1992), especially those which have evolved without mammals (Atkinson 1985). All three rodent species are omnivorous, preying upon birds, small mammals, reptiles, insects, amphibians and molluscs, and consuming a wide variety of vegetative material (Buckle & Fenn 1992). Rats have also been found to have significant effects on forest regeneration (Campbell 1976) and were responsible for the destruction of a high proportion of tree seedlings planted on Mokoia Island in 1960 (Beveridge & Daniel 1965).

The house mouse, *Mus musculus*, is another rodent introduced to New Zealand. However, the effects of this smaller animal have often been overlooked. In New Zealand, wild mice eat both invertebrates and plant material (Murphy & Pickard 1990). Studies into the diet of mice in native forests have revealed they consume large numbers of invertebrates including tree weta, *Hemideina* spp., earwigs, cockroaches, centipedes, lepidopteran larvae and pupae, spiders and amphipods (Badan 1986, Miller & Miller

1995). They also eat seeds (Badan 1986) and may eat birds' eggs and nestlings (Flack and Lloyd 1978). On Mana Island, lizard and bird remains were found in mouse stomachs (Pickard 1984).

The number of invertebrate extinctions brought about by these rodents will never be known (Buckle & Fenn 1992). However, their effects on vertebrates are better documented. On a few islands rat invasions have had such a marked effect on the avifauna that they are best described as rat-induced catastrophes (Moors et al. 1992). For example, the recent colonisation of Big South Cape Island, off Stewart Island, by ship rats gives us some insight into the extent and speed with which this devastation can occur. On Big South Cape Island major declines or extinctions of more than 40% of the landbird fauna occurred between 1962 and 1964 (Atkinson & Bell 1973). Thus, there is no doubt that introduced rodents have had and still have a considerable impact on our native fauna.

New Zealand fauna and offshore refugia

New Zealand is well known for its unusual fauna, especially its birds. So much so that Jared Diamond (1990) stated that New Zealand is as close as we will get to the opportunity to study life on another planet. A long evolutionary history without mammals meant that birds became the dominant vertebrates before humans arrived (Craig 1997). Accordingly, they are a primary focus of New Zealand's conservation efforts. New Zealand has already lost 48% of its avifauna since the arrival of humans, barely 1000 years ago (Towns & Atkinson 1991). Currently, New Zealand has 29 species of bird that are endangered or rare, giving the country 11% of the world's rare birds on just 0.2% of the world's land area (Glasby 1991). Thus, a short term solution has been to create offshore predator free sanctuaries. New Zealand has been most fortunate in that it has a large number of offshore islands. There are over 700 islands of which more than 273 are larger than 5 ha (Atkinson 1989), most within close proximity of the mainland. Many of these islands now provide predator free refuges for a number of endangered species. However, some islands, otherwise suitable as refugia, still have

populations of rodents and other mammalian predators (eg. Rangitoto Island, Mokoia Island).

It is these islands inhabited by introduced rodents that have caused New Zealand biologists to forge the way in island restoration. New Zealand scientists have been described as distinct in the innovativeness with which they are now seeking to mitigate the impacts of human arrival (Diamond 1990). This ecological restoration requires active management, coordination and considerable planning (Towns & Atkinson 1991). Land-based conservation in New Zealand is now reaching beyond protection, to the eradication of pests from islands and restoration of their terrestrial ecosystems (Towns & Ballantine 1993). Taylor & Thomas (1993) stated that the last 10 years had seen significant advances in rodent eradication on islands. Tasks previously thought impossible are now being tackled with confidence (Taylor & Thomas 1993). By 1992 over 60 successful pest eradication campaigns, including 28 rodent eradications, had been conducted on islands around New Zealand (Veitch 1992). By 1995 that number had risen from 28 to 49 successful rodent eradications, with a further 18 rodent eradications remaining to be formally classed as successes or failures (Clout & Saunders 1995). Mice have been eradicated from three islands in New Zealand, of which the most outstanding success has been 217-ha Mana Island (Moors et al. 1992). The Department of Conservation (DoC) is now developing a strategy to eradicate rodents from a series of islands up to 3,000 ha (Clout & Saunders 1995). Thus, the impacts of these eradications on non-target species need to be fully understood.

The second-generation anticoagulants

A key factor in the advances of these eradication campaigns has been the development of a range of second-generation anticoagulants (eg. difenacoum, bromadiolone, flocoumafen and brodifacoum) that are more potent than the first-generation anticoagulants (eg. warfarin, fumarin and coumachlor) (Quy et al. 1995). The aerial application of these rodenticides has also meant that these poisons can be spread over large areas cost effectively, in comparison to largely impractical traditional bait-stations and ground based methods. However, the recent eradication of Norway rats from

Langara Island (3105 ha) in British Columbia using 3,784 bait stations baited with brodifacoum baits (Kaiser et al. 1997), questions exactly what is practical and what isn't.

The second-generation anticoagulants were developed in response to the resistance of rodents to first-generation compounds, especially warfarin, in some parts of the world (Jackson & Ashton 1992). Resistance to first-generation anticoagulants is inherited, and does not simply result from repeated exposures to low doses (Jackson & Ashton 1992). Resistance to difenacoum and bromadiolone has already been recorded in some rodent populations, and in regularly poisoned populations there are strong indications of tolerance to brodifacoum (Lund 1984, Quy et al. 1995). A small number of rats survived and continued to feed on brodifacoum baits on Ulva Island, until they were trapped out, after apparently evolving resistance to brodifacoum (Taylor et al. in prep. cited in Kaiser et al. 1997). Resistance to all the new anticoagulant compounds evolves when used continually (Quy et al. 1995). These findings reinforce the need for eradication at the first attempt and for the use of alternative poisons so that prolonged exposure does not result in resistance.

The second-generation compounds work in much the same way as the first-generation poisons (Kaukeinen & Rampaud 1986, Hadler & Buckle 1992). That is, they bind to specific sites in the liver of vertebrates. They block the epoxide reductase enzyme, which stops the recycling of activated vitamin K. As a result there is insufficient incoming vitamin K to maintain the carboxylation reaction. This critically reduces the production of clotting factors, such as prothrombin. Eventually the clotting mechanism fails and haemorrhaging begins (Hadler & Buckle 1992). Because this mechanism is common to all anticoagulants, there is no difference in the time to death once the enzyme is blocked (Hadler & Buckle 1992). What can differ is the time taken to achieve the blocking of this enzyme. Anticoagulants cause lethal haemorrhages to occur within the same sites (Hadler & Buckle 1992). The major difference between the first and second-generation anticoagulants is their binding potential in the liver, with the second-generation compounds forming much stronger bonds. The second-generation compounds also have half-lives of several months rather than several weeks (Jackson & Ashton 1992). This means they persist in tissue for much longer periods. The second-

generation poisons are also about 100 times more potent (Hadler & Buckle 1992), requiring less poison to block the enzymatic pathway.

Brodifacoum and its use in New Zealand

Perhaps the most potent of these second-generation anticoagulants is brodifacoum, the chemical name of which is 3-[3-(4'-bromobiphenyl-4-yl)-1,2,3,4-tetrahydro-1-naphthyl]-4-hydroxycoumarin. Brodifacoum was developed primarily as a rodenticide in the mid-1970s, and first licensed in New Zealand in September 1981. However, in New Zealand it has been used to target rodents as well as a number of other pest species, particularly rabbits, *Oryctolagus cuniculus*, (Rammell et al. 1984, Williams et al. 1986, Flux 1993, Towns et al. 1993) and possums, *Trichosurus vulpecula*, (see Eason et al. 1994 for a review). Two types of brodifacoum baits are commonly used in New Zealand: a 15 gram cereal-based wax block containing 50 ppm brodifacoum (Talon® 50WB), and a 2–4 gram cereal-based pellet containing 20 ppm brodifacoum (Talon® 20P and Talon® Possum Bait) (Eason & Spurr 1995a). These baits are either placed in bait-stations or spread from the air. Talon® 20P is usually aerially spread at rates of between 10–20 kg ha^{-1}. The use of brodifacoum baits in bait-stations is generally considered safe to non-target species. However, this neglects the potential for secondary poisoning which still exists. Aerial sowing is considered a greater risk, particularly to ground-feeding birds (Robertson et al. 1993, Towns et al. 1993, Brown 1997b).

Holloway et al. (1992) stated that the environmental impacts of 'new' toxins, such as brodifacoum, are less understood than sodium monofluoroacetate (1080) and careful consideration of potential impacts must be made before the toxin is used. New Zealand is breaking new ground with the use of brodifacoum and it is not being used in the way in which it was originally intended - that is as a control rodenticide placed in bait stations. Consequently, aerial sowing is permitted only by DoC and only on offshore islands without livestock (Eason & Spurr 1995a). However, trials currently being

conducted with this poison may well mean that aerial distribution on the mainland becomes a management strategy.

Brodifacoum has several advantages over acute poisons, such as 1080, which make it a useful alternative poison for use in New Zealand. Firstly, it takes several days to weeks to produce symptoms. This overcomes the problem of bait shyness caused by the fast acting compounds such as 1080 (which can produce symptoms within several hours). Rodents are often wary when encountering new food (neophobic) and will sometimes 'taste' a bait before eating a substantial amount. If enough bait is consumed to cause symptoms, the rodent can recognise cause and effect and becomes 'poison' or 'bait shy' (Hadler & Buckle 1992). Secondly, it is highly toxic to all pest species against which it has been used in New Zealand (eg. rabbits, possums and rodents). Thirdly, only a single feed of the bait is sufficient for the animal to ingest a lethal dose (Hadler & Buckle 1992). This means that concentrations of the poison in baits can be kept to a minimum. Fourthly, in the event of accidental ingestion, there is more time between ingestion and onset of symptoms, and vitamin K_1 has been shown to be an effective antidote. Lastly, brodifacoum has a far lower toxicity to dogs than 1080 (Rammell et al. 1984).

Little is known of what happens to brodifacoum in the environment. The life of brodifacoum in soil has not been properly investigated. The manufacturers of brodifacoum (ICI) suggest a half-life of 84–175 days depending on the soil type (Haydock & Eason 1997). The World Health Organisation (1995) suggests a half-life of 157 days in soil under aerobic conditions. Brodifacoum has extremely low solubility in water (Haydock & Eason 1997). Tests conducted on soil and water on Lady Alice Island following the Talon® 20P drop in 1994 revealed no traces of brodifacoum (Ogilvie et al. 1997). However, only five samples of each were taken and brodifacoum would only be expected to be found in soil near baits. Toxicity of brodifacoum to humans is also unknown.

Impact of brodifacoum on target and non-target species

Brodifacoum has been used successfully in recent rodent eradication programmes on offshore islands (Towns et al. 1993, Towns et al. 1994, Towns et al. 1995, Ogilvie et al. 1997). However, because of the high toxicity of brodifacoum, all vertebrates that eat baits or poisoned prey are at risk (Eason & Spurr 1995a), which increases the potential for killing non-target animals (Lund 1985, Moors et al. 1992). This is in spite of the baits themselves containing lower concentrations of the poison.

It has been suggested that invertebrates are unlikely to be killed by anticoagulants, as they have different blood-clotting systems from vertebrates (Shirer 1992). However, insects that feed on poison baits may still accumulate poison and thus be dangerous to insectivorous birds (Taylor & Thomas 1989). Invertebrates have been observed eating baits and collected from baits containing brodifacoum (Taylor & Thomas 1993, Eason & Spurr 1995a, Ogilvie et al. 1997), and on Stewart Island residues of brodifacoum were found in beetles collected from bait-stations with Talon® 50WB baits (Eason & Spurr 1995a). No brodifacoum residues were detected in tree weta, cockroaches or black beetles collected at Lady Alice Island following a kiore eradication (Ogilvie et al. 1997). However, a cave weta, *Gymnoplectron* spp., collected off brodifacoum baits on Lady Alice Island contained 4.3 mg kg^{-1} brodifacoum (Ogilvie et al. 1997). No signs of brodifacoum were found in any invertebrate samples taken from Stanley Island following a Talon® 20P and Talon® 50WB operation. Nevertheless, it was suggested that further sampling should be undertaken to check for the possible cumulative effects of the toxin in invertebrate food chains (Towns et al. 1993). Several birds, including avocets, pittas, plovers, honeycreepers, finches, thrushes, warblers and crakes, died in a zoo aviary after apparently feeding on ants and cockroaches which had earlier fed on brodifacoum baits (Godfrey 1985). Brodifacoum residues of 0.081 to 1.69 mg kg^{-1} were found in tissues of the birds. As the birds could not gain access to the bait stations and no baits were spilt it was assumed the insects were carriers of the poison (Godfrey 1985). Apart from these mainly anecdotal observations there have been very few

quantitative studies into the effects of anticoagulants on invertebrates or the potential of secondary poisoning from consuming invertebrates. In one of the few studies, Morgan et al. (1996) found that large-headed weta, *Hemideina crassidens*, showed no significant effects of being orally dosed with brodifacoum. Thus, from the few examples presented above, it appears that invertebrates themselves may not be affected by brodifacoum, but can act as vectors of the poisons to insectivorous vertebrates. This form of secondary

Table 1. Native and introduced bird species or subspecies found dead from brodifacoum poisoning for rodent control or eradication in New Zealand: (*) through eating poison baits; (†) through secondary poisoning. Some species assumed to have died from eating poison baits may also have been affected by eating invertebrates which had consumed poison baits (eg. robins). Adapted from Spurr & Powlesland (1997)[1], Eason & Spurr (1995a)[2] and Ogilvie et al. (1997)[3].

		Native bird species
*		Little spotted kiwi, *Apteryx owenii* [1]
*		Paradise shelduck, *Tadorna variegata* [2]
*		Brown teal, *Anas aucklandica* [2]
	†	Australasian harrier, *Circus approximans* [2]
*		Spotless crake, *Porzana tubuensis* [2]
*	†	Western weka, *Gallirallus australis australis* [2]
*	†	Stewart Island weka, *Gallirallus australis scotti* [2]
*		Pukeko, *Porphyrio porphyrio* [2]
	†	Southern black-backed gull, *Larus dominicanus* [2]
*		Red-crowned parakeet, *Cyanoramphus novaezelandiae* [3]
	†	Morepork, *Ninox novaeseelandiae* [2]
*		South Island fernbird, *Bowdleria punctata punctata* [1]
*		North Island robin, *Petroica australis longipes* [2]
*		South Island robin, *Petroica australis australis* [2]
*		Silvereye, *Zosterops lateralis* [2]
*		North Island saddleback, *Philesturnus carunculatus rufusater* [2]

	Introduced bird species
*	Skylark, *Alauda arvensis*[2]
*	Dunnock, *Prunella modularis*[2]
*	Song thrush, *Turdus philomelos*[2]
*	Blackbird, *Turdus merula*[2]
*	Chaffinch, *Fringilla coelebs*[2]
*	House sparrow, *Passer domesticus*[2]
*	Indian myna, *Acridotheres tristis*[2]
*	Australian magpie, *Gymnorhina tibicen*[2]

poisoning is one that has been overlooked even more than secondary poisoning via poisoned rodents.

In birds, the acute toxicity of brodifacoum varies from an LD_{50} (lethal dose which kills 50% of the test animals) of <1 mg kg^{-1} in pukeko, *Porphyrio porphyrio*, to >20 mg kg^{-1} in paradise shelduck, *Tadorna variegata* (Eason & Spurr 1995a). Sixteen native and eight introduced bird species and subspecies have been reported killed during field use of brodifacoum in New Zealand (Table 1). Populations of three native birds (western weka, *Gallirallus australis australis*, Stewart Island weka, *Gallirallus australis scotti*, and pukeko) have been severely reduced in some poisoned areas (Eason & Spurr 1995a). These are only the species for which there are data. Most reports of dead birds come from anecdotal observations or ground based searches by DoC staff following eradication attempts. This is not adequate to assess mortality as these are highly inaccurate methods (Wobeser & Wobeser 1992, Philibert et al. 1993, Atkinson et al. 1995). There have been few quantitative studies on the effects of brodifacoum on native non-target species in New Zealand (Robertson et al. 1993, Towns et al. 1993, Alterio et al. 1997, Brown 1997b). This is not to say that anecdotal records are not valuable and should not be made. Rigorous scientific studies, however, need to be conducted to quantify the impacts of anticoagulants on non-target species so that sensible management protocols can be formulated.

Assessing secondary poisoning

There have been very few studies in New Zealand, or in fact world wide, that have investigated the effects of brodifacoum on predators and scavengers which may ingest poison from the primary victim's tissue (secondary poisoning). With a second-generation anticoagulant such as brodifacoum, which has high toxicity and persistence in tissue, there is a serious risk of secondary poisoning. This is especially apparent when the effects of these anticoagulants on rodent behaviour are investigated. Hooker & Innes (1995) found that most ship rats died in their nests after brodifacoum poisoning, suggesting they would not be eaten by scavenging vertebrates. However, they also found that movements and home ranges of the rats showed no significant changes following lethal doses of brodifacoum. As a consequence they may be available to predators for several days. Poisoned rodents may also have a greater chance of being preyed upon if they leave blood trails or react sluggishly to touch as was observed by Cox & Smith (1992) with Norway rats. Cox & Smith (1992) observed a prelethal reversal of light-dark activity pattern, meaning that rodents are more active during the day. This sort of behaviour would potentially make poisoned rodents far more accessible to diurnal predators, thereby increasing the risk of secondary poisoning to these animals. However, no evidence of this was found by Hooker & Innes (1995) in ship rats.

