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# **USE OF KINLEITH FOREST BY NATIVE NEW ZEALAND BATS AND EFFECTS OF FORESTRY**

A thesis presented in partial fulfilment of the requirements for the degree of Master  
of Science in Ecology at Massey University, Palmerston North, New Zealand.

**GERALDINE ELAINE MOORE**

**2001**







**Frontispiece** The Redwood Reserve, Galaxy Rd, is frequented by long-tailed bats. Planted in 1927, the redwoods are among the oldest trees in the forest.

## ABSTRACT

New Zealand's vulnerable microbats, the long-tailed bat (*Chalinolobus tuberculatus*, Vespertilionidae) and short-tailed bat (*Mystacina tuberculata*, Mystacinidae), are typically tree-roosting and generally associated with indigenous forest. However, bats have been seen at the edge of Carter Holt Harvey Forests' central North Island Kinleith Forest, a 131,000 ha exotic forest predominantly in *Pinus radiata*. Requested by Carter Holt Harvey Forests, this study investigates bat presence and distribution in Kinleith Forest, forest use by long-tailed bats, and the effects of forestry practices on bats, with focus on tree felling operations. It is the first comprehensive study of native bats' use of exotic plantation forest in New Zealand.

A broad-scale bat detector-based survey of 32 disparate sites, and comprising 720.5 km of driving transects over three routes, found long-tailed bats to be widespread in Kinleith Forest. In places activity was high, on some nights exceeding 60 bat passes/hour, or 100 passes/night, and at one site, averaging 46.0 passes/night ( $n = 189$  bat detector-nights from throughout the year). Given the decline in this species elsewhere, it is significant that long-tailed bats are present in some areas from which they were known historically. Mapping of bat sites in relation to forest type indicates long-tailed bats may have a fairly continuous distribution in the central North Island. Results suggest that instead of approaching unsurveyed plantation forests with the expectation that long-tailed bats are absent, they should be assumed present until proven otherwise. Anecdotal evidence of short-tailed bats, and of *Dactylanthus taylorii* — a rare plant they naturally pollinate, indicates short-tailed bats could potentially be present in Kinleith Forest.

Bat activity monitoring in adjacent forest interior and road habitats showed long-tailed bats commonly used roads in young (without canopy closure) and mature *P. radiata* forest, and podocarp broadleaf forest. Bats probably favoured roads for reasons of habitat structure, though roads may also play a role in navigation. This behaviour can be used to advantage when surveying for long-tailed bats in plantation forest.

Survey work identified long-tailed bats to be present in all topographies and a range of habitats including harvested/unstocked land, young *P. radiata* forest, and mature ( $\geq 17$  years) *P. radiata*, *Eucalyptus* spp., *Pseudotsuga menziesii* and *Sequoia sempervirens* forest, wetlands, and native forest remnants. Comparison of 46 "bat habitats" with habitat availability along 194 km of transects revealed long-tailed bats to select older pine forest and generally avoid unstocked land or younger forest. This pattern is supported by findings from monitoring work in young and mature pine forest. Older pine forest retains more heat, has a different understorey, and may offer more shelter than younger forest, potentially influencing insect prey abundance and bat activity. Bats' differential use of habitat may partially explain the lower number of bat encounters in the Wainui area than the Galaxy area. Six sites, including a wetland, older pine forest, and areas in or adjacent to native forest, had high bat activity.

The relative importance of exotic plantation forest and native podocarp broadleaf forest reserve land to foraging long-tailed bats was investigated in a replicated bat detector-based study. Insect abundance and ambient temperature were also monitored. Bat activity and foraging activity were much greater in the plantation forest than the native forest, possibly because of the greater abundance of moths — important prey. Forest type was the best predictor of bat activity.

Anecdotal accounts indicated several bat roosts to be in production trees (*P. radiata*), including old crop trees. One record was of a roost in a barely noticeable crevice in a 30-year-old pine, others were from areas of native forest, rocky crevices and a cave. Four accounts were of communal roosts. There is evidence that maternity roosts may occur in production forest. Most observations were made during the process of habitat modification and so roosts no longer exist. At least one possible communal roost was identified from bat activity data. A review of roosting ecology suggests that while highly mobile, long-tailed bats use many roosts in a small area, often roost near forest edges, are highly selective of roosts, and may face inter- and intra-specific competition for roosts.

Long-tailed bats may be very sensitive to roost site disturbance and habitat fragmentation. Tree felling, an important part of forestry, could threaten long-tailed bats at an individual and a population level by causing injury or death, reducing available habitat, and isolating bat groups. However, tree felling could create foraging (e.g. edge) habitat and facilitate access for bats. Overall, effects are likely to depend on the scale of operations. Other forestry operations which could negatively affect long-tailed bats include site preparation, pesticide use, infrastructure works, transportation and quarrying. Pest mammal control operations and the conservation of cave, wetland and reserve areas potentially benefit long-tailed bats in Kinleith Forest. The complex habitat mosaic may be favourable to long-tailed bats. However, there are many questions yet to be answered. Sensitive management may be needed to ensure bat survival in Kinleith Forest.

Long-tailed bats probably prey on a number of forestry pests including *Helicoverpa armigera* and may be an effective biocontrol agent. Artificial roost boxes could be used to encourage bats in this role and reduce the number of bats potentially harmed in tree felling operations.



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## **AUTHOR'S NOTE**

In the interests of clarity and ease of reading, the following chapters are structured as eight interrelated but standalone papers. While this leads to some repetition of material, it is thought that the benefits of this format far outweigh its limitations. Style decisions have been guided by the recommendations of the Council of Biological Editors. Supplementary information, including statistical analyses, is included in appendices at the back of this volume.

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# 1

## GENERAL INTRODUCTION

*"During the last millenium human activity has resulted in grasslands and shrublands replacing forest over much of New Zealand. Against this trend of deforestation, 5% (1.3million ha) of New Zealand's land surface has been planted in exotic conifers for timber production over the last century. These plantations add a comparatively new, and rapidly expanding, component to the landscape, and can provide a forest environment in areas with little such habitat. . . .*

*The role of land management in the maintenance of biodiversity is a major issue."*

— Allen and others 1995, p 301 , 302

# 1

## GENERAL INTRODUCTION

### ABSTRACT

Bats (Chiroptera) are among the most successful, most threatened, and most misunderstood mammals on Earth. They play important ecosystem roles. The long-tailed bat (*Chalinolobus tuberculatus*, Vespertilionidae) and short-tailed bat (*Mystacina tuberculata*, Mystacinidae), are New Zealand's only native terrestrial mammals. Long-tailed bats are aerial insectivores, and considered "edge" bats. They forage along forest margins. They roost in crevices commonly in trees including exotic species, but also in rocky outcrops or caves. Short-tailed bats, "deep forest" bats, are omnivorous, often hunting in the leaf litter of the forest floor. They generally roost in hollow indigenous trees. Both species have large home ranges. Both have declined in distribution and are considered vulnerable. Threats include habitat loss. Plantation forestry, predominantly based on exotic *Pinus radiata*, is an important industry in New Zealand. Bats have been seen in central North Island plantation forests, including Carter Holt Harvey Forests' Kinleith Forest. This study, requested by Carter Holt Harvey Forests, investigates bat presence and distribution in Kinleith Forest, examines bats' use of the forest, and considers the effects of forestry practices on bats, especially tree felling operations. It is the first comprehensive study of native bats in exotic plantation forest in New Zealand.

### 1. INTRODUCTION

The purposes of this chapter are 1) to introduce bats in general and New Zealand's two species, 2) to briefly detail the importance of exotic forestry in New Zealand and the place of Kinleith Forest, and 3) to outline the problem this research seeks to address. A synopsis of the following chapters is also given.



## 2. BATS

### *Why are bats special?*

Bats are among the most successful mammals. In species richness, bats are only exceeded by the rodents, but bats are probably more abundant overall (Kunz 1982). Nearly one quarter of all mammal species are bats (Tuttle 1992). Most numerous in the tropics (Yalden and Morris 1975), bats are found right across the globe, colonising almost every region except Antarctica (Kunz 1982) from forests to deserts to grasslands, from coastal to montane ecosystems (Hill and Smith 1984). Bats are the only mammals capable of sustained flight (Daniel 1990) and their diverse diet is unparalleled in other extant mammals (Kunz 1982). Bats are superbly adapted to their nocturnal lifestyle, and the challenges of energy balance, given their fast metabolic rate, use of flight, and generally large surface area to volume ratio. However, for all this, bats are perhaps the most misunderstood animals on earth (Fenton 1992).

### *Ecological roles and importance of bats*

British bats effectively prevent the fatal blood loss due to mosquito bites of 710,000 people per year (Webb 1996). While perhaps tongue in cheek, this calculation serves to illustrate just one of the important ecological roles of bats — they are the principal predators of vast numbers of night-flying insects (Tuttle 1992) including forestry and agricultural pests (Pierson 1998). Bats also play key roles in pollination and seed dispersal (Wilson 1997), and nutrient cycling (Marcot 1996). They have the ability to influence the population levels of other animals, and some support their own specialised ecto-parasitic fauna (Marcot 1996). The influence of bats may be wide, affecting the ecological processes, productivity and diversity of the ecosystems they inhabit, and reaching into the soils, forest canopies, caves, wetlands and riparian areas (Marcot 1996).

Further information about the origins of bats, the mega- and micro-bats, and other features characteristics is provided in Appendix 1.1.

## 3. NEW ZEALAND BATS

New Zealand has its origins in Gondwanaland. Breaking away from the remaining Australia–Antarctica landmass around 80 million years ago, late Cretaceous (Vickers-Rich and Hewitt Rich 1993), the flora and fauna have largely evolved in isolation. New Zealand's separation, before the widespread diversification of mammals (Vickers-Rich and Hewitt Rich 1993), means bats (pekapeka) are New Zealand's only native terrestrial mammals. Despite this, they are not widely known and knowledge of their ecology is limited.

New Zealand has two species of microbats, the long-tailed bat *Chalinolobus tuberculatus* (Forster 1844<sup>1</sup>), and the lesser short-tailed bat *Mystacina tuberculata* (Gray 1843) (hereafter referred to as the "short-tailed bat"). One further species (but see Higham 1992; O'Donnell 1993, 1994), the greater short-tailed bat, *Mystacina robusta* (Dwyer 1962) is now considered extinct (Daniel and Williams 1984; O'Donnell 1999a).

## Origins

Long-tailed bats belong to the Vespertilionidae, the "evening bats", the most widespread of bat families (Daniel and Williams 1984) and among the most widely dispersed mammals (Daniel 1990). The genus *Chalinolobus* includes five other species in Australia, Papua New Guinea, New Caledonia and Norfolk Island (Daniel 1990). Ancestors of long-tailed bats probably arrived one million years ago, being blown across the Tasman Sea (O'Donnell 1994).

The origin of *Mystacina* (Mystacinidae) has been widely debated (e.g. Pierson and others 1986; Hand and others 1999; Lloyd 2001). However, there is growing evidence of their association with the South American superfamily Noctilionoidea (Phyllostomoidea) (e.g. Pierson and others 1986; Kirsch and Lloyd 1999; Lloyd 2001). It is probable that ancestral Mystacinidae were widespread in Gondwanaland after New Zealand's separation, and subsequently arrived in New Zealand from Australia (Kirsch and Lloyd 1999; Lloyd 2001).

## Description

### Long-tailed bats

Long-tailed bats are the smaller of our two species. They weigh between eight and 11 g (O'Donnell 1999a), the same amount as a 20c piece, though pregnant females may reach 14–16 g<sup>2</sup>. They are chocolate brown, juveniles are slightly darker than adults<sup>3</sup>. Long-tailed bats have small rounded ears and their tails are fully enclosed in the uropatagium. Aerial insectivores (Daniel 1990; Higham 1992), long-tailed bats are regarded as "edge" bats (Daniel and Williams 1984), foraging along forest margins, over farmland and wetlands (Daniel 1990). Their diet includes flies, moths and beetles (Gillingham 1996).

Long-tailed bats roost in hollows or crevices, most commonly in trees or under bark, but also in caves, rock crevices and sometimes buildings or bridges (Daniel and Williams 1984). Tree roosts are not limited to indigenous species, roosts have also been found in e.g. *Eucalyptus* sp., *Acacia* sp, and *Populus* sp., as well as *Pinus radiata* (Daniel 1981; Daniel and Williams 1984). Bats may roost alone, or in groups of generally fewer than 70 individuals (Sedgeley and

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<sup>1</sup> O'Donnell 2001

<sup>2</sup> Personal field observation, assistant in Landcare Research project, Ball's Clearing, Puketitiri, Hawkes Bay, 1995.

<sup>3</sup> Personal field observation, assistant in Department of Conservation project, Grand Canyon Cave, Piopio, King Country, 2000.

O'Donnell 1997). Bats move frequently between tree roosts — average summer occupancy is 1.6 days (Sedgeley and O'Donnell 1996). Hibernation occurs during the late autumn and winter in colder parts of New Zealand (Daniel 1990) although long-tailed bats may forage on milder nights (Daniel and Williams 1984). As in other temperate vespertilionids, long-tailed bats give birth in late spring (MacKenzie 1995; Gillingham 1996). Mating probably occurs in the autumn (Daniel 1990; O'Donnell 2001).

Amongst microbats, long-tailed bats have comparatively large home ranges (O'Donnell 1999a). Fifty bats from three roosting groups in the Eglinton Valley, Fiordland, were found to collectively range over 11,700 ha, though this may be an underestimate of their actual requirements (O'Donnell 1999a). Median individual ranges varied between 1,589 ha (adult males), and 237 ha (newly volant juveniles). The median range of post-lactating females was 1,361 ha (O'Donnell 1999a). Long-tailed bats frequently fly more than 16 km to feeding grounds and perhaps travel some 30–40 km in a night (O'Donnell 1994).

### *Short-tailed bats*

Short-tailed bats are larger than long-tailed bats, weighing 10–19.7 g (Lloyd 2001) but up to 22 g in Fiordland (O'Donnell and others 1997). They have short grey thick frosted velvet-textured fur, a free tail and long ears. There are three recognised subspecies, *Mystacina tuberculata aoupourica* — the Kauri forest short-tailed bat, *M. t. rhyacobia* — the Volcanic Plateau short-tailed bat, and *M. t. tuberculata* — the Southern short-tailed bat (Molloy 1995).

The short-tailed bats, having evolved in isolation for so long, possess some unusual characters (Daniel 1990). They are the most terrestrial of all bats (Daniel 1990) and are very agile. Able to fold up their wings into pouches (Dwyer 1962), and with robust hind limbs and feet (Daniel 1979), they hunt through the leaf litter of the forest floor for arthropods (Daniel 1990). They are also foliage and tree trunk gleaners (Daniel 1979), take flying arthropods (Arkins 1996), and unusually among microbats, feed on plant material — fruit, nectar and pollen (Daniel 1990). Short-tailed bats seem to have the broadest diet of any bats (Fenton 1992). Additionally rare among bats, short-tailed bats have a lek mating system (Higham 1992). Parturition occurs in summer in Northland (Daniel 1990) and the central North Island (Lloyd and McQueen 1997) but may differ for other populations (Daniel 1990).

Unlike long-tailed bats, short-tailed bats are deep forest bats (Daniel and Williams 1984). They roost and feed within indigenous forest (Daniel and Williams 1984), though low numbers have been recorded in a variety of habitats, including pine plantations, close to areas of undamaged old growth forest (Lloyd 2001). Roosts are generally in hollow trees e.g. kauri, beech or podocarp species (Daniel and Williams 1984; Daniel 1990). However, sometimes tomos and caves, and occasionally buildings close to large tracts of forest are used (Daniel and Williams 1984). Short-tailed bats are the only bats known to actively enlarge roost cavities (Daniel 1979;



Fenton 1992). They may roost alone or in small groups (< 200) during their winter hibernation, but throughout the rest of the year roosts may contain between 1,400 and 4,500 individuals (Lloyd and McQueen 1996). Like long-tailed bats, short-tailed bats switch roosts frequently (Lloyd and McQueen 1996).

Short-tailed bats have large home ranges. In Fiordland, four bats ranged over an area of 130,000 ha with individual ranges varying from 3,150 to 69,332 ha (though there was insufficient data to fully reveal home ranges) (O'Donnell and others 1999). Foraging was observed over a 35 km stretch of the Eglinton Valley, with bats often ranging 15–17 km from their roosting area (O'Donnell and others 1997). Some movements were recorded at around 60 km/h and bats also flew over 1–2km tracts of open grassland (O'Donnell and others 1997).

### ***Conservation status, national distribution, and threats***

While long-tailed bats have been previously regarded as the more common of the two bats (e.g. Daniel and Williams 1984), both species are now classed as vulnerable i.e. "facing a high risk of extinction in the wild in the medium-term" (IUCN 2000a) by the IUCN based upon evidence of population decline (IUCN 2000b, 2000c; long-tailed bats: Dwyer 1960a, 1960b, 1962; Daniel 1990; O'Donnell 1997, 2000; short-tailed bats: Dwyer 1960a, 1960b, 1962; Daniel and Williams 1984; Daniel 1990; O'Donnell 1997). The New Zealand Department of Conservation classifies short-tailed bats as "Category A" (Molloy 1995), threatened species of highest conservation priority (Molloy and Davis 1994) and long-tailed bats as "Category B" (Molloy 1995), second priority species (Molloy and Davis 1994).

Long-tailed bats appear less numerous in some regions than previously thought, being very rare or now even absent from areas where they were present 20–30 years ago (O'Donnell 1997). Populations may still be declining (O'Donnell 1997). Comparatively few large roosts have been observed in the last 30 years (Daniel 1990). However, long-tailed bats are widely distributed in New Zealand (Daniel and Williams 1984; Daniel 1990; O'Donnell 1994). MacKenzie (1995), Molloy (1995), and O'Donnell (2000) indicate occurrence throughout much of the North Island, particularly north of the Manawatu Gorge. In the South Island, long-tailed bats are mainly present on the western side of the alps, in the east they are only found in south Canterbury and Southland (Griffiths 1996). Populations also exist on Kapiti Island, Little and Great Barrier Islands, and Stewart Island (MacKenzie 1995; Molloy 1995).

Short-tailed bats, which presumably once occurred throughout mainland New Zealand, have disappeared from large areas (Daniel 1990). Their range is far more restricted than that of long-tailed bats (O'Donnell 1994), and more fragmented. Short-tailed bats are known from only two locations in the South Island (Lyll 2000): northwest Nelson (Lyll 1996), and the Eglinton Valley — Fiordland (Christie 1997; O'Donnell and others 1999), though they may be present in Punakaiki (Lyll 1998, 2000). They also occur on Codfish Island (e.g. Molloy 1995; Sedgely

1997). In the North Island, short-tailed bats are found in Northland, central areas from north-east Taranaki through to the East Coast, and the Tararua (Molloy 1995; O'Donnell 1995b, 1996; McQueen 1996; Garrick 1997; Heaphy 1997; Smuts-Kennedy 1997; Blick 1998; Lloyd and Whiteford 1998; McManus 1998, 1999; Speedy 1998; Trafford 1998; Williams 1998, 1999, 2000; Foster 1999; Quirk 1999; Speed 1999; Arkins 2000; Gasson 2000; Lloyd and McQueen 2000; M Lewis unreferenced personal communication 2001; C Speedy unreferenced personal communication 2001). Sizable central North Island populations occur at Waitaanga, Waitotara, Pureora, Whirinaki, Waikareiti Conservation Area, Kaimanawa Forest Park, and Rangataua (O'Donnell 1999b). Short-tailed bats also exist on Little Barrier Island (Molloy 1995; Arkins 1996). Some of these populations have only been discovered in the last five years. Further unknown populations could yet be discovered.

Bats as a group are vulnerable to extinction. O'Donnell (1999c, p 27) succinctly summarises:

"Many characteristics of bats make them unique among animals and cause them to have specific conservation problems. Bats are particularly vulnerable to disturbance and environmental change because they are very slow breeders, have large home range requirements, specialised roosting site requirements, complex social structures, and limited flexibility because of specific energy and feeding requirements. Complex life styles can be disrupted very easily".

In fact, of 957 known bat species (Neuweiler 2000), 448 (some 47%) are listed as threatened, conservation dependent or near threatened, a further 12 are already extinct, while for another 60 there is insufficient data to make an assessment (IUCN 2000d).

Threats to New Zealand's bats potentially include predation (e.g. by rats, mustelids, possibly possums, feral cats, and moreporks), habitat loss and disturbance, toxins such as those used in possum and rodent control, and competition (Daniel and Williams 1994; Molloy 1995).

However, the significance of these is largely unquantified (O'Donnell 1993, 1994, 2000; Molloy 1995; but see Daniel and Williams 1984; Daniel 1990; Lloyd and McQueen 2000; and Sedgely and Anderson 2000). While New Zealand has made extensive use of predator-free offshore islands in the conservation of indigenous wildlife which has for the most part evolved in the absence of terrestrial predators, Volcanic Plateau short-tailed bats, unlike the northern and southern sub-species, do not occur on any predator-free offshore islands (Gaze 1998).

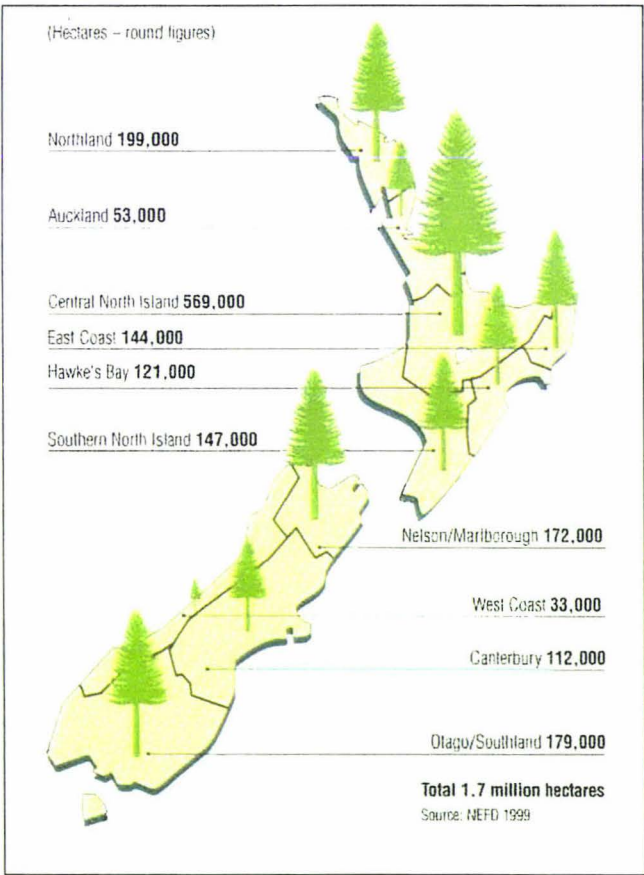
The effects of logging on bats is of particular concern. The decline in range of both species, particularly since the arrival of Europeans (Griffiths 1996; O'Donnell 1997), is correlated with patterns of native forest clearance (Dwyer 1960a, 1960b, 1962). Of 36 long-tailed bat specimens, at least 13% had been killed when roost trees were felled (Daniel and Williams 1984). (However, this proportion may be artificially high compared with other causes of death due to greater chances of observation.) Short-tailed bats also died when a roost tree was toppled during a storm (Daniel and Williams 1984). Further studies investigating roosting

requirements have highlighted the vulnerability of both bat species to logging of indigenous forests (O'Donnell 1999b; O'Donnell and others 1999; O'Donnell and Sedgely 1999; Sedgely and O'Donnell 1999a, 1999b).

4. PLANTATION FORESTRY IN NEW ZEALAND

The main sources for the following summary are New Zealand Forestry (2000) and New Zealand Forest Owners Association (2000a).

Plantation forestry in New Zealand is an important industry accounting for 4% of gross domestic product (GDP) and NZ\$2.75b in annual export earnings, making it New Zealand's third largest export earner. The 1.7 million ha of plantation forest comprises 6% of the country's total land area (in comparison with 24% naturally occurring forest, and 51% pasture and arable land). One third of the national plantation forest estate is located in the central North Island (Figure 1).



**Figure 1** Location and extent of plantation forests in New Zealand. Reproduced from New Zealand Forest Owners Association (2000b) with permission.

Forest owners are mainly registered public (47%) and private companies (44%). Carter Holt Harvey Forests, a public company, is the second largest company in New Zealand and the largest forest owner with approximately 332,000 ha (CHH 2000). Some 40% of this area is

made up of Carter Holt Harvey Forest's central North Island Kinleith Forest, the focus of the present study.

*Pinus radiata* is the dominant species of New Zealand's plantation forestry industry (90.3% of total). Although a native of California, it grows extremely well in New Zealand's temperate climate. Trees reach maturity in 25 to 28 years. Management regimes vary, however, of the national estate in 1999, most trees had been pruned without production thinning.

Radiata pine is extremely versatile. Products include logs, poles, wood chips, sawn timber, chemicals, newsprint, paper, paperboard, fibreboard, plywood, veneer, and particleboard. Several different grade logs may come from a single tree.