Captive experiments assessing secondary poisoning

Several experiments using captive predators to assess the secondary poisoning potential of anticoagulants have been conducted. One of the first studies found that nutria or coypu, *Myocastor coypus*, killed using a variety of first-generation anticoagulants (50% warfarin and 50% sulfaquinoxaline, diphacinone, pindone and PMP, oxycoumarin) were a secondary poisoning risk when eaten by commercially farmed female mink, *Mustela vison*, and mongrel dogs, *Canis familiaris*, in a lab situation (Evans & Ward 1967). Fifteen of 16 mink and nine of 17 dogs died from eating the meat, and one mink and two

dogs haemorrhaged to death when blood samples were taken. These animals showed various signs consistent with anticoagulant poisoning, such as bloated abdomens, blood in faeces and urine, lethargy, increased blood coagulation times and internal body cavities full of blood. This was the first indication that anticoagulants may pose a secondary poisoning threat.

Several more trials were conducted in the early 1980s investigating secondary poisoning. Mendenhall & Pank (1980) conducted one of the first experiments investigating the effects of several first- and second-generation anticoagulants on owls. In a preliminary trial they fed diphacinone-killed mice to three great-horned owls, *Bubo virginianus*, and one saw-whet owl, *Aegolius acadicus*. The saw-whet owl died on day seven and two of the great-horned owls died on day 14. The surviving great-horned owl showed signs of haemorrhaging and its blood coagulation time was greatly elevated. In the principal trial, 36 barn owls, *Tyto alba*, were fed poisoned rats, six each with diphacinone, chlorophacinone, fumarin, difenacoum, bromadiolone, or brodifacoum. In this experiment six owls died - five of the six that were fed brodifacoum rats and one of the six fed bromodiolone rats. Haemorrhages occurred throughout the owls' bodies, including subcutaneous areas and visceral organs. Four of the six dead birds also had extensive bruising on the insides of the limbs, apparently due to normal pressure against the body. Three of the six had regurgitated blood. All other birds survived the treatment. However, three of the surviving birds fed difenacoum rats showed signs of haemorrhaging, one severely. The birds that did die behaved normally until 24 hours or less before death, when they became lethargic and stopped eating. Thus, it appears that brodifacoum presents the most risk through secondary poisoning, although difenacoum, diphacinone and bromadiolone also present some risk. Later experiments reported by Gray et al. (1994b) question this ranking of relative toxicity. Nevertheless, there is general agreement with Mendenhall & Pank's (1980) conclusion that caution is needed in the use of anticoagulants for rodent control where avian predators may be exposed to poisoned prey.

Townsend et al. (1981) assessed the secondary poisoning hazard of warfarin to tawny owls, *Strix aluco*. They fed four treatment birds with mice which had been fed on warfarin-treated wheat for 3 days. All treated birds survived a three-month treatment

period. The livers of birds, including tawny owls, appear to possess an enzyme system capable of metabolising warfarin. It was discovered, however, that a biochemical response in the levels of plasma prothrombin (blood clotting factors) occurred in all treated birds. The significance of this sublethal effect in wild tawny owls is not known (Townsend et al. 1981) (see below for sublethal effects).

Townsend et al. (1984) found that weasels, *Mustela nivalis*, are susceptible to secondary poisoning from warfarin in lab conditions. Most treatment animals that died had extensive haemorrhaging and showed signs consistent with anticoagulant poisoning. It was also found that food consumption in weasels decreased during the period immediately before death, when fed on warfarin treated mice (Townsend et al. 1984). It was suggested weasels could be at risk during gray squirrel, *Sciurus carolinensis*, control using warfarin in the United Kingdom. Thus, even the first-generation anticoagulants may pose a secondary poisoning risk in field situations, at least to mammals.

Conflicting evidence regarding the relative toxicity of second-generation anticoagulants comes from a study by Gray et al. (1994b). Captive barn owls were fed mice which had been dosed with brodifacoum, difenacoum or flocoumafen for 15 days. Three out of four owls survived a dose equivalent to the consumption of two 25 gram mice containing brodifacoum or difenacoum residues of 1.0 mg kg^{-1} per day for 15 days. Only two out of four survived the flocoumafen poisoned mice. This differs from the suggestions of Newton et al. (1994) that flocoumafen was less toxic to barn owls than brodifacoum.

Gray et al. (1994b) found no evidence that toxicity of rodenticides (brodifacoum, difenacoum and flocoumafen) was related either to sex or weight of barn owls. Gray et al. (1994b) confirmed that the liver retains the highest concentration of rodenticide residues, with abdominal fat and breast muscle containing low levels of residue. For each rodenticide, the concentration appears to be largely independent of dose, providing evidence that the owl liver contains saturable binding sites (Gray et al. 1994b). It should be noted that owls survived with liver residues of up to 0.7 mg kg^{-1} brodifacoum, and the one owl that died in the 15-day trial had a liver residue level of 1.7 mg kg^{-1} brodifacoum (Gray et al. 1994b). The seemingly high resistance of barn owls to these rodenticides may be a species specific phenomena. It has been suggested before that

barn owls may have a higher resistance to some anticoagulants (Mendenhall & Pank 1980) and it is known that toxicity of these compounds varies among birds and mammals (Godfrey 1985, Eason & Spurr 1995a, Eason & Spurr 1995b).

These, captive experiments indicate that there is potential for secondary poisoning to occur when anticoagulants are used. Additionally, these studies show that there is variation between anticoagulants and the susceptibility of species to these poisons. It should also be remembered that these experiments were conducted on captive birds, which are obviously not exhibiting the same behaviours as wild birds.

Assessing secondary poisoning in field situations

In the United States, damage by voles to apple trees is a problem in many areas (Merson et al. 1984). Thus, the development of rodenticide baits for the control of voles has become an important focus, in many ways paralleling that in New Zealand. The first of several studies into the effects of brodifacoum on owls in field situations was in 1984 (Merson et al. 1984). This study assessed the secondary poisoning hazard to raptors when using brodifacoum as an orchard rodenticide. Three screech-owls, *Otus asio*, a barn owl and an American kestrel, *Falco sparverius*, were radio-tagged and monitored. Pellets were collected from all birds and assayed for brodifacoum. Residues were confirmed in several of the screech-owl pellets, indicating some exposure to the poison. However, no residues were detected in the barn owl or kestrel pellets. One of the screech-owls was found dead post-treatment and showed traces of brodifacoum. However, its death could not be directly attributed to brodifacoum. The other two screech-owls were captured and sacrificed 24–34 days following treatment. One of these birds showed subcutaneous and intramuscular haemorrhaging, but none inside the body cavity. The bird contained 0.21 mg kg^{-1} averaged over the entire body. The other bird had no signs of haemorrhaging or brodifacoum. Both the barn owl and kestrel survived at least one month following treatment.

Later, Hegdal & Blaskiewicz (1984) conducted a study to evaluate the secondary poisoning hazard of brodifacoum to barn owls when used for controlling rats and mice

on farms. Thirty-five active nests were monitored and 26 adult nesting barn owls were radio-tagged. Farms were baited using TALON® (50 ppm brodifacoum) for several months. Pellets were collected from owls to determine diet. It was found that rats and mice made up a very small part of their diet. The owls had large home ranges from 6 to 3278 ha, with mean ranges of 682 ha for males and 752 ha for females. Thus, birds hunted over extensive areas, most of the time well away from the baited farms. Therefore, they would not have preyed upon large numbers of affected rodents. The use of tail mounted transmitters created problems, in that many transmitters fell off before meaningful data could be collected. Only three owls were monitored for more than 26 days, with most being monitored for less than 20. Brodifacoum did not appear to have caused the deaths of any barn owls, but one bird that was found electrocuted did contain traces of the poison. This indicates that exposure to the poison was occurring at low levels. Barn owls, however, seem to be at low risk of secondary poisoning when brodifacoum is used to control rodents around farms. This is because owls generally hunted away from the baited farms and buildings.

Low levels of exposure to rodenticides in barn owls is backed up by studies on the effects of brodifacoum and other anticoagulants on barn owls in Southern Eire. In a study by Eadsforth et al. (1996) it was found that most farmers (73%) interviewed used rodenticide baits (difenacoum 30%, flocoumafen 30%, bromadialone 12%, warfarin 7%, brodifacoum 4%, chlorphacinone 1%, 16% used other baits or could not provide information) to control rat and/or mouse infestations. Despite the fact that 48% of farmers reported barn owls in the area of their farms, 97% of pellets collected from roosts and nests in these areas contained undetectable levels of brodifacoum, difenacoum and flocoumafen. Only two pellets collected contained apparent residues of these rodenticides, and these may have been due to errors in residue extraction (Eadsforth et al. 1996). The analytical method for determination of residues of these three second-generation anticoagulants in owl pellets is considered to be a sensitive and appropriate method for non-invasive monitoring of the exposure of barn owls to these rodenticides in their prey (Newton et al. 1990, Gray et al. 1994a, Eadsforth et al. 1996). It has been shown that on average 25–27% of consumed rodenticides (brodifacoum, difenacoum and flocoumafen) is regurgitated in the owl's pellets (Gray et al. 1994a, Newton et al. 1994). This indicates that during the study period, none of the owls monitored by Eadsforth et

al. (1996) were exposed to significant residues of brodifacoum, difenacoum and flocoumafen in their prey.

It has, nevertheless, been found that exposure of barn owls to low levels of second-generation rodenticides is widespread in Britain, with about a third of birds analysed between 1990–94 having residues in their liver (Wyllie 1995). The poison residues found in these owls for each of the four years closely matched the usage frequency of the four poisons used on British farms (difenacoum 54–62%, bromadiolone 32–37%, brodifacoum 5–7% and flocoumafen 0.5–1.5%) (Wyllie 1995). Second-generation rodenticides were also detected in 31% of polecats, *Mustela putorius*, accidentally killed in Britain between 1992–94 (Shore et al. 1996), again in similar proportions to that used by farmers (Wyllie 1995). If the new rodenticides were ever used away from buildings for controlling animals, such as voles, the potential for secondary poisoning of owls and other rodent predators would be greatly increased (Wyllie 1995). The potential for sub-lethal doses of these toxins to affect predators is also indicated.

Hegdal & Colvin (1988) radio-tagged 38 screech-owls, five barred owls, *Strix varia*, three red-tailed hawks, *Buteo jamaicensis*, two great-horned owls and two long-eared owls, *Asio otus*. Volid® (10 ppm brodifacoum) rodenticide was broadcast in orchards to control voles and the radio-tagged birds were monitored post-treatment. Screech-owls were shown to use the orchard habitat to varying degrees. On average 25% of their home range consisted of orchard. All screech-owls had treated areas within their home range. Eleven screech-owls were found dead post-treatment. Levels of brodifacoum residue ranging from 0.4–0.8 mg kg^{-1} were detected in the livers of five of these birds and extensive haemorrhaging was found in all of these birds and one other. Thus, secondary brodifacoum poisoning was the most probable cause of death in these six birds. One owl had neither haemorrhaging nor detectable residues and the remaining four had been consumed by predators and could not be analysed. Furthermore, six owls whose transmitters had failed were recaptured 31–57 days post-treatment. The livers of these birds were assayed for brodifacoum residue. In four of these birds detectable brodifacoum residue was present in the liver, from 0.3–0.6 mg kg^{-1}. The radio-tagged barred owls were all known to be alive at least 42 days post-treatment, except for one bird whose transmitter failed. Barred owl use of the treated orchards appeared to be less

than that of screech-owls and probably accounts for the difference in survival. The red-tailed hawks, great-horned owls and long-eared owls either survived the drop or contact with the birds was lost. However, an untagged long-eared owl was recovered near a treated orchard and showed signs of severe haemorrhaging - its death was attributed to brodifacoum. Levels of residue detection in this study were stated as being inadequate as the lower limit of detection was 0.3 mg kg^{-1}. This may mean that brodifacoum was not detected in some birds which did from secondary poisoning.

Hegdal & Colvin's (1988) study suggests that the use of brodifacoum in field conditions away from farm buildings, poses a serious risk to some species of owls and other predators. In addition to the studies outlined above, Duckett (1984, cited in Newton et al. 1990) attributed the collapse of a barn owl population in a Malayan oil palm plantation to the use of brodifacoum and coumachlor against rats, which were the owls' main prey. Anecdotal evidence from Australia also suggests a severe decline in some raptor populations in sugar cane areas poisoned with Klerat (active ingredient brodifacoum) (James 1995). During the eradication campaign against Norway rats on Langara Island, British Columbia, the impact on birds was greater than expected (Kaiser et al. 1997). Brodifacoum residues were detected in bald eagles, *Haliaeetus leucocephalus*, Northwestern crows, *Corvus caurinus*, and song sparrows, *Melospiza melodia*, but these species suffered no detectable population decline (Kaiser et al. 1997). However, probably more than 50% of the local common raven, *Corvus corax*, population was killed from scavenging rat carcasses and by eating baits from bait stations. It is likely that immigrants from a much larger raven population nearby could repopulate Langara (Kaiser et al. 1997).

Sublethal effects and persistence of anticoagulants

The sublethal effects of anticoagulants on birds are as yet unstudied. However, sublethal doses of 2.0 mg kg^{-1} brodifacoum have been shown to cause abortions in 45% of pregnant domestic sheep, *Ovis aries*, (which have an LD_{50} of 10 mg kg^{-1}) and when administered to pregnant ewes one week before giving birth, 35% of the lambs born died

within three days of birth (Godfrey 1985). Thus, sublethal effects on pregnant vertebrates are potentially severe.

Sublethal levels of other contaminants (eg. PCBs, parent material DDT, DDE and organophosphorus pesticides) have been found, and their effects well documented in owls and other birds of prey (Buck et al. 1996, Henny et al. 1996, Johnstone et al. 1996). Several reviews have been written on the effects of these compounds (see Fry 1995, Blus 1996, Peakall & Lincer 1996, Blus et al. 1997). The effects of these pesticides on embryos include mortality or reduced hatchability, failure of chicks to thrive and skeletal abnormalities and hormone mimicking (Fry 1995). The range of chemical effects on adult birds includes acute mortality, sublethal stress, reduced fertility, suppression of egg formation, eggshell thinning and impaired incubation and chick rearing behaviours (Fry 1995). The types of pollutants shown to cause reproductive effects include organochlorine pesticides and industrial pollutants, organophosphate pesticides, petroleum hydrocarbons, heavy metals and in a fewer number of reports, herbicides and fungicides (Fry 1995). Many of the effects, such as eggshell thinning by DDE, could not have been predicted before initial use of the compounds (Fry 1995). Only close monitoring of wild populations over prolonged periods allows us to investigate the effects of these chemicals.

The situation may well be the same with anticoagulants. Sublethal effects of rodenticides, however, have not as yet been identified in birds. Residues of brodifacoum have been shown to persist in dosed birds and mammals for prolonged periods. Six blackbirds, *Turdus merula*, collected on Red Mercury Island eight months after a Talon® 20P aerial drop (with some ground spread Talon® 50WB) to eradicate kiore, all had brodifacoum residues in their livers (Towns et al. 1994). Residue levels ranged from 0.004–0.200 mg kg^{-1}. Furthermore, possums administered with sub-lethal doses of brodifacoum (0.1 mg kg^{-1}) were found to retain substantial concentrations (0.085 mg kg^{-1}) in the liver for at least eight months (Eason et al. 1996). No animals were tested past eight months and it is possible that residues are retained for much longer. This highlights the potential risk for secondary and even tertiary poisoning (Eason et al. 1996) and indicates substantial capacity for sub-lethal effects. It is also important to note that differences in concentrations of anticoagulant residue have been found within

samples from a single liver. This has been attributed to non-uniform distribution of residue within the liver tissue (Newton et al. 1994), and is an important consideration when investigating residue levels in poisoned animals.

Secondary poisoning research in New Zealand

Alterio (1996) investigated the secondary poisoning hazard of small mammals in New Zealand when Talon® 20P was applied to coastal grasslands. He radio-tagged three stoats, *Mustela erminea*, five ferrets, *Mustela furo*, and three cats, *Felis catus*, and found that all except one cat died within 30 days of the treatment area being poisoned. All dead predators contained brodifacoum in their livers or showed signs consistent with anticoagulant poisoning. Since these predators are unlikely to eat the cereal baits used during the operation directly, it is almost certain they died from secondary poisoning through eating poisoned mice and/or rabbits which declined dramatically following poisoning (Alterio 1996). Thus, the use of brodifacoum was considered by Alterio (1996) to be an effective multi-species approach to pest control.

Another study in a South Island *Nothofagus* forest showed that all eleven radio-tagged stoats died between 6–9 ($\bar{x}$=7.6) days following poisoning operations using ground spread Talon® 20P (Alterio et al. 1997). A male weasel, also radio-tagged, died from secondary poisoning. Dead ship rats collected after the operations showed that massive brodifacoum residues had accumulated in the animals' livers, averaging 16 mg kg^{-1} (range=10–29) (Alterio et al. 1997). Levels found in these rats are on average 25 times the ship rat LD_{50} found by Kaukeinen & Rampaud (1986), and similar levels may have occurred in mice in these areas (Alterio et al. 1997). This led Alterio et al. (1997) to suggest that this new multi-predator poisoning technique may be especially valuable in restoring native forest bird populations because it kills stoats, weasels, ship rats and probably possums in a single operation.