## **5. OCCURRENCE OF BATS IN PLANTATION FOREST AND WITHIN THE KINLEITH FOREST AREA**

Long-tailed bats sometimes roost in exotic trees. The first record from a plantation pine forest was in 1976, when part of New Zealand Forest Products' Waikato Block of *Pinus radiata* [now a part of the Kinleith Forest (R Black unreferenced personal communication 1999)], near Lake Arapuni, was clearfelled (Daniel 1981). About 15 bats were observed flying around a felled dead pine. A further five bats were found alive inside a small cavity in the 300 mm tree trunk. Daniel (1981) suggests the typical forest management regime of harvesting trees at a comparatively young age, and thinning out the undesirable malformed and decaying trees before the final crop, means suitable bat roosts are likely to be scarce in plantation pine forests. He hypothesises that the bats probably came from an area of native forest about 3 km across Lake Arapuni to the west, and used the lake and pine forest for foraging. Daniel (1981) concludes "[b]ats may be more common in exotic forests than was previously thought" (p 110), a sentiment later echoed by Garrick (1997). The flexibility of long-tailed bats regarding foraging areas, and their adaptability to foraging in new habitats such as willow copses, is emphasised by Griffiths (1996). Research in the New Forest area in England found "more [bat] activity in the coniferous plantations than in the overgrazed ancient woodlands" (Fawcett 1997, p 4).

Three additional records of bats roosting in plantation pines exist from the central North Island Taupo Volcanic Zone. Two bats were found when a large pine was felled in Tauhara Forest east of Taupo in 1978 (Daniel 1981). These were probably long-tailed bats as this species was known from a nearby reserve (Daniel 1981). More recently, in September 1996, 50–100 long-tailed bats were reported to have emerged from an 86-year-old *Pinus strobus* tree felled at Waiotapu (Garrick 1997). Photos and measurements were taken of seven bats, five females and two males (Garrick 1996a). Logging was halted and monitoring revealed up to 87 passes (bat echolocation calls) per night in the vicinity one week later, and up to 26 passes per night six weeks later (Garrick 1996b, 1997). Subsequent work found bats still present (Owen 1997). In



mid December of the same year, 20 long-tailed bats were seen coming out of a felled 30-year-old *Pinus radiata* by a logging contractor working near Upper Atiamuri in Kinleith Forest (Wilke 1996a; Garrick 1997). A juvenile and a female were recovered (Garrick 1997).

Bats have also been seen flying in Kinleith Forest in a eucalypt block to the west of Tokoroa (R Black unreferenced personal communication 1997).

While short-tailed bats are regarded as deep forest bats (Daniel and Williams 1984) and thought to be largely restricted to indigenous forest (Daniel and Williams 1984; Daniel 1990), it was suggested by B Lloyd (unreferenced personal communication 1996) that short-tailed bats may be using the Karioi pine forest as a corridor between the indigenous forest of southern Ruapehu and the Kaimanawa Ranges. Lloyd (2001) has recorded low numbers of short-tailed bats in a variety of habitats, including pine plantations, close to areas of undamaged old growth forest. Short-tailed bats are remarkably elusive — it took just over six years to discover them in the well researched Eglinton Valley in Fiordland (research described in e.g. O'Donnell 1993, 1999a; Christie 1997) and dedicated effort in the Tararuas (e.g. Foster 1999). Hence, while there is little knowledge of their use of commercial exotic forest, they could well be present!

Long-tailed bats have been reported from the Mokaihaha Ecological Area (Marsh and Blake 1997) and there is a possibility that short-tailed bats are present (Garrick 1997; Griffiths 1999). This 2,136 ha (Marsh and Blake 1997) podocarp broadleaf forest, administered by the Department of Conservation, is located on the Mamaku Plateau to the north-east of Tokoroa and is largely surrounded by Kinleith Forest. Three bats were seen flying in the south-west corner of the reserve, at the boundary between the pine forest and unlogged podocarp broadleaf forest (Marsh and Blake 1997, Wilke 1996b). An initial review of the National Bat Database<sup>4</sup> revealed records of bats at Orakei Korako geothermal park (long-tailed bat, 1995) around 2.3 km from the Kinleith Forest, Mamaku village (short-tailed bat, 1971) about 4.3 km from the Forest, and at Pureora Conservation Park (both species). “Pureora” is close to the southern Pouakani and KK blocks of Kinleith Forest.

Dwyer's (1960a, 1960b, 1962) anecdotal bat records are discussed in Chapter 3.

## 6. INITIATION AND SIGNIFICANCE OF THIS STUDY

Carter Holt Harvey Forests (CHHF) was aware of the bat sightings on the edge of Kinleith Forest (see Marsh and Blake 1997) and identified a need to find out more about the bats so the company would be in a position of knowledge when making management decisions (R Black unreferenced personal communication 1998). They were particularly interested in whether forestry operations may be affecting bats. Strong support for a study of the Kinleith Forest bat

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<sup>4</sup> Located at: Department of Conservation Head Office, PO Box 10-420, Wellington.

population also came from a consultative meeting of interested parties including the local Department of Conservation (September 1997) (R Black unreferenced personal communication 1998). Fieldwork began in early 1998.

Although great strides have been made in New Zealand bat research in the last 10 years, facilitated by technological advance e.g. the advent of ultrasonic bat detectors, minute radio-transmitters, safe bands, portable (harp) traps, and infrared cameras and nightscopes (Tidemann and Woodside 1978; Fenton 1983, 1992; O'Donnell and Sedgely 1994; Molloy 1995; Gillingham 1996; O'Donnell 1996, 2001), at the start of this study, comparatively little was known about New Zealand bats. Few long-term studies had been completed (Higham 1992) and very little was known of the status, stability, limiting factors and ecology of either species (O'Donnell 1994; O'Donnell and Sedgely 1994; Molloy 1995). While emphasis had previously been on short-tailed bat research, in 1997 the conservation status of long-tailed bats was becoming of increasing concern (O'Donnell 1997). Long-tailed bats appeared rare or absent from areas where they were previously widespread, but little information was available from the North Island. Both species have declined in range with forest clearance (Dwyer 1960a, 1960b, 1962) and forest fragmentation, processes which threaten bats worldwide (e.g. Kunz 1982; Fenton 1983, 1992; O'Donnell 1995a).

The present study is significant nationally as it is the first comprehensive study of native bats' use of exotic forest. It will increase knowledge of bat ecology, particularly in modified habitats, and provide a basis from which forest management decisions can be made, and will help meet the Department of Conservation's species recovery objectives 1, 2, 4 and 5 (Molloy 1995). It is significant internationally as there is comparatively little known about forest-dwelling microbats (O'Donnell 1995a; Brigham and Barclay 1996), let alone of the impacts of anthropogenic habitat modification (e.g. Grindal 1996; Hayes and Adam 1996; Lacki 1996).

## **7. OBJECTIVES**

Objectives were threefold:

1. To determine the presence and distribution of bats in the Kinleith Forest
2. To assess bats' use of the forest
  - To investigate bats' use of roads as flyways in different forest types
  - To ascertain habitat preferences and locate important foraging areas
  - To determine home range sizes
  - To locate and describe communal, maternity and solitary roosts
3. To assess the effects of forestry operations on bats.

## 8. THESIS STRUCTURE

This chapter sets the scene of the present study. The next chapter describes the study area. The objectives of this research are then addressed in the following six chapters. Chapter 3 details the presence and distribution of bats in Kinleith Forest and considers the results in terms of our knowledge of bat distribution in the central North Island. Bats' use of forest roads is examined in Chapter 4. Habitat preferences and important foraging areas are considered in Chapters 5 and 6. Chapter 5 examines broad-scale patterns of habitat use within Kinleith Forest, and details investigations into range. Chapter 6 focuses on the value of exotic plantation forest compared to native forest to foraging bats. Roosting ecology is addressed in Chapter 7. Chapter 8 draws on all the results of this study to discuss the effects of forestry practices on bats, with special focus on tree felling operations. The role of long-tailed bats in the forest ecosystem and possible opportunities to maximise the benefits to forestry are also briefly considered. I close with a summary of the main findings and contributions of this study, and presentation of the key recommendations and conclusions.

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# 2

STUDY AREA



# 2

## STUDY AREA

### ABSTRACT

Kinleith Forest is located in the South Waikato, central North Island, New Zealand. Landforms and soils are largely volcanic. The topography varies from flat to steeply dissected hill country. The climate is cool and humid with 1,731 mm mean annual rainfall. Much of the forest was planted on fire-induced scrubland. *Pinus radiata* is the dominant commercial species, followed by *Eucalyptus* spp. and *Pseudotsuga menziesii* (Douglas-fir). At least 10% of the land area is managed as non-production reserve land. Reserves include gullies of podocarp broadleaf forest descending from the Mamaku Plateau. There has been a long and complex history of Māori occupation of the area.

### 1. INTRODUCTION

This chapter briefly describes the physical setting for the present study.

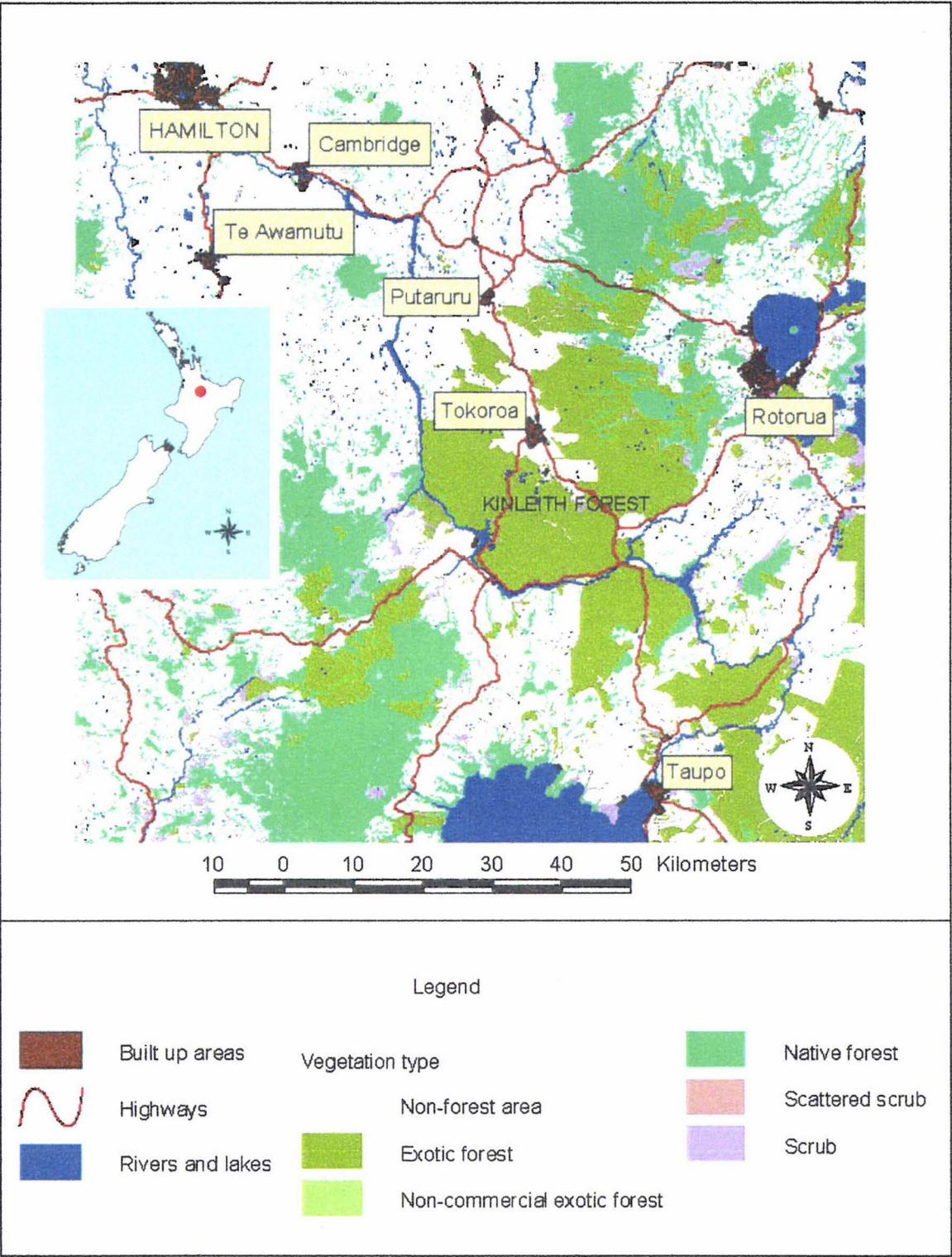
### 2. LOCATION

Carter Holt Harvey Forests' Kinleith Forest (centred around 38°17'S 175°53'E) is a commercial forest of 131,000 ha predominantly in *Pinus radiata*, in the South Waikato, central North Island, New Zealand (Figure 1). The main forest area occurs within the triangle formed by the main urban centres of Taupo, Hamilton and Rotorua. To the north, State Highway 5 on the Mamaku Plateau delineates the boundary with Kaimai Mamaku Forest Park. Much of Kinleith Forest's western side is bordered by the Waikato River. The eastern side backs on to native bush and farmland but lies predominantly to the west of Galaxy and Mamaku South Roads and to the north-west of State Highway 30, before adjoining Lakes Atiamuri and Ohakuri. The Forest stretches as far as Poihipi Road in the south, but discontinuous blocks can be found to the south-west extending down beyond Pureora, and to the west of Lake Taupo.

### 3. GEOLOGY AND SOILS

The following summary, except where referenced otherwise, is based on Molloy (1988). The geological history of the Kinleith Forest area and resulting soils have greatly influenced patterns





**Figure 1** Location of Kinleith Forest

of land use, contributing to the establishment of extensive areas of plantation forestry. Landscape features such as caves and rocky bluffs, influenced by parent material and past geological events, present potential roost sites for native bats.

The landforms of the central North Island are generally of volcanic origin, and the land supporting Kinleith Forest is no exception. Much of the Forest lies in the Taupo Volcanic Zone. The north-western half of Kinleith Forest perches on vast ignimbrite plateaux formed by eruption of molten rhyolite 170,000–750,000 years ago, and the whole Forest area has been influenced by various comparatively recent rhyolitic eruptions of the volcanic centres of Taupo (to the south) and Okataina (north-east). A large Taupo eruption (estimated at around 130 or 186 A.D.) devastated an area of around 20,000 km<sup>2</sup> (Wardle 1991). Nuées ardentes “swept across the landscape as incandescent mud flows, incinerating the forest and flowing into valleys and depressions, filling them to a considerable depth with pumice” (Molloy 1988, p 41).

The Whakamaru hills on the northern side of the Waikato River are part of a chain of extinct volcanoes (Miles 1984). On the southern side, jutting high above the landscape is Pohaturua — the remnant plug of an ancient volcano (Miles 1984). Further along the river, is the active thermal field of Orakei Korako, now largely drowned by the hydroelectric power generation lake of Ohakuri (Miles 1984). North, adjacent to the Matahena Basin forest blocks, and skirted by State Highway 30, is the Horohoro rhyolite dome. At a height of 835 m, it is the highest point of the ignimbrite flows that make up the Mamaku Plateau. Parts of the Mamaku Plateau are characterised by numerous ignimbrite tors and conical mounds, formed by erosion of the jointed surface layer overlying a more resistant fused base.

The main soil-forming surface tephras of the Kinleith Forest area today are the Taupo Pumice (130 or 186 A.D.) and the Kaharoa Ash (deposited 660 years ago). These give rise to weakly weathered, coarse textured and free draining yellow-brown pumice soils that are generally deep, and predisposed to erosion because of their low cohesion. The soils from these tephras are naturally poor in potassium, magnesium, calcium, phosphorus and sulphur, and in some trace elements including copper, cobalt and selenium, initially making them unsuitable for pastoral farming. However, they respond well to fertiliser. The highly vesicular nature means sufficient moisture is available (where soils are deep) to support *Pinus radiata* and other deep rooting plants. To the north there is a small but significant area where the volcanic soils are much older, weathering having produced volcanic yellow-brown (and some red and brown) loams. These contain a greater clay content than the pumice soils but have lower moisture retention, there are no significant trace element deficiencies (though cobalt may be marginal) and populations of soil organisms are high.

The range of specific soils in the Forest area is vast — erosion has redistributed the parent materials and mixed them with non-volcanic material meaning soils vary with topography. Climate and biological factors also influence soil type.

## 4. TOPOGRAPHY

Kinleith Forest lies between around 100 to 800 m asl ranging from flat land through to steep hills, gorges and river terraces. Broadly, the forest comprises four distinct blocks. The north and east are dominated by the high Mamaku Plateau. A multitude of rivers originate on the plateau, descending in steep gorges in a generally easterly or south-easterly direction. Roads typically follow ridges. The forest at the southern end of the Plateau including the Matahana Basin, has a more southerly drainage pattern, rivers joining to meet the Waikato River at or near Lake Atiamuri. To the west, on the other side of Tokoroa, the land is in rolling hills, reflected by the road polygons which are wider and more rounded. The southern area of forest (mainly south of the Waikato River) is characterised by steep round hills, reaching up to 822 m asl. Some roads have a distinctly circular look in this area. In addition, there are several relatively flat areas of forest, mainly located at the forest margins e.g. in a band around Tokoroa, and adjoining the Waikato River. The topography of the area has an important influence on land use patterns and forestry practices (from establishment to harvesting). All of these are likely to influence bat distribution and ecology.

## 5. CLIMATE

The climate is cool and humid (Allen and others 1995; Ogden and others 1997) with mean annual rainfall of 1,731 mm. Rainfall can be very intense at times (Wards 1976) and there is no pronounced dry period (Allen and others 1995).

The mean annual temperature for the forest area (at 12 noon) is 15.1°C, with a mean monthly noon maximum in February of 24.6°C and mean monthly noon minimum in July of 6.5°C. The average minimum temperature of the warmest quarter (Mills and others 1996) at noon is 13.6°C.

The forest experiences calm conditions (winds under 2 knots<sup>1</sup>) for 36.7% of the year. Prevailing winds are westerly (>15% of occasions), with other notable winds coming from the north, south-west and south-east. Winds generally range in intensity between 6 and 12 knots. Clear nights with radiation frosts are common in winter (Ogden and others 1997).

## 6. HISTORIC VEGETATION

The Taupo eruption left remnant beech forest on leeward slopes, but incinerated the forest of exposed areas (Wardle 1991). There followed a succession of bracken, *Haloragis*, grasses, composites, manuka and *Pseudopanax*, which gave way to bog pine, and later *Phyllocladus*. Colonisation was probably rapid on the shallow unconsolidated tephra of the slopes, with slower

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<sup>1</sup> 1 knot = 1.853 km/h.



invasion of the pumice flats by slow-growing podocarps (Wardle 1991). Podocarps were again dominant in the area within 450 years (Wardle 1991) long before human settlement (McGlone 1983).

Burning by Polynesians e.g. to encourage bracken and fernland — a source of food, to keep tracks free for travel, and to keep the land clear around fortifications for defence (McGlone 1983) may have begun within 800 years of the eruption, and by the time of European settlement had induced heath and tussock grassland over most of the pumice plains and depressions, scrub in frosty gullies, and bracken fernland over higher and steeper ground (Wardle 1991).

There resulted a mosaic of vegetation types in the Kinleith Forest area, with tall podocarp forest in the south (e.g. Pouakani, Tauri — south east of Lake Ohakuri, Whakamaru hills), and north to north-east (e.g. Mokaihaha, Te Whetu, Mamaku), large areas of scrubland, and areas of wetlands.

## 7. FOREST ESTABLISHMENT

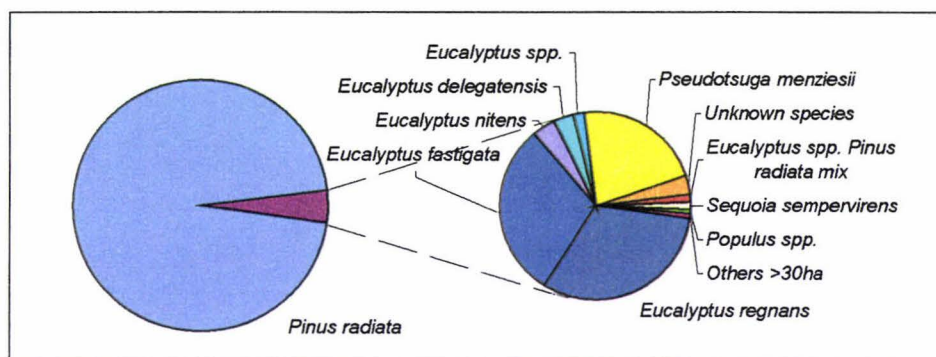
The first tree planting was undertaken in 1924. Kinleith Forest has grown with further planting and a series of land acquisitions. The somewhat piecemeal development has given rise to a forest of varying ages — some areas are in their first rotation (crop), while others, particularly areas central to the pulp and paper mill, are in their third (B Cuff unreferenced personal communication 2000).

## 8. CURRENT VEGETATION

The breakdown of commercial species of Kinleith Forest is shown in Figure 2. The dominant species is *Pinus radiata*, followed by eucalypt species and Douglas-fir (*Pseudotsuga menziesii*). Extensive areas of a single commercial species occur in places, but in older stands [ $\geq 20$  years (Ogden and others 1997)], there is a rich understorey of indigenous species relative to other New Zealand forest types (Allen and others 1995). Common understorey shrubs are *Coprosma robusta*, *Pittosporum tenuifolium*, *Fuchsia excorticata*, *Aristotelia serrata* (Ogden and others 1997). Widely occurring “ground” ferns and fern allies are *Dicksonia squarrosa* seedlings, *Blechnum ‘capense’*, *Paesia scaberula*, *Pteridium esculentum*, *Asplenium polyodon*, *Histiopteris incisa* (Ogden and others 1997). Tree ferns are prominent in older stands, reaching densities of 2000–2500 /ha (Ogden and others 1997). Most common is *Dicksonia squarrosa*, followed by *Dicksonia fibrosa*, *Cyathea dealbata*, *Cyathea medullaris*, and *Cyathea smithii* (Ogden and others 1997).

At least 10% of the Kinleith Forest is managed as (non-production) reserve land (R Black unreferenced personal communications 2001), protected voluntarily under the New Zealand





**Figure 2** Commercial species of Kinleith Forest

Forest Accord (1991) and its complementary Principles for Commercial Plantation Forest Management in New Zealand<sup>2</sup>. Reserves include gorges of podocarp broadleaf tawa forest descending from the Mamaku Plateau. The management of the larger forest reserves, which are generally on Crown Forests land, has recently been transferred to the Department of Conservation (R Black unreferenced personal communications 2001). Smaller areas of riparian scrubland, fernland and wetlands are retained within the Carter Holt Harvey freehold (R Black unreferenced personal communications 2001).

Kinleith Forest is mainly surrounded by pasture, used for dairying (especially in recent years) and sheep and beef. However, there are also some areas of exotic forest and lowland podocarp broadleaf forest sometimes with scrub (Newsome 1987). Adjoining the north-eastern Forest is the 2,136 ha Mokaihaha Ecological Area, a podocarp broadleaf forest with a significant component of unlogged podocarp tawa kamahi forest (Griffiths 1999).

## 9. IWI

There has been a long and complex history of Māori occupation of the wider Waikato area. Iwi include the Tainui subtribe Ngati Raukawa, whom displaced the Ngati Kahupungapunga in the seventeenth century (Grace 1959; Palmer 1964; Miles 1984; Kiwanis Club of Tokoroa Inc in association with Telecom Directories Ltd 1999; Watkin 2001), Te Arawa and Ngati Tuwharetoa (Environment Waikato 1999). Many wāhi tapu (sites sacred to Māori) exist within the area of the present Kinleith Forest. Known archaeological sites are protected (CHHF 1997) and were given due respect during the present study.

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# **3**

**BAT PRESENCE AND DISTRIBUTION IN KINLEITH  
FOREST, AN EXOTIC PLANTATION FOREST IN THE  
CENTRAL NORTH ISLAND, NEW ZEALAND**

"The first step may be finding the bats. . . . Often bats are hard to find because they are relatively small and nocturnal."

— Fenton 1992, p 21.

# 3

## BAT PRESENCE AND DISTRIBUTION IN KINLEITH FOREST, AN EXOTIC PLANTATION FOREST IN THE CENTRAL NORTH ISLAND, NEW ZEALAND

### ABSTRACT

Native bats have been seen in Kinleith Forest, a 131,000 ha predominantly *Pinus radiata* forest in the central North Island. This could have significant implications for forest management. Long-tailed bats, *Chalinolobus tuberculatus* (Vespertilionidae) were confirmed to be present and their distribution was surveyed using bat detectors at fixed sites generally spread over a broad area, and by continuous monitoring for bat calls using driving transects. Sightings were also collected from the public. Evidence for the presence of the more cryptic short-tailed bats, *Mystacina tuberculata* (Mystacinidae) was evaluated from anecdotal accounts of sightings of the bats themselves, and of *Dactylanthus taylorii*, a rare plant they naturally pollinate. Results were considered in light of distribution records reviewed for the central North Island. Long-tailed bats are widespread in Kinleith Forest. In places activity is high. Given the decline in this species elsewhere, it is significant that long-tailed bats are present in some areas from which they were known historically. Long-tailed bats may have a fairly continuous distribution in the central North Island. Results suggest that instead of approaching unsurveyed plantation forests with the expectation that long-tailed bats are absent, long-tailed bats should be assumed present until proven otherwise. The presence of short-tailed bats in Kinleith Forest cannot be ruled out.