Conclusions

It appears that anticoagulants, in particular the second-generation anticoagulants, are capable of being transferred from the primary victim (in this case rodents) to avian and mammalian predators. Additionally, these anticoagulants may be transferred to insectivorous species through invertebrates consuming poison baits and acting as vectors of the toxins.

Secondary poisoning of owls and other predators has been demonstrated in field situations when anticoagulants, in particular brodifacoum, are used for rodent control or eradication. The levels of secondary poisoning in these predator populations seems to be related to several factors. There appears to be species specific susceptibility to poisons, with some species having a far lower LD_{50} than others. Also factors such as time of year may have an impact on the outcome of secondary poisoning. Physiological changes within birds, such as moulting or egg laying may be important. Time of year may also affect the diet of wild birds, which may only eat the target rodent species at certain times of the year. Species specific information may even be needed on a finer scale - that is, within the particular habitat that the poison is being used. Better quantitative data need to be collected as most evidence gathered so far is anecdotal.

A large amount of research is currently being conducted on the secondary effects of poisons on mammalian predators in New Zealand and the potential for multi-species control (eg. Alterio 1996, Alterio et al. 1997, Brown 1997a, Gillies 1997, Murphy 1997). Multi-predator control using brodifacoum is potentially a very valuable technique for restoration of native bird communities, provided it does not also kill a significant number of non-target native species such as birds, lizards and invertebrates (Brown 1997b). As outlined above, rodents and other introduced mammals have significant impacts on New Zealand's flora and fauna. A method for the control and eradication of these animals is required, and if mustelids can be killed as a by-product then this is an added bonus. The benefits of rodent control, however, need to be weighed against the costs. Unfortunately, this is extremely hard to quantify when little

is known about the impacts on non-target species. Therefore, there needs to be an assessment of these poisons on our non-target native wildlife to determine whether the risks of this management strategy are too great. If deaths of non-target species cause significant population decreases, then research into multi-species control is a waste of precious resources.

From the studies outlined in this paper it appears that rodent eradication programmes operating in New Zealand could be having some effect through secondary poisoning. The studies already conducted into the effects on introduced predators in New Zealand have already highlighted this. However, we have up to now, very little information on the effects of this poison on our native predators, such as morepork, *Ninox novaeseelandiae*, and New Zealand falcon, *Falco novaeseelandiae*. We also have very little knowledge of the impacts of brodifacoum on many of our native insectivorous birds, such as tomtit, *Petroica macrocephala*, and fantail, *Rhipidura fuliginosa*. Moreover, we still know little about the effects on other non-target species which may be affected by primary poisoning. However, information on these impacts is slowly being accumulated (see Brown 1997b for impacts on South Island robin).

Assessment of mortality of non-target species caused by poison drops ideally requires several years data both before and after the drop. However, there are three levels at which the effects of poison drops can be examined. Firstly, a population can be marked just before a poisoning operation and mortality assessed following the operation. This is usually pointless, because there is no background data to estimate normal sightability and mortality rates. Secondly, a population can be marked and examined for a year before a poison drop. This allows mortality, breeding and diet to be examined and compared with data collected after the drop. This is perhaps the most realistic method. However, it may still be confounded by year to year variation. Thirdly, a population can be marked and examined for several years before and after a poison drop. This will not only give indications of direct mortality following the operation, but also data on sub-lethal effects of the poison used. This last option is the best, although it requires a great deal of commitment, planning and financial support. Unfortunately financial support of New Zealand conservation projects is often hard to get. Another alternative, which has been used successfully, is to monitor control populations at untreated sites.

This is an acceptable and useful method. However, care in choosing the site is necessary to minimise differences between the sites. This also requires a large amount of time and money to set up the sites and monitor the populations before the treatment occurs.

For all of these methods radio-tagging is an important tool that can be used to assess direct mortality, as bodies of dead animals can quickly be located and analysed for poison. Searching for dead birds following poison drops is an inaccurate and inefficient method of determining non-target deaths (see Chapter 5) (Wobeser & Wobeser 1992, Philibert et al. 1993, Atkinson et al. 1995). This method should not be used to assess mortality of non-target species following poison drops.

We should completely re-evaluate the use of brodifacoum and other second-generation anticoagulants in New Zealand. Brodifacoum has not been adequately tested. We know little about its effects on non-target species, its sub-lethal effects and persistence and breakdown in animal tissue and the environment. Alternative methods of rodent control and eradication are available, most of which are also poisons. Trials of alternative toxins originally developed as rodenticides, such as cholecalciferol, have shown to be effective on possums (Jolly et al. 1995, Eason et al. 1994). Cholecalciferol appears to present less of a secondary poisoning risk, especially to birds (Eason et al. 1994, Haydock & Eason 1997). However, there have been problems with rodents not accepting cholecalciferol baits. Cholecalciferol is currently marketed as a rodenticide in many countries (Jolly et al. 1995) and further research in New Zealand may well reveal an acceptable and cost effective bait. To date research on cholecalciferol has been limited, although Landcare Research scientists are currently developing cholecalciferol baits for rodent control in New Zealand. Brodifacoum baits, however, can be supplied for around $4.00 per kg, whereas cholecalciferol baits cost around $40.00 per kg. The cost of baits may mean that eradication attempts are more expensive or that smaller areas must be chosen for eradication attempts (eg. smaller islands). However, if non-target impacts are drastically reduced then this may be worth the extra expense.

This is a key area for future research. If a safer alternative could be found, which had less of an impact on non-target species or was mammal specific, then its use would both increase the conservation potential of rodent eradication and increase public support. It

would also lessen the likelihood of rodents developing resistance to poisons. At present there is much animosity towards the use of poisons in pest control, particularly the use of 1080 against possums. Much of this conflict is due to the lack of public education. However, there is still too little information on the impacts of these poisons on non-target species. Further scientific knowledge in these areas is sorely needed.

Once data on the effects of poisons and the use of alternatives have been collected it is necessary to use the information. This brings about questions on how we should use information on the impacts of these management techniques. What level of non-target mortality is acceptable? Is the use of population viability models (PVA) necessary? Are ethical considerations important? These questions are beyond the scope of this paper, but are nonetheless important considerations. It is not enough to collect data. They need to be interpreted by managers and applied to address clear objectives. It needs to be clear what are we trying to achieve by removing these pests and what are we trying to conserve at sites from which rodents are to be eradicated.

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5

Potential secondary effects of the rodenticide brodifacoum on morepork

Introduction

The aerial broadcast of brodifacoum is being increasingly used to eradicate rodent pests from islands. Offshore refuges free from rodents can be created on the large number of offshore islands surrounding New Zealand. As anticoagulants have proven to be extremely effective in eradicating rodents from these islands, they constitute a potentially powerful management tool. With a strategy being developed by Department of Conservation (DoC) to eradicate rodents from a series of islands up to 3,000 ha (Clout & Saunders 1995), it is obvious that the impacts of these eradications on non-target species need to be fully understood.

Brodifacoum is one of the more toxic second-generation compounds designed in the 1970s (see Chapter 4 for a review of brodifacoum, its use and hazards). However, the environmental impacts of these 'new' toxins are less understood than other alternative poisons such as compound 1080, and careful consideration of potential impacts must be made before brodifacoum is used (Holloway et al. 1992). This is a worrying statement considering that at the population level there have been very few quantitative studies of the impacts of 1080, let alone the second-generation anticoagulants. In New Zealand we are breaking new ground with the use of brodifacoum and we are not using it in the way in which it was originally intended (Holloway et al. 1992) - that is as a control rodenticide placed in bait stations.

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Brodifacoum has been shown to be toxic to non-target vertebrate species in New Zealand (Eason & Spurr 1995a). Species such as North Island robin, *Petroica australis longipes*, and North Island saddleback, *Philesturnus carunculatus rufusater*, have been observed to peck at poison baits and to die through primary poisoning (Towns et al. 1993, Eason & Spurr 1995a, Brown 1997). Avian and mammalian predators that feed on poisoned prey are also known to die from the toxic effects of anticoagulants (Evans & Ward 1967, Mendenhall & Pank 1980, Townsend et al. 1981, Merson et al. 1984, Townsend et al. 1984, Hegdal & Colvin 1988, Gray et al. 1994, Newton et al. 1994, Alterio 1996, Alterio et al. 1997). This effect is termed 'secondary poisoning'.

Though secondary poisoning can be advantageous in multi-species control (eg. Alterio 1996, Alterio et al. 1997), the impact of secondary poisoning on our native avian predators, such as morepork, *Ninox novaeseelandiae*, and New Zealand falcon, *Falco novaeseelandiae*, is not well understood. Morepork are at risk from secondary poisoning because they are known to prey upon house mice, *Mus musculus*, (see Chapter 2) (Cunningham 1948, Hogg & Skegg 1961, Lindsay & Ordish 1964, Clark 1992) and rats (Chambers et al. 1955, Imboden 1975, St.Paul 1977, Saint Girons et al. 1986, Anderson 1992). If invertebrates, such as weta and beetles, have ingested or are carrying brodifacoum, then this is an additional means by which morepork may be affected by this poison. Morepork were included in a list of indigenous bird species as "probably would not eat cereal-based baits if encountered, but might be at risk from secondary poisoning" (Eason 1995b). Morepork were also recognised as a species at risk from secondary poisoning in several recent poisoning operations (Robertson et al. 1993, Taylor & Thomas 1993, Towns et al. 1993, Walker & Elliott 1997).

Morepork have been found dead following pest control operations using Talon® 20P or Talon® 50WB (Eason & Spurr 1995b) and there is some evidence of a decline in morepork populations on some islands. A morepork was found dead following a brodifacoum poisoning operation on Stanley Island, but was not tested (Towns et al. 1993). Following a Talon® 20P poison drop to eradicate kiore, *Rattus exulans*, from Lady Alice Island in 1994 two dead morepork were found (Ogilvie et al. 1997). One was also found on Inner Chetwode Island following a Talon® 20P drop (Eason & Spurr

1995a). One of the birds found on Lady Alice was assayed and its liver contained 3.4 mg kg^{-1} of brodifacoum. The other was too decayed to determine the cause of death (Ogilvie et al. 1997). Two sources of information provide opposing views as to the extent of decline in the morepork population on Lady Alice. E. Minot & A. Booth (pers comm.) suggested that the population decreased severely following the operation, with many roosts once occupied no longer being used and a general impression of far fewer birds seen. However, Ogilvie et al. (1997) stated that the poisoning appeared to have little effect on the morepork population. Of four regular roosts, three were still used by morepork throughout the 1994/95 summer and two were used regularly and one intermittently throughout the 1995/96 summer (Ogilvie et al. 1997). On Tiritiri Matangi Island morepork numbers also appeared to decrease after aerial distribution of Talon® 20P (Eason & Spurr 1995a). There was no evidence that morepork were killed by the use of Talon® 50WB in bait stations for eradication of Norway rats, *Rattus norvegicus*, on Breaksea Island (Taylor & Thomas 1993), and morepork were also considered to be numerous five months after the drop on Red Mercury Island (Robertson et al. 1993). Morepork call counts conducted before and after a brodifacoum poison drop on Nukuwaiata Island, were inconclusive due to large variations in calling activity between nights (Walker & Elliott 1997). However, there was a drop in calling after the poison drop (though not significant), and a dead morepork with a lethal level of brodifacoum residue in its liver was found (Walker & Elliott 1997). Thus, the effects of brodifacoum poison drops on morepork are inconclusive.

Island restoration attempts in New Zealand which use brodifacoum provide an ideal opportunity to gather more information on the secondary poisoning impacts of this poison on native species. The house mouse eradication attempt on Mokoia Island provided an excellent opportunity to study the effects of a brodifacoum eradication attempt on the survival, breeding and diet of morepork. This chapter aims to outline these effects. Information presented in this paper can assist with future island restoration attempts, such as that on Little Barrier Island.

Study site and methods

Study site

Mokoia Island is a 135-ha island in Lake Rotorua, North Island, New Zealand (38° 05' S Lat.; 176° 17' E Long.) (Fig. 1). It is the largest inland island in New Zealand and the shortest distance from the mainland is about 2.1 km. Mokoia is a steep sided rhyolitic volcanic plug which was formed about 150,000 years ago. It rises to about 156 m above the lake level (Andrews 1992). The island is covered with regenerating secondary forest, dominated by mahoe, *Melicytus ramiflorus*, kohuhu, *Pittosporum tenufolium*, five-finger, *Pseudopanax arboreus*, cabbage trees, *Cordyline australis*, and mamaku tree ferns, *Cyathea medullaris* (Beadel 1990). Large areas of blackberry, *Rubus fruticosus*, cover the northeastern flats and some grassy areas are also maintained.

Mokoia Island is Maori owned, administered by the Mokoia Island Trust and is managed in association with DoC Bay of Plenty. The island has a high intrinsic and conservation value for several reasons. Firstly, Mokoia is of considerable cultural value to the Maori people of the area (Te Arawa). Mokoia has for hundreds of years been occupied, at some time or other, by members of nearly all the hapu (sub-tribes) around Lake Rotorua, who valued it both as a defensive site and as a unique kumera plantation (Andrews 1992). Secondly, Mokoia is relatively free of introduced mammals. The exception was Norway rats, which were reportedly abundant on Mokoia in the 1960s (Beveridge & Daniel 1965), and mice. Thirdly, the Rotorua area is a very high use tourist area, attracting both New Zealanders and thousands of overseas tourists annually. Thus, it can be developed as a scientific reserve open to the public, to perform much the same function as Tiritiri Matangi Island in the Hauraki Gulf (see Galbraith & Hayson 1994).

Figure 1. Photo of Mokoia Island as seen from the boat leaving Mokoia and heading towards Rotorua. The island is thickly vegetated and rises to 156 m above the lake level.

The first restoration efforts began in the 1960s when thousands of seedlings and ferns were planted. Most of these were destroyed by rats (Beveridge & Daniel 1965). Goats, *Capra hircus*, were introduced onto the northeastern flats in 1985 to control blackberry. However, they escaped from the fenced area, into the bush. Goats and Norway rats were eradicated from the island in 1989–90. Goats and a few remaining sheep, *Ovis aries*, were removed by shooting and bait stations were provided with Talon® 50WB to eradicate the rats. The vegetation was much thinner due to browsing at that time and so the placement of bait stations was possible. The removal of these species has allowed natural revegetation of the island, and introduction of several threatened bird species. The North Island robin was the first species translocated to the island in 1991.

Following this, North Island saddlebacks were established in 1992 and stitchbirds (hihi), *Notiomystis cincta*, in 1994 (Armstrong & Van Essen 1996). Mokoia is currently seen as a potential site for further translocations of threatened birds, such as little spotted kiwi, *Apteryx owenii*, insects, such as giant weta, *Deinacrida* spp., and possibly lizards. The eradication of mice would constitute a major step towards the restoration of this island.

Morepork pre-poisoning methodology

From November 1995 to July 1996 adult morepork were captured using mistnets and playback of calls. Capture and radio-telemetry techniques and transmitter attachment are described in full elsewhere (see Chapter 2 and Appendix 1). A variety of morphometric measurements were recorded and a blood sample taken (for sexing the birds using DNA techniques - see Chapter 6). Birds were banded using E-size numbered metal bands and a coloured plastic band. Thus, birds are referred to by the last three digits of their numbered metal band. However, some birds are referred to by their colour combinations (ie. w/w, w/y and g/w). Transmitters were designed and built by SirTrack Limited (Havelock North, New Zealand). Transmitters weighed between 6.5–7 grams and were attached using back-pack style harnesses. Because of the length of the study, harnesses were used in preference to other transmitter attachment methods.

The poison drop and mouse monitoring

The poison operation was scheduled for June - July 1996. However, because two feral horses had not been removed from the island the poison drop was postponed. Wet weather further delayed the drop. A week of clear weather without rain is needed following poison drops to maintain bait structure and toxicity. The poison drop was finally conducted on 18 September 1996. A helicopter fitted with a global positioning system (GPS) and bucket type device aerially applied Talon® 7–20 cereal baits (3–4 grams) containing 20 ppm brodifacoum at a rate of 10 kg ha^{-1}. Extra baits were applied

by hand around the buildings and hot pool. The cylindrical baits were dyed green and contained a biotracer (Pyranine 120%) (Fig. 2). Pyranine 120% is an odourless non-toxic dye which fluoresces under UV light. Thus, it is possible to place faeces or animals under UV light to determine whether any bait has been ingested.

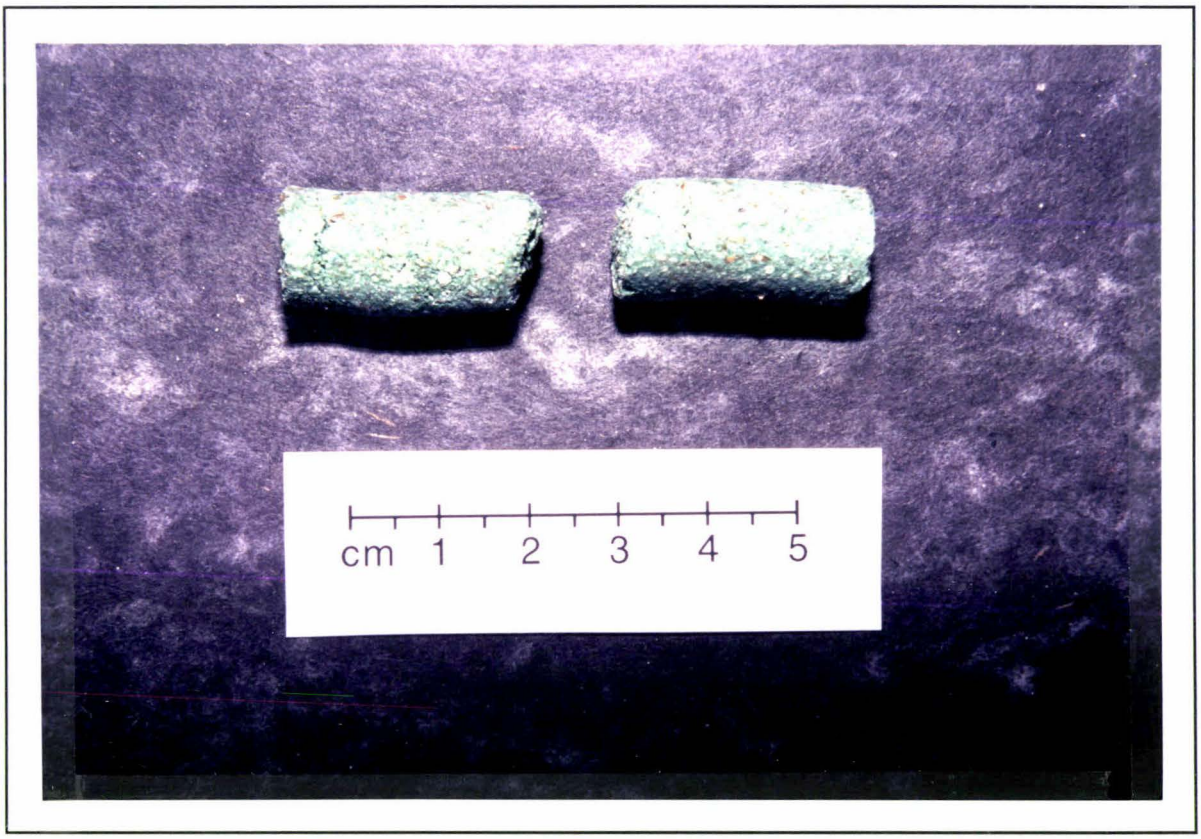

Figure 2. Photo of the cereal-based baits containing 20 ppm brodifacoum used on Mokoia Island during the poison drop.

The mouse population on Mokoia was monitored by Rotorua Lakes High School and DoC Bay of Plenty before and after the poison drop. Mouse abundance was usually monitored monthly from March 1995 to March 1997. Monitoring was conducted using tracking tunnels consisting of plastic tubes about 30 mm square and 350 mm long. Tracking tunnels contained a sponge loaded with red food colouring in the middle and two pieces of tracking paper on either side. An index of mouse numbers was calculated

as the percentage of tunnels which had mouse foot prints on the paper after being set for one night. Thus, if 24 out of 25 tunnels set for one night had prints, a 96% index would be recorded. Tunnels were sometimes baited with peanut butter. However, this was found to have little effect on tracking indices.

Dead mice and other non-target species were noted during movements on the island while monitoring morepork.

When referring to dates following the poison drop, the day of the drop (18 September 1996) is designated as day 0. Thus, monitoring began on day 1 (19 September 1996).

Morepork post poison monitoring

Following the poison drop, an initial intensive monitoring period was conducted (days 1–13). During this intensive period, an attempt to visually locate all radio-tagged birds (n=17) was made each day. The birds' appearance and general behaviour were noted, as well as the appearance and behaviour of their mates. Searches for banded, but untagged birds (n=8), were also conducted. However, this type of search was known to be unreliable, with some birds being unable to be located for some time. Owls were not observed or tracked at night between days 1–13 to reduce disturbance which may have affected their behaviour and potentially their survival. For the same reasons, disturbance during daily visual location of each bird was kept to a minimum.

Following the intensive monitoring period all radio-tagged birds were located in early November and then at monthly intervals until the end of monitoring in February 1997.

Following the poison drop, DoC staff did routine ground searches for dead birds and assessed bait distribution. All dead birds, including morepork, collected during these searches were necropsied by DoC staff at a later date, to determine whether poisoning was the cause of death. Livers of morepork were removed and sent to the National Chemical Residue Laboratory (New Zealand Ministry of Agriculture and Fisheries) for brodifacoum assays using the Anticoag. v2 method with detection levels of ± 0.01 mg

kg^{-1}. Liver tissue has been shown to be the main site of toxin accumulation (Gray et al. 1994) (see Chapter 4).

Results

Effect of the poison drop

Anecdotal observations by staff from DoC Rotorua during pre-poisoning ground work suggested there was a drop-off in the mouse population just before the poison drop (Fig. 3). Mouse populations usually peak in autumn and decline through winter (Murphy & Pickard 1990). Thus, the operation occurred when food was expected to be a limiting factor to mice. Ground based searches by DoC staff revealed that effective poison bait coverage appeared to have been obtained by the helicopter applying the poison over the island. That is, baits were found at approximately the rate applied (10 kg ha^{-1}). It appeared that poison baits had filtered effectively and evenly through the canopy in most places. Dead mice were first discovered on day 4 and were frequently found on the forest floor throughout the intensive monitoring phase (days 1–13). Many of the mice showed external bleeding from the mouth, ears and anus. Several species of birds were also found dead within this initial period. The most common were chaffinch, *Fringilla coelebs*, but species such as North Island robin, North Island weka, *Gallirallus australis greyi*, and North Island saddleback were also found dead. One stitchbird was also witnessed in a very distressed condition feeding from a feeder provided on the island as part of their management. This bird was not seen again (D. Armstrong pers comm.) and possibly died as a result of poisoning.

No mice were recorded using tracking tunnels during the October mouse monitoring. However, on 16 December (90 days after the drop) a live mouse was seen near the hut. Mouse tracking data collected in January 1997, using the standard procedure, show that mice appeared to have survived the drop only in the northeastern flats area. The

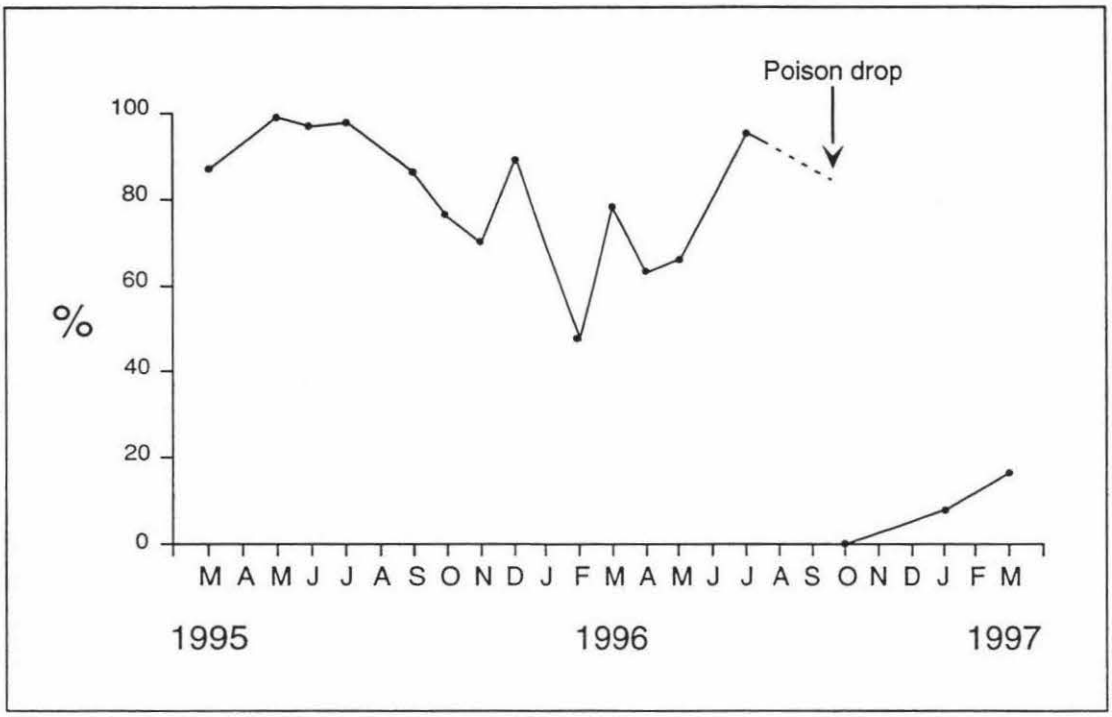

Figure 3. Mouse tracking index data from Mokoia Island. The dashed line represents a drop-off in mouse numbers suggested by anecdotal observations of DoC staff just before the poison drop. The poison drop occurred on 18 September 1996 and the mouse index dropped to 0% in October following the operation. The indices shown for January and March 1997 are averages over the entire island, but tracks were recorded from only one area of the island (the northeastern flats). These data are from unpublished results of work conducted by Rotorua Lakes High School and DoC Bay of Plenty.

tracking index shown for January 1997 (Fig. 3) is an average for the whole island, but tracks were recorded only from this one area. However, when tracking tunnels were left set between monitoring periods in January and March 1997 (therefore set for approximately 2 months rather than the standard 1 night), mice were found to be in low numbers in all areas of the island. This is not shown in Fig 3. Data were collected for March using the standard technique, and show an increase in mouse numbers. Again the index was an average over the whole island, but tracks were only recorded on the northeastern flats. No data were collected after March 1997. Anecdotal observations,

however, suggest that by November 1997, mice had re-established themselves over the entire island to pre-poisoning levels.

Morepork survival post poisoning

Radio-tagged birds

Seventeen radio-tagged morepork (11 ♂♂, 6 ♀♀) were monitored following the poison drop (Table 1). Two of these birds (1 ♂, 1 ♀) were juveniles fledged from the 1995/96 breeding season. One bird (909) could not be located after day 2 because its transmitter battery failed. This bird, however, was seen alive and well on day 137. The remaining 16 birds were alive at the end of the intensive monitoring stage (day 1–13) and had working transmitters (Fig. 4).

On day 13 an untagged dead morepork was found by DoC staff during a ground search. This bird was sent to DoC Bay of Plenty for storage and necropsy. On day 22, one of the radio-tagged birds (907) was found freshly dead by DoC staff using a radio telemetry receiver. This bird was also sent to DoC Bay of Plenty and was confirmed to have a lethal level of brodifacoum in its liver tissue (see Necropsy and brodifacoum analysis below).

In early November (day 51) an attempt was made to relocate the remaining 15 radio-tagged morepork. Signals were received from 13 radio transmitters. Two morepork with functioning transmitters (924 and 927) were found dead. The remains of both of these birds were collected, but they had been dead for some time (<39 days). One of the dead birds (924) had been scavenged, possibly by a weka. The wings and clavicle were still joined and were found about 3 m from the legs and tail. There was no flesh left on the bones. Therefore, brodifacoum analysis was not possible. The other dead bird (927) was found about 4 m from its nest. It had also been dead for some time and was very decomposed. This bird was a female and had a fully formed egg in its body cavity. This egg was intact and was collected. The bird could not be assayed for brodifacoum

Table 1. Summary of results from radio-tagged morepork on Mokoia Island monitored following the aerial brodifacoum poison drop on 18 September 1996. Note that some birds were seen alive following the removal or failure of their transmitters. A = Alive, † = died 138-389 days after the poison drop, †† = died within 51 days of poison drop, ? = unknown due to transmitter failure

No.	Sex/ Age	Tracking period	No. of days tracked post poison	No. of days seen post poison	Result	Comments
901	♂ ad	08/11/95 - 01/02/97	136	198	A	Survived poison drop, attempted to breed with 915 (untagged) but failed
905	♀ ad	18/06/96 - 04/02/97	139	197	A	Survived poison drop, attempted to breed but failed
906	♂ ad	23/11/95 - 03/02/97	138	138	†	Survived poison drop, raised one chick to fledging with 910; Found dead 03/02/97, cause of death unknown
907	♀ ad	30/11/95 - 10/10/96	22	22	††	Found freshly dead 10/10/96, positive brodifacoum analysis
909	♂ ad	07/12/95 - 19/09/96	1	137	A	Transmitter dead, but bird sighted alive 02/02/97
910	♀ ad	12/12/95 - 17/12/96	90	90	A	Survived poison drop, raised one chick to fledging with 906
911	♀ juv	02/01/96 - 01/10/96	13	13	?	Transmitter dead on day 13, but bird alive when last sighted
918	♀ ad	11/11/95 - 03/02/97	138	138	A	Survived poison drop, attempted to breed with 914 but failed
922	♂ juv	15/01/96 - 01/10/96	13	13	?	Transmitter dead on day 13, but bird alive when last sighted
924	♂ ad	17/06/96 - 08/11/96	>13, <51	>13, <51	††	Found dead 08/11/96, corpse unable to be analysed for brodifacoum
925	♂ ad	19/06/96 - 16/12/96	89	89	A	Survived poison drop, unsure if breeding attempted
926	♂ ad	22/07/96 - 16/12/96	89	89	A	Survived poison drop, unsure if breeding attempted
927	♀ ad	23/07/96 - 08/11/96	>13, <51	>13, <51	††	Found dead 08/11/96, corpse unable to be analysed for brodifacoum
928	♂ ad	24/07/96 - 26/06/97	137	281	A	Survived poison drop, unsure if breeding attempted
g/w	♂ ad	22/02/96 - 17/12/96	90	90	†	Survived poison drop, unsure if breeding attempted; Found dead 17/12/96, transmitter caught on tree fern
w/w	♂ ad	29/03/96 - 04/02/97	139	389	†	Survived poison drop, unsure if breeding attempted; Found dead 12/10/97, cause of death unknown.
w/y	♂ ad	30/03/96 - 03/02/97	138	138	A	Survived poison drop, unsure if breeding attempted

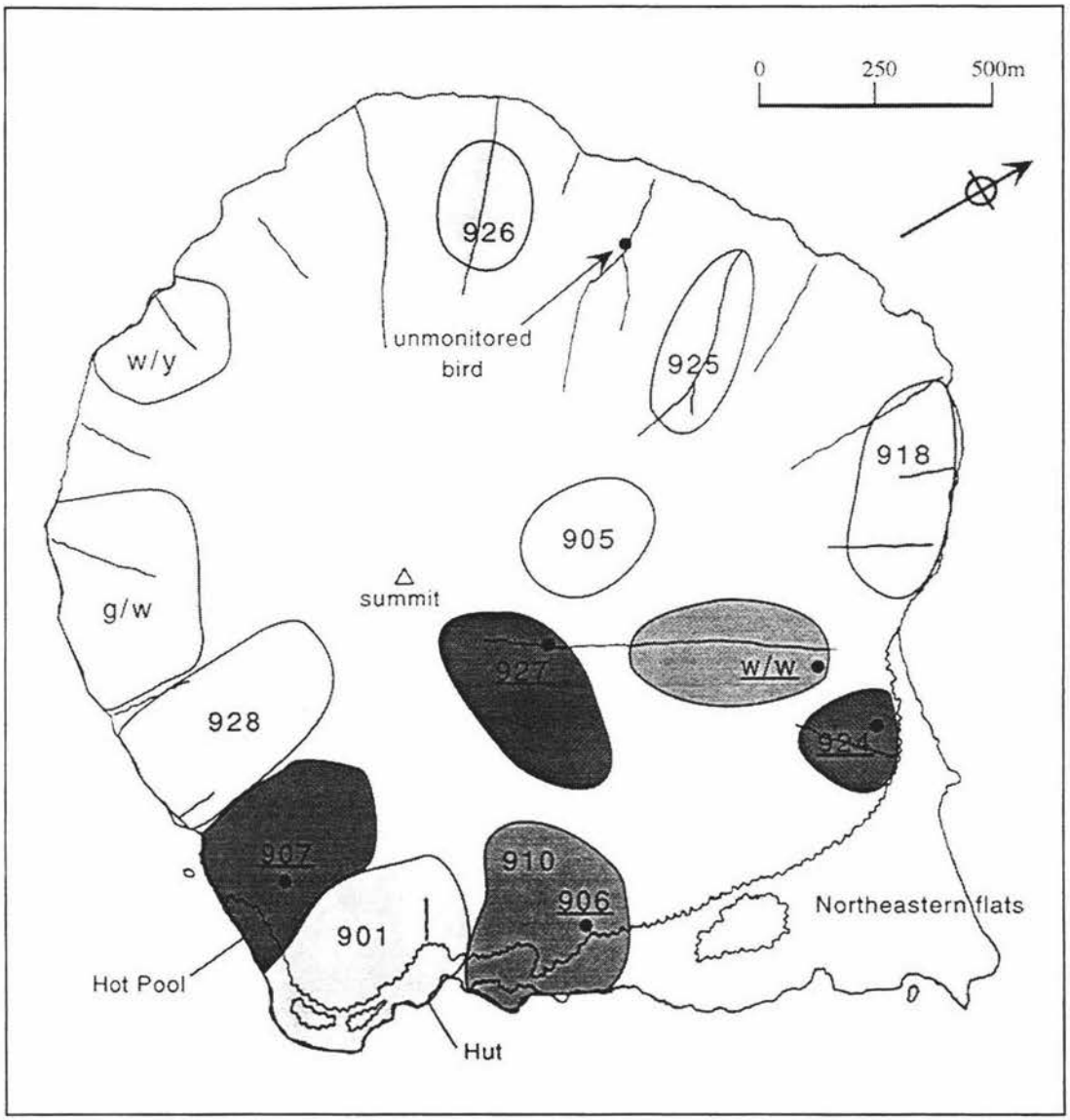

Figure 4. Map of Mokoia Island showing the approximate home ranges of radio-tagged morepork monitored following the poison drop. Only the 14 birds monitored for longer than 14 days after the poison drop are shown. Shading indicates outcome of monitoring (light shading = survival, medium shading = death at least 138–389 days after the poison drop due to unknown causes and dark shading = death within 51 days of the poison drop, attributed to the poison). Underlined birds are those that died. Dots indicate the position of dead birds. The position of the unmonitored bird found during DoC ground searches is also shown.

because of its state of decomposition. Two morepork (911 and 922) whose radio transmitters could not be located were not seen during the rest of the study.