### 1. INTRODUCTION

New Zealand's two remaining species of native bats, long-tailed bats (*Chalinolobus tuberculatus*, Vespertilionidae) and short-tailed bats (*Mystacina tuberculata*, Mystacinidae), like one quarter of all known bat species [239 (IUCN 2000a) of 957 (Neuweiler 2000)], are threatened (Molloy 1995; IUCN 2000b, 2000c). Typically tree roosting (O'Donnell 1994; Molloy



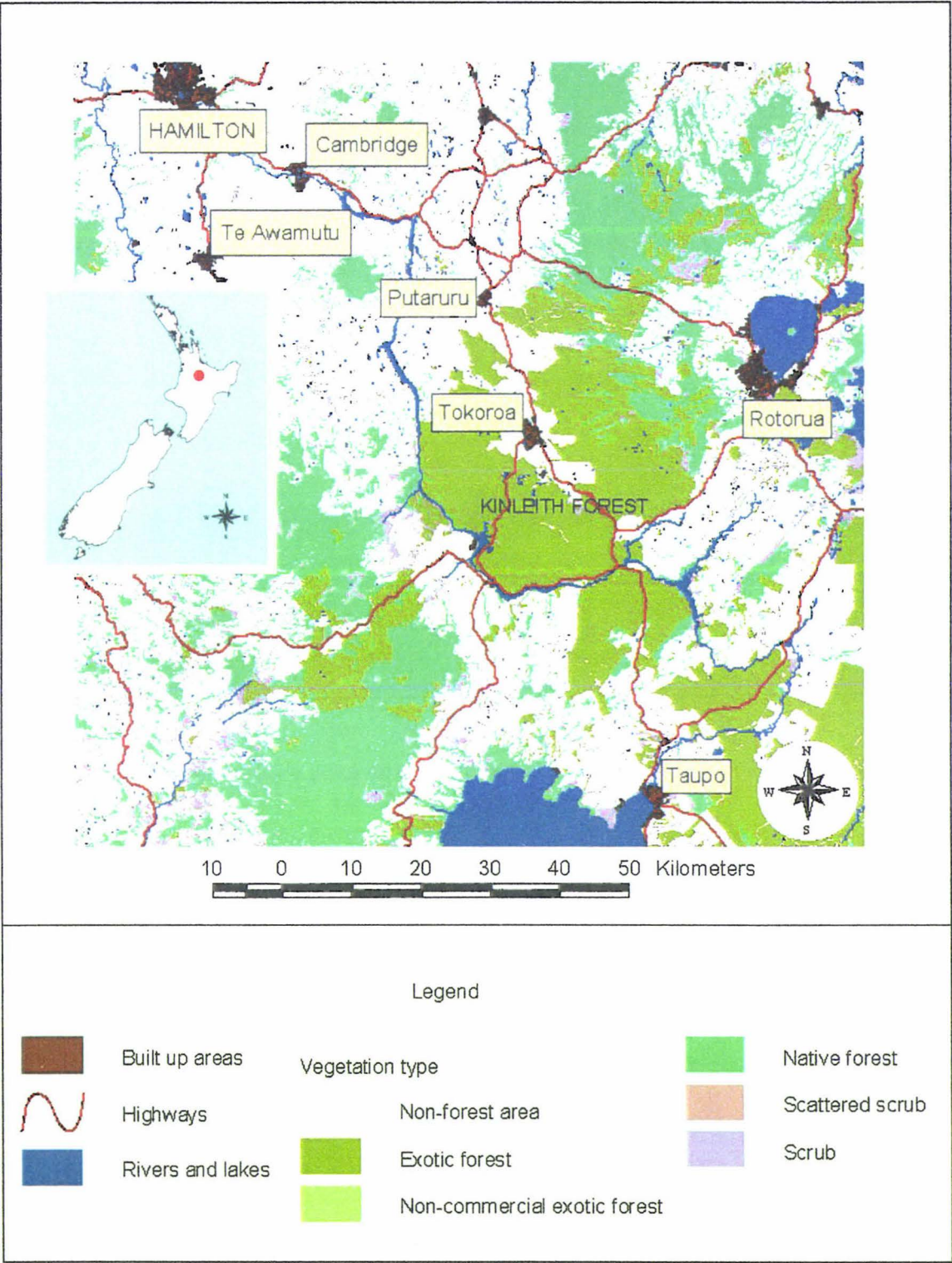
1995), and generally associated with indigenous forest (Dwyer 1960a, 1960b, 1962; Daniel 1990; Higham 1992; O'Donnell 1994; Molloy 1995), sightings in commercial exotic forest are surprising (Daniel 1981). However, both Daniel (1981) and Garrick (1997) acknowledge bats could be more prevalent in exotic forest than previously thought.

Bats are known from the Kinleith Forest area (Marsh and Blake 1997) and have been seen in the exotic plantation Forest itself (Daniel 1981; Wilke 1996; Garrick 1997; R Black unreferenced personal communication 1997) (Chapter 1). The present study investigates the distribution and ecology of native bats in Kinleith Forest and the impacts of forestry operations. This research is significant nationally as it is the first comprehensive study of native bats' use of exotic forest, bat distribution has not previously been investigated at this scale within the South Waikato, and comparatively little bat research has been undertaken in New Zealand in areas outside of the estate of the Department of Conservation (DoC). Internationally, there is comparatively little known about forest-dwelling microbats (O'Donnell 1995; Brigham and Barclay 1996), let alone of the impacts of anthropogenic habitat modification (e.g. Grindal 1996; Hayes and Adam 1996; Lacki 1996).

With only a handful of recent sightings of bats in the Kinleith Forest and surrounding area (Chapter 1), and potential for both species to be present (Chapter 1), the first task was to identify species presence and distribution within Kinleith Forest. Long-tailed bats formed the main focus because this species was more likely to occur in exotic forest (e.g. Daniel 1981, 1990; Daniel and Williams 1984), however, the presence of short-tailed bats was also investigated. The purpose of this chapter is to summarise these investigations and to place results in the central North Island and New Zealand context.

## 2. STUDY AREA

Carter Holt Harvey Forests' Kinleith Forest (centred around 38°17'S 175°53'E) is an exotic plantation forest of 131,000 ha in the South Waikato, central North Island, New Zealand (Figure 1; Chapter 2). *Pinus radiata* is the dominant commercial species, followed by *Eucalyptus* spp. and Douglas-fir (*Pseudotsuga menziesii*). Areas vary from first to third rotation. At least 10% of Kinleith Forest is managed as (non-production) reserve land (R Black unreferenced personal communication 2001). Reserves include gorges of podocarp broadleaf tawa forest descending from the Mamaku Plateau as well as smaller areas of riparian vegetation of scrubland, fernland and wetlands (R Black unreferenced personal communication 2001). Adjoining the north-eastern Forest is the 2,136 ha Mokaihaha Ecological Area, a podocarp broadleaf forest with a significant component of unlogged podocarp-tawa-kamahi forest (Griffiths 1999).



**Figure 1** Location of Kinleith Forest

**3. METHODS**

Fieldwork was undertaken between early 1998 and mid 2000.

### ***Bat presence and distribution in Kinleith Forest***

#### Collection of anecdotal records

A bat sighting form (Appendix 3.1), based on those used by DoC but designed for the commercial forest environment, was distributed to pig hunters in May 1998, and to deer stalkers and pig hunters with their permits in 1999. Bat sightings were also collected from local people including forestry workers, hunters, farmers and DoC staff. An e-mail raising the profile of the bat project and hoping to solicit sightings was also sent out to forestry staff in 1998 (R Black unreferenced personal communication 1998).

#### *Long-tailed bats*

#### Broad-scale ABM survey

##### Bat detection

A broad-scale survey of the forest was undertaken using automatic bat monitoring units (ABMs) which record bat echolocation calls. Developed in 1994 (O'Donnell and Sedgeley 1994), these are now standard equipment in bat monitoring in New Zealand (Lloyd and McQueen 1996b; Douglas 1998), though several designs and models exist. The units used were mainly DoC Science and Research 22, 22b and 22c models each incorporating a Stag Electronics (West Sussex, UK) Batbox III bat detector (a narrow band heterodyne bat detector), voice activated tape recorder (Sony TCM-359V, Sanyo TRC 950C or Sanyo TRC 1196 Japan), talking clock (Voicer Talking Key Chain, Japan), Grasslin timer (Grasslin Controls Corporation, New Jersey, USA), and a 12 v sealed gel lead-acid battery. Some units were also fitted with a rain switch.

The bat detector picks up the ultrasonic echolocation calls of nearby bats [see O'Donnell and Sedgeley (1994) for sensitivity diagram], translating them into audible sound, this triggers the voice-activated tape recorder which records the calls. A time check is recorded from the voice clock every hour from sunset. The timer ensures ABMs turn on just before sunset and off just after sunrise, while the battery powers the ABM for up to five nights at a time. When used, the rainswitch checks for minute vibrations on the ABM's lid, generally indicative of rain. If detected, the switch turns the ABM off until five minutes after the rain stops (Douglas 1997). Each period of disablement is signalled at each end by a tone followed by the voice time.

Bat detectors were set at 40 kHz for long-tailed bats (Parsons 1997). ABMs were generally programmed to come on at least half an hour before mean monthly sunset and off half an hour after mean sunrise, capturing the period of nightly bat activity (G Moore unpublished data) while economising on battery use. Choice of levels for other ABM settings was dictated by the need to optimise ABM performance given each ABM had its own idiosyncrasies. Generally, tape

recorders were set on a volume of 5–7 (Lloyd and McQueen unpublished<sup>1</sup>; Douglas 1996), or low sensitivity (depending upon model), and the volume of bat detectors to medium to low (Douglas 1996). The calibration of each bat detector was checked by observing whether the arrow and 20 kHz mark were flush when the frequency dial was turned backwards as far as it could go (M Douglas unreferenced personal communication 1998) or with a 40 kHz generator (when available).

#### Survey method

The survey was undertaken between April 1998 and late January 1999. To achieve broad-scale forest coverage, I initially aimed to site one ABM on land shown on each of the twenty 1:60,000 forest road atlas pages. However, this proved logistically impossible (many roads were inaccessible), and so a more haphazard method was adopted. Forest coverage achieved over the 121,196 ha main area (B Cuff unreferenced personal communication 1999) of Kinleith Forest is shown in Figure 2.

Survey sites were biased towards those that looked like good bat sites (O'Donnell unpublished a<sup>2</sup>). All but one were forest edge sites (Daniel and Williams 1984; Molloy 1995) — mainly roadsides, (O'Donnell unpublished a, 1994, 1997c; O'Donnell and Sedgeley 1994; Griffiths 1996), and often road junctions for ease of relocation. Seventy two percent of (18) sites were in pines over 15 years old. Half had a mapped stream or wetland in at least one of the adjoining blocks, two sites directly faced wetlands. Areas of visible or imminent forestry operations (e.g. roading, spraying, harvesting) were avoided. Several locations where there was anecdotal evidence of past bat presence were chosen (e.g. Wiltsdown, Johnstone-Wainui, Star Rd–Mokaihaha area) as well as some areas of particular interest to CHHF (e.g. the Redwood Reserve on Galaxy Rd — one of the oldest blocks in the forest).

ABMs were generally positioned facing clearings (such as roads or road junctions) at 1 m above general ground level (O'Donnell and Sedgeley 1994; Lloyd and McQueen unpublished), e.g. on banks and angled slightly upwards (Lloyd and McQueen unpublished). They were disguised with materials to hand and often hidden behind vegetation in an attempt to minimise theft.

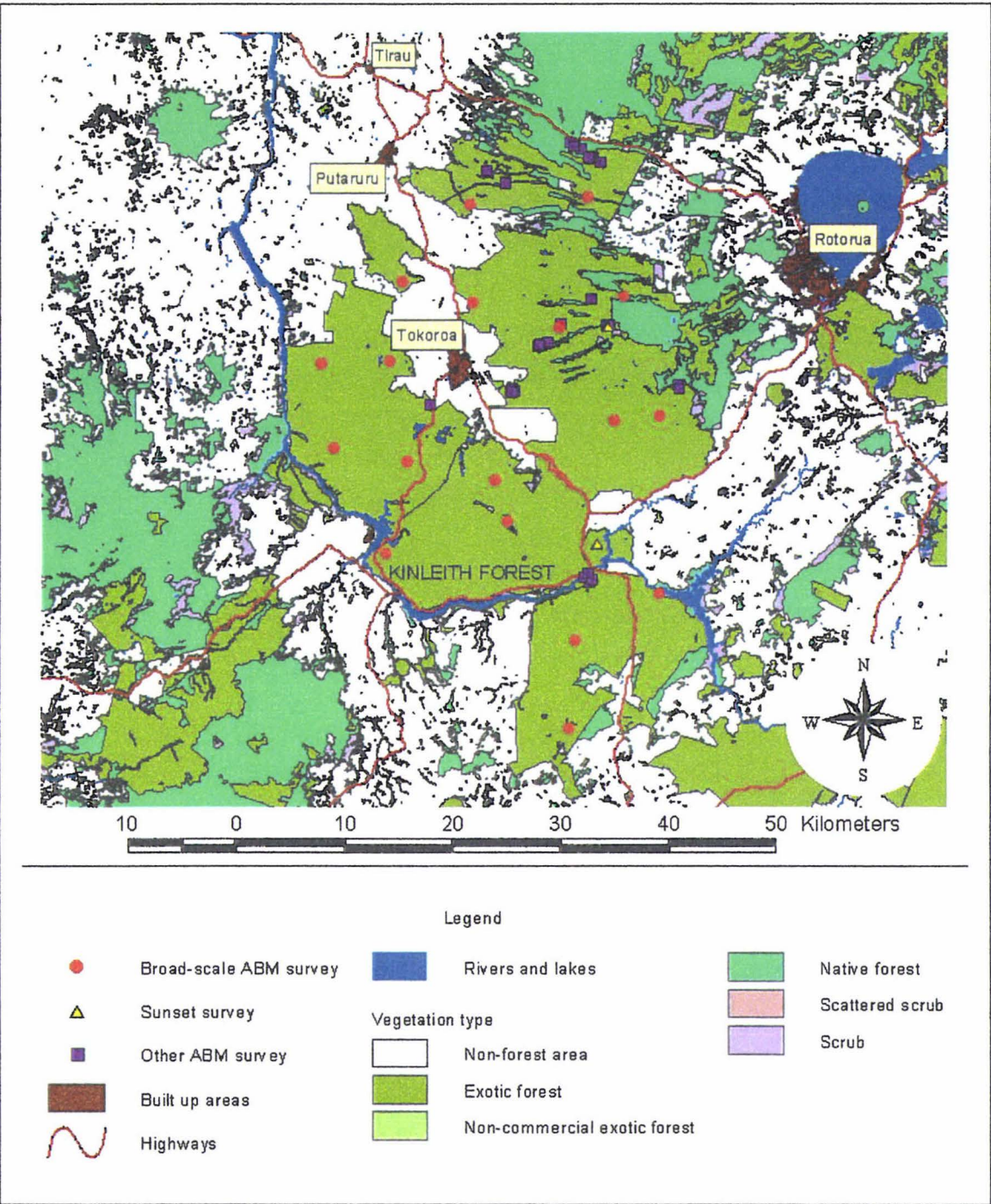
ABMs were serviced where possible once every four days and after rain. The noise of rain is readily detected by bat detectors and may rapidly fill up cassette tapes leaving no room for collection of more data. Additionally, ABMs are not very waterproof, and their components are

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<sup>1</sup> Lloyd B, McQueen S. Instructions for field use of automatic bat monitors. [Handout at the Second New Zealand Bat Conference, Ohakune, New Zealand, 28–29 March 1998]. 3 p.

<sup>2</sup> O'Donnell C. A Department of Conservation bat record scheme draft proposal. 8 p. Available from: Colin O'Donnell, Department of Conservation, Private Bag, Christchurch, New Zealand.





**Figure 2** Location of bat survey sites in Kinleith Forest

easily damaged by water. During servicing, cassette tapes were changed or turned over, batteries replaced, and the inner workings and settings checked.

The amount of time each location was surveyed varied due to a number of factors including season, weather, ABM reliability, researcher's skill in setting them up, any delay in analysing tapes and level of other work commitments. Where bats were detected quickly, ABMs were moved on to survey new sites. However, two sites (Star Rd and Redwood Reserve) were

monitored on a long-term basis (at least 19 months) to provide a picture of bat activity throughout the year.

#### Data analysis

Tapes were transcribed and the number of bat passes per hour of real time sampled was tallied, identifying bat presence or absence (during the time monitored), and giving an indication of the relative level of bat activity. A bat pass is "a set of two or more echolocation calls as a single bat [flies] past the microphone" (O'Donnell unpublished a, p 5).

#### Other ABM survey work

Further sites were surveyed to identify areas with potential for trapping bats for radio-telemetry (Chapter 5, 7) and areas suitable for examining bat behaviour more systematically — e.g. investigating their use of roads, and use of native versus exotic forest (Chapter 4, 6). An additional two areas of particular interest to CHHF, J904273 Rd (off Waihou Rd), an area of natural springs and potential public reserve site, and Pohaturoa, an area significant to local iwi still in old crop trees (radiata planted 1927) and coming up for harvesting, were also surveyed for bats. Altogether 12 disparate sites were surveyed (Figure 2). Survey effort varied between sites as required. For example, in part to counteract the effects of surveying at a less than optimum time (winter) Pohaturoa was surrounded by four ABMs, whereas only one was used on Rewarewa Rd (in spring).

#### Sunset surveys

Two areas (Figure 2) where it was undesirable to survey with ABMs e.g. because of high public use, or where a quick result was required, were surveyed at sunset for bats. Researchers watched for bats and listened for them with Batbox III bat detectors (already described) set on 40 kHz for long-tailed bats (Parsons 1997) from around sunset for at least an hour where bats were reasonably active, longer if there was little or no activity.

#### Driving transects

Driving transects were also undertaken to clarify bat distribution in Kinleith Forest. Used in Australia (e.g. de Oliveira 1998; Conole and Baverstock 1997) and Europe (Ahlén 1980–81; Haffner and Stutz 1985; Jüdes 1989; de Jong and Ahlén 1991; Rydell 1992), this method was practically unknown in New Zealand although a few researchers had tried it (e.g. Griffiths 1996). Driving transects seemed an ideal rapid-survey method given the large area of forest. The method was also considered safer than the more widely used and labour intensive walking transects (O'Donnell 1993, O'Donnell unpublished a; O'Donnell and Sedgeley 1994; Griffiths



1996; and currently being developed further by O'Donnell, unpublished b<sup>3</sup>) in the commercial forestry environment where logging trucks operate around the clock and there is a significant level of unauthorised public access.

### Equipment set-up

A Batbox III bat detector was affixed pointing skywards on each wing-mirror of the vehicle just below the upper lip of the mirror to minimise wind noise. These were set at 40 kHz (Parsons 1997). Used with earphones, or earphone-speakers combination, the output volume was set high enough so that a bat pass (simulated by rubbing one's fingers together above the sensor) would be clearly heard over the vehicle and road noise. A digital thermometer attached to the outside of the vehicle allowed ambient temperature to be monitored throughout the transect. The trip meter was zeroed at the start of the transect.

### Routes and reconnaissance

Routes (Figure 3) of around 50 km (Jüdes 1989), and usually loops, were chosen from the forest road map, and generally driven once during the day to check road condition and note major landmarks before night-time transects were begun. Further daytime reconnaissance was carried out to record the distance between road junctions and other features so that the researchers could better pinpoint their location in the dark.

### Doing the transect

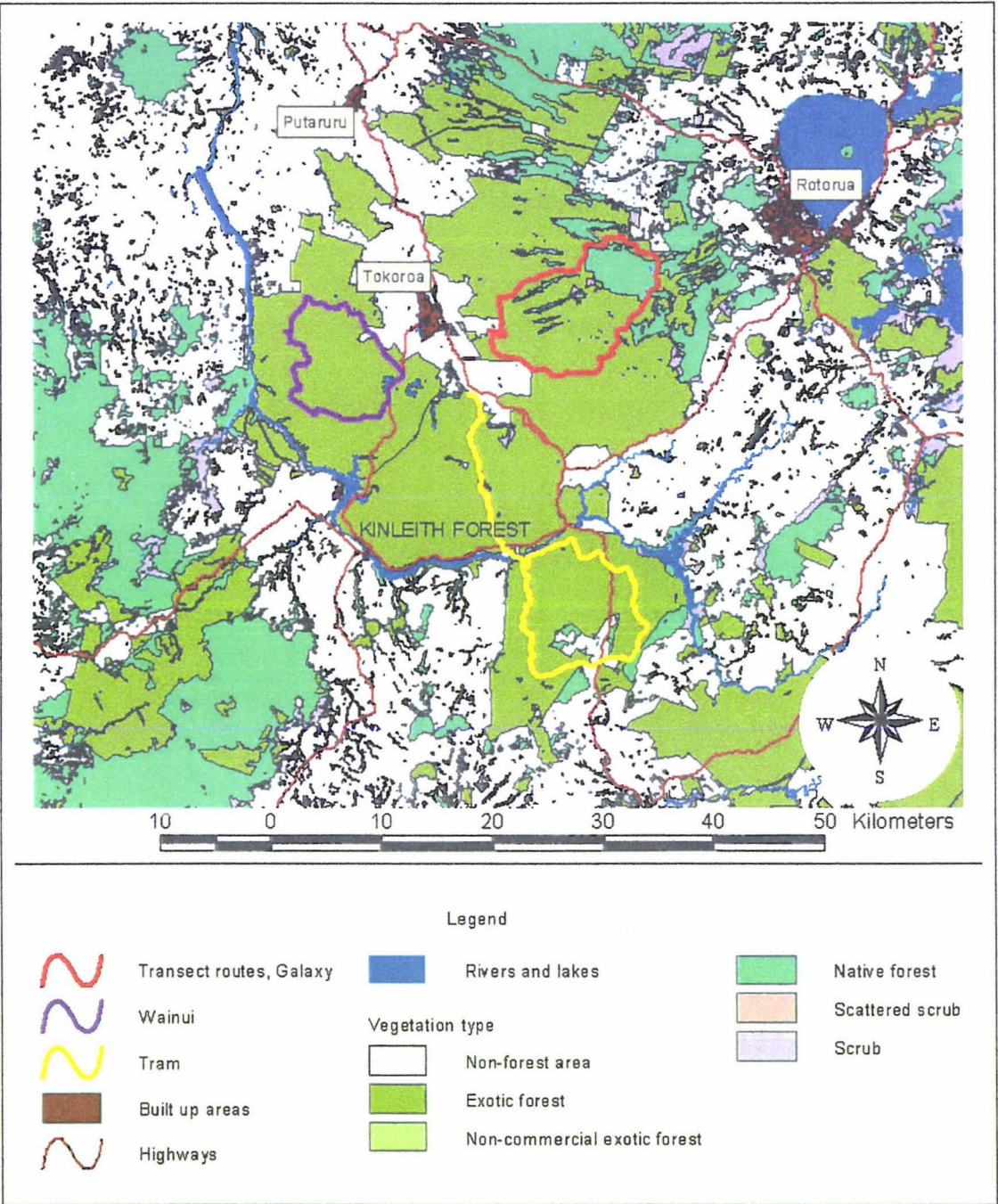
Driving transects were carried out at 30 km/h where possible. This speed is not too dissimilar to Jüdes' (1989) 20–25 km/h and was considered slow enough to detect bats flying perpendicular to the road — long-tailed bats have been clocked flying at about 60 km/h (WWF 1997).

Transects were started on average 1 h 8 min after sunset (range: 44 min before to 2 h 27 min after) aiming to coincide with peak bat activity (e.g. O'Donnell and Sedgeley 1994; Griffiths 1996; G Moore unpublished data) and took between 1 h 28 min and 3 h 12 min to complete. Details of weather and ambient temperature (O'Donnell unpublished a; O'Donnell and Sedgeley 1994), as well as moon presence (Arkins 1996), were recorded at the start of the transect, and generally every 5 km thereafter and if any significant change occurred. Transects were abandoned if there was persistent rain. An assistant helped to record data and listen for bats.

When a bat pass was heard, a brief stop was made to record the trip meter reading, temperature, weather conditions, observations of the spot so it could be found again in daylight,

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<sup>3</sup> O'Donnell C. Draft guidelines for surveying long-tailed bats and monitoring their populations using standardised 1-km transect counts. 11 p. Available from: C O'Donnell, Science and Research Unit, Department of Conservation, Private Bag, Christchurch, New Zealand.



**Figure 3** Driving transect routes, Kinleith Forest

and any details of the bat pass(es). Where a bat pass was questionable, a conservative approach was taken.

Site mapping and description

Bat sites were relocated during the daytime and their location mapped. Habitat features were also noted. The accuracy with which sites were relocated was estimated to be  $\pm 1\text{--}100\text{ m}$ .



Survey effort

While I initially planned to survey in all the 10 major sectors of the main forest area, various factors meant that only three routes, Galaxy–Mamaku South (“Galaxy”), Tram and Wainui–Jack Henry (“Wainui”) (Figure 3) were driven. However, the results combined with those of the ABM survey, provided a good indication of bat distribution.