The other 11 birds (8 ♂♂, 3 ♀♀) were located alive and apparently well on day 51 and most were again located on days 52–53. Transmitters on all of these birds were still functional through to at least day 89 (Table 1). Seven of these birds were later captured and their transmitters removed. Five birds were located on days 136–139, and three were seen alive on days 197–198. One bird (928) was also captured and its transmitter removed on day 281. Thus, the poison drop caused the deaths of at least one and probably three out of the 14 radio-tagged birds (21%) (1 ♂, 2 ♀♀) monitored for 51 days after the operation. Eleven out of 15 radio-tagged birds (73%) survived for at least 89 days after the poisoning operation.

On day 90 a radio-tagged morepork (g/w) was found dead. It had killed an incubating starling, *Sturnus vulgaris*, which was nesting inside the hollow top of a mamaku tree fern and its transmitter antenna had become caught. The weak-link in the harness did not break to release the bird as it should have. This was the only bird to die because of its transmitter and harness. This death is obviously not directly linked to the poison drop.

One of the male radio-tagged birds (906) was found dead on day 138. It was found lying on the ground with wings closed. It was very decomposed and therefore was not necropsied or analysed for brodifacoum. The cause of death is unknown, but there appeared to be no broken bones. The transmitter was not caught and did not restrict any part of the bird. On day 389 (12 October 1997) another bird (w/w) was recovered in similar circumstances. This male bird was found on a track in its home range having died just hours before being found. The transmitter, which was still attached, did not appear to have caused any bruising or to be the cause of death.

Banded and unbanded birds

A further eight banded adult morepork (4 ♂♂, 4 ♀♀) (Table 2) were monitored following the poison drop. As they were not radio-tagged they could not be located reliably.

Four of these birds (2 ♂♂, 2 ♀♀) were seen at least 89 days after the poison drop, and three were seen on days 137–138. However, four birds were not seen outside the intensive monitoring period following the poison drop. This does not necessarily mean that they died. Therefore, the maximum mortality of these banded birds is 50%.

A further six unbanded adult birds (1 ♂, 5 ♀♀) (Table 3) were associated with morepork that were radio-tagged following the drop. Three of these birds were seen only within the intensive monitoring period and were not seen later in the study. The three remaining birds were seen on days 198–199. Again, maximum mortality of unbanded birds is 50%.

Morepork behaviour

Most radio-tagged morepork were observed to behave normally during the intensive monitoring period. That is, they roosted at sites that were typical or in roosts they had used before. They usually appeared preened and showed no signs of external bleeding or blood in their faeces (found below their roosts).

Eight of the radio-tagged birds were found roosting with mates during days 1–13. Several of the pairs were also roosting together within several metres of nest sites they used later. This is normal pair bonding behaviour at this stage of the breeding season.

On day 11 a radio-tagged bird (924) allowed a close approach. Normally this bird flew from us before we saw it roosting, often before we were 20 m away. On day 12 it again allowed a very close approach to within 7 m and only flew when the observer slipped and fell. On day 13, the last day it was checked, the bird allowed a very close approach to within 6 m and did not fly. The observer commented that its feathers were fluffed up and unpreened and it did not appear well. It was roosting about 30 m from where it was found dead on day 51.

Table 2. Survival of banded morepork on Mokoia Island monitored following the brodifacoum poison drop on 18 September 1996.

No.	Sex/Age	Date first captured	No. of days after poisoning seen	Result
904	♀ ad	15/11/95	138	Survived poison drop, failed to breed with 908
908	♂ ad	04/12/95	138	Survived poison drop, failed to breed with 904
914	♂ ad	15/12/95	89	Survived poison drop, attempted to breed but failed with 918
915	♀ juv	29/12/95	137	Survived poison drop, attempted to breed but failed with 901
916	♀ ad	29/12/95	0	Survival uncertain, not seen again
917	♂ ad	29/12/95	0	Survival uncertain, not seen again
920	♂ ad	02/01/96	0	Survival uncertain, not seen again
921	♀ ad	12/01/96	0	Survival uncertain, not seen again

Table 3. Survival of unbanded morepork on Mokoia Island monitored following the brodifacoum poison drop on 18 September 1996. All birds are mates of birds either banded or radio-tagged.

Name	Sex/Age	No. of days after poisoning seen	Result
905 mate	♂ ad	199	Survived poison drop, attempted to breed with 905 but failed
924 mate	♀ ad	9	Survival uncertain, not seen again
925 mate	♀ ad	199	Survived poison drop, uncertain if breeding with 925 attempted
926 mate	♀ ad	5	Survival uncertain, not seen again
g/w mate	♀ ad	12	Survival uncertain, not seen again
w/w mate	♀ ad	198	Survived poison drop, attempted to breed with w/w but failed

Necropsy and brodifacoum analysis

The two birds (907 and the unmonitored bird) collected and sent to DoC Bay of Plenty were necropsied on 11/11/96. Both birds showed extensive internal haemorrhage consistent with anticoagulant poisoning. The stomach also fluoresced under UV light, showing signs of the biotracer Pyranine. The livers of both birds were analysed for brodifacoum. The radio-tagged bird's (907) liver contained 1.10 mg kg^{-1} brodifacoum and the unmonitored bird's liver contained 0.97 mg kg^{-1} brodifacoum.

The bird (w/w) found on day 389 (12 October 1997) was necropsied by M. Alley and C. Twentyman at Massey University in October 1997. This bird was found to be in poor condition with no body fat and very thin chest muscle. There were no external injuries and no gross abnormalities of internal organs. The liver showed histology suggestive of lead poisoning. However, the liver was analysed by MAF and lead levels were insignificant. A diagnosis of subacute hepatitis of unknown aetiology was also made. However, this was not likely to be related to brodifacoum toxicity. Unfortunately there was not enough liver available for brodifacoum analysis.

Possible sub-lethal and indirect effects

Breeding success during the season before the poison drop (1995/96) and the season following the drop (1996/97) gives an indication of possible sub-lethal effects (see Chapter 3 for full details on breeding). In the pre-poisoning season nine breeding pairs were monitored. From these nine pairs, nine chicks were known to have fledged, giving a fledging rate of one chick per breeding pair in the 1995/96 breeding season.

During the breeding season following the poison drop a very different pattern emerged. Out of eight breeding pairs that were monitored, one chick fledged. This gives a fledging rate of 0.13 chicks per breeding pair. The seven other breeding attempts failed for a variety of reasons.

Discussion

Unfortunately the poison drop conducted during this study was unsuccessful in eradicating mice from Mokoia Island. The most likely cause was incomplete coverage of the island by the helicopter applying the poison bait. The GPS unit readout was analysed by staff from DoC Bay of Plenty following the re-discovery of mice in December 1997. It showed gaps in bait coverage in the northeastern flats area where mice were first rediscovered. A thick ground cover of blackberry in this area may also have caused poor distribution of the baits. However, the very low tracking index of mice around the rest of the island, recorded by the tracking tunnels left active from January to March suggests bait was either distributed too thinly, or there were gaps between helicopter paths that harboured unpoisoned mice. It is unlikely that mice on Mokoia were resistant to brodifacoum, as Mokoia mice have not had prolonged exposure to this poison.

The discovery of several dead non-target bird species following the poison drop is consistent with most poison drops conducted in New Zealand (eg. Towns et al. 1993, Towns et al. 1994, Brown 1997, Ogilvie et al. 1997). The chaffinch, North Island robin and North Island saddleback found dead are likely to have directly consumed the poison baits. Secondary poisoning through poisoned invertebrates is also a possibility that cannot be ruled out until further research in this area has been conducted. Weka would have probably scavenged dead and dying mice, although they may also have eaten some baits and thus have died due to a combination of primary and secondary poisoning. This is the first record of death from a poisoning operation for this subspecies of weka. The morepork that were poisoned following the drop are most likely the victims of secondary poisoning. Morepork are unlikely to eat poison baits.

Mokoia has been affected by large populations of mice. During the period that mouse numbers were lower, following the poison drop, anecdotal observations indicate that invertebrates, such as weta and other insects were more common than before the drop. Speckled skinks, *Oligosoma infrapunctatum*, were also seen regularly around the summit

area following the drop, but were rarely seen before the poison drop. During fieldwork on Mokoia in the 1996/97 summer, birdlife also appeared to be more common, with large flocks of silvereye, *Zosterops lateralis*, and fantail, *Rhipidura fuliginosa*, and large numbers of North Island robin and North Island saddleback being seen. The monitored population of saddleback on Mokoia is estimated to have lost 30% of adult birds following the poison drop, many of these due to poisoning (D. Armstrong pers comm.). Some stitchbirds disappeared following the operation, but the level of mortality incurred is similar to that over the same period in the previous two years (Armstrong et al. 1997). Perhaps the most surprising finding was that North Island weka were still common, with birds heard calling in most parts of the island. Although 34 weka were captured and taken from the island before the poison drop and 32 were released five months after the drop, it appeared that a large number of weka left on the island survived. Weka have been decimated on other islands where brodifacoum baits have been aerially distributed (Eason & Spurr 1995a).

Transmitter attachment

The backpack transmitters used in this study provided valuable data on the ecology of morepork (see Chapters 2 and 3). They were also a necessary tool in assessing the survival of morepork following this poison drop. The use of transmitters was not without problems however. For several transmitters the batteries ran out during the intensive monitoring phase of the study. This was because many transmitters had been fitted in the previous breeding season (November 1995-February 1996), and some of these contained posture sensors which used more battery power. The estimated life for the standard transmitters was 12.5 months, while the posture sensor transmitters only had lives in the order of 9–10 months. This would have been long enough had the poison drop occurred in June-July as proposed. Hegdal & Colvin (1984) suggested that harnesses may cause bruising which could lead to haemorrhaging or irritation and thus influence results. However, I did not record any damage caused by harnesses, except for the one bird that died due to its transmitter becoming caught on a tree fern. Alternative methods for transmitter attachment, such as glue-mounting tail transmitters, also present problems. Hegdal & Colvin (1988) stated that the use of harnesses would have been

helpful. Many of the owls in their study shed the tail-mounted transmitters, and similar problems were encountered by Hegdal & Blaskiewicz (1984). I am therefore confident that attaching transmitters with harnesses was appropriate and unlikely to have influenced survival of the birds following the poison drop.

Mortality rates

After the poison drop 14 radio-tagged birds were successfully monitored, of which three (21%) died within 51 days of the drop. The banded and unbanded birds suffered a maximum mortality of 50%. This is probably an overestimate due to the difficulty locating untagged birds as mentioned before. True mortality was probably closer to the 21% mortality experienced by the radio-tagged birds, however, this figure gives us an upper limit for mortality. In comparison with the mortality found in screech-owls, *Otus asio*, by Hegdal & Colvin (1988), the mortality found in this study is low. It is also low considering the near 100% mortality of stoats, *Mustela erminea*, ferrets, *Mustela furo*, cats, *Felis catus*, and weasels, *Mustela nivalis*, during similar operations (Alterio 1996, Alterio et al. 1997). This may be due to several reasons. Mustelids and other mammalian predators may scavenge dead rodents as well as slow moving poisoned ones. Therefore they may be exposed to far more poison. Also, morepork and other members of the *Ninox* genus are primarily insectivorous (see Chapter 2). Although 40% of morepork pellets (by volume) consisted of mice during September when the poison drop occurred, invertebrates and birds were also important prey at this time. It is interesting to note the speed with which mice reappeared in morepork pellets. By February 1997 mice remains made up about 13% of analysed pellets (by volume).

Liver analysis and lethal doses

Analysis of the livers of two dead morepork on Mokoia revealed brodifacoum residue levels (0.97–1.1 mg kg^{-1}) comparable with levels found in other poisoned owls. Necropsy also revealed signs consistent with anticoagulant haemorrhaging (Evans & Ward 1967, Mendenhall & Pank 1980). In a previous study a screech-owl killed

following field use of brodifacoum showed evidence of haemorrhaging and contained a residue of 0.21 mg kg^{-1} brodifacoum in its liver. Analysis of livers from screech-owls that died during Hegdal & Colvin's (1988) study found levels between 0.4–0.8 mg kg^{-1}. However, some birds that showed signs consistent with anticoagulant poisoning contained no detectable levels of poison in their livers. The lower limits of brodifacoum detection in Hegdal & Colvin's (1988) study was 0.3 mg kg^{-1}. This may mean that levels of poison below 0.3 mg kg^{-1} can be lethal in screech-owls. The one barn owl, *Tyto alba*, that died during experiments conducted by Gray et al. (1994) had a residue of 1.67 mg kg^{-1} brodifacoum in its liver. Ogilvie et al. (1997) present the only published record of brodifacoum residues in morepork found following poison drops. They found a residue of 3.4 mg kg^{-1} in the liver of a dead bird from Lady Alice Island. Walker & Elliot (1997) reported a morepork found dead with a lethal dose of brodifacoum but do not state the liver residue level. The levels of brodifacoum found in livers may be more than a lethal dose. Because of the slow action of this poison, birds may have continued to consume poisoned prey after a lethal dose had already been ingested.

Mortality justification and population effects

During our study, two birds that died within 51 days of the poison drop were not analysed for brodifacoum. Nevertheless, brodifacoum poisoning or mortality, which is related to the poison drop (eg. stress due to lack of prey or sub-lethal effects), is the most likely cause of death for these two birds. One bird (924) appeared lethargic and did not fly during monitoring as it normally did when observed. Its corpse was found close to where it was last seen. The other bird (927) was a female, found near its nest with a fully formed egg inside it. We assume this bird also died due to the poison, but cannot dismiss the possibility that it died of other causes. The loss of three out of 14 birds within 51 days extrapolates to an annual mortality of around 82%. This is greatly in excess of the normal rate of mortality and further supports the assumption that the two birds were killed by brodifacoum. Our tracking data support this point. Transmitters were fitted to morepork for 3839 bird days prior to the poison drop. During this time one bird died because of injury from a band and two juveniles less than a year old died, possibly killed by a harrier. Thus there was one morepork death per

1279 bird days. In the first 51 days following the poison drop transmitters were fitted to live birds for no more than 762 bird days. During that time contact was lost with two birds and three are known to have died. This extrapolates to one morepork death per 254 days; a five-fold increase in the death rate over the pre-poison drop period.

Of the four birds known to have died following the poison drop (including the unmonitored bird found by DoC), three (75%) were female. This female bias is not statistically significant. Gray et al. (1994) found no evidence of the toxicity of anticoagulants including brodifacoum, to be related to sex or weight. Gray et al. (1994), however, conducted cage trials outside the breeding season. At the time that the poison drop occurred on Mokoia, morepork were starting their breeding season. Birds were roosting with their mates and eggs were probably being laid by early October. At this time of the year female morepork would be undergoing various physiological changes in preparation for breeding and would be laying eggs. These various behaviours may have made females more susceptible to haemorrhaging and thus contributed to the sex bias in mortality recorded in this study. Stress following the poison drop due to lack of prey may also have been an important factor influencing mortality. However, this is difficult to distinguish from sub-lethal effects of the poison.

The deaths of the three monitored morepork within 51 days of the poison drop are attributed to secondary poisoning. Diet analysis of morepork on Mokoia has shown that mice are important prey at certain times of the year and were present in their diet at the time of the drop (see Chapter 2). At that time invertebrates and birds were also being preyed upon. Morepork hunt by watching and listening for movement. They were likely to have preyed on mice that were still active despite having ingested a lethal dose of brodifacoum. At this stage the mice may have behaved normally as Hooker & Innes (1995) found with ship rats, *Rattus rattus*. However, if mice exhibited changed behaviours, such as light-dark reversal activity pattern or sluggishness as seen in Norway rats (Cox & Smith 1992), then morepork faced an even greater risk. Morepork are unlikely to eat dead mice from the forest floor, but can hunt during the day (see Chapter 2).

Brodifacoum levels in mice poisoned on Mokoia were not tested. It can only be speculated as to how many mice it would take to affect a morepork. Ship rats analysed by Alterio et al. (1997) contained residues averaging 16 mg kg^{-1} in their livers. It could be assumed that mice contain similar amounts of poison, if not more since mice are more tolerant to anticoagulants than rats (Kaukeinen & Rampaud 1986, Jackson & Ashton 1992). Mice were still being found freshly dead on at least day 11. Poisoned rodents appear to feed until just before death (Cox & Smith 1992), hence the mice would have been able to consume a large amount of poison in this time. A large dose of poison such as this may well mean that few mice are needed for a lethal dose to be ingested. Suggestions that invertebrates may also be vectors of brodifacoum (Godfrey 1985, Eason & Spurr 1995a, Ogilvie et al. 1997) also mean that the invertebrate content of their diet may have led to increased exposure of morepork to brodifacoum.