Survey effort is shown in Table 1. The Galaxy transect received the most effort as I used this route in the initial evaluation and refinement of the method. The Tram transect was optimistically undertaken in the middle of winter (when the bats are likely to be in “semi”-hibernation). This transect was shortened on a couple of occasions as it was too long to comfortably do after a full day’s surveying work, and forestry operations left one road impassable. The Galaxy route, characterised by large areas of indigenous forest, was later driven on alternate nights with Wainui, an area with little native forest, in an effort to compare bat distribution in these contrasting forest areas (Chapter 5).

**Table 1** Driving transect survey effort

Date	Transect	Direction	Distance (km)	Duration (h:min)
22/04/1998	Galaxy	Clockwise	54.5	≈2:58
23/04/1998	Galaxy	Anticlockwise	54.5	3:12
24/04/1998	Galaxy	Clockwise	54.5	≈2:45
04/06/1998	Tram	South	40.7	≈1:40
05/06/1998	Tram	South	69.0	≈2:27
06/06/1998	Tram	South	66.0	2:30
08/06/1998	Tram	South	40.7	1:28
11/02/1999	Wainui	Clockwise	44.2	2:58
12/02/1999	Galaxy	Clockwise	52.4	2:28
18/02/1999	Galaxy	Clockwise	52.4	2:28
19/02/1999	Wainui	Clockwise	44.2	2:00
12/04/1999	Galaxy	Anticlockwise	49.9	2:19
13/04/1999	Wainui	Anticlockwise	43.0	1:57

Tunnel inspection

In an effort to find bat roosts and/or potential bat trapping areas (Chapter 7), old tram tunnels were identified from maps and with the help of locals. Two tunnels, the western-most tunnel on Tunnel Rd, and that between Mackney and Lower Crimp Rds, were located and checked for signs of bats. A further tunnel was known to be inaccessible by vehicle, and a fourth was given low priority for searching given the time it would have taken to find in the rough terrain.

Opportunistic survey work

During the course of this study, the opportunity was also taken to listen for long-tailed bats when primarily engaged in other work. Bat detectors were set at 40 kHz (Parsons 1997).

### *Short-tailed bats*

Short-tailed bats were less likely to be present in the Kinleith Forest than long-tailed bats (e.g. Daniel 1981, 1990; Daniel and Williams 1984) and so investigations focussed on identifying and evaluating evidence for their presence rather than potentially unproductive and time-intensive field surveys. As mentioned in Chapter 1, short-tailed bats can be remarkably elusive!

Anecdotal bat sightings were collected as detailed earlier, so too were sightings of *Dactylanthus taylorii*, a threatened and largely cryptic native parasitic flowering plant, naturally pollinated by short-tailed bats (e.g. Ecroyd 1993; Holzapfel and others 2000). Monitoring of *Dactylanthus* sites has previously revealed new short-tailed bat populations (e.g. Ecroyd 1994).

Some fieldwork with paired ABMs, bat detectors set at 28 kHz for short-tailed bats (Parsons 1997) and 40 kHz for long-tailed bats (Parsons 1997), was undertaken at one site which overlooked a steep gorge of podocarp broadleaf forest. Additionally, some of the initial driving transects (described previously) were undertaken with at least one bat detector at 28 kHz (Table 2). However, surveying for short-tailed bats in this manner was discontinued because they are more commonly associated with the forest interior (Daniel and Williams 1984; O'Donnell and others 1998) than forest edges, and at 28 kHz, bat detectors pick up a lot of vehicle noise.

**Table 2** Driving transect survey effort

Date	Transect	Direction	Distance (km)	Duration (hr:min)
23/04/1998	Galaxy	Anticlockwise	54.5	3:12
24/04/1998	Galaxy	Clockwise	54.5	2:09
06/06/1998	Tram	South	66.0	2:30

As the calls of long- and short-tailed bats overlap in frequency (e.g. Parsons 1995, 1997; Lloyd and Whiteford 1998; O'Donnell and others 1998), all recordings made during the present study were critically analysed for calls other than those of long-tailed bats and expert advice was sought. Most field research concentrated at edge sites, but several forest interior sites were surveyed, including three in indigenous podocarp broadleaf forest. No kauri forest and little or no beech forest (Newsome 1987; R Black unreferenced personal communication 2001), used by short-tailed bats elsewhere (e.g. Daniel 1979, 1990; Lloyd and McQueen 1995, 1996a, 1998b; Christie and others 1998; O'Donnell and others 1999), is present within Kinleith Forest.

### *Reliability checking*

For all field methods, the reliability with which bat passes were identified was checked. Reliability was assessed from a range of recordings by an independent assistant after a period of training. Tapes encompassing most of the models of ABMs used in combination with various results e.g. tapes with little bat activity, bat calls interspersed with extraneous environmental noise and tapes with considerable bat activity. Reliability was calculated focussing on whether

results e.g. tapes with little bat activity, bat calls interspersed with extraneous environmental noise and tapes with considerable bat activity. Reliability was calculated focussing on whether there was agreement in the number of bat passes for each hour sampled by the ABM using the formula:  $\text{Reliability} = \text{Agreements} / (\text{Agreements} + \text{Disagreements})$ . Reliability was checked in the field during driving transects and sunset surveys with the aid of a trained assistant.

### ***Putting the Kinleith results in context***

Bat sightings for both species in the central North Island were reviewed from published and unpublished literature including DoC reports, databases (Sites of Special Wildlife Interest<sup>4</sup> and the National Bat Database<sup>5</sup>) and species files<sup>6</sup>, and the Bat Recovery Group Meeting Minutes (1997–2000 inclusive<sup>7</sup>).

### ***Data analysis***

#### ***Making a database***

A dBASE IV database was made of all mappable bat sites allowing the construction and mapping of specific queries using ArcView (version 3.2, Environmental Systems Research Institute Inc, USA).

#### **Entering the Kinleith data**

Anecdotal records where grid references were provided or where people pinpointed the location in their description were included in the database. Generally, there was not enough information to be able to classify the particular bat species seen, and so "species unknown" was coded. Grid references were obtained for the areas I surveyed by using point queries of the forest geographic information system (GIS) generally at a scale of around 1:10,000, use of a global positioning system (GPS) in the field, or for a couple of sites, consultation of topographic maps. Where I had surveyed a site more than once, generally the earliest survey date was recorded as the bat sighting date. Multiple records for the same individual site were not entered.

One driving transect record where the bat was detected at 28 kHz was coded as "species unknown".

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<sup>4</sup> Located at: Department of Conservation, Head Office, 59 Boulcott St, Wellington, New Zealand.

<sup>5</sup> Electronic version available from: John Lyall, Department of Conservation, Private Bag 701, Hokitika, New Zealand.

<sup>6</sup> Located at: Bay of Plenty Conservancy, Department of Conservation, 1166 Amohau St, Rotorua, New Zealand.

<sup>7</sup> Unpublished documents, 1997–1999 available from: Colin O'Donnell, Recovery Group Leader, Science and Research, Department of Conservation, Private Bag, Christchurch, New Zealand; 2000 available from: John Lyall, Recovery Group Leader, Department of Conservation, Private Bag 701, Hokitika, New Zealand.



### Entering data from the literature and threatened species files

For these sources, the independence of sightings at the same location was difficult to judge, and so where multiple records existed, all were included in the database. When reviewing records from the Bat Recovery Group Meeting Minutes, some appeared to be duplicated. All those of the same year, grid reference and general location description were treated as the same and only entered into my database once. Where different species classifications were given in record duplicates, a conservative approach was taken i.e. records specifying unknown species were kept over those stating a specific bat species. It was assumed for all other records that bat species had been correctly identified. Where two dates were given for a sighting e.g. '97/'98, the earliest date was chosen.

Sightings from the threatened species files were checked against records in the National Bat Database. Only those that were not represented in the National Bat Database were included.

Eastings and northings were each commonly given in a three figure format. These were changed to the required seven figure format for mapping by appending the correct two figure prefix (obtained from the relevant topographical maps), and adding two zeros to the end of each reference.

### Entering data from the National Bat Database

Data from the National Bat Database was also arranged in the database for mapping. Data from the following Conservancies was included to put the Kinleith bat sightings in context: Waikato, Bay of Plenty, Tongariro–Taupo, East Coast, Hawke's Bay, Wanganui. Given the Database is known to contain mistakes (O'Donnell 2000a) it was checked for duplication of records and questionable species designations. A list of revisions made to the data before mapping is given in Appendix 3.2. O'Donnell's (2000a) amended data set was not available at the time of analysis, nor were the criteria he used to check entries (C O'Donnell unreferenced personal communication 2001).

While long-tailed bats typically seem to use edge habitats and fly in the open, fly fairly high, emerge around dusk, and do not have audible calls, and short-tailed bats hunt in the forest interior, fly lower, emerge after dark, and have some audible calls, these generalisations were not regarded as rigorous enough to base judgement of the accuracy of species classifications from the sighting descriptions in the National Bat Database. For example, one record states "[f]ound 200+ bats roosting 50 ft up in a limestone cave. Bats started to squeak and fly around, resettled" (Card 106413). If using the above generalisations, one might be tempted to call these bats short-tailed bats. However, the bats were actually observed at Grand Canyon Cave, a known long-tailed bat "strong-hold" (e.g. O'Donnell 2001a). Hence, the only alterations made to species classifications was in the direction of more conservatism — some records (Appendix



3.2) in which bat species was stated were changed to “species unknown”. Most records however, did not contain enough information for the accuracy of species designation to be judged and were left unaltered.

Grid references were already in the required seven figure format, but were probably only accurate to the nearest hundred metres.

Breakdown of source contributions

The selection of data for inclusion into any database is likely to introduce some bias into the results. To this end, a breakdown of the proportion of bat sites contributed from data sources other than that of my own is provided in Table 3.

**Table 3** The contributions of central North Island bat site data from the literature, species files and National Bat Database. These gave a total of 382 sites while the present study contributed 90 sites.

Data source	Contribution of bat sites to total (472) (n %)	
• National Bat Database: Waikato, Bay of Plenty, East Coast, Wanganui, Tongariro–Taupo and Hawke’s Bay Conservancies	274	58.1%
• Selected threatened species files from DoC Bay of Plenty	57	12.1%
• Bat Recovery Group Meeting Minutes 1997–2000 inclusive		
• Borkin 1999	51	10.8%
• Griffiths 1999		
• Marsh and Blake 1997		
• Moorcroft and others 2000a		
• Moorcroft and others 2000b		
• Wildland Consultants Ltd 1997		

*Querying and mapping the data*

The database was queried e.g. by bat species, bat sighting date, data source/method used, and various combinations of these, and results mapped using ArcView (version 3.2, Environmental Systems Research Institute Inc, USA). Suspicious looking points in an early draft were checked, and two records deleted from the base data set because the grid references had clearly been misreported (a Rotoehu Forest site ended up off the coast of Bay of Plenty, and a Pureora Forest site ended up in Kinleith Forest). Maps of bat distribution were produced using background data from Terralink (New Zealand).

***Evaluation of driving transects***

As driving transects are relatively novel in New Zealand, the method’s effectiveness in finding new bat sites was compared with the more widely used ABM-based survey method using basic modelling. I listed the key parameters e.g. number of ABMs used simultaneously, length of driving transect route, and all the steps involved in carrying out each of the two survey methods.

Values given to the starting parameters were based on actual data, except for average speed of travel for putting out ABMs which was estimated at 50 km/h (roads ranged from State Highways to unsealed forestry roads). The number of new bat sites found per transect was calculated as 2.3, the average from 10 transects undertaken in April and February. The number of new bat sites found using ABMs was calculated at 100% minus the failure rate due to malfunction or human error (calculated from work described in Chapters 4 and 6), but not the weather. Although the overall success rate in basic survey work using ABMs was 96% ( $n = 27$  sites), success early on was lower due to the many technical problems encountered, and so the calculation used is thought to be fair. The time taken to perform each step was estimated based on my average experience during the course of the study, though driving transect durations were averaged to arrive at the figure of 2.5 hours, and tape transcription was estimated at 45 minutes per tape.

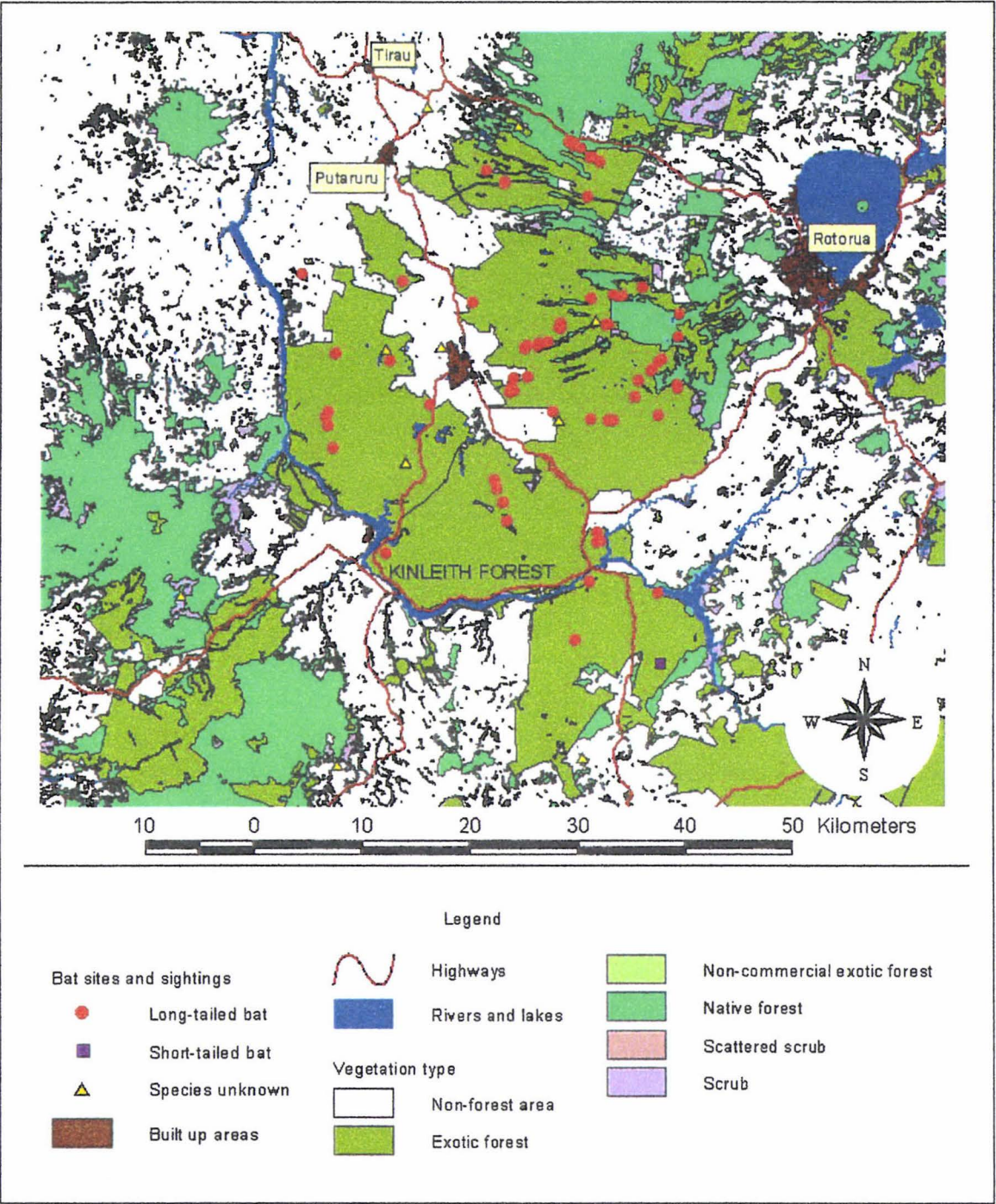
## 4. RESULTS

### *Bat presence and distribution in Kinleith Forest*

Bat distribution in Kinleith Forest, as identified from fieldwork and through the collection of anecdotal records, is shown in Figure 4. The presence of long-tailed bats was confirmed visually (by author and S Pilkington, lecturer, International Pacific College, Palmerston North), and long-tailed bats were detected at the places shown in red (circles). Of the 15 broad-scale survey sites successfully surveyed (i.e. either bats were recorded, or at least eight complete night's data was obtained from ABMs with no known nor suspected problems), there was only one site where long-tailed bats were not clearly recorded. Other ABM survey work identified long-tailed bats as being present at a further 12 (of 12) disparate sites. Repeated driving transects identified 19 bat sites along the Galaxy loop, two on Tram, and four on the Wainui route. Some bat sites identified with driving transects were right next to those found with ABMs. Bats were found at two of two locations using sunset surveys, and in four areas from opportunistically listening for bats. The habitats in which bats were found are discussed in Chapter 5.

Eleven anecdotal accounts of bats in the Forest area provided sufficient detail for the sites to be mapped. Records in which a date was given are mainly from the mid 1990s. Largely, the species seen was unable to be determined (Figure 4: yellow triangles). However, discussion of the earliest sighting, from east of Maroa around 1968, revealed it was most probably of short-tailed bats (B Snowsill unreferenced personal communication 2000). Several bats were found when a native tree was felled. In the late 1960s, the area was in thick native forest which contained some remarkably large trees (B Snowsill unreferenced personal communication 2000). Bats have also been seen in the forest at Cashmore's Rd\* (about 1997), Deer Rd (about 1987), Glass Rd\* (1999), Gorilla Rd\*, Jupiter Rd, the old State Highway, Paheke Rd (around 1994), Pouakani South Block (potentially several different records, including one May/June





**Figure 4** Bat sites and sightings in the Kinleith Forest area

1997), Sutcliffe Rd\*, Wolf Rd\* (around 1994), Mamaku South Rd\* (1968–early 1970s, 1984–5), and Sneddon Block\*. (Asterisked sites are close to bat sites identified by fieldwork).

Of the two tunnels inspected, one tunnel was very wet, and flooded at one end, it is not thought to be used by bats. In the other no bats were seen although bats were active in the area (G Moore unpublished data), but bat-like droppings were found. However, these may have been from cave weta (*Rhaphidophoridae*) (present in the tunnel) or mice (*Mus musculus*). Regrettably no droppings were collected for analysis.



### *Long-tailed bat activity*

Bat activity varied enormously between nights and sites. However, in places activity was high with  $\geq 60$  passes/hour or  $\geq 100$  passes/night (see also Chapter 5, 7). At Star Rd there was an average pass rate of 46.0 passes/night ( $n = 189$  ABM-nights — summer: 55, autumn: 35, winter: 46, spring: 53). Star Rd is located in a narrow tongue of pine forest between the native forest clad valleys of the Takapuhurihuri and Onukutauira Streams, and runs along part of the northern border of the Mokaihaha Ecological Area. The ABM was located at the junctions of Star and Galaxy Rds, opposite the steep valley of the Takapuhurihuri Stream, but surrounded on other sides by 19 and 21-year-old pine forest.

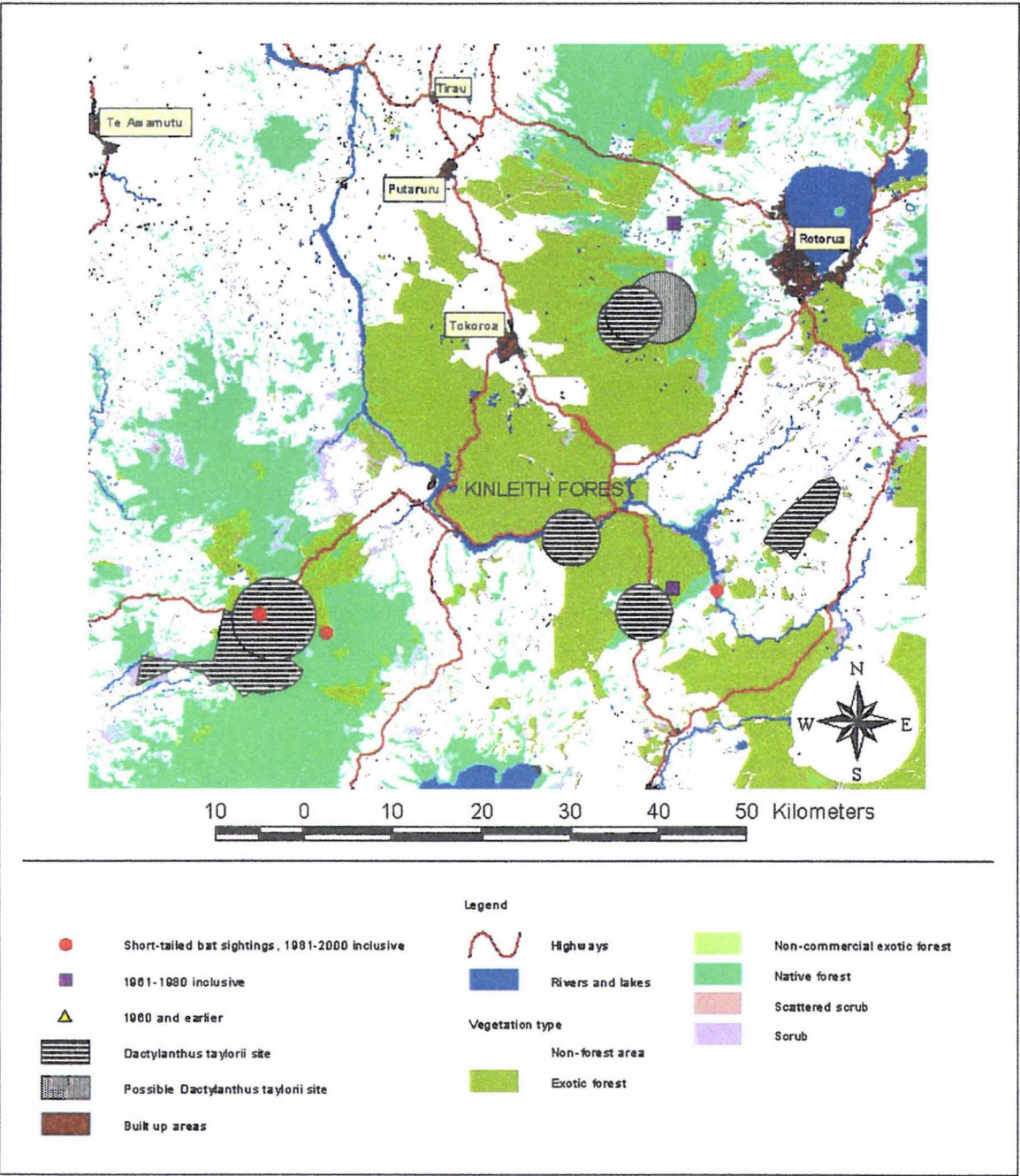
### *Presence of short-tailed bats*

Short-tailed bat and *Dactylanthus* sightings in the broader Kinleith Forest area are shown in Figure 5. Short-tailed bats are present at Pureora Conservation Park to the south-east of Kinleith Forest (National Bat Database; Higham 1992; Hunt 1992; Ecroyd 1993; Molloy 1995), and there are two records from the southern Forest area — one from Rautapu Cave at Orakei Korako in 1991 (Scrimgeour 1991), and one (around 1968) from east of Maroa, now part of Kinleith Forest (described previously). In the north, a short-tailed bat was found in a house in Mamaku village in 1971 (National Bat Database; Daniel and Williams 1984). Short-tailed bats have also been very recently discovered<sup>8</sup> near Kinleith Forest in Kaimai Mamaku Forest Park between State Highway 5 (between Rotorua and Tirau, Figure 5) and State Highway 29 to the north (Figure 1).

*Dactylanthus taylorii* occurs in Pureora Conservation Park (e.g. Higham 1992; Hunt 1992; Ecroyd 1993), and has been reported from Kinleith Forest's south-eastern KK Block (B Atkinson unreferenced personal communication 2000). It has also been seen near Maroa near the southern part of the forest (B Snowsill unreferenced personal communication 2000), in an area along the Waikato River (J Dodgson unreferenced personal communication 2001), and in the Paeroa Range (B Atkinson unreferenced personal communication 2000; J Dodgson unreferenced personal communication 2001). It is known from a forestry road in the north-east of Kinleith Forest (B Middleton unreferenced personal communication 1999; J Dodgson unreferenced personal communication 2000) and one (J Dodgson unreferenced personal communication 2000; M Wilke unreferenced personal communication 2000), maybe two (R Griffiths unreferenced personal communication 2000; M Wilke unreferenced personal communication 2000) nearby areas. [See also Ecroyd's (1993) distribution map]. However, various work in the north-east has so far failed to confirm the presence of short-tailed bats (Ecroyd 1993; Marsh and Blake 1997; Griffiths 1999). [Locations though known, have been

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<sup>8</sup> Subsequent to drafting Figure 5.



**Figure 5** Short-tailed bat (*Mystacina tuberculata*) and *Dactylanthus taylorii* sightings in the Kinleith Forest area

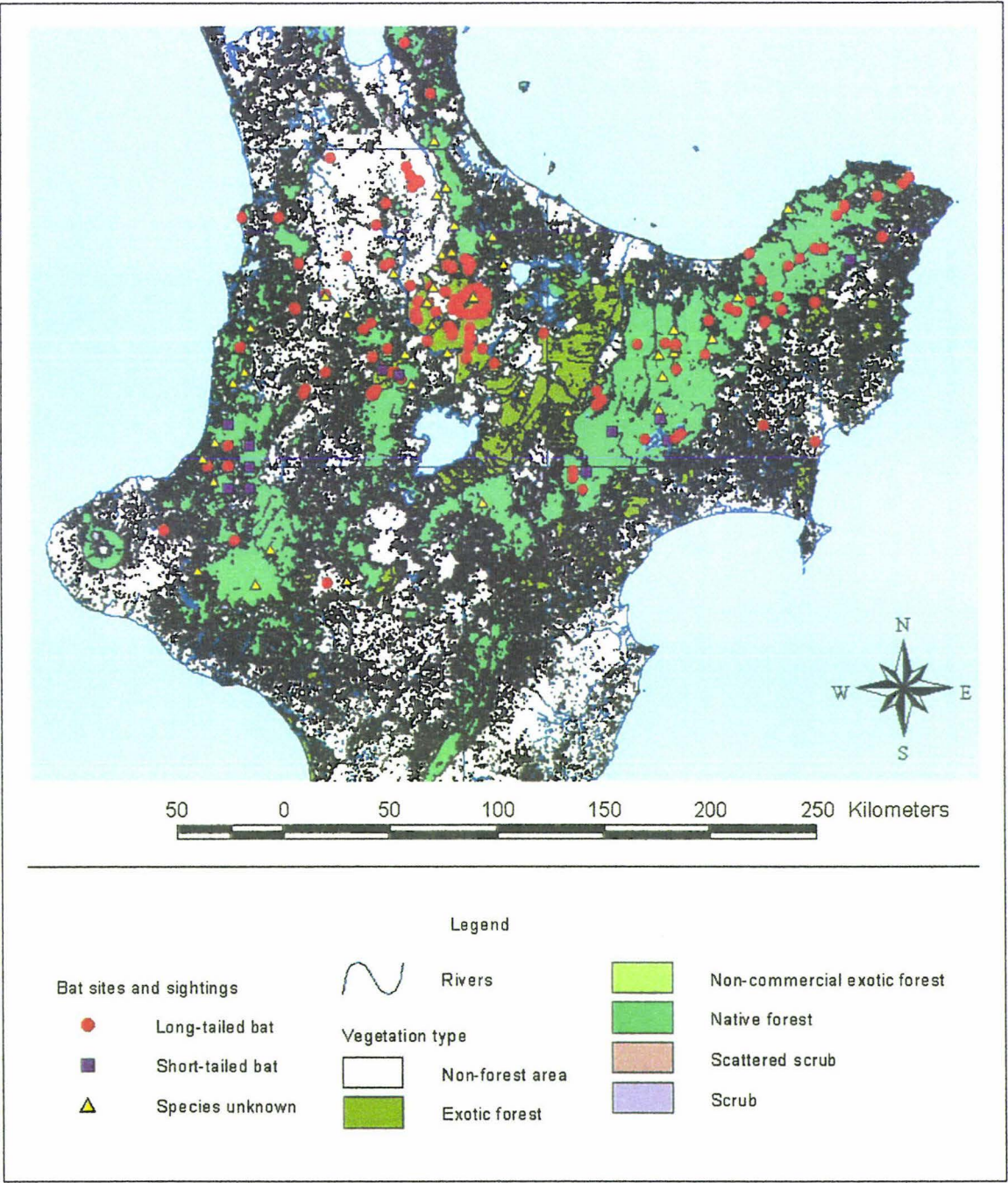
kept deliberately vague because unauthorised collecting threatens this rare and “vulnerable” plant (e.g. Ecroyd 1993).]

A summary tape of questionable calls and noises recorded during this study at 40 and 28 kHz was kindly analysed by Brian Lloyd. He reported that it contained nothing that sounded like short-tailed bats, though he cautions that due to natural variations in pulse intervals and pulse length it is not always possible to distinguish between the echolocation calls of short and long-tailed bats at 40 kHz (B Lloyd unreferenced personal communication 2001). No other calls sounding like short-tailed bats were heard nor recorded.



*Reliability of coding*

There was total agreement in coding ABM-nights with no bat activity, and so these were omitted from subsequent analysis. Coding reliability was hence conservatively calculated to be 85% (n = 213 sampled hours). There was generally a good level of agreement in the field when identifying bat passes, but if there was any doubt, a conservative approach was taken.



**Figure 6** Bat sightings, central North Island, New Zealand, 1990–2000 inclusive in relation to vegetation type



### ***The Kinleith results in the context of the central North Island***

The results from this study are illustrated in relation to bat sightings from the central North Island in Figure 6. This map shows that bats are widespread in the central North Island, there are more reported sightings of long-tailed bats than short-tailed bats, and bat sites are generally associated with medium to large areas of native forest apart from the Kinleith Forest sites. There are few bat sightings in other areas of commercial exotic forest, and there are no reported bat sightings from Mt Taranaki in the west, nor from the Ruahine Ranges in the south.

### ***Evaluation of driving transects***

Driving transects were found overall to be faster than ABMs at finding new bat sites (Table 4), not counting the delay between putting out ABMs and retrieving tapes for transcription. By eliminating mid-survey servicing of ABMs, efficiencies became fairly equal (5.00 h for ABMs compared with 4.99 h for transects).

## **5. DISCUSSION**

### ***Bat distribution in the Kinleith Forest area***

Dwyer (1960a, 1960b, 1962) is commonly credited as the first to comprehensively review bat distribution in New Zealand (Daniel and Williams 1984; O'Donnell 2000a), though the efforts of Phillipps (unpublished<sup>9</sup>), who compiled many sightings, are notable [also supported by Dwyer (1960a)]. Bat distribution has been reviewed more recently by Daniel and Williams (1984), Molloy (1995) and O'Donnell (1999a, 2000a). The distribution of bats in the Kinleith Forest is considered in relation to all of these sources, as well as Daniel (1981). For ease, I have summarised sightings of bats in the Kinleith Forest area from the literature in Table 5.

Most information in the literature is presented in map form. Generally the maps (Dwyer 1960a, 1960b, 1962; Daniel and Williams 1984; O'Donnell 2000a) are small and lack major landmarks, and those of Dwyer (1960a, 1962) showing river courses seemingly contain some errors, and so the locations of sightings from these have been estimated. Areas up to 15 km from the Forest boundary are considered as part of the Kinleith Forest area — this is within the distance bats can travel during a night (long-tailed bats: O'Donnell 1999a; short-tailed bats: O'Donnell and others 1997, 1999a).

The sightings summarised in Table 5 are believed to be largely independent. Phillipps' (unpublished) work is the earliest and stands alone. Dwyer (1960a, 1962) was careful to acknowledge his sources which include Phillipps. Daniel and Williams (1984) distinguish in

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<sup>9</sup> Transcript available from: C Paulin, Collection Manager (Fishes), Museum of New Zealand Te Papa Tongarewa, P.O. Box 467, Wellington, New Zealand.

**Table 4** Comparison of efficiency of an ABM-based survey and driving transects in finding new bat sites in Kinleith Forest

Starting parameters		
<b>ABMs</b>		
Number ABMs	5	
Distance of circuit (km)	127	
Average speed (km/h)	50	
Season	N/A	
<b>Transects</b>		
Distance of transect (km)	50.4	
Average speed (km/h)	20.16	
Number new sites found	2.3	
Season	Not winter	
Time taken (h)		Activity
<b>ABMs</b>	<b>Transects</b>	
1	0.5	Work out route (and possible ABM sites)
0	4	Drive it during the day
Same	Same	Pack car
Same	Same	Work out sunset times
0.25	0	Make voicer times spreadsheet
1	0.25	Check equipment works
1.5	0	Pre-set-up ABMs
6	2.5	Drive circuit/put out ABMs
1–4 days	Next day/later	Waiting time
2.54	2.5	Drive circuit/route
3.75	1.73	Map and describe sites
2.5	0	Service ABMs
Same	Same	Break
3.75	0	Transcribe tapes
1–4 days	0	Waiting time
4	0	Bring in ABMs
1	0	Check over settings
3.75	0	Transcribe tapes
31.04	11.48	Total hours
11.05%	0	Equipment failure rate
0	0	Weather failure rate
4.45	2.3	Number new sites found
<b>6.98</b>	<b>4.99</b>	<b>Approx time to find one new bat site (h)</b>

their maps between their more recent sightings and those of Dwyer (1962). O'Donnell (2000a) also distinguishes Dwyer's (1962) sightings. Sightings mapped by Molloy (1995) and O'Donnell (2000a) were easily recognised as belonging to the same locations. However, there is some potential for sightings from Daniel and Williams (1984) to be duplicated in Molloy's (1995) work. Molloy's (1995) "pre 1980" short-tailed bat record from the Mamaku Plateau is thought to be the same as that shown by Daniel and Williams (1984) so is omitted here. Molloy's (1995) map of long-tailed bat distribution though is harder to interpret because it does not distinguish between sightings prior to 1983 [probably largely attributable to Daniel and Williams' (1984)] and those

**Table 5** Review of bat sightings in the Kinleith Forest area. U: species unknown, L-t: long-tailed bat (*Chalinolobus tuberculatus*), S-t: short-tailed bat (*Mystacina tuberculata*).

Species	Period <sup>10</sup>	Sighting date(s) <sup>11</sup>	Approximate location	Source
<b>Southern Kinleith Forest area</b>				
U	1980–1995		Kinloch	Molloy 1995; O'Donnell 2000a
U	1961–1983		Aratiatia	Daniel and Williams 1984
U	1930–1960		Tahorakuri	Dwyer 1960a
U	1980–1995		Tahorakuri/Aratiatia	Molloy 1995; O'Donnell 2000a
U; L-t	Pre 1930	U: 1928, 1948; L-t: 1950	Orakei Korako	Phillipps (unpublished); Dwyer 1960a
L-t	1961–1983		Orakei Korako	Daniel and Williams 1984
U	1961–1983		Orakei Korako	Daniel and Williams 1984
U	1930–1960	1959	Atiamuri	Dwyer 1960a
L-t	1961–1983		Atiamuri	Daniel and Williams 1984
U	1930–1960		Ongaroto	Dwyer 1960a
L-t	1930–1960		Maroanui (between Maroa and Oruanui)	Dwyer 1960a
U	Pre 1930	1905	Mokai <sup>12</sup> /west of Mokai	Phillipps (unpublished); Dwyer 1960a
<b>Pureora Conservation Park</b>				
U	1930–1960	Before 1959	Rangitoto Range (Pureora Conservation Park — north)/Ngaroma	Dwyer 1960a
U	1930–1960		Rangitoto Range (Pureora Conservation Park — north)	Dwyer 1960a
U	1961–1983		Pureora Conservation Park ( — south)	Daniel and Williams 1984
S-t	1980–1995		Pureora Conservation Park (mention in text, unmapped)	Molloy 1995
<b>Western Kinleith Forest area</b>				
L-t	1980–1995		Maraetai	Molloy 1995; O'Donnell 2000a
L-t	1961–1983		Waipapa	Daniel and Williams 1984
L-t	1980–1995		Waipapa/Ngaroma	Molloy 1995; O'Donnell 2000a
U		1935–1945	Arohena (mentioned in table, seemingly unmapped)	Dwyer 1960a
L-t	Pre 1930	1907	Arapuni/Lake Arapuni/Waotu	Dwyer 1960a

<sup>10</sup> As mapped.

<sup>11</sup> As provided in additional information. For Dwyer (1960a), where records in the appended table of Distribution Records are thought to correspond with the localities mapped, dates from the table have been reproduced here. For other sources, see individual citations.

<sup>12</sup> Misreported by Dwyer (1960a) in table of Distribution Records as "Mokaio", but clearly the same record as Phillipps' (unpublished) "Mokai".



Species	Period <sup>13</sup>	Sighting date(s) <sup>14</sup>	Approximate location	Source
L-t		1976	<i>Pinus radiata</i> forest near Lake Arapuni (now Kinleith Forest)	Daniel 1981
L-t	1961–1983		Arapuni	Daniel and Williams 1984
U	1961–1983		Arapuni	Daniel and Williams 1984
U	1930–1960		Lichfield/Wiltsdown	Dwyer 1960a
U	1961–1983		Lake Karapiro	Daniel and Williams 1984
L-t	1980–1995		Maungatautari township/Puketurua	Molloy 1995; O'Donnell 2000a
<b>Northern and north-eastern Kinleith Forest area</b>				
U	1961–1983		North of Ngatira	Daniel and Williams 1984
U	1961–1983		Northeast of Tapapa	Daniel and Williams 1984
L-t	1980–1995		Edge of Kaimai–Mamaku Forest Park, near Selwyn	Molloy 1995; O'Donnell 2000a
U	1961–1983		Mamaku Plateau north of State Highway 5	Daniel and Williams 1984
L-t	1980–1995		Mamaku Plateau near Galaxy North Rd and State Highway 5	Molloy 1995; O'Donnell 2000a
S-t	1961–1983	Possibly 1971 <sup>15</sup>	Mamaku township	Daniel and Williams 1984 <sup>16</sup>
U	1961–1983		Tarukenga <sup>17</sup>	Daniel and Williams 1984
U	1930–1960	≈ 1920, 1947	Awahou/Oturoa	Phillipps (unpublished); Dwyer 1960a
U	1961–1983		Rotorua <sup>18</sup>	Daniel and Williams 1984
Unclear; S-t; U	1930–1960	1930	Paradise [Valley Springs] Rotorua	Phillipps (unpublished); Dwyer 1960a;
U	1961–1983		Paradise Valley Springs <sup>19</sup>	Daniel and Williams 1984
U	Pre 1930		East of Mamaku South Rd, northwest of Horohoro	Dwyer 1960a
L-t	1961–1983		Mamaku Plateau between Horohoro and Te Whetu	Daniel and Williams 1984
U	1961–1983		Te Whetu	Daniel and Williams 1984

<sup>13</sup> As mapped.

<sup>14</sup> As provided in additional information. For Dwyer (1960a), where records in the appended table of Distribution Records are thought to correspond with the localities mapped, dates from the table have been reproduced here. For other sources, see individual citations.

<sup>15</sup> Seemingly near Mamaku, this sighting is possibly the same as that in the National Bat Database detailing the occurrence of a short-tailed bat a house in Mamaku village in 1971.

<sup>16</sup> However, this sighting is not reproduced in Daniel's 1990 map (Daniel 1990) of confirmed short-tailed bat sightings since 1961.

<sup>17</sup> The exact number of different localities mapped in this small area is somewhat unclear.

<sup>18</sup> The exact number of different localities mapped in this small area is somewhat unclear.

<sup>19</sup> The exact number of different localities mapped in this small area is somewhat unclear.

made after. One of the three sightings in the Maraetai–Ngaroma–Waipapa area (Table 5) could be a duplicate.

### *Southern Kinleith Forest area*

There is a long history of bat sightings in the southern Kinleith Forest area (Table 5), with several from Orakei Korako. Sightings where the species is not known are probably mostly of long-tailed bats (Daniel and Williams 1984). However, that there are no recent sightings (Molloy 1995; O'Donnell 2000a) from the Whakamaru–Orakei Korako area is surprising. At face value, this could be taken to possibly indicate a decline in bats in this area, now comprised largely by Kinleith Forest. However, my study (1998–2000) identified long-tailed bats as being present at Pohaturoa, Ngautuku hill (between Atiamuri and upper Atiamuri), and near Lake Ohakuri. A colony of long-tailed bats was found in a pine tree felled in Kinleith Forest near Upper Atiamuri in 1996 (Chapter 1). Further south I recorded long-tailed bats on Poplar Rd off Tatua Rd. I also received an anecdotal record of an unidentified bat on Oruanui–Forests Rd although the date of this sighting is uncertain. There is actually a (January) 1995 record of a long-tailed bat at Orakei Korako in the National Bat Database [seemingly not represented in the map of Molloy (1995)] and I found two further records from 1991 (short-tailed bat) (Scrimgeour 1991) and 1994 (species unknown) (Garrick 1994). While the short-tailed bat sighting was not confirmed, [although Scrimgeour (1991) suggests that the observer was accustomed to seeing long-tailed bats and this bat was within inches of his head,] it is interesting that the location is not far from the area east of Maroa, where Mr Snowsill (B Snowsill unreferenced personal communication 2000) reported a short-tailed bat sighting.

The location of bat sightings between 1930 and 1960 reviewed by Dwyer (1960a) is strongly correlated with the extent of native forest (Dwyer 1960a). Certainly the forest near Ongaroto, Mokai and Maroanui was admirable at least some time prior to these sightings (e.g. Palmer 1964; Miles 1984; B Snowsill unreferenced personal communication 2000; Putaruru Timber Museum). Phillipps' (unpublished) record of bats at Mokai notes that they were seen at dusk, suggesting that they were probably long-tailed bats (e.g. O'Donnell 2001a compared with Lloyd 2001), and in large numbers.

### *Pureora Conservation Park*

While I limited my broad-scale survey to the main contiguous area of Kinleith Forest, I have two anecdotal records from Pureora Conservation Park. There are a wealth of records from the literature and the National Bat Database. This would seem to be a bat stronghold (both species are present), and there could possibly be movement of bats between the park and Kinleith Forest, especially the more southern blocks.

### *Western Kinleith Forest area*

As for the southern area, there is a good number of records from the western Kinleith Forest area. Most are located along the Waikato River, with four from near Arapuni/Lake Arapuni. A long-tailed bat was seen near Waotu in 1907 (Dwyer 1960a) and long-tailed bats are still present in the area — I detected one at Barnett's Reserve, a native remnant, in 2000. Long-tailed bats are also present in Kinleith Forest near to the Lake. A Carter Holt Harvey Forests staff member recalled the colony of long-tailed bats found in the Waikato Block in 1976 (Daniel 1981) as being from the Commons Rd area (R Black unreferenced personal communication 1999). While an ABM located on this road was stolen before bat presence could be assessed, a long-tailed bat was heard nearby on Jack Henry Rd. Long-tailed bats were also present in the Forest in the Waipapa area (Duncan, Cameron and Renahan Rds).

There have been various bat sightings from the Wiltsdown area (Garrick 1992; J Dodgson unreferenced personal communication 1998; F Rodwell unreferenced personal communication 2000) and long-tailed bats were confirmed to be present at Mercer Rd during the current study. There are three recent records from the Maungatautari area of bats, two of long-tailed bats (from 1998) [originally reported by Borkin (1999)], one where the species was unidentified (1990, National Bat Database).

### *Northern and north-eastern Kinleith Forest area*

The areas of bat sightings from the literature for the north and north-eastern Kinleith Forest area (Table 5) can further be subdivided into Ngatira–Selwyn–State Highway 5, Mamaku–Awahou–Paradise, and Horohoro–Te Whetu. The sightings of the first area are all from after 1960. The present study found long-tailed bats present in the northern block of Kinleith Forest suggesting bats are still present near many or all of these sites. Certainly I recorded long-tailed bats at two sites directly north of Ngatira: Waihou Rd and Tunnel Rd (west), and there was good bat activity along Capricorn Rd (Chapter 6). A sighting from Whites Rd (B Atkinson unreferenced personal communication 2000), not too far from Tapapa, dates from about 1985, while one from nearby Waimakariri Rd (Owen 1992) is from around late 1991 or early 1992. J Heaphy confirms long-tailed bats to occur throughout the Kaimai Mamaku Forest Park between State Highway 5 and the more northern State Highway 29 (J Heaphy unreferenced personal communication 2001).

There is a greater range of dates for the sightings in the second group, but Phillipps (unpublished) and Daniel and Williams (1984) seemingly independently record bats from the Paradise Valley Springs area. Long-tailed bats were present on Mamaku South Rd, not too far from here, and they are also known from the Mokaihaha Ecological Area (e.g. Marsh and Blake 1997; Griffiths 1999). The more northern sites (Mamaku, Tarukenga and Awahou) are nearest to my observations of long-tailed bats on Capricorn Rd, Tunnel Rd (east), and on Galaxy Rd before its junction with Mamaku South Rd. There are certainly long-tailed bats still present



within the general area of these sightings, though the presence of short-tailed bats remains uncertain.

Near Horohoro, long-tailed bats were present in Kinleith Forest at Glass Rd (Matahana Basin) and along the Mamaku South Rd. There is a vast tract of Kinleith Forest lying between Horohoro and Te Whetu. Long-tailed bats appeared widespread in this part of forest being heard along Mamaku South Rd and at numerous sites along the Galaxy Rd between Mossop Rd and Mamaku South Rd. Near Te Whetu, long-tailed bats were present at both ends of Puriri Rd, and in the Redwood Reserve.

Around the 1960s, it would seem there were reasonable numbers of bats in the Kinleith Forest area. Dwyer (1960a) notes that bats were regularly reported from regions including southern South Auckland and Rotorua–Taupo. The regions with the most sightings of colonies or large flights after 1930 were Rotorua–Taupo and Gisborne (six each), and South Auckland (two) (Dwyer 1960a). That Rotorua–Taupo was a notable bat area is also illustrated in Dwyer's (1960b) map relating the nature of bat observations e.g. frequency and number of bats seen. Dwyer (1960a) reports slightly greater numbers of colonies or large flights (arbitrarily defined as > 12 animals) of bats of unknown species in South Auckland and Rotorua–Taupo after 1930 than before 1930. Isolated sightings and sightings of small flights of long-tailed bats and bats of unknown species similarly increase with time, although it is uncertain whether these figures represent actual trends.

### ***Long-tailed bats are “still” present***

That there are still long-tailed bats present in the Kinleith Forest area, and in the areas of historical sightings, is perhaps surprising given the general picture of species decline (e.g. Dwyer 1960a, 1960b, 1962; Daniel 1990; O'Donnell 1993, 1994, 1997a, 1997b, and recently investigated in detail by O'Donnell 2000a). O'Donnell (1997b, p 15) reports that “. . . large amounts of survey work in some areas have yielded few or no records at sites where [long-tailed bats] were present 20–30 years ago”. Molloy's (1995) and O'Donnell's (2000a) maps show an absence of recent long-tailed bat sightings from all but the periphery of Kinleith Forest, in stark contrast to Dwyer's (1960a, 1960b, 1962) and even Daniel and Williams' (1984) work. Although such distribution maps have their problems (e.g. Dwyer 1960a, 1962; Daniel and Williams 1984; Osborne and Tigar 1992; O'Donnell 1993, 1999a, 2000a), this does lead one to wonder whether long-tailed bats have not reduced further in range in the last couple of decades. However, long-tailed bats are not only still present in many of the areas of past sightings — perhaps most notably in the Waotu area, where I confirmed their presence some 93 years after Dwyer's (1960a) 1907 record, but activity is high in some locations. (To guard against misinterpretation here, I am not arguing that long-tailed bats have not declined drastically in range in New Zealand, nor that they may not have declined in the South Waikato,

but, that in the Kinleith Forest area, in recent years, they have been largely overlooked! This example well illustrates the potential pitfalls in interpreting distribution maps.)

### ***Long-tailed bats are present in pine forest***

Not only is it perhaps surprising that long-tailed bats are still present in the Kinleith Forest area and the Forest itself, but that they are present in an area of commercial predominantly *P. radiata* forest. Exotic pine forest is considered undesirable by some in New Zealand (Walsh 1995; Maclaren 1996) partly because of its perceived lack of biodiversity, a matter of much contention (e.g. Rosoman 1994, 1995; Allen and others 1995; O'Loughlin 1995; Spellerberg and Sawyer 1995; Sutton 1995; Walsh 1995; Spellerberg 1996; Dyck 1997; Ogden 1997). Commercial forests likely offer fewer roosting opportunities for cavity-reliant organisms (e.g. Hunter 1990; Newton 1994; Kirkby and others 1998), including long-tailed bats (Daniel 1981; Sedgeley and O'Donnell 1999a, 1999b), than non-production forests due to short rotation times and intensive management (Daniel 1981; Hunter 1990; Newton 1994). Additionally, conifers provide few tree trunk cavities relative to broadleaf trees (Hunter 1990; Gerell and Lundberg 1993; Newton 1994). In the United Kingdom, a national bat survey found that bats selected semi-natural broadleaf woodland over mixed or coniferous woodland (Racey 1998), though research at a much smaller scale in the New Forest found greater bat activity in the coniferous plantations than in the overgrazed ancient woodlands (Fawcett 1997).

Although long-tailed bats are known to use a variety of habitats (Daniel 1981, 1990; Daniel and Williams 1984; O'Donnell 2000c), long-tailed bats are most commonly associated with indigenous forest, whether considering their distribution, roosting ecology, or apparent decline (Dwyer 1960a, 1960b, 1962; Daniel 1990; O'Donnell 1999a, 2000a, 2000c, 2001a). There is comparatively scant acknowledgement of the large-scale afforestation which has occurred, let alone consideration of the potential value of this to long-tailed bats. Indeed, mine appear the only large-scale distribution maps to consider bat sightings in relation to vegetation type, as opposed to solely the extent of indigenous forest. Daniel and Williams (1984) do mention that exotic, mainly *P. radiata* forests (and mainly in the central North Island) have matured and more have been planted between the period of Dwyer's (1960b, 1962) study and their own. However, this is done in the context of environmental changes thought to be detrimental to bats although Daniel (1981) had earlier reported the finding of a communal roost in such forest and stated that "[b]ats may be more common in exotic forests than was previously thought" (p 110), a sentiment echoed by Garrick (1997). No further consideration of the effects of exotic afforestation on bats is given.