Those birds that survived the initial 51 days following the poison drop may still have been affected by the poison drop. Most birds on Mokoia would have been exposed to sub-lethal levels of brodifacoum. The effects of these sub-lethal doses on birds has not been investigated. Experiments on sheep, however, show that sub-lethal doses of brodifacoum can cause abortions and death of new born lambs (Godfrey 1985). Possible sublethal effects of other pollutants and other chemicals on adult birds and embryos have been established (Fry 1995). Breeding effects such as reduced fertility, suppression of egg formation, egg shell thinning and impaired incubation and chick rearing behaviours may well explain the drop in breeding success following the poison drop. This could also be the cause of the two morepork deaths some time after the poison drop (906 and w/w). Sublethal effects on chicks such as mortality or reduced hatchability, failure of chicks to thrive and teratological effects that produce skeletal abnormalities and hormone mimicking may also have been responsible for lowered breeding success following the drop (see Chapter 4). Such effects have yet to be associated with rodenticides as research in this area is lacking. Another possible cause for the decline in breeding success following the poison drop may have been the lack of prey rather than sub-lethal effects. Only extensive monitoring of wild populations will allow us to test for such sub-lethal effects by eliminating natural year to year variation.

Possible long-term effects of these compounds also needs to be investigated. Substantial brodifacoum residues can remain in animal tissue for more than eight months (Towns et al. 1994, Eason et al. 1996). This suggests that long-term effects may last at least as long. Moreover, if other non-target species carry sub-lethal doses of brodifacoum following an eradication operation such as on Mokoia (eg. blackbirds on Red Mercury Island (Towns et al. 1994)) then a morepork could accumulate a lethal dose well after the poison drop.

Conclusions

Only one morepork was found dead during extensive ground searches by DoC staff. This gives some indication as to how many dead birds are missed. If 21% of the entire Mokoia morepork population died within 51 days of the poison drop, then 10–12 morepork probably died (assuming a population of 50–55). Thus, it is likely that at least 9–11 dead morepork were not found. Other poison operations in New Zealand have also reported one or two dead morepork (Towns et al. 1993, Ogilvie et al. 1997, Walker & Elliott 1997), suggesting a lot more birds were killed (Wobeser & Wobeser 1992, Philibert et al. 1993). Although the time and area searched has not been quantified, the results from Mokoia suggest that these recoveries may under estimate true mortality by at least a factor of ten. This therefore puts in question the use of this technique to assess mortality and relate this to acceptable mortality levels.

An acceptable level of mortality could be seen as one which acts instead of natural mortality or one from which a population is able to recover. With passerines such as robins and saddleback which may produce several clutches per breeding season and fledge several young per clutch, the population will probably recover within one or two breeding seasons from a loss of 30% during a poison drop. However, long-lived species, such as morepork which may fledge less than one offspring per year (see Chapter 3), will be less able to recover from mortality induced by secondary poisoning. Additionally, this study indicates morepork have a high risk of secondary poisoning and that potential exists for morepork to be affected by sub-lethal poison residues. On the

basis of immediate mortality alone, Mokoia Island morepork could have been expected to recover from the poison drop within two to three breeding seasons. However, in the breeding season following the poison drop very few chicks were fledged and probably even fewer survived to breeding age. Thus, their recovery may be further hindered by sub-lethal or dietary factors following the poison drop. Due to changes in prey species composition, including the temporary elimination of an important food source, the carrying capacity of Mokoia Island may also have changed for morepork.

More research is required to quantify the 'risks' to native predators, such as morepork and to assess the time populations take to recover to pre-poisoning levels. This study confirms that morepork are at risk from secondary poisoning. Morepork were killed by brodifacoum poisoning and may have been affected by sub-lethal doses of this poison. This indicates that caution needs to be exercised in the use of brodifacoum as an eradication tool. Moreover, it is apparent from this study that brodifacoum may not be the best toxin for multi-species control (controlling both rodents and introduced predators), as has been suggested (Alterio et al. 1997). More information on the impacts of brodifacoum on non-target species at the population level is needed before brodifacoum is used on the mainland as a multi-species control. This study provides an indication of the short-term mortality we can expect in a morepork population following an eradication attempt. However, the findings of this study should only be extrapolated to other islands on which mice are the only introduced mammal. The impacts of such a poison drop may be totally different if the island has kiore or Norway rats present. Thus, extrapolating effects of brodifacoum to such islands as Little Barrier and Codfish Island may give incorrect estimates of short-term mortality and sub-lethal effects. More information is needed on breeding post-eradication and the population dynamics of a morepork population in the long term on other islands and at other eradication sites.

In addition, it is suggested that DoC search for safer alternative poisons. Development of a cheap, effective, environmentally safe predator control method is an international and urgent need (Brown 1997). Presently, New Zealand is relying on the use of brodifacoum as a rodent control/eradication tool. Yet we know very little about the impacts of these two poisons on non-target species and the environment. We are presently applying thousands of tons of 1080 aerially per annum over thousands of

hectares of forested areas. The use of brodifacoum in this way, if it is considered a useful multi-species control, could be counter productive if it negatively affects native species at the population level. We should remember that aerial broadcast is not the method of application for which brodifacoum was originally developed.

The perceived hazards of secondary poisoning to non-target wildlife have prevented second-generation anticoagulants such as brodifacoum from being registered for field use in the United States (Colvin et al. 1991). For this reason brodifacoum is only registered for use around farms and buildings as a control rodenticide. This is largely due to the numerous species of indigenous small mammals which New Zealand lacks. However, we do have important avian predators which appear to be affected in the same manner.

In summary, this study has shown there is a very real risk of secondary poisoning to morepork. The exact pathway of this secondary poisoning has not been defined. However, mice are probably the main vector for secondary poisoning, with invertebrates providing additional risk. Adverse effects of brodifacoum poisoning on morepork are probably dependent on the method of poison bait application, the time of year, and possibly also the concentration of poison applied per hectare. Use of this poison at certain times of the year may present less risk to species such as morepork due to the physiological state of the bird (eg. whether the bird is moulting or producing eggs) or dietary changes over time (eg. may only prey on mice at certain times of the year). Thus, this is another possible area of research. Eradication attempts should be conducted using strict protocols and with complete dedication to ensure eradication. Data presented here put in question the widespread use of brodifacoum as a safe and effective rodenticide for eradicating/controlling rodents within New Zealand. However, it is recognised that this poison has led to a large number of islands becoming rodent free refugia. These refuges are not only benefiting endangered species such as kakapo, *Strigops habroptilus*, but are also providing habitat for other native species of lizards, invertebrates and birds.

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6

Molecular sexing of morepork

Introduction to avian sexing

Identifying sexes of individuals is often important when conducting research into the ecology of a species. In many species of birds, however, the sexes are not easily distinguished, that is their plumage is often very similar and the sexes are similar in size. This has often meant that the identification of an individual's sex depends upon the observation of rarely performed sex-specific behaviours involved with things such as copulation or egg laying (Ellegren & Sheldon 1997). Moreover, recent questions into the evolution of behaviour have relied upon accurate sexing of nestlings or juveniles, which in most cases show no obvious or reliable sexual differences.

The lack of sexual dimorphism in morepork was apparent from the start of this study. Thus, the decision was made to collect blood samples in the hope that I would be able to accurately sex morepork using recently developed DNA-based methods (Griffiths & Tiwari 1995, Griffiths et al. 1996, Ellegren & Sheldon 1997). In birds, the male is the homogametic sex (ZZ) and the female is the heterogametic sex (ZW). The sex of sexually monomorphic avian species, such as morepork, can be determined by differential restriction of the W-linked (CHD-W) and non W-linked (CHD-NW) copies - amplified using the PCR primers P2 and P3 developed by Griffiths & Tiwari (1995). The avian chromo-helicase-DNA binding (CHD) protein gene exists in two genomic copies, the CHD-W which is linked to the female-specific W chromosome and the CHD-NW which is situated within either the Z chromosome or an autosome (Griffiths et al. 1996). Thus, DNA samples from females are expected to produce two polymerase chain reaction (PCR) products (of the same size), whereas samples from males produce one.

Using this technique I hoped to be able to accurately sex morepork and compare this with morphological measurements and behavioural observations.

Blood sample collection

Blood samples were collected from all morepork captured on Mokoia Island. Following capture, the area containing the brachial vein of either wing was cleaned using cotton wool and 70% ethanol. This allowed the vein to be clearly seen and blood to form droplets at the puncture. Birds were bled by venipuncture of the brachial vein, using disposable 25-gauge needles. Blood was collected in 32 x 0.8 mm heparinised capillary hematocrit tubes as long as blood flowed or until 3 tubes were filled (maximum of 60 µl). Filled tubes were placed into 1.5 ml screw-topped *Nunc* tubes containing 100% ethanol. Tubes were then shaken rapidly to homogenise the blood and alcohol solution. Each tube was labelled with the bird's band combination, band number and the date and time of blood collection. Cotton wool was placed over the puncture wound until bleeding stopped. Birds were then placed in banding bags while blood samples were processed. Prior to release the wound was checked to make sure bleeding had stopped. Samples were stored at 4°C in the field soon after collection, then later stored permanently at 4°C in the laboratory.

DNA extraction and molecular techniques

DNA extraction

Extraction and purification of DNA was performed using a standard phenol/chloroform method as outlined by Sambrook et al. (1989). DNA was extracted from the blood/ethanol solution using the following technique. Twenty microlitres of the

blood/ethanol solution was centrifuged at 13 000 rpm for five minutes and the supernatant discarded. The remaining pellet was re-suspended in 400 µl of SET buffer (0.1 M NaCl, 1 mM EDTA, 0.1 M Tris-HCl pH 8.0) by vortexing. Proteins were digested with the addition of proteinase K (20 µl, 20 mg ml^{-1}) and sodium dodecyl sulphate (20 µl, 10% SDS), and incubated overnight at 55°C in a rotisserie incubator.

Proteins were removed from samples with a series of phenol/chloroform washes. Briefly, 400 µl of Tris-buffered phenol was added and rocked for 30 minutes. Following centrifugation at 13 000 rpm for five minutes, the bottom layer was removed using a 200 µl pipette. Four hundred microlitres of phenol/chloroform/isoamyl was added and rocked (30 minutes) and spun at 13 000 rpm for five minutes. The bottom layer was removed and another phenol/chloroform/isoamyl wash was performed. Finally, a single wash of 400 µl chloroform/isoamyl was rocked for 30 minutes, centrifuged and then the bottom layer was removed as above. Samples were centrifuged again at 13 000 rpm for five minutes, and the last of the remaining bottom layer was removed.

DNA was precipitated in 40 µl 3 M NaOAc pH 5.2 and 1 ml of 100% ethanol (room temperature) by rocking for 15 minutes, followed by vigorous shaking. Tubes were stored at -80°C for one hour to allow DNA to precipitate fully. Samples were then spun at 13 000 rpm for five minutes to pellet the DNA. The supernatant was removed and the pellet washed twice with 70% ethanol by gentle inversion. Ethanol was decanted off and the DNA pellet was left to dry at room temperature for approximately 0.5–1 hour. All DNA pellets were re-suspended in milli-Q water and stored at 4°C. Resuspension volumes varied proportionately to the size of the DNA pellet (ie. 40–100 µl).

Molecular sexing protocol

PCR amplifications were done in a total reaction volume of 25 µl that included PCR buffer II (Perkin Elmer: 1 x 10 mM Tris-HCl, pH 8.3, 50 mM KCl), 1.5 mM $MgCl_2$ (final concentration), 200 µm each dNTP (final concentration), P2 (5'-TCT GCATCGCTAAATCCTTT-3') and P3 (5'-AGATATTCCGGATCTGATAGTGA-

3') primers (1 µm final concentration), 50–100 ng of whole genomic DNA and 0.5 units of *Taq* DNA polymerase (*Amplitaq*: Perkin Elmer). The thermal profile was 95°C for 2 min followed by 35 cycles of 94°C for 45 sec. 50°C for 1 min and 72°C for 1 min with a finish of 72°C for 10 min. Eight microlitres of each PCR reaction was size fractionated on agarose gels containing ethidium bromide (2% *NuSieve* / 1% agarose in Tris acetic acid pH 8.0 buffer) run at 10 V cm^{-1} for 30 min, and visualised under UV light (Fig. 1a). Negative controls were run in all experiments. Eight microlitres of the remaining reaction was digested with *Hae*III (5 units: Gibco Life Technologies) in 1 x Gibco Life Technologies enzyme buffer 2, BSA (100 ng ml^{-1}) and spermidine (4 mM final concentration) to a total volume of 10 µl. Samples were incubated at 37°C for 2 hours. The digested samples were then size fractionated and visualised as above (Fig. 1b).

As Figure 1 shows, the male band cuts into two bands, a 65 bp and a 45 bp band. The female band, however, remains uncut at 110 bp. This pattern is similar to that found in a range of other New Zealand species (B. Stephenson unpublished data).

Results

Thirty morepork (17 ♂♂, 13 ♀♀) were examined and all were successfully sexed using this technique. Of these 30 birds, six were chicks which could not have otherwise been sexed.

The sex of most (n=18) of these birds was uncertain at the time of molecular analysis. However, field observations allowed the sex of 12 birds to be determined (assuming females incubated and attended nests) and I used this to make sure the molecular sexing technique worked properly. Of particular interest was a morepork pair (the Hot Pool pair, 907 & 909) which were sexed in the hand using morphology and weight. Following molecular analysis, it was discovered that the 'male' was in fact female and the 'female' male. This was further supported when the female died following the poison drop in September 1996 and was necropsied. Ovaries were discovered instead of testes. This reinforces the uncertainty of sexing based only on morphology.

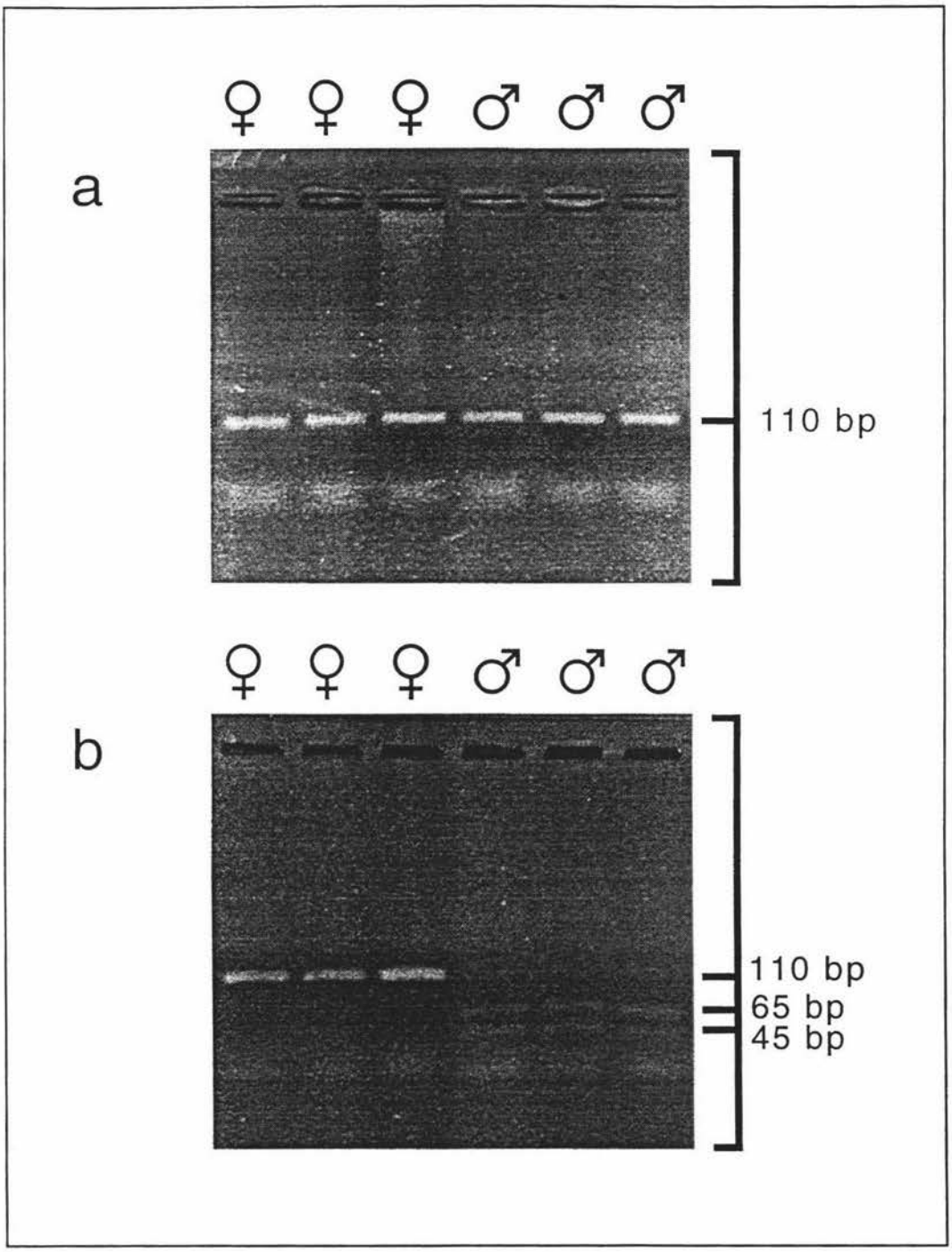

Figure 1. PCR products obtained using the P2 and P3 primers, (a) undigested and (b) digested. It can be seen that in (a) bands of both males and females are 110 bp in size. However, once digested with the restriction enzyme *Hae*III, the male band is cut into two bands of 65 and 45 bp respectively. Thus males can easily be distinguished from females.