### ***Long-tailed bat activity***

While ultrasonic bat detectors do not permit the number of bats in an area to be directly quantified they do provide an index of activity (Thomas and La Val 1988; O'Donnell and

Sedgeley 1994; Parsons 2001). Although bat activity is hugely variable (this study; O'Donnell 2000b), it would seem that the level of long-tailed bat activity observed in parts of Kinleith Forest compares favourably with that observed elsewhere in New Zealand. For example, in Fiordland National Park, O'Donnell (2000b) observed an average pass rate of 30.8 passes/night during spring, and 31.7 passes/night during summer. In a road habitat, O'Donnell (2000b) recorded 5583 passes over 145 nights, giving a mean of 38.5 passes/night. Activity at Star Rd, in Kinleith Forest, observed over a comparable period, averaged 46.0 passes/night.

### ***Possible explanations***

Long-tailed bats are still present in the Kinleith Forest area having declined in distribution and in number elsewhere in New Zealand (e.g. O'Donnell 2000a). They are present in exotic pine forest, though they are more usually associated with indigenous forest (e.g. O'Donnell 2001a). In places activity is high. A key question is why? To begin to answer this, more information about how the bats are using the area is needed. Hence, these issues are reconsidered in Chapter 8.

### ***Short-tailed bats***

Short-tailed bats occur at two locations within 15 km of Kinleith Forest, Pureora Conservation Park (National Bat Database; Higham 1992; Hunt 1992; Ecroyd 1993; Molloy 1995) and Kaimai Mamaku Forest Park (J Heaphy unreferenced personal communication 2001). There are credible-sounding, if unconfirmed, sightings from Orakei Korako (Scrimgeour 1991), east of Maroa (B Snowsill unreferenced personal communication 2000) and Mamaku village (National Bat Database; Daniel and Williams 1984<sup>20</sup>). *D. taylorii*, naturally pollinated by short-tailed bats (e.g. Ecroyd 1993; Holzapfel and others 2000), occurs in several locations in the Kinleith Forest area. However, no calls resembling short-tailed bats were heard during this study, a couple of the sightings are pre-1980, and work in the north-eastern forest area has to date failed to confirm the presence of short-tailed bats (Ecroyd 1993; Marsh and Blake 1997; Griffiths 1999). Overall, given their cryptic nature (O'Donnell and others 1999; and evidenced from Foster 1999), their potential use of the landscape at a large scale (e.g. Lloyd and Whiteford 1998; O'Donnell and others 1999), their occurrence in pine plantations elsewhere (albeit in low numbers) (Lloyd 2001), and the proximity of short-tailed bats to the Forest, the presence in Kinleith Forest of short-tailed bats cannot be ruled out. Griffiths (1999) similarly suggests that the presence of short-tailed bats in the adjoining Mokaihaha Ecological Area cannot be discounted.

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<sup>20</sup> This site is not included in Daniel's (1990) map of confirmed short-tailed bat sightings.



### ***The Kinleith results in the context of the central North Island***

Many researchers (Dwyer 1960a, 1960b, 1962; Daniel and Williams 1984; Molloy 1995; O'Donnell 2000a) have produced distribution maps based largely on sightings. While such maps have their caveats (e.g. Dwyer 1960a, 1962; Daniel and Williams 1984; Osborne and Tigar 1992; O'Donnell 1993, 1999a, 2000a), it was felt that there was sufficient merit in repeating the exercise. My map (Figure 6) differs from those before in that it covers the period from 1990–2000 (inclusive), shows bat sightings in relation to vegetation type, and focuses on a smaller area (central North Island) showing more detail (and hopefully being of greater use to the reader). Blank areas still likely reflect to an extent a lack of survey effort (in some cases even because bats are known to be present and so there is little point in repeating surveys) rather than the confirmed absence of bats in those areas. However, that the current study has found bats to be widespread in an area outside the DoC estate, and in exotic plantation forest, is significant. Since this map was made, long-tailed bats have also been found in various blocks of exotic plantation forest in Hawke's Bay (M Hansen unreferenced personal communication 2001).

Figure 6 highlights the lack of sightings reported from exotic forest (other than Kinleith Forest). There are sightings from either side of the "Kaingaroa" band of exotic plantation forest [spanning from east of Lake Taupo to near Putauaki (Mt Edgecumbe)], in the west from Kinleith Forest, and in the east near the Napier–Taupo Rd, in Whirinaki Forest Park and Urewera National Park. However, there are comparatively few sightings from the exotic forest itself [Waiotapu 1996, Broadlands 1996, and Flaxy Lake–Wheao 1992, though Fletcher Challenge Forests inform me of some additional sightings (C Tozer unreferenced personal communication 2001)], and this area remains largely unsurveyed (A Garrick; C Tozer unreferenced personal communication 2000; though see Garrick 1996; Owen 1997). Given my findings, long-tailed bats are likely to be present in this area, and they may actually have a fairly continuous distribution in the central North Island.

Dwyer (1960a) notes that bats were regularly reported from southern South Auckland (approximately Waikato Conservancy), Rotorua–Taupo, Gisborne, northern North Wellington (approximately Tongariro–Taupo Conservancy) and northern Hawke's Bay. Figure 6 shows bat sightings in all these areas. Some are seemingly in the same locations or very close to those from which Dwyer (1960a) reported sightings e.g. Waikaremoana, northern Hawke's Bay, northern North Wellington. The comparatively low number of sightings (Figure 6) for northern North Wellington reflects more the short time period illustrated than a paucity of bat records (G Moore unpublished data) — both long and short-tailed bats are known from this area and Rangataua Forest has been the site of much research activity (e.g. Lloyd and McQueen 1995, 1996a, 1998a, 1998b, 2000; McQueen and Lloyd 1995; McQueen 1996; Lloyd and Whiteford 1998). There are sightings from Urewera National Park, an area observed by Dwyer (1960a) to

yield many sightings, but there have also been recent sightings from the north-eastern Raukumara Range as well as near the Taranaki coast.

Many sightings like Dwyer's (1960a) are from the edge of forest or along rivers — e.g. the Waimana River where bats are seemingly still present. Dwyer (1960a) concluded that pre-1930 bat sightings were generally nearer population centres than is now the case. There are very few recent bat sightings near urban centres, especially major urban centres. However, long-tailed bats occur remarkably close to Tokoroa and the pulp and paper mill, though the forest is not far from either.

The main differences between O'Donnell's (2000a) and Molloy's (1995) maps and Figure 6, apart from the records from the Kinleith Forest, is that they span a longer time period and so display a greater number of sightings. However, they also show more sightings from southern coastal Hawke's Bay and the Ruahine Ranges and from the Kaweka Ranges (inland Hawke's Bay). The majority of these sightings appear to be pre-1990 and so were not included in Figure 6. The main areas the current study has located "new" bat sightings are the Waikato [mainly due to the work of Borkin (1999)], inland Gisborne and the belt of forest spanning Urewera–Raukumara (largely sightings reported by the East Coast and Hawke's Bay Conservancies in the Bat Recovery Group Meeting Minutes).

Volcanic plateau short-tailed bats (*Myztacina tuberculata rhyacobia*) are now known from a wide variety of areas outside of those for which Dwyer (1960a) had sightings e.g. Waikaremoana–Urewera, Whirinaki, Raukumara Forest Park, north-eastern Taranaki and Pureora. They also occur in the Ohakune area (e.g. Lloyd and McQueen 1995, 1996a, 1998a, 1998b, 2000; McQueen and Lloyd 1995; McQueen 1996; Lloyd and Whiteford 1998) as illustrated by Molloy (1995) but not Figure 6 (though there are sightings pre-dating 1990). Figure 6 shows a larger number of recent short-tailed bat sightings in the eastern belt of native forest than Molloy (1995). Two of these result from recent survey effort by Wildland Consultants Ltd (1997), one from survey work by the Gisborne Area Office of the Department of Conservation (Harrison 2000), a further sighting was of a dead short-tailed bat found on a track (Anonymous 1997). Short-tailed bats have been confirmed in the Raukumara Range (Harrison 2000), mentioned by Daniel (1990) as a possible short-tailed bat site. It is thought that there are fewer short-tailed bat sightings than long-tailed bat sightings in part because short-tailed bats are generally less visible, e.g. they emerge after dark (Daniel 1990; Molloy 1995; Lloyd 2001) and generally forage in the forest interior (Molloy 1995; O'Donnell and others 1999).

Bats appear generally associated with medium to large areas of continuous forest. There are still many questions to answer about the scale at which both species of bats use the landscape (e.g. O'Donnell and others 1999; O'Donnell 2001b), the importance of habitat mosaics (O'Donnell 2001b) [for observations in two modified landscapes see O'Donnell (2000c, 2000d,

2000e)], and the level of gene flow between populations (Lloyd and Whiteford 1998; Lloyd 2001; O'Donnell 2000f). Hopefully, by furthering our knowledge of bat distribution, this study can help us as we begin to embark on these.

### ***Scope and limitations***

#### *Survey work*

##### Collection of anecdotal records

##### Bats

As the distribution of bat sighting forms was administered by Forest Information (who co-ordinated permitting) the total number of bat forms distributed is unknown. However, for various reasons this was smaller than the total number of permits issued. Eight responses were received from deer stalkers (who have to make a "return" stating how many deer they take). No forms were returned by pig hunters. Only one person had seen a bat and was able to provide helpful information. Another offered useful suggestions on where I should look, and another was apologetic that he had not seen bats during his 31 years as a forest-user! This method of survey was unable to be repeated in 2000 as permitting was in the process of being handed over to an external contractor.

A greater number of sightings was obtained talking with local people and forestry staff during this study. I obtained nine mappable sightings this way, and Robin Black identified a further two.

##### *Dactylanthus*

The quality of the information gathered about *Dactylanthus* locations is unknown. However, many of the people consulted were DoC officers or keen forest-users familiar with the area. Various sightings were backed up by more than one person. The information obtained is thought to provide a good starting point given the cryptic nature of the plant and general elusiveness of short-tailed bats.

##### Broad-scale survey and other ABM survey work

A number of factors meant it was impractical to survey each site with equal effort. However, the effects of this appear negligible. Bats were considered present if they were detected within eight clear nights for which data was obtained. For all the sites with bats, bats were recorded at 69% (of 26) of sites by the end of the first night, at 88% of sites by the end of two nights, and at 100% of sites by the end of five nights, even given that many sites were surveyed between April and October, a less than ideal time for undertaking bat survey work (e.g. O'Donnell and Sedgely 1994; G Moore unpublished data).



### Driving transects

The distribution of bat sites identified using driving transects seems to reflect survey effort (see later). As well, the probability of detecting bats is likely to have varied within each transect with time. However, with the large variation in actual start times, and by alternating the direction travelled round transect routes, this effect would have been minimised. Indeed, for the Galaxy transect, over a series of seven transects a fairly even distribution of new bat sites was obtained.

There was potential for the vehicle to scare bats away, but it is not known whether this occurred. In all, 25 new bat sites were found from 10 transects. Transects also turned up bat sites near where bats were known to occur from the ABM survey. As the aim was solely to find bats, this potential problem is not significant.

The effective range of each bat detector may have been reduced by attachment to the wing-mirror of the vehicle. The side of the vehicle would affect the signal response of each detector at different angles, due to reflection and shielding effects (M Douglas unreferenced personal communication 2000). However, the wing-mirrors provided a practical point of attachment because they partially sheltered the detectors from wind and wet vegetation on the side of the road, and were in easy reach should the bat detectors need adjusting. Using two detectors simultaneously compensated for any reduced range.

### Reliability of coding

The coding of bat passes was fairly accurate, and a conservative approach was taken in the field. It is doubtful that coding inaccuracies influenced the results significantly, especially given the presence-absence focus of this investigation.

### *Literature review*

#### Sightings from the literature and threatened species files

The quality of information in the sources reviewed probably varies. Some bat sighting records were from members of the public, others are locations where bats were found during organised survey work with bat detectors. Swallows and puriri moths are sometimes mistaken for bats (Daniel and Williams 1984), and it can be difficult to tell New Zealand's two bat species apart in flight (Daniel and Williams 1984), or from their calls which overlap in frequency (Parsons 1996, 2001; Lloyd and Whiteford 1998; O'Donnell and others 1998, 1999). In addition to the two sightings deleted in which the grid references were found to be incorrect, there may be other errors which were not detected. Some sighting dates were probably estimated rather than actual. All these inaccuracies probably occur in the results of the present study, but they likely exist in the work of others as well.

## The National Bat Database

The electronic version of the National Bat Database was compiled from information collected largely from the public (O'Donnell 2000a), though some bat detector work and observations of DoC staff are included. Records span from 1890 to 1995. Data were originally entered on field sheets. As well as potential inaccuracies in the original information reported, further inaccuracies probably occurred during data entry and in the interpretation and entry of species designations (three examples were identified, Appendix 3.2). I did not have the benefit of being able to check the database against the original field sheets and so took a conservative approach, altering or deleting those records that were clearly questionable but cataloguing these changes (Appendix 3.2) for the reference of my readers and future researchers, and leaving the remainder of entries alone. I did produce a map which should have enabled the "long-tailed bat" sightings to be compared with those O'Donnell (2000a) considered accurate. However, the large number of points, and the small size and lack of landmarks on O'Donnell's (2000a) map, meant this comparison was practically impossible. While not perfect, it is felt that the value of displaying the data as I have outweighs the negative effects of the uncertainties and inaccuracies within it.

During my analysis, there was no need to check that data was entered into correct chronological periods when mapping bat sightings by period, as done by O'Donnell (2000a), because ArcView grouped them for me using the parameters I set in my query e.g. "Date ≥ 1990". However, in providing a four figure date field in my database instead of the eight figure field used in the National Bat Database, I made sure to conscientiously check my data entry.

### *Data quality overall*

While much effort was put into ensuring the accuracy of the data forming the final database, it is possible that undetected errors remain. There was variation in the precision with which grid references were reported, but most were given to the nearest hundred metres. The age of the Terralink data was unavailable, however, at the scale mapped, it seems fairly accurate.

### *Reflection of survey effort and observer distribution*

In Kinleith Forest, bats were found almost everywhere I looked for them. Hence, the resulting map (Figure 4) most probably reflects survey effort rather than being a true representation of bat distribution. However, it demonstrates that long-tailed bats are widespread in Kinleith Forest.

Figures 5 and 6 also likely reflect observer distribution and survey effort. Many researchers, many of who contributed to or also used some of the data analysed here (e.g. Dwyer 1960a,

1962; Daniel and Williams 1984; Osborne and Tigar 1992; O'Donnell 1993, 1999a, 2000a) present eloquent discussions of these issues to which the reader is referred.

Bias is likely to be present in my results due to the sources of information I included in the database. A breakdown of relative contributions is given earlier (Table 3). Other recognised biases result from a) not including data from the National Bat Database from the Auckland Conservancy meaning that for a small area in the north-westernmost part of Figure 6 data from the National Bat Database is not represented; b) reviewing DoC Bay of Plenty's threatened species files selectively, and focussing on sites thought to be within the general area of the Kīnleith Forest, files of other nearby Conservancies were not searched [though bat distribution in the Waikato was investigated by Borkin (1999)]; and c) only East Coast and Hawke's Bay Conservancies provided specific bat sighting data in the Bat Recovery Group Meeting Minutes reviewed. The reports consulted detailed the results of bat survey work in the following areas: Waikato Conservancy (Borkin 1999), Mokaiha Ecological Area (Marsh and Blake 1997; Griffiths 1999), Pureora Conservation Park (Moorcroft and others 2000a, 2000b), and Pohokura, east of Taupo (Wildland Consultants Ltd 1997).

The relative effect of the variation in effective survey effort between areas in Figures 4, 5 and 6 is not thought to be so significant so as to negate the value of producing these maps. Indeed, an early map produced of all 472 data points shows fairly even coverage of the central North Island (G Moore unpublished data). Simply, some caution must be advised in the interpretation of these results. That seemingly little survey effort has gone into some areas is a result in itself, and one that may need consideration in the recovery of these species.

### *Habitat use*

Patterns of habitat use by long-tailed bats in Kīnleith Forest as revealed by this work are discussed in Chapter 5.

### ***Appraisal of main survey methods***

Given the youth of bat research in New Zealand and need for the development of appropriate survey methods (O'Donnell 1993; unpublished b, 2000b; Molloy 1995), the challenges and opportunities the commercial exotic forest environment presents, and the seemingly increasing interest among forest managers in bat survey work, a brief appraisal of my main survey methods is given here.

### *Collection of anecdotal records*

The methods yielded valuable new records, but the quality of information obtained was variable, and one can expect a low response rate. There are some options for improvement e.g. in prior publicity and in bat form distribution. This research complemented fieldwork, and anecdotal



accounts can be used to help focus survey effort, especially where there is a large area to survey.

### *ABM survey*

The ABM survey was successful in finding bat locations and also provided bat activity data (useful e.g. for determining the best time for undertaking driving transects). It was relatively straight forward to carry out, though somewhat reliant on knowledge of the areas of forestry operations. Problems encountered included the large potential for human error in setting up ABMs, ABM breakdown or malfunction, spells of bad weather, and theft. However, the magnitude of some of these lessened with experience. A further problem, although overcome thanks to the support of various parties, is that ABMs are relatively expensive and it can be difficult to obtain enough to be able to survey a large area quickly. Despite these potential setbacks, ABMs offer advantages in surveying locations with comparatively few bats, and surveying at less than optimal times of year, e.g. when bat activity may be sporadic.

### *Driving transects*

Of all the methods used, driving transects are the most novel in the New Zealand setting, and so are discussed in a little more detail.

In Kinleith Forest, driving transects were effective in finding new long-tailed bat sites and turned up some adjacent to sites identified with ABMs suggesting the method is comparatively strong. Perhaps the largest problem was getting a feel for the vehicle noises versus bat passes coming across on the bat detectors. However, this was overcome relatively quickly, helped by having two people listening which provided a system of instantaneous reliability checking. Driving transects had the benefit that they covered a large area quickly, they were more economic of equipment (in terms of amount and cost) than ABM survey work, provided instantaneous results, we were able to diagnose faulty equipment instantly and generally fix it easily, and transects could be abandoned if the weather turned bad without generating much extra work. However, an assistant was required for safety and to help record data.

The driving transect method was faster overall in finding new bat sites than the ABM-based survey (Table 4). Ahlén (1980–81, p 136) also found driving transects to be "highly efficient as to the large number of bat observations per time unit". They were also more rewarding because there were fewer things to go wrong, and results were instantaneous. By eliminating mid-survey servicing of ABMs, efficiencies became fairly equal. While several quantities in Table 4 were estimated, on the basis of the experience gained in both methods during this study, it is felt that these approximations were fair. This is not to say that driving transects would be more efficient in other situations too, nor that the methods used cannot be made more efficient (in fact there are several savings to be made). However, this calculation does illustrate the potential of

the driving transect method, compared to a method more commonly used in New Zealand. In reality, both methods have their advantages and limitations, and to combat these, the use of both is advocated. The methods are also complementary in that ABM survey work can be done during the day and transect work undertaken at night.

Driving transects appear to be a good rapid-survey method with more widespread applicability (see also Ahlén 1980–81; Jüdes 1989; Chapter 4, 5). Given the current focus on identifying bat presence in many areas both within the DoC estate and on private land (e.g. Lloyd and Whiteford 1998; Adams 1999; Anonymous 1999; Griffiths 1999; McKinlay and McQueen 1999; O'Donnell 1999b; Quirk 1999; Roberts 1999; Lyall 2000; B Gilmore unreferenced personal communication 2001; and apparent from the 2<sup>nd</sup> New Zealand Bat Conference, Ohakune, 28–29 March, 1998) and the shifting emphasis to conservation on private land (DoC and MfE 1998; MfE 2000), the development of such methods can only help. However, there is also a need to assess the health of bat populations (O'Donnell 1993, 2000a; Molloy 1995). Long-tailed bats appear to have declined significantly (O'Donnell 1993, 1994, unpublished b, 2000a, 2000b), but we have little information on whether this state is continuing (O'Donnell 1993, 1994, 2000a) or its actual causes (O'Donnell 1993, 1994, 2000a; Molloy 1995). We also seem relatively ill-equipped to gauge the effect of various management regimes on bat populations [also implied by O'Donnell (2000b), though the significant contributions of O'Donnell (2000a, unpublished b) are recognised]. Standardised methods of monitoring which can be repeated over time are needed (O'Donnell 1993, unpublished b, 2000a; Molloy 1995) and it is thought that driving transects (admittedly with some refinement and calibration with known bat populations,) could help meet this need. Indeed, Ahlén (1980–81) and Jüdes (1989) suggest that driving transects may be able to be used to compare relative abundance in different areas or to measure population trends. While the New Zealand bat field is small, and it would probably not be beneficial overall to have too large a range of potentially competing methods because the pool of comparable studies could be limited, driving transects, in certain situations, do have advantages over DoC's recently drafted standardised walking transect method (O'Donnell unpublished b). With calibration against known bat populations, these methods could be complementary.

### ***Future work***

This work raises many further questions especially concerning the possible presence of short-tailed bats in Kinleith Forest, the health of long-tailed bat populations in the Kinleith Forest area, the level of interaction between different long-tailed bat populations, the significance of exotic plantation forest to long-tailed bats, whether long-tailed bats are widespread in exotic plantation forest in New Zealand, and the implications of this — for both forestry and conservation.

## 6. CONCLUSIONS

Long-tailed bats are widespread in Kinleith Forest, and in places activity is high. Given the other areas from which the species is known, they may have a fairly continuous distribution in the central North Island. The results of this work, particularly in relation to other survey work recently undertaken in commercial exotic forest, suggest the need for a paradigm shift: instead of anticipating long-tailed bats to be absent from unsurveyed exotic plantation forest, they should be assumed present until proven otherwise.

The presence of short-tailed bats in Kinleith Forest cannot be ruled out.

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# 4

**THE USE OF ROADS BY LONG-TAILED BATS  
(*Chalinolobus tuberculatus*) IN DIFFERENT FOREST  
TYPES, KINLEITH FOREST**

## 4

## THE USE OF ROADS BY LONG-TAILED BATS (*Chalinolobus tuberculatus*) IN DIFFERENT FOREST TYPES, KINLEITH FOREST

### ABSTRACT

This research investigates the use of roads by long-tailed bats (*Chalinolobus tuberculatus*, Vespertilionidae) in exotic plantation forest to examine the implications for bats of additional roading, and to evaluate whether survey methods concentrating on road habitats are appropriate in plantation forest. Bat activity was compared at roadside and forest interior habitats in young and mature *Pinus radiata* forest, and in mature *P. radiata* and indigenous podocarp broadleaf forest using bat detectors. In all forest types, bat activity was higher at roadsides than in the forest interior, even where the forest had not yet developed canopy closure. Bats probably showed a preference for roadsides for reasons of habitat structure, though roads may also play a role in navigation. Bats' use of roads can be used to advantage when surveying for them in plantation forest.

### 1. INTRODUCTION

New Zealand's native long-tailed bats (*Chalinolobus tuberculatus*, Vespertilionidae) are generally associated with indigenous forest (Dwyer 1960a; Daniel 1990; Higham 1992; O'Donnell 1994; Molloy 1995). They are insectivorous (Daniel 1990) and considered "edge" bats [Daniel and Williams (1984), and indicated by Dwyer (1960a), though with caveats], foraging along forest margins, over farmland and wetlands (Daniel 1990; Molloy 1995). Work concerning wing morphology (e.g. Daniel 1990), and echolocation call structure (e.g. Parsons 1997; Parsons and others 1997; Lloyd 1998), and considering the relationship between these and habitat use (e.g. Neuweiler 1984; Fenton 1990; Altringham 1996; de Oliveira 1998) also supports this view, as do recent field studies of habitat use (notably O'Donnell and Sedgeley 1994; O'Donnell 1997; and later more detailed works 1999, 2000; Griffiths 1995, 1996). Further, O'Donnell and Sedgeley (1994), and Griffiths (1996), showed that roads — a variety of edge habitat, may be preferentially exploited by long-tailed bats in indigenous beech (*Nothofagus*) forest and tussock grassland, and lowland podocarp broadleaf forest respectively. Krusic and Neefus' (1996) study, in hardwood and spruce/fir forest with areas managed for timber production (north-eastern USA),



also suggests the importance of linear features, such as roads, to bats. These likely offer “relatively uncluttered commuting “highways” and foraging areas” (p 196), and may provide, with other elements, “the mosaic of habitats that encourage bat use and diversity” (p 196).

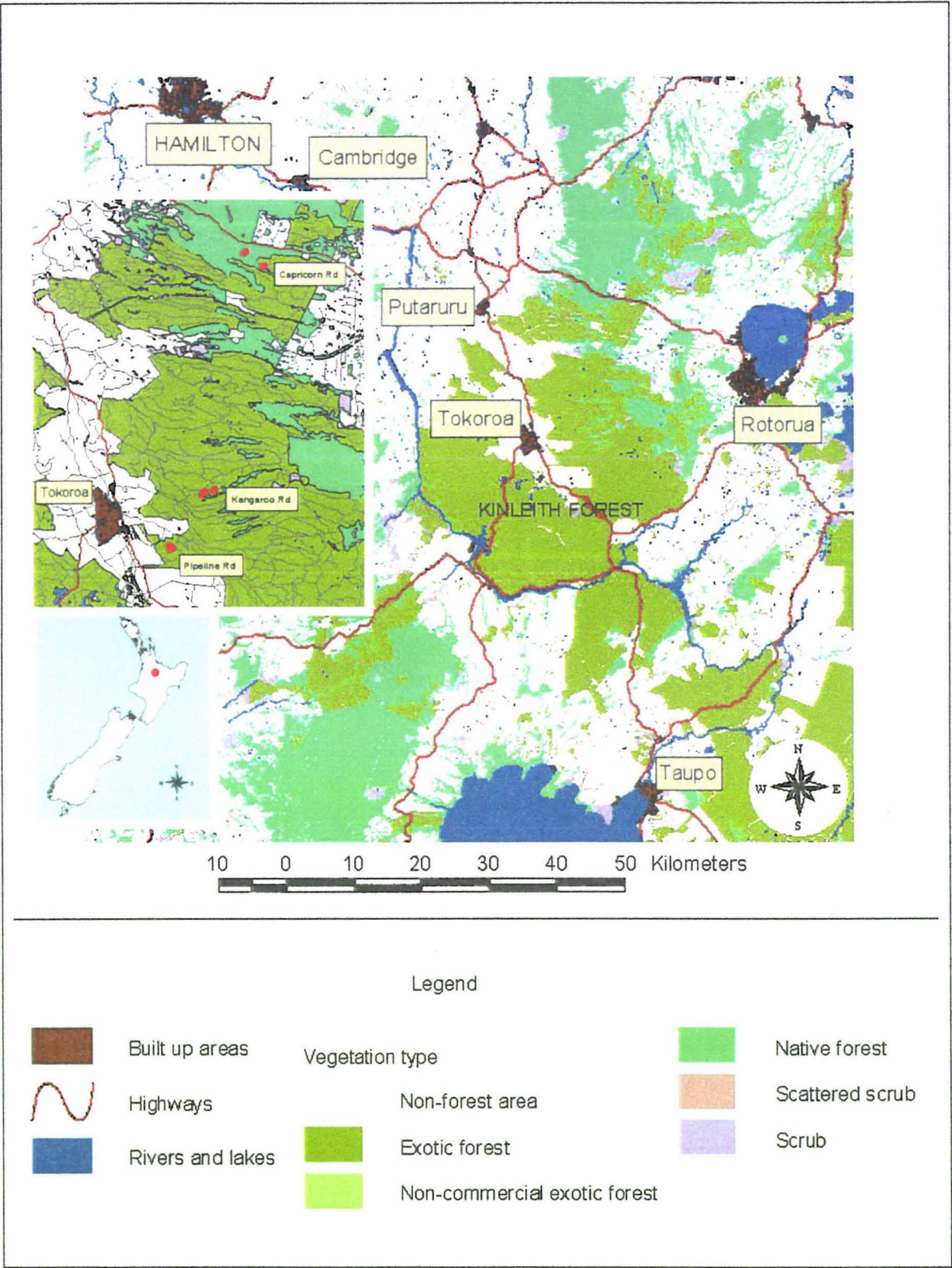
Long-tailed bats are widespread in Kinleith Forest (Chapter 3), a 131,000 ha exotic plantation forest in the central North Island, New Zealand. Roothing is an integral part of modern plantation forest management (Robinson 1995). Road has displaced rail transport in New Zealand’s plantation forests (Allsop 1964) and Kinleith Forest is well rooded in relation to other plantation forests (R Black unreferenceed personal communication 1999). While the road network is extensive, harvesting operations usually require additional rooding and road maintenance. Harvesting operations and rooding are planned together to ensure sensible design and minimise overall cost (Robinson 1995). Roads may be formed some six to 18 months ahead of harvesting (R Black unreferenceed personal communication 1998). Given long-tailed bats’ reported use of edge habitats, and that they do not travel far into the forest interior to roost (Gillingham 1996; Sedgely and O’Donnell 1999), perhaps the formation of new roads helps open up new forest areas to them. Road formation may confer benefits of increased area for foraging and easy access to suitable roost sites, but these may be compromised by subsequent forest harvesting.

This investigation is the first in New Zealand to look at long-tailed bats’ use of roads in plantation forest. Additional justification for this study comes from the extensive use of roads made during the initial investigation of bat distribution (Chapter 3). While the methods used were intuitively sensible, scientifically based, provided a starting point and were successful in identifying bat presence, their usefulness in exotic plantation forest, especially for providing information about habitat use and possible preferences, is largely unevaluated. Aims were to compare bat activity on roads and inside the forest in mature and young forest, to learn more about how bats use the plantation forest environment, how this compares with their use of rooded native forest, how rooding may affect long-tailed bats, and whether survey and monitoring methods concentrating on road habitats are appropriate in a commercial exotic forest.

## 2. STUDY AREA

Carter Holt Harvey Forests’ Kinleith Forest (centred around 38°17’S 175°53’E) is an exotic plantation forest of 131,000 ha in the South Waikato, central North Island, New Zealand (Figure 1; Chapter 2). *Pinus radiata* is the dominant commercial species, followed by *Eucalyptus* spp. and Douglas-fir (*Pseudotsuga menziesii*). Three areas formed the focus for the present study (Figure 1: topmost inset): Pipeline Rd (380–400 m asl), located south-east of Tokoroa and not far from the Kinleith Pulp and Paper Mill; Kangaroo Rd (400–420 m asl), which is east of Tokoroa and adjoins Galaxy Rd; and Capricorn Rd (480–520 m asl) in the north of the forest on the Mamaku Plateau, between Leslie Rd and State Highway 5 and running parallel to these.





**Figure 1** Location of Kinleith Forest and of study sites (topmost inset)

### 3. METHODS

#### ***Comparison of bat activity at road and forest interior habitats in two contrasting ages of exotic forest***

##### *Site selection*

Pipeline Rd, an area of 22 and 23-year-old *P. radiata* with closed canopy, and Kangaroo Rd, with five and six year old *P. radiata* and no canopy closure, were selected for comparison in this study. They were considered (respectively) representative of the mature and young pine forest within Kinleith Forest. Additionally, these sites had fairly homogeneous forest, which was not due to be harvested for some time; were relatively flat (meaning topography should not bias bat activity); and had no major streams (also a potential influence on bat activity). Both areas were bisected by roads which appeared to be used infrequently (reducing the potential of equipment theft). Bats were found to be present at each location during a pilot study.

Within each area, three paired sampling sites of roadside and forest interior habitats were chosen. These were located to avoid, where possible, unplanted skid sites (and those with trees that were clearly much younger than the surrounding forest), other roads within 100 m, and road junctions, all of which may bias the bat activity. Wāhi tapu, sites of cultural significance to local Māori, were also avoided.

##### *Site description*

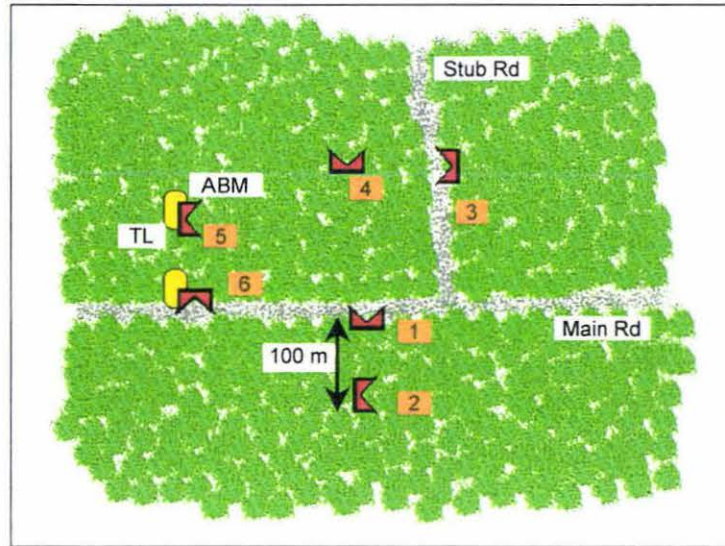
Refer Appendix 4.1 for site details.

##### *Bat detection*

Bat calls, indicating bat activity, were detected with automatic bat monitoring units (ABMs, 22, 22b and 22c models Science and Research, Department of Conservation) (Chapter 3). The rainswitch feature of 22b and c models was not used. Bat detectors were set to 40 kHz for long-tailed bats (Parsons 1997), and were calibrated with a frequency generator at the start of the investigation and rechecked as necessary. ABMs turned on at least half an hour before mean monthly sunset and off half an hour after mean sunrise, capturing the period of nightly bat activity (G Moore unpublished data). They were serviced daily — the cassette tape was changed or turned over, the battery was assessed and replaced with a fresh one when ever possible to maximise performance, and the inner workings and other settings checked. Previous work indicated that individual ABMs may differ in their sensitivity to bat calls (G Moore unpublished data). This was addressed by the investigation design adopted.

### *Sampling bat activity*

Bat activity was sampled between October and November 1999 at Pipeline Rd, and between November and December 1999 at Kangaroo Rd. The investigation design is shown schematically in Figure 2. For both locations, bat activity was monitored at two paired sites along the main road (Pipeline/Kangaroo), and at one on an adjoining stub road. Additional ABMs were set up at the long-term monitoring sites of Star Rd and Redwoods (Chapter 3) to act as controls.



**Figure 2** Generalised investigation design. ABM: automatic bat monitoring unit, TL: temperature logger, #: site number.

Six ABMs sampled nightly bat activity as three roadside-forest interior pairs (Figure 2). Pair members were located opposite one another 100 m apart to ensure independence of sampling (based on O'Donnell and Sedgeley 1994). The distance between pairs was  $\geq 100$  m. Forest interior ABMs faced parallel to the road and all in the same direction [further guaranteeing independence as ABMs' sideways range is smaller than that directly to the front (O'Donnell and Sedgeley 1994)]. Roadside ABMs faced the road.

ABMs were systematically cycled among the six sites to 1) enable specific site effects to be separated out from ABM effects, 2) provide enough degrees of freedom to allow any ABM effect to be identified in the results, and 3) minimise the possible interaction between specific site and weather effects given that the weather on any two consecutive days is likely to be similar. To illustrate, ABM "A" started at Site 1 (a roadside site) on Night 1, was moved to Site 2 (the opposite forest interior site) for Night 2 and so on. On night 7, it started again at Site 1. All odd numbered sites corresponded to road sites, and even numbered sites to forest interior sites, except for Sites 5 and 6 which were reversed to maximise the efficiency of ABM cycling. The investigation was considered complete when 12 nights' data had been obtained for each



roadside–forest interior pair, with each ABM having monitored each habitat twice. For Pipeline Rd this took 27 nights to achieve, for Kangaroo Rd, 21 nights.

### *Collecting environmental data*

Loggers (SAPAC, SAR Ltd, Kent, UK) recorded the ambient temperature at one roadside and forest interior site pair every half hour. Qualitative descriptions of all monitoring sites were made (summarised in Appendix 4.1). Road width, and the tree trunk to tree trunk distance across the road, were measured to quantify "openness". To provide a general measure of stand stature, three representative tree heights were retrospectively measured with a clinometer at all but one site which was unable to be relocated given the subsequent establishment of a trail bike track in the area.

### *Data analysis*

Tapes were transcribed and the number of bat passes per hour of real time sampled was tallied. A bat pass is "a set of two or more echolocation calls as a single bat [flies] past the microphone" (O'Donnell unpublished<sup>1</sup>, p 5).

An independent assistant helped check the reliability of coding. This was done from a range of tapes encompassing most of the models of ABMs used in combination with various results e.g. tapes with little bat activity, bat calls interspersed with extraneous environmental noise and tapes with considerable bat activity. Reliability focussed on whether there was agreement in the number of bat passes for each hour sampled by the ABM using the formula: Reliability = Agreements / (Agreements + Disagreements).

### *Bat activity in each habitat type*

The difference in bat activity per treatment (road or forest interior habitat) was tested for significance using a general linear model in SAS (version 8.01, SAS Institute Inc, Cary, North Carolina, USA). A log transformation was used to improve normality. Factors in the model, in order of entry, were: date, ABM, treatment, site, and interaction term ABM x treatment. The mean number of bat passes per site and standard error was calculated for the log transformed data, then back transformed and graphed, hence, the error bars displayed are not symmetrical about the mean.

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<sup>1</sup> O'Donnell C. A Department of Conservation bat record scheme draft proposal. 8 p. Available from: Colin O'Donnell, Department of Conservation, Private Bag, Christchurch, New Zealand.

### Proportionate use of habitat

The proportionate use of each habitat type by bats was compared between Pipeline (mature forest) and Kangaroo Rd (young forest) areas using a Chi-square test.

### Habitat use with time of night

The mean number of passes per hour throughout the night for road and forest interior habitats was calculated and graphed for both Pipeline and Kangaroo Rds. Means were calculated from 36 observations (12 nights x 3 sites).

### Ambient temperature

Temperature data were analysed for the nights from which bat activity data was obtained (though temperature data was not gathered during the first night at Kangaroo Rd). Night was defined as the period from sunset to sunrise. Loggers recorded every half hour regardless of sunset and sunrise times, and so one temperature reading either side of "night" was included in the analysis.

The two data loggers were found to differ significantly in their readings in a controlled environment over several days prior to the investigation ( $T_{159} = 8.03$ ,  $P = 0.000$ ) (Appendix 4.2), and so the mean difference in temperature was subtracted from the generally higher-reading logger before further analysis. Overall means were compared between roadside and forest interior sites using paired t-tests (Minitab version 13.1, Minitab Inc, Pennsylvania, USA) as were mean nightly minimum temperatures — an important predictor of bat activity (e.g. O'Donnell 2000). For the latter, though sample size was considerably smaller, differences followed a normal distribution (Ryan-Joiner test, Pipeline Rd:  $R = 0.9858$ ,  $P > 0.1000$ , Kangaroo Rd:  $R = 0.9239$ ,  $P = 0.0528$ ) (Appendix 4.3).

### Proportion of foraging calls

The level of foraging calls or buzzes (Griffin and others 1960) to passes was calculated, and for Pipeline Rd, the relative levels occurring in road and (mature) forest habitats were compared using a Chi-square test.

### ***Investigation of bat activity at road and forest interior habitats in exotic and native forest***

A further study was undertaken at Capricorn Rd (Figure 1), to compare bat activity at the road and inside the forest in native forest and adjacent *P. radiata* forest. This study aimed to assess whether bats use roads as corridors in both forest types, or whether they disperse randomly in native forest. It followed an earlier investigation which compared the level of bat activity and

foraging activity in the two forest types (Chapter 6), and was designed to test the underlying assumptions of this.

### *Site selection*

The siting of the previous study dictated where this work could be done. Capricorn Rd was originally chosen as it was the only passable road in the main Kinleith Forest area bisecting a substantial area of both native and mature exotic forest. A pilot study revealed bats to be present.

Two roadside ABM sites, one in native forest and one in exotic forest were retained from the previous investigation. Forest interior sampling sites were to be located opposite up to 200 m into the forest, and so the roadside sites retained were chosen on the basis of the adjacent terrain. Capricorn Rd is sited on a high ridgeline, and several areas investigated were not wide enough to allow the positioning of ABMs before dropping steeply away to the rivers below.

### *Site description*

Site details are provided in Appendix 4.4.

### *Bat detection*

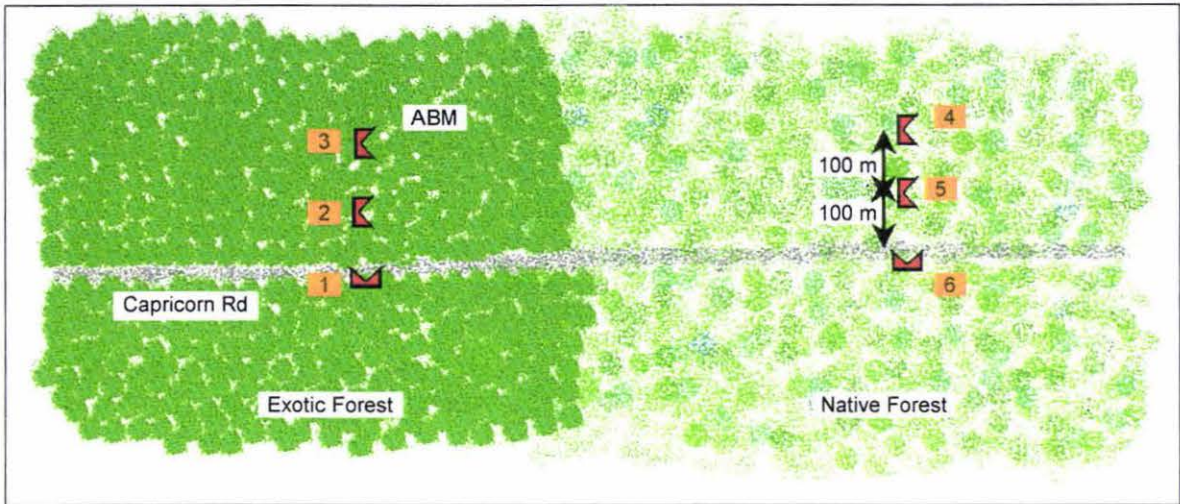
Bats were detected as described previously. ABMs were set to come on half an hour before mean monthly sunset and to turn off half an hour after mean sunrise. However, for the two final nights of the investigation, units were on only  $\geq 12$  minutes either side of the hours of darkness.

### *Sampling bat activity*

The method adopted was similar to that of the Pipeline Rd and Kangaroo Rd studies. However, ABMs were set up in a group of three in each of the native and exotic forest blocks (Figure 3). One was located on the roadside, the others were placed perpendicular to the road, one at 100 m into the forest, the other at 200 m. This spacing was adopted to ensure independence of sampling (based on O'Donnell and Sedgeley 1994). The roadside ABM faced the road, while forest ABMs faced parallel to the road.

ABMs were serviced and checked as for Pipeline and Kangaroo Rd studies, and cycled among sites (numbered as in Figure 3) until six clear nights' data had been obtained for all ABMs together, with each having sampled each site. This investigation was carried out between April and May 2000.





**Figure 3** Generalised investigation design. ABM: automatic bat monitoring unit, #: site number.

### *Collecting environmental data*

Each site was described and had three representative tree heights measured to provide a general idea of stand stature. At road sites, the tree to tree distance across the road was also measured to quantify “openness” (Appendix 4.4).

### *Data analysis*

#### Bat activity in each habitat type

Tapes were transcribed and the results graphed. The small sample size precluded detailed statistical analysis.

#### Proportion of foraging calls

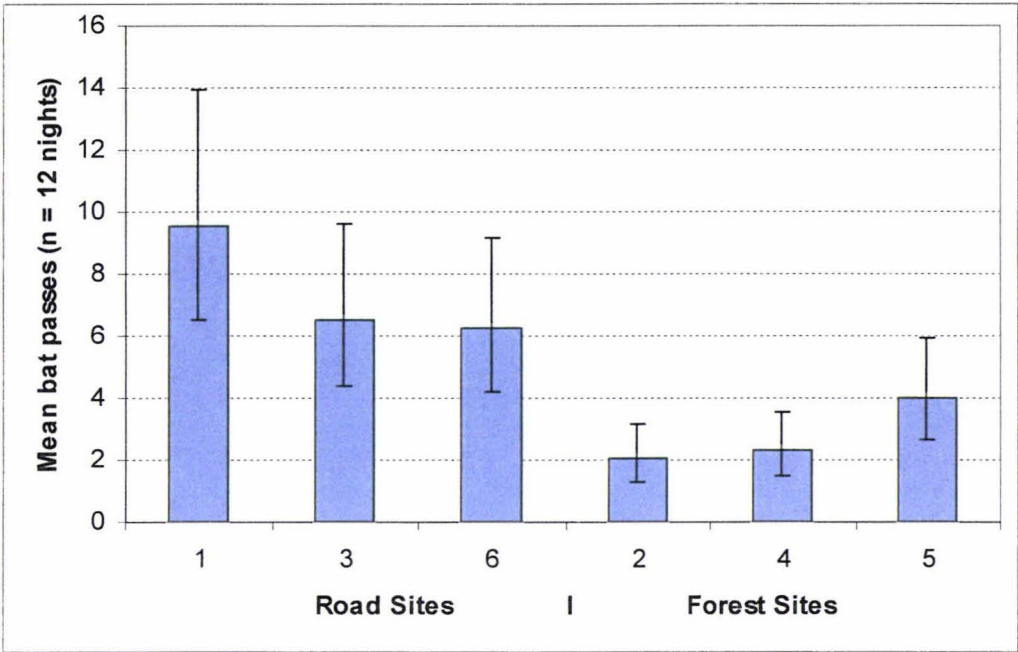
The level of buzzes (Griffin and others 1960) to passes was calculated.

## **4. RESULTS**

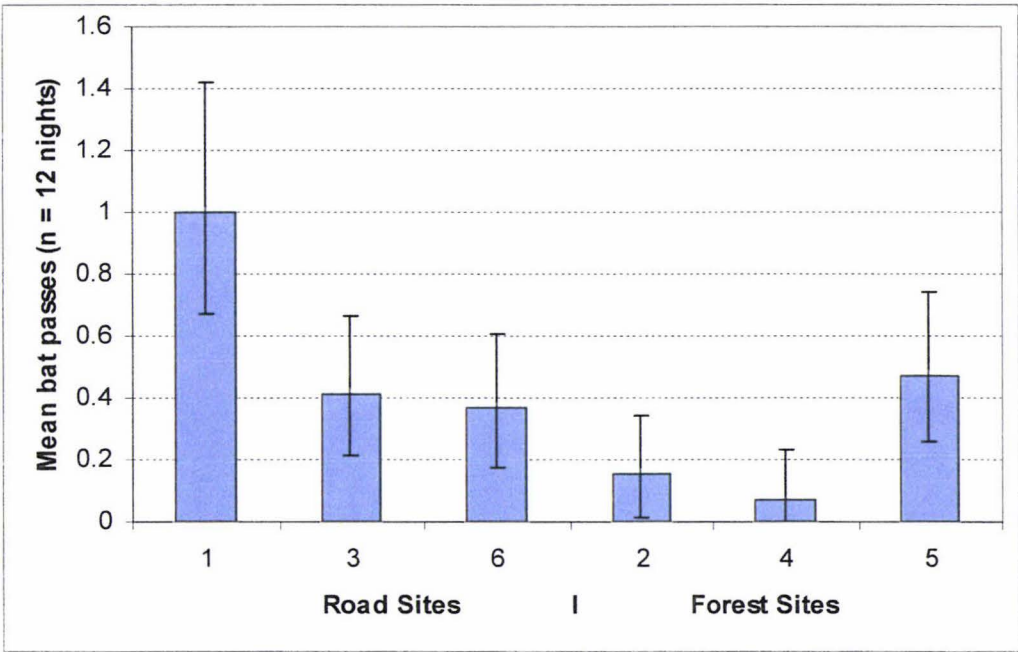
### ***Comparison of bat activity at road and forest interior habitats in two contrasting ages of exotic forest***

#### *Bat activity in each habitat type*

Bat activity was significantly higher at roadsides than in the forest interior in both the mature pines (Pipeline Rd,  $F_1 = 23.96$ ,  $P < 0.0001$ ) and the young pines (Kangaroo Rd,  $F_1 = 5.72$ ,  $P = 0.0220$ ) (Appendix 4.5). Mean nightly bat activity for all sites is shown in Figures 4 and 5. In the model of bat activity in mature pines, date and ABM used explained a significant proportion of the variation ( $F_{19} = 7.29$ ,  $P < 0.0001$ , and  $F_5 = 4.98$ ,  $P = 0.0014$  respectively). However, even



**Figure 4** Comparison of bat activity at roadside and forest interior habitats in mature pines, Pipeline Rd, Oct–Nov 1999. Nightly variation in bat activity is illustrated by standard error bars.



**Figure 5** Comparison of bat activity at roadside and forest interior habitats in young pines, Kangaroo Rd, Nov–Dec 1999. Nightly variation in bat activity is illustrated by standard error bars.

when these were included in the model, treatment effect (roadside or forest interior) was still significant. There was no significant interaction between treatment and ABM ( $F_5 = 0.57$ ,  $P = 0.7221$ ). In the young pines, only treatment was significant in explaining the patterns in bat activity observed.