Discussion

This DNA-based technique is of value to scientists studying morepork, and also species closely related to morepork. Several closely related species or sub-species are endangered or threatened (eg. Norfolk Island boobook, *Ninox novaeseelandiae undulata*, Christmas Island hawk-owl, *Ninox natalis*). Management of these species may involve the need to be able to sex individuals. Molecular sexing would enable quick identification of the sex of individuals and allow researchers to make decisions rapidly. For example, the Norfolk Island boobook consists of a population of 16 hybrid individuals (crossed with morepork) and one male morepork (Norman et al. in press). Knowing the sex of these surviving birds is an advantage when making decisions about this species' future.

The reliability of using morphometric data to sex morepork has been questioned due to the large degree of overlap between sexes in morphology and weight (see Chapter 2). Difficulty in sexing closely related species may also prevent positive identification of sex. Thus, the use of this PCR test using the CHD P2 and P3 primers is a rapid and low risk (to the bird) method to sex monomorphic species and is of importance to avian scientists.

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Appendix one

Climate on Mokoia Island

Weather data were provided by the National Institute of Water and Atmospheric Research Ltd (NIWA) for the duration of this study. All weather data were recorded at the Rotorua Airport (Weather Station B86133), which is situated on the shore of Lake Rotorua, approximately 3.5 km to the southeast of Mokoia.

Rainfall was recorded hourly and I collated the data into monthly totals (Fig. 1). Average monthly rainfall was 129.2 mm for the duration of the study (November 1995 - February 1997). The records show no large seasonal fluctuations, with the minimum monthly rainfall being 46.8 mm in January 1997 and a maximum monthly rainfall being 212.6 mm in December 1995.

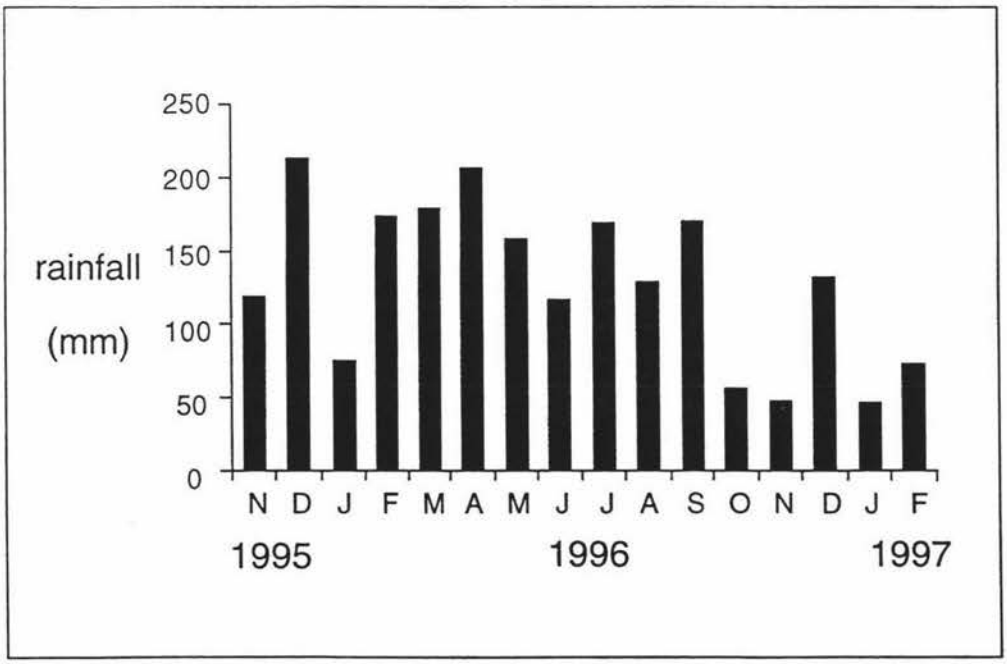

Figure 1. Total monthly rainfall recorded at Rotorua Airport, near Mokoia Island, between November 1995 and February 1997.

Ambient temperature was also recorded hourly and collated into monthly means (Fig. 2). Mean annual temperature for 1996 was 12.4 °C. The minimum temperature was -5 °C in August 1996, and the maximum temperature was 28 °C in February 1996. Because of Mokoia's altitude, minimum temperatures were low year round with 7.0 °C being the highest monthly minimum, recorded in December 1995.

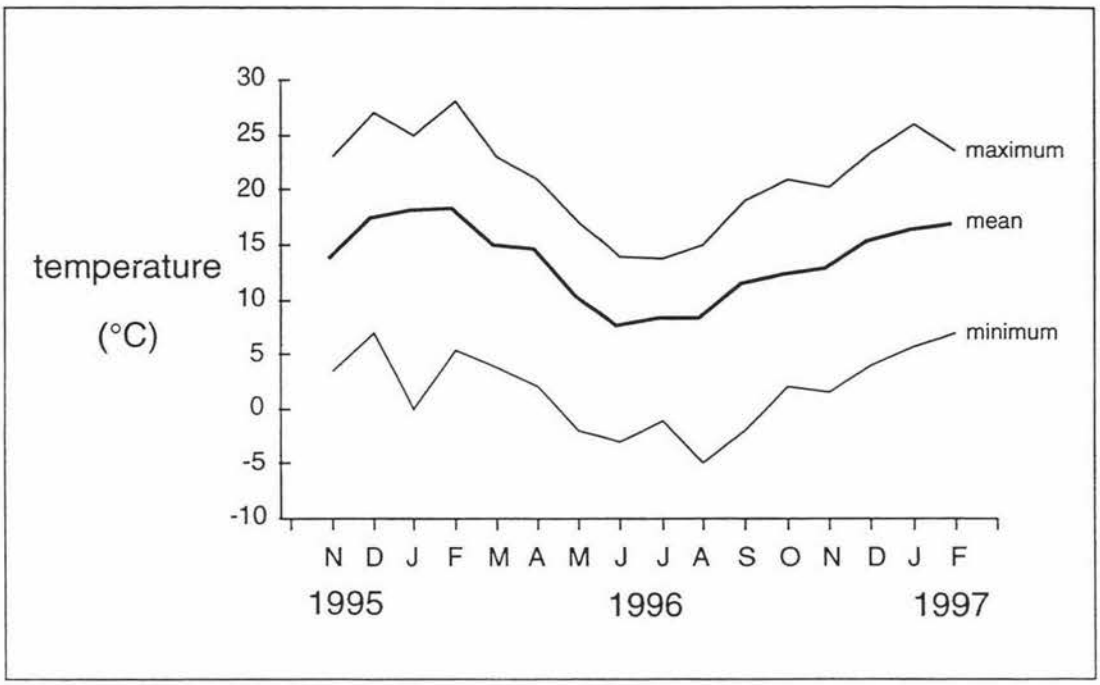

Figure 2. Ambient temperature recorded at Rotorua Airport, near Mokoia.

Wind speed and direction were also recorded hourly and collated into monthly means, with the direction being in degrees from true north. Hours in which the wind direction was variable were excluded from the analysis. A total of 10,832 hours were analysed. The maximum wind speed recorded was 18.5 m s^{-1} in November 1996 (Fig. 3). Mean wind speed for the duration of the study was 3.8 m s^{-1} and was 3.7 m s^{-1} for 1996. No wind (0 m s^{-1}) was recorded in 225 hours (2.1%) over the duration of this study. On Mokoia the prevailing wind comes from the northeast, although wind from the south to southwest was also common (Fig. 4).

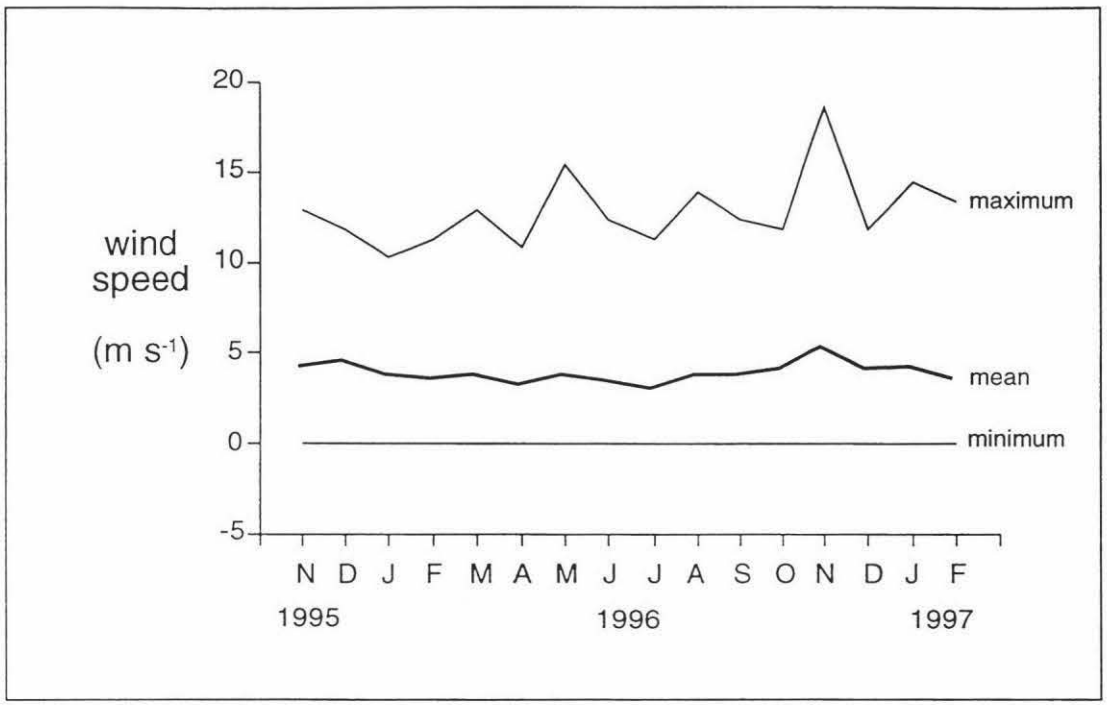

Figure 3. Wind speed recorded at the Rotorua Airport, near Mokoia.

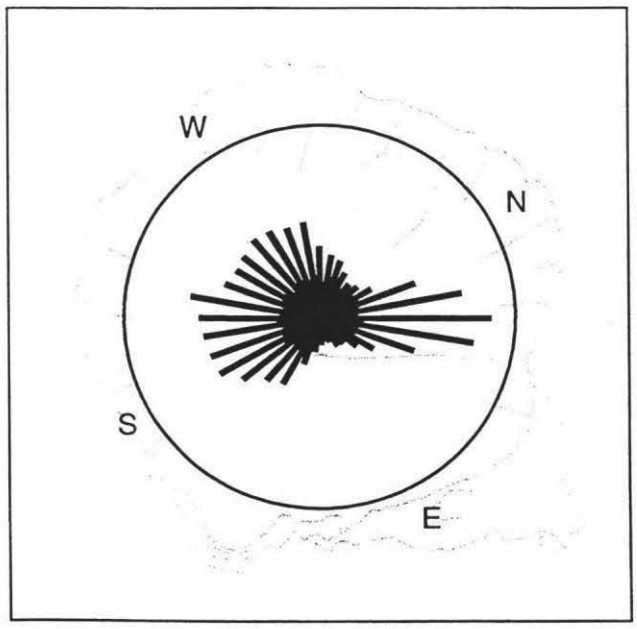

Figure 4. Wind direction overlaid upon a map of Mokoia Island. The lengths of lines indicate the number of hours for which a direction was recorded.

Appendix two

CAPTURING, MARKING AND RADIO-TRACKING A SMALL OWL, THE SOUTHERN BOOBOOK *NINOX NOVAESEELANDIAE* IN AUSTRALASIA

BRENT M. STEPHENSON[1], EDWARD O. MINOT[1] AND PENNY OLSEN[2]

[1] Ecology Section, Institute of Natural Resources, Massey University, Private Bag 11-222, Palmerston North, New Zealand

[2] Behavioural Ecology Group, Division of Botany and Zoology, Australian National University, Canberra ACT 0200, Australia

Running title: Boobook study techniques

ABSTRACT

This paper describes capture, marking and radio-tracking techniques for the Southern Boobook *Ninox novaeseelandiae* in Australasia. Techniques outlined include the use of taped calls and mist-nets, colour bands and reflective tape, handling and attachment of radio transmitters using harnesses.

INTRODUCTION

For many studies of birds, it is necessary to have a marked population so that individuals can be recognised. Bands are by far the most common means of marking birds (Calvo and Furness 1992). Coloured or numbered leg bands may be used to identify free-ranging wild birds, but for many owls such bands are often difficult to see, even at the best of times (Forsman *et al.* 1996). Thus, owls often require alternative methods for effective individual recognition. This not only requires effective marking techniques, but also suitable capture methods. This paper outlines methods for the capture, handling and marking of Southern Boobooks *Ninox novaeseelandiae* (known as Morepork in New Zealand), including the use of transmitters and coloured reflective markers.

The Boobook is one of several small (ca. 200–300 g) *Ninox*, represented throughout much of Australasia, the south-west Pacific islands and the Indonesian archipelago (Schodde and Mason 1980). Two members of the genus are listed as vulnerable and one as near-threatened (Collar *et al.* 1994) and very little is known about most members. The techniques described in this paper will be useful in investigating the ecology of these species for conservation purposes. Also, owls have often been overlooked in

studies on the effects of pesticides and poisons, such as the use of rodenticides (Blus 1996). Moreover, predators such as owls tend to be good indicator species for ecosystem health and habitat change. The identification of effective capture and marking techniques can be of value in such studies of owls. Unless otherwise noted, results are from a study of Morepork on Mokoia Island, Lake Rotorua, New Zealand.

CAPTURING

Several capture methods have been trialed on small *Ninox*. Hand-nets were used on Boobooks, but were effective only on fledglings (Stephenson pers. obs.). Adults were usually too cautious to allow hand-nets near them. Nooses on poles have been used to snare low-roosting small *Ninox* on Christmas Island (Hill and Lill 1998) where vegetation is dense. However, birds tend to flush in more open situations. This method was also used by Maori to catch Morepork in New Zealand (Best 1977). A bow-net set above a live mouse in a cage has been used successfully both on the ground and suspended from a tree (Bartos *et al.* 1989).

Mist-nets set up around a light in the bush within a Boobook's territory have been found to be successful (Robertson *et al.* 1983). The light attracts moths and other flying insects, which in turn attract Boobooks (a taped call may also be used to lure the birds closer). While the bird is hawking for insects it becomes entangled in the mist-nets. Nets can also be set around a regularly used low roost. They can be set to trap the owl returning to roost or set while the owl is absent and opened when it settles, in which case the owl is flushed into the nets.

As part of a study on the impact of a mouse eradication operation in New Zealand, we (Stephenson and Minot) captured Morepork in mist-nets, using playback of recorded calls to lure them to the site. This was in response to concern that Morepork may be affected by secondary poisoning during rodent eradication and control programmes. The nets were set in the early evening (average of 48 minutes before sunset), and also in the early morning (average of 1 hour 23 minutes before sunrise). Nets were set for an average of 1 hour 51 minutes in the evening (range = 7 minutes – 4 hours 30 minutes), and 1 hour 40 minutes in the morning (range = 12 minutes – 2 hours 15 minutes) before either a bird was caught or we gave up. Nets were often taken down if a bird was caught early in the netting session. They were usually set up in a line along a track, but could also be placed across gullies, and in a V-formation, with the nets at right angles to each other. Two mistnets (60.5 mm mesh, four tier, 9 m nets), were set up on portable aluminium poles. Height above ground varied, but the nets were usually set with the bottom tier approximately 1 m off the ground. Nets were always watched and were never left unattended whilst open. This was extremely important when it was still light, because small birds could be caught accidentally. Boobooks are very quick to arrive at the scene when passerine species are giving distress calls (Imboden 1975). Records were kept of moon phase, weather, cloud cover and time in relation to sunrise and sunset.

Boobooks are territorial all of the year (Stephenson unpubl. data). However, their reactions to the broadcast calls were variable. Sometimes they reacted by landing in the canopy nearby, where they called back while sitting with body feathers erected, wings held slightly open and drooped at their sides. Olsen *et al.* (1989) noted the same behaviour in a subspecies of the New Zealand Morepork, the Norfolk Island Boobook Owl *Ninox novaeseelandiae undulata*, and it is well known in the Boobooks of mainland

Australia and Tasmania (Olsen pers obs.). Sometimes birds arrived silently to investigate the calling and then disappeared, whereas at other times they were known to be present (they already had transmitters fitted) but appeared not to investigate or respond vocally.

One of the main problems we encountered was the owls flying over, rather than into, the mist-nets. Others have noted the same problem (Walker 1997; K. Brown pers. comm.). The erection of higher nets, as was used on Norfolk Island (Olsen unpubl. data), is a possible solution, but takes time and requires climbing skill. Two techniques provided a partial solution to the problem. Firstly, playing the tape on one side of the net and then on the other sometimes lured the bird closer to the ground, especially where the landscape was uneven. This could also be done by setting up two speakers, one on either side of the mist-net, with a means of controlling the speaker from which the sound is played. Secondly, once lured into the area, birds were often highly responsive to a Boobook chick 'alarm' call. This call was recorded whilst handling a chick during the breeding season (September–February in New Zealand) and consisted of a high-pitched trilling. The chick alarm call worked well on most birds, including birds which had not raised chicks that year. It was also effective in June and July, outside the breeding season. Nonetheless, some birds were extremely difficult to catch, especially in June and July, when they seemed to be least responsive to the call. In conjunction with the use of taped calls, we also experimented with visual lures. A model Boobook was constructed from polystyrene and painted. However, the owls appeared to take no notice.

A total of 161 hours was spent mistnetting (25 hours in the morning and 136 hours in the evening) and from this we made 44 captures. Capture success was 0.36 birds per hour in the morning and 0.26 birds per hour in the evening.

We performed a discriminant function analysis on capture success or failure using the following variables: time the net was set up, average wind, average temperature, average rain, average cloud cover, time of sunrise, time of sunset, hours of light, time of moonrise, time of moonset, hours of moon, phase of the moon and whether the moon was up when the net was set. From this analysis no strong relationship was found and none of the variables was a good predictor of catching success. Thus weather and the other variables tested had little effect on capture success when mistnetting. Nevertheless, for the health and safety of the birds, the nets were never set up during rain.

Most Boobooks, once captured, are easily removed from the net. Care should be taken when handling the birds as their talons are extremely sharp. The legs and talons should be held securely at all times. Though their beaks are strong, they are not very sharp and so do not pose much threat. When correctly handled, most birds are calm and do not struggle. A cotton bag can be used for weighing the bird and is also useful for covering the bird's head to keep it calm. Assistance is virtually essential when fitting a transmitter and makes capturing, handling and banding much easier.

MARKING

Boobooks have short, feathered legs and tend to perch with their legs obscured by body

feathers. Because bands are difficult to see it is important to have other ways of identifying individuals.

We tried using a strip of coloured PVC approximately 25 X 10 mm fitted to the colour bands. This protruded out from the band in an attempt to make them more visible. However, most birds removed these soon after release.

The Boobook's short tarsi limit the number of bands which can be applied to one on each leg. To provide more colour combinations we glued coloured reflective tape onto the metal bands (see Olsen 1996). We also covered each colour band with reflective tape of a matching colour. This made the birds far easier to find and identify at night as the tape reflects light from a headlamp.

Other ways of marking the birds are possible. These, however, usually involve placing dyes (Calvo and Furness 1992) or iridescent nail polish (Olsen *et al.* 1989) onto the plumage. These methods therefore have a limited use, in that they only help identify the bird until it moults or removes the colour, and are difficult to see at night.

RADIO-TRACKING

Boobooks carrying a transmitter can be located relatively easily and regularly and identified unambiguously. Olsen and Bartos (1997) fitted a single-stage transmitter to the central tail feathers of an Australian Boobook following the method of Kenward (1978). This was used successfully to estimate home range size, but is not suitable for long-term use or on moulting birds. The single-stage transmitters we fitted to the New Zealand birds were supplied by Sirtrack Limited (Havelock North, New Zealand).

These weighed approximately 6.5–7 g, had a 180 mm whip antenna and were encased in epoxy resin with transverse lug holes for fitting the harness. They were powered by EP675E silver oxide cells and designed to last 10–12 months. Signal pulse rate was 40 pulses per minute, with an 18 millisecond pulse width. The transmitter (Fig. 1) was attached with a back-pack style harness made from nylon cord. This had a weak-link on the front that was designed to break should the bird become entangled (Karl and Clout 1987). A small piece of reflective tape was also placed on the end of the whip antenna to make the birds more visible at night, in the light of a headlamp.

The transmitters were fitted by passing both ends of the top loop (which goes around the neck) through the top lug of the transmitter. This loop was then passed over the head of the bird, but not yet tied. The ends of the other loop of the harness were then passed around the body posterior to the wings and through the bottom lug of the transmitter, which was sitting roughly over the back. The top loop was then tightened and a temporary knot tied. The loop passing under the wings was then tightened, and another temporary knot tied. If the transmitter was sitting correctly, the knots were tied tightly on top of the transmitter (as in Fig. 1). The knot was then strengthened with super glue and the ends trimmed and melted to prevent fraying which would weaken the knot. The harness was just loose enough so that a finger (about 1 cm in diameter) would fit under the weak-link on the breast of the bird. The transmitter sat flat on the bird's back, on top of the spine, between the wings.

Some problems seem to be caused by individual variation in the behaviour of the birds. For example, one bird caught its beak in the neck loop of the harness. While this may

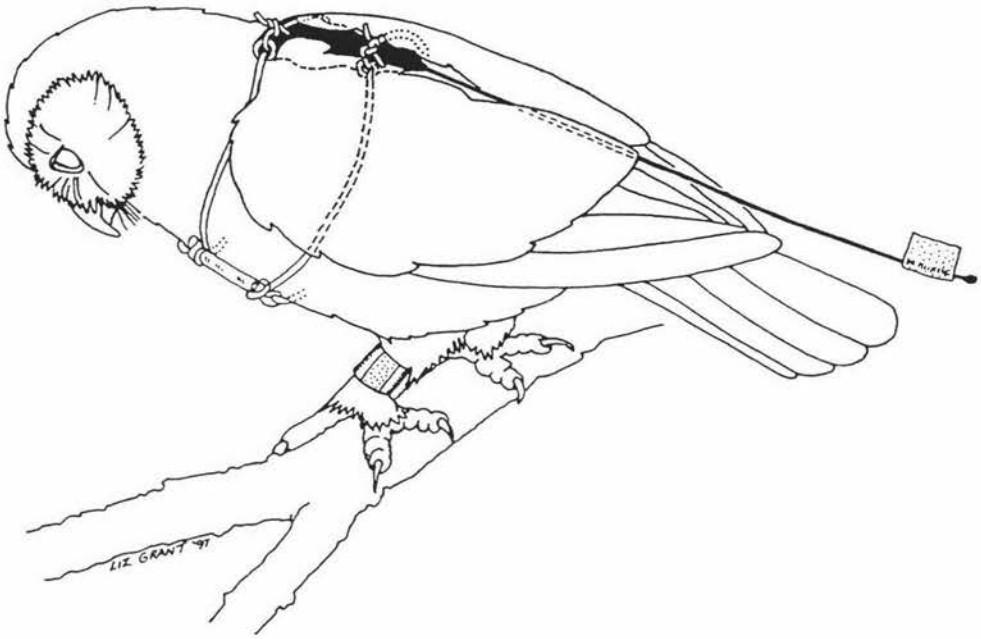

Figure 1. New Zealand Morepork fitted with a transmitter. Note reflective tape on the end of the transmitter antenna and the colour band with reflective tape attached.

have been caused by incorrect fitting, it was probably also because of abnormal persistence in tugging on the harness following release. This bird was captured and refitted with a transmitter the next day and no further problems occurred.

The time from capture to release was approximately 40 minutes. This included time to fit bands and a transmitter, and to take a blood sample. Fitting the transmitter was the longest part of the operation. Once the birds were released they usually flew up to a perch and tugged on their harness until they flew out of sight. Birds were occasionally

seen to tug on their harnesses the following day. Tugging, however, was not observed after birds had been fitted with the transmitter for several days. The transmitters were not usually visible the day following fitting, having nestled down among the bird's feathers.

We fitted transmitters to birds 27 times. Of these, four transmitters came off when the weak-link broke. We do not know if this resulted from entanglement or because the birds broke the link. We recaptured seven owls and removed their transmitters, but were unable to recover eight transmitters. Three birds died during the brodifacoum poisoning operation to eradicate mice from the study site (Stephenson and Minot in press). The most likely cause of death was secondary poisoning. Two other birds also died, of unknown causes, some time after the poison operation and their transmitters were recovered from their bodies. A further two birds (juvenile) were killed, possibly by predation, and their transmitters were recovered. Only one owl was found dead because of problems with the transmitter and harness. That individual had killed an incubating Common Starling *Sturnus vulgaris* on a nest in the hollow trunk in the top of a broken tree fern. The aerial of its transmitter became jammed in a split in the tree fern containing the nest hole and the weak-link did not break. All transmitters lasted the full length of their battery life and none failed.

The combination of colour bands and transmitters was particularly effective. Even without transmitters, colour bands (with reflective tape) allowed identification of birds at night. With patience, banded birds could be identified at their roosts, by waiting for them to scratch themselves with their feet, or when stretching. However, these silent-flying, nocturnal birds are extremely hard to find and observe, during the day or night.

The additional use of transmitters (with reflective tape on the antenna) was found to be invaluable. It meant that birds could easily be located on a daily basis and followed at night. Females fitted with transmitters also revealed the location of nesting sites. These techniques will therefore be important when investigating the ecology of *Ninox* owls and other small owls. However, careful fitting of both bands and transmitters is necessary as both devices could cause serious injury.

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Appendix three

Table 1. Tracking period and duration (in days) of all birds fitted with transmitters on Mokoia. Also shows the number of times each bird was captured.

Bird	Sex	Age	Mate	Date first captured	Tracking period	No. of days tracked	No. of times captured
901 *	♂	ad	902	08/11/95	08/11/95 - 01/02/97	450	5
902 *	♀	ad	901	10/11/95	10/11/95 - 21/12/95	41	3
904	♀	ad	908	15/11/95	15/11/95 - 20/09/96	309	2
905	♀	ad	unbanded	22/11/95	18/06/96 - 04/02/97	231	3
906 *	♂	ad	910	23/11/95	23/11/95 - 03/02/97	437	4
907 *	♀	ad	909	30/11/95	07/12/95 - 10/10/96	307	2
909 *	♂	ad	907	07/12/95	30/11/95 - 08/08/96	252	2
910 *	♀	ad	906	12/12/95	12/12/95 - 17/12/96	370	4
911	♀	ch	w/y	16/12/95	02/01/96 - 01/10/96	272	4
913	♂	ch	none	29/12/95	29/12/96 - 19/07/96	202	1
918	♀	ad	914	11/11/95	11/11/95 - 03/02/97	449	2
919	♀	ch	none	30/12/95	30/12/95 - 01/01/96	2	1
922	♂	ch	none	15/01/96	15/01/96 - 01/10/96	259	1
924	♂	ad	unbanded	17/06/96	17/06/96 - 08/11/96	148	2
925	♂	ad	unbanded	19/06/96	19/06/96 - 16/12/96	180	2
926	♂	ad	unbanded	22/07/96	22/07/96 - 16/12/96	145	1
927	♀	ad	920	23/07/96	23/07/96 - 08/11/96	108	1
928	♂	ad	w/-	24/07/96	24/07/96 - 26/06/97	337	2
g/w	♂	ad	unbanded	22/02/96	22/02/96 - 17/12/96	298	1
w/w	♂	ad	929	29/03/96	29/03/96 - 04/02/97	312	1
w/y	♂	ad	911	30/03/96	30/03/96 - 03/02/97	311	1

* Indicates birds from the three intensively studied pairs

ad = adult

ch = chick/fledgling

Table 2. All birds captured and banded on Mokoia, but not fitted with transmitters. Shows date of first capture and the number of times each bird was captured.

Bird	Sex	Age	Mate	Date first captured	No. of times captured
908	♂	ad	904	04/12/95	2
912	♂	ch	none	09/12/95	1
914	♂	ad	918	15/12/95	1
915	♀	ch	901	29/12/95	1
916	♀	ad	917	29/12/95	1
917	♂	ad	916	29/12/95	1
920	♂	ad	927	01/01/96	2
921	♀	ad	unbanded	12/01/96	1
929	♀	ad	w/w	04/04/97	1
w/-	♀	ad	928	26/06/97	1

Appendix four

Moult in adult morepork

Moult in adult *Ninox* owls is previously described only from museum specimens (Mayr & Mayr 1954). Moult in adult *Ninox novaeseelandiae* has not been described at all. Data collected from morepork on Mokoia provides information on the frequency, timing and sequence of moult.

Morepork moulted following the breeding season (September - January), from December through to March. For successful breeders the moult began after the chicks fledged. Unsuccessful breeders started their moult at the end of their breeding attempt. Similar patterns have been observed in other owls (eg. tawny owl, *Strix aluco* (Southern 1970, Hirons et al. 1984), spotted owl, *Strix occidentalis* (Forsman 1981) and burrowing owl, *Speotyto cunicularia* (Courser 1972)). On Mokoia, a male morepork (909) whose nesting attempt failed early in the 1995/96 breeding season, was found to be regrowing several moulted primaries when captured on 7 December. A pair (904 and 908) whose breeding attempt also failed in the 1995/96 season, were found to be moulting their body feathers within a week of their chick dying.

It appears that all birds on Mokoia moulted their body feathers annually. This is consistent with reports for all other owls (Forsman 1981). Almost all birds observed during January and February 1996 and 1997, were showing signs of body moult. They usually appeared shabby and body feathers were commonly found under their roosts. In fact, morepork feathers were frequently used by other birds, especially hihi, *Notiomystis cincta*, to line their nests. Body moult was usually nearing completion during moult of their flight feathers (remiges and rectrices).

Morepork also appeared to moult all of their flight feathers annually. This differs from some owl species, such as spotted and Tengmalm's owls, *Aegolius funereus*, which typically replace some primaries one year and the remaining feathers the next year

(Forsman 1981, Hornfeldt et al. 1988). All morepork captured and examined for signs of moult in January and February showed regrowing primaries. The typical pattern was that feathers were replaced from the inner wing to the wing tip (that is 1st primary to the 10th). Often, corresponding primaries on the two wings were regrowing at the same time. Typically boobooks moult their wing and tail feathers sequentially, more or less in pairs (one on each wing, or one from each side of the tail), timed with the growth of replacements so that never more than two are missing at any one time (Olsen & Bartos 1997). Five out of six morepork captured on Mokoia during moult had more than one primary in each wing regrowing simultaneously. These feathers were sometimes at different regrowth stages to the corresponding feathers on the other wing, ie. 1/4 grown on left and 1/2 on the other.

Both of these patterns have been observed in tawny owls (Hirons et al. 1984) and Tengmalm's owls (Hornfeldt et al. 1988). Order of primary moult in owls in general is from the innermost out (Mayr & Mayr 1954). However, primary moult in spotted owls has been described as complex (Forsman 1981). The direction of moult in morepork was evident, as feathers on the inside of the moulted or regrowing feathers were always new, and feathers on the outside were old (based on feather colour and wear). Almost all birds captured following the end of moult had a completely new set of primaries.

Moult of secondary feathers was not thoroughly investigated. However, one bird (906) in which secondary moult was evident, showed a random pattern. Forsman (1981) detected no consistent order in which secondaries were moulted in spotted owls. Morepork, based on one individual, appear to follow this pattern.

Tail moult in morepork on Mokoia appeared to be both 'rapid', that is they moulted them all within a day or so (Forsman 1981), and progressive (gradual moult). Mayr & Mayr (1954) found 'rapid' or 'simultaneous' tail moult in many owl species (Mayr & Mayr 1954). Mayr & Mayr (1954) also investigated tail moult in several species of *Ninox* owls. They concluded that species with a wing length of less than 210 mm have essentially a simultaneous tail moult, although the central pair or two pairs may lag behind the others. Those with a wing length of 210–230 mm may have either a

centripetal (outer pair to inner pair), irregular, or simultaneous tail moult. However, forms with a wing length of more than 230 mm usually have a centripetal tail moult, although it may be somewhat irregular. Thus Mokoia morepork, which have an average wing length of 195.7 mm, should have a simultaneous tail moult. Most birds, both male and female, were 'tailless' at some stage during January or February 1996. Several of these birds were later captured and it was found that all tail feathers were growing back evenly and were the same length. This indicates a very rapid tail moult in these birds, perhaps only taking several hours as described in Mayr & Mayr (1954). As part of a ptilochronology experiment, I pulled a tail feather from each bird at the time of capture. Interestingly, in all cases of simultaneous moult, the tail feather I had pulled was either regrowing or fully regrown, and did not fall out in this moult. Several other birds seen in the field had many tail feathers missing during this period, but never appeared completely tailless. One bird (918) when captured was found to have five central tail feathers all broken at two thirds of their length. This suggests that these feathers had all been moulted and regrown at the same time, but the outer feathers hadn't. Another bird (w/w), was found to have the outer left and right tail feathers broken in the same place, and one tail feather about 1cm out of pin. Both of these birds show an irregular or semi-simultaneous moult. Thus, morepork seem to fit into Mayr & Mayr's (1954) middle category of *Ninox* owls, being either simultaneous, irregular or centripetal. Courser (1972) found a similar pattern in burrowing owls, and noted that moult occurred in adult birds after their young had reached some form of independence. It was also noted that the birds which were tailless seemed to fly unimpaired, but takeoffs were slow and wobbly. Effects of tail loss on morepork were not investigated, but there appeared to be no obvious effects.

The tail moult in morepork appears to be annual. Several morepork whose tails were fully moulted in early 1996 were also found to have new tails in early 1997, indicating another full moult. This is consistent with what has been found in other small owls (eg. tawny owl, long-eared owl, *Asio otus,* little owl, *Athene noctua,* elf owl, *Micrathene whitneyi,* saw-whet owl, *Aegolius acadicus*, scops owl, *Otus scops*) which apparently undergo a complete annual moult of their retrices as well as their remiges (Forsman 1981). Spotted owls have a similar pattern of simultaneous tail moult, except the tail is only completely moulted every two years (Forsman 1981).

The timing of tail moult was essentially the same as primary moult, and birds were usually at some stage of tail moult at the same time as they were regrowing primaries. Thus January and February appeared to be the peak period of feather moult in morepork.

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