### *Proportionate use of habitat*

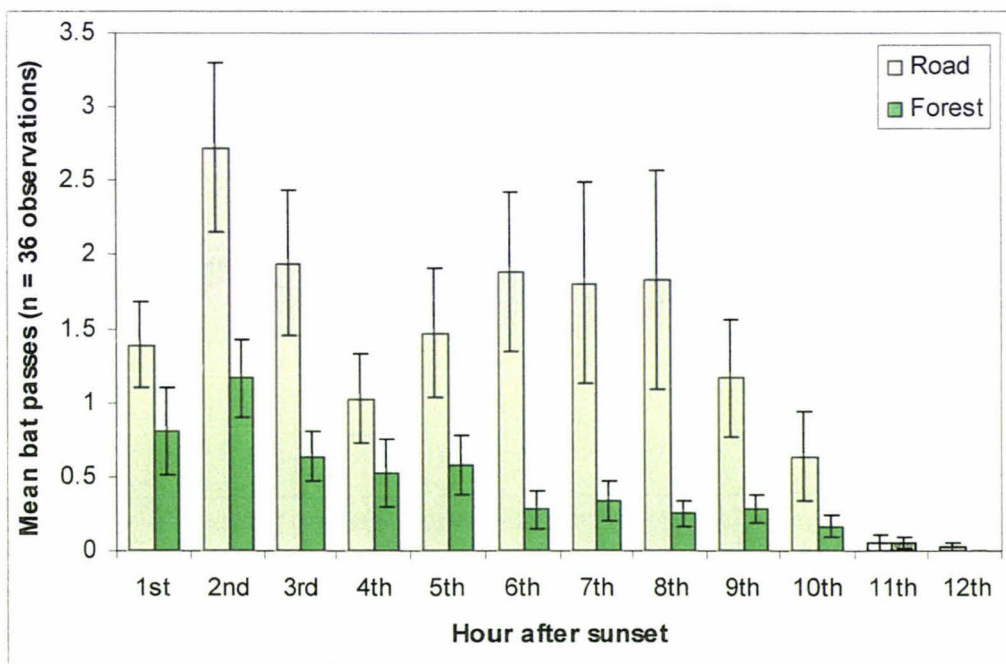
In the two ages of forest, there was no significant difference in the proportion of bat activity in roadside and forest interior habitats ( $\chi^2_{1,1} = 0.087$ ,  $P = 0.768$ ) (Table 1; Appendix 4.6).

**Table 1** Bat activity by habitat in each forest type

	Roadside % bat passes (n)	Forest interior % bat passes (n)
Mature forest (Pipeline Rd)	75.9% (575)	24.1% (183)
Young forest (Kangaroo Rd)	74.1% (40)	25.9% (14)

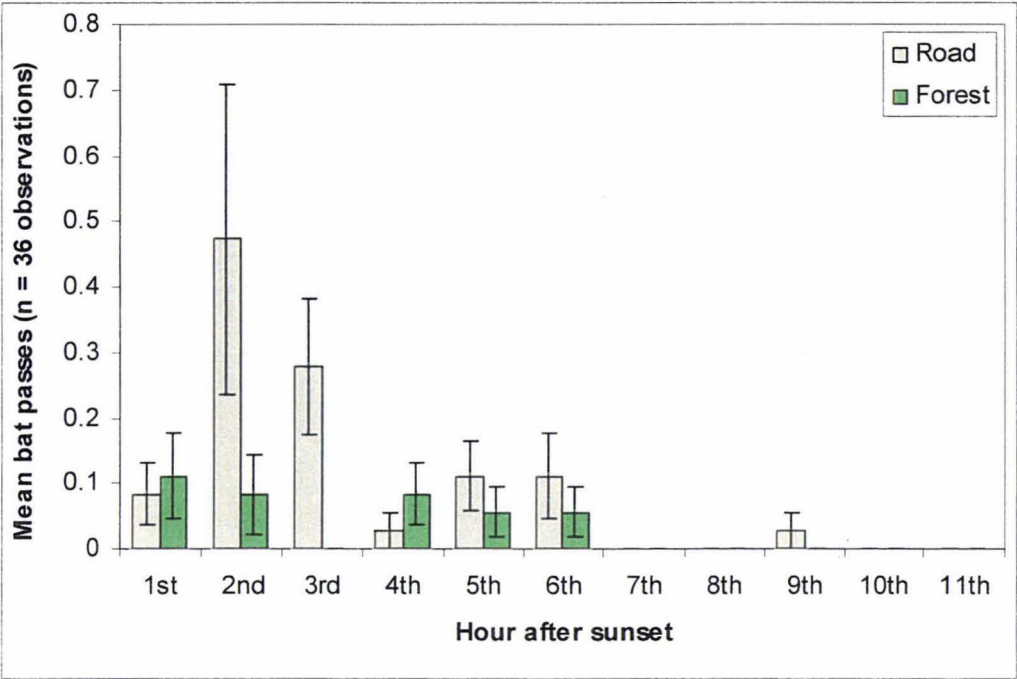
### *Habitat use with time of night*

In the mature forest, bat activity occurred throughout the night in the forest interior and at the road (Figure 6). However, activity was generally greater at the road. In the young pines, activity appeared slightly higher in the forest than at the road in the first and fourth hours after sunset (Figure 7). However, there were a couple of hours during the night (the third and ninth) where there was only activity at the road.



**Figure 6** Nightly activity profile of bats at roadside and forest interior habitats, mature pines, Pipeline Rd, Oct–Nov 1999. Bars represent standard error.





**Figure 7** Nightly activity profile of bats at roadside and forest interior habitats, young pines, Kangaroo Rd, Nov–Dec 1999. Bars represent standard error.

*Ambient temperature*

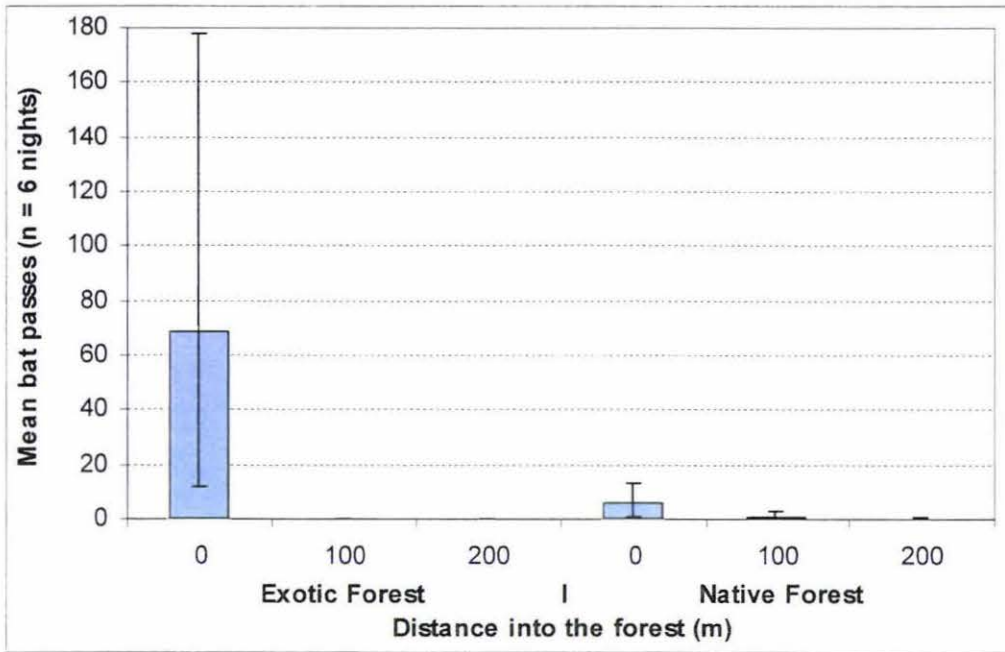
The forest interior of the mature forest was slightly warmer than the roadside ( $T = -12.98$ ,  $P = 0.000$ ), in the young pines the opposite occurred ( $T = 2.60$ ,  $P = 0.010$ ) (Appendix 4.7). The same pattern was evident from analysis of the mean nightly minimum temperatures (Pipeline Rd:  $T = -3.02$ ,  $P = 0.012$ ; Kangaroo Rd:  $T = 5.78$ ,  $P = 0.000$ ) (Table 2; Appendix 4.7).

**Table 2** Ambient temperature by habitat in each forest type

	Overall mean (°C)		Mean nightly minimum temperature (°C)	
	Road	Forest	Road	Forest
Mature forest (Pipeline Rd)	8.429	8.609	5.93	6.20
Young forest (Kangaroo Rd)	9.684	9.579	6.23	5.53

***Investigation of bat activity at road and forest interior habitats in exotic and native forest***

Bat activity was greater at the roadside than in the forest in both exotic and native forest (Figure 8).



**Figure 8** Comparison of bat activity at roadside and forest interior habitats in exotic and native forest, Capricorn Rd, Apr–May 2000. 0 m: roadside site. Bars illustrate maximum and minimum observations.

### *Proportion of foraging calls*

Rates of foraging calls were comparatively low for all areas (Table 3). There was no significant difference between rates for the two habitat types for the Pipeline Rd area ( $\chi^2_{1,1} = 0.093$ ,  $P = 0.761$ ) (Appendix 4.8) and no difference at Kangaroo Rd.

**Table 3** Summary of bat activity and foraging activity by habitat in each forest type. M: mature, Y: young.

Area	Forest type	Habitat	Nights' data	Sites pooled	Total bat passes	Total buzzes	% calls with buzzes
Pipeline Rd	M Exotic	Roadside	12	3	575	8	1.39%
	M Exotic	Forest interior	12	3	183	2	1.09%
Kangaroo Rd	Y Exotic	Roadside	12	3	40	0	0%
	Y Exotic	Forest interior	12	3	14	0	0%
Capricorn Rd	M Exotic	Roadside	6	1	411	10	2.43%
	M Exotic	Forest interior	6	2	0	0	0%
	M Native	Roadside	6	1	35	0	0%
	M Native	Forest interior	6	2	6	0	0%

### *Reliability of coding*

There was total agreement in coding ABM-nights with no bat activity, and so these were omitted from subsequent analysis. Coding reliability was hence conservatively calculated to be 85% ( $n = 213$  sample hours).

## 5. DISCUSSION

### *Bat response to habitat type*

Bats appeared to make greater use of the road than the forest in all forest types, even where the forest had no canopy closure. These findings are similar to those of O'Donnell (2000) and Griffiths (1996). O'Donnell (2000) found that of four habitat types — roads, indigenous beech forest interior and edge, and open grassland — bat activity was highest on roads. Griffiths (1996) found significantly higher bat activity in road, pond and native podocarp broadleaf forest canopy habitats at Peel Forest, than in forest interior, forest edge, river and grassland habitats. Greater bat activity at forest edge sites than forest interior sites has also been observed in North American bats (e.g. Furlonger and others 1987; Clark and others 1993; Crampton and Barclay 1996; Grindal 1996; Krusic and Neefus 1996; Grindal and Brigham 1998) and European bats (e.g. Walsh and Mayle 1991; Rachwald 1992). Other studies stress the importance of linear landscape elements to bats (e.g. Limpens and others 1989; Limpens and Kapteyn 1991; Walsh and Harris 1996). While long-tailed bats are potentially flexible in their foraging strategies (e.g. Griffiths 1996; O'Donnell 1999), they appear to behave similarly in pine plantation and native forest.

The proportion of bat activity in forest interior sites in young and mature pines was remarkably similar. This suggests long-tailed bats are consistent in their apparent preference for road habitats.

### *Possible explanations*

#### Ambient temperature

Although there were differences in the mean temperature, and mean nightly minimum temperatures, between the forest interior and roadside habitats, these differences were relatively small, and were not consistent between the different ages of forest. They probably contribute little in explaining the bat activity observed.

#### Prey abundance

There was no apparent difference in foraging rate between habitat types in these forest areas<sup>2</sup> suggesting no significant difference in prey abundance (as interpreted from Racey and Swift 1985). Though a comparison of insect abundance between habitat types was not carried out, Grindal (1996), in a comparable study with similar results, found no correlation between bat activity and insect availability. He suggested that while coniferous forest offered an abundance

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<sup>2</sup> though terminal buzzes are not always associated with foraging (Griffin and others 1960) and thus may have been used differently between the habitat types.



of potential prey, the greater environmental clutter<sup>3</sup> associated with it prevented bats from using this resource.

## Habitat structure

### Adaptations and limitations of long-tailed bats

Discussion of the possible significance of differing habitat structure between road and forest interior habitats requires an appreciation of long-tailed bats' ecomorphology and echolocation.

Long-tailed bats have moderate wing-loading, aspect ratio, and tip shape index associated with moderate to fast flight speeds, relatively low energetic costs of flight and limited manoeuvrability (O'Donnell 1999). Their echolocation calls are generally broad-band frequency modulated (FM) sweeps with a short, less modulated (quasi-constant frequency, QCF) "tail" (Parsons 1996, 1997; Parsons and others 1997). Search calls, centred around 40 kHz, have a relatively long pulse (10 ms) (Lloyd 1998). The interpulse length is around 100 ms (Parsons and others 1997; Lloyd 1998). These calls have an operational range of around 17 m (Lloyd 1998).

Wing morphology and/or echolocation call properties have been related to habitat use in a raft of studies (notably Neuweiler 1984; Aldridge and Rautenbach 1987; Norberg and Rayner 1987; Kalko and Schnitzler 1993; Fenton 1990; and recently O'Donnell 1999) although caution is expressed by Fenton (1986). Such studies indicate that long-tailed bats are probably limited in their manoeuvrability in dense vegetation (Neuweiler 1984; Aldridge and Rautenbach 1987; Fenton 1990), restricted in echolocation ability in highly cluttered habitats (Neuweiler 1984; Aldridge and Rautenbach 1987; Fenton 1990) where short high frequency FM call structures (Krusic and Neefus 1996) with short interpulse intervals (Fenton 1990) dominate among bats, and are somewhat inefficient predators in open habitats where flying insects are likely to be scarce and where long-ranging concentrated (shallow modulated or pure tone) calls (Neuweiler 1984; Aldridge and Rautenbach 1987; Fenton 1990; Krusic and Neefus 1996) with corresponding long interpulse intervals (Fenton 1990) and high flight speeds (Aldridge and Rautenbach 1987; Fenton 1990) would be beneficial.

The search call of long-tailed bats, which combines structures associated with both clutter-adapted and open-foraging bats, seems well suited to distinguishing moving targets from a stationary background like a forest edge (Parsons and others 1997; also indicated by Aldridge and Rautenbach 1987). The QCF tail may help maximise the range over which potential obstacles and prey are detectable (Aldridge and Rautenbach 1987; Kalko and Schnitzler 1993; Parsons and others 1997). A couple of factors are involved in this. The tail section is

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<sup>3</sup> "Clutter" is "a term from radar theory referring to echoes from other than the target of interest" (Fenton 1990, p 412).

concentrated in frequency, presumably at a pitch to which the bat's hearing is most sensitive<sup>4</sup> (Neuweiler 1984; and implied by Parsons and others 1997). This terminal call frequency for long-tailed bats is seemingly at the lowest extent of their call range. As lower frequency sound suffers less attenuation than high frequency sound (Neuweiler 1984), it can be used over a longer range. Long-tailed bats' call frequency of around 40 kHz is intermediate to low on the call frequency continuum which ranges from low (e.g. 17 kHz), generally associated with open area foragers, to very high (e.g. over 150 kHz), associated with clutter-adapted foragers (Neuweiler 1984). Several vespertilionid bats are intolerant of call-echo overlap (Kalko and Schnitzler 1993), and the interpulse interval of long-tailed bats of around 100 ms would provide a moderate interval (in time and hence space) in which to process echoes before emitting the next call (O'Donnell 1999; and indicated by Fenton 1990).

All this evidence suggests that long-tailed bats are adapted for foraging along forest edges, though they may be somewhat flexible.

### Why long-tailed bats may prefer edge habitat

Long-tailed bats seem to be limited in their ability to hunt efficiently (especially given the high energetic costs of flight) in cluttered habitats such as the forest interior (O'Donnell 1999). Edge habitats not only present less clutter, but may present it in an ordered and predictable way (Fenton 1990), allowing bats to deal with it in two dimensions (Fenton 1990). One way of minimising the problem of overlap of echoes returning from clutter and those from potential prey items, is to separate these in space (Kalko and Schnitzler 1993). A bat flying along a forest road, parallel to the forest edge, would receive clutter echoes from either side and the ground, but should have no trouble in separating these out from prey echoes from ahead (Kalko and Schnitzler 1993). Indeed, Kalko and Schnitzler (1993) found pipistrelle bats often searched for prey along vegetation edges and Grindal (1996) observed greater activity at edge than in clearcut or forest interior habitats.

Attempts to observe bats in the road habitat at Pipeline Rd, were unfortunately unsuccessful. It was too dark to see bats with the naked eye, and the field of vision of the nightscope was too restricted. However, elsewhere in New Zealand long-tailed bats forage along forest edges (Daniel 1990; Molloy 1995; C O'Donnell unreferenced personal communication 2001). There is also some evidence that in plantation forest long-tailed bats orientate along roads. For example, on a driving transect (Chapter 3), a bat was heard for several seconds seemingly right above the vehicle, had the bat been flying across the road the call would have quickly faded. Additionally, several bats have been collected on the grilles of logging trucks (S Garner unreferenced personal communication 2001) and bats have been seen in the headlights of

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<sup>4</sup> Neuweiler (1984, p 449) notes that the frequency "of best hearing . . . always coincides with that frequency band of the emitted echolocation sounds containing the most energy". For long-tailed bats this is around 37.5 kHz (calculated from Parsons 1997).

vehicles (personal observation; G Newton unreferenced personal communication 1999; S Garner unreferenced personal communication 2001). The chances of these occurring are greater if bats are flying along the road. Further, while it was desired not to locate monitoring sites near road junctions, a compromise had to be made for Site 1 of the Pipeline Rd investigation. This site experienced nearly the same amount of bat activity as the other two road sites put together. Due to its position (approximated in Figure 2), bats may have travelled to this site along roads from three directions.

Hence, edge sites, and specifically roads, because of their lower structural complexity than the interior of the forest, are likely to offer favourable foraging areas (Krusic and Neefus 1996) to long-tailed bats. Indeed, O'Donnell (1999) suggests that roads provide long-tailed bats with a structural "corridor" through the forest allowing them to feed on invertebrates that may not be otherwise available. However, roads may also be beneficial to bats in other ways. They may facilitate travel (Kalko and Schnitzler 1993; Grindal 1996; Krusic and Neefus 1996; Walsh and Harris 1996; Grindal and Brigham 1998) between roosting and foraging sites and sites which fulfil social functions. Flight corridors may have an important role in enhancing the long-term survival of bat populations in fragmented habitats (indicated by Walsh and Harris 1996). For example, they may link patches, giving access to additional foraging areas, or "by providing an additional food supply that enables the bats to travel over a wider area in search of profitable feeding areas" (Walsh and Harris 1996, p 516).

### Navigation and orientation

Roads may be used in navigation and orientation (Limpens and others 1989; Grindal 1996; Krusic and Neefus 1996; Grindal and Brigham 1998), either directly (bats flying along roads) or indirectly, e.g. acting as landmarks or "beacons" to overhead bats in an otherwise homogeneous forest (Grindal and Brigham 1998). It is interesting that bat activity at Kangaroo Rd was also generally greater at roads than in the forest although the pines were comparatively short (mean 6.3 m) and there was no canopy closure. Given the low height of this forest, and potential 50 m horizontal range (O'Donnell and Sedgeley 1994) and 25 m vertical range (C O'Donnell unreferenced personal communication 2001) of the Batbox III bat detectors, bat activity was probably sampled above the forest in this area. While Griffiths (1996) found significant long-tailed bat activity above the forest canopy, the Kangaroo Rd results suggest that in this area at least, long-tailed bats may have been using the road for navigation. No foraging calls were recorded. However, at other sites these formed a small proportion of calls recorded, and at Kangaroo Rd there was comparatively little activity during the time of study.

### Predation, competition, roosting opportunities

Foraging outside of the forest itself is probably not a response to predators. Moreporks (*Ninox novaeseelandiae*), the only likely natural predator of volant bats (Dwyer 1960a, 1960b, 1962;



Daniel and Williams 1984), frequently hunt from perches along the forest edge (O'Donnell 1999). Neither does the high level of activity at road habitats seem likely to be a response to interspecific competition (O'Donnell 1999), though short-tailed bats are not evident in Kinleith Forest (Chapter 3). A further factor that can influence the presence, abundance and activity of a bat species in an area is proximity to roost sites (Krusic and Neefus 1996). It is not known whether bats were roosting near any of the sites monitored during this study. However, by using multiple replicates, the chance of a nearby roost site having a significant influence on the results was diminished. (See also next.)

### *The relative value of road and forest interior habitats during the night*

The nightly activity profile of long-tailed bats was analysed for forest and road sites (Pipeline and Kangaroo Rd) to see whether the apparent value of these habitat types to the bats changed during the night. This analysis also has potential to indicate possible movement of bats from one habitat to another (e.g. O'Donnell 1999, 2000), and to suggest possible roost emergence (e.g. Grindal 1996). At Pipeline Rd, activity in the forest paralleled that at the road, but at a reduced level. There was no indication of bats moving from one habitat to the other, nor of emergence from any nearby communal roost. The activity patterns at Kangaroo Rd were less even. However, apart from generally greater activity on the road, no significant pattern is evident (though this may reflect the small sample size).

The low average numbers of passes per hour for both Pipeline and Kangaroo Rds is strongly influenced by the many zero values. Bats were not active at monitoring sites every night, and there was some variation between nights in the times bats were active.

### *Proportion of foraging calls*

The proportion of foraging calls observed overall was very low compared with Griffiths' (1996) 6.7% and 7.4% and O'Donnell's (2000) 4.9% (which he indicates is low compared to some Northern Hemisphere species). There are several possible explanations including: 1) The bats observed in the present study were mainly commuting to feeding areas, but foraging a little as they went (both inside the forest and above the road). 2) Food was limited (as suggested by O'Donnell 1999). 3) Bats were eating bigger insects and so did not need to hunt as much. Finally, 4), our studies may not be comparable. O'Donnell's (2000) and Griffiths' (1996) studies took place in mature native forest in the South Island, using a different model of ABM, and were of longer duration. These are considered further in Chapter 6.

There is evidence that foraging calls may parallel bat passes, though at reduced levels [as suggested by the Pipeline Rd data and found by e.g. Furlonger and others (1987); Griffiths (1996); O'Donnell (2000)]. Sites in the present study where no feeding buzzes were recorded also had low bat activity, possibly explaining the absence of foraging calls observed.

### ***Differences in bat activity among replicates***

Bats appeared to be more active at some sites at Pipeline and Kangaroo Rd than others. For instance, Forest Site 5 at Pipeline Rd had the greatest activity of the three forest sites, with 85 passes ( $n = 12$  nights). Perhaps there was more activity at this site than the others because the forest was more open. A couple of pines at this site had lost their tops, and there was a small gully adjacent in which no tall trees were growing. Bats may have possibly roosted in the area too.

At Kangaroo Rd, the level of bat activity was very similar between the paired Road Site 6 (8 passes) and Forest Site 5 (9 passes). Site 5 was actually located part way up a gentle hill. Bats may have used this habitat differently to the surrounding flatter land. Additionally, while the ABM was set facing along the hill, it may have effectively had a larger range than that on the road, or sampled a greater proportion of airspace above the trees.

### ***Scope and limitations***

#### *Difference in ABM sensitivity between forest interior and road habitats*

It is likely that there was some difference in the sensitivity of ABMs between habitats (Hayes and Adam 1996; Parsons 1996; O'Donnell 1999). However, this alone does not appear to account for the large difference in pass rates observed between interior and road sites (Table 1; Figure 8).

#### *Potential variability in bat calls between forest interior and edge habitats*

Possibly variability in bat call structure or intensity between habitat types influenced the results of the present study. There is evidence that bats (e.g. Griffin and others 1960; Neuweiler 1990; Kalko and Schnitzler 1993; O'Donnell 1995; Kalko and others 1998; Parsons 1998) including long-tailed bats (Parsons 1996; Corben 1997; Parsons and others 1997; Lloyd 1998) are flexible in their call structure, and long-tailed bat calls vary regionally in New Zealand (Parsons 1997). However, very little work appears to have been done looking at the call structures of long-tailed bats in different habitat types (see Corben 1997 for preliminary observations). There was no observed difference in calls recorded in the forest interior and at the roadside.

#### *Potential for sampling bat activity above the canopy*

Given the forest height at Pipeline Rd, it is unlikely that above-canopy bat activity was sampled. However, at Capricorn Rd, the forest was generally not as tall, and one of the six sites was on a ridgeline, and another overlooked a substantial gorge. Activity above the canopy was probably sampled at most sites. Griffiths (1996) found a significant level of bat activity above the canopy of podocarp broadleaf forest. The relative effects of above-canopy

sampling on the results of this study are unknown, however, there were very few bat calls recorded from forest "interior" sites.

### *Potential sensitivity differences between individual ABMs*

ABMs are somewhat variable in their sensitivity to bat calls. This was countered by calibrating the bat detectors, and cycling the ABMs around sampling sites, so bat activity at each site was sampled twice by each ABM. However, for Pipeline Rd, there was still a significant ABM effect. It is not clear exactly why this occurred, although three recently purchased late model 22b ABMs (total 32 ABM-nights) were thought to under-represent bat activity, based on evidence from a controlled trial of one against a model 22 unit at a site with consistently high bat activity (G Moore unpublished data). The newer units were subsequently found by the manufacturer to have a problem of non-linearity of the tape recorder. This effectively decreased the sensitivity of the system to certain types of bat calls (M Douglas unreferenced personal communication 1999, 2001). Unfortunately, a solution to this was not available before the start of this study. Additionally, while all ABMs had been checked prior to the study, the bat sensor of one was later found to be damaged, likely reducing its sensitivity. Various other technical difficulties were also encountered, and some deviations from the planned rotation scheme were unavoidable. Despite an ABM effect, the effect of habitat type (conservatively entered later into the model) was highly significant.

### *Other factors*

The spacing of ABMs adopted, though smaller than the 150 m used by Griffiths (1996), is thought to have been appropriate to avoid recording overlap and to objectively investigate long-tailed bats' use of road and forest interior habitats.

While minimal disturbance of forest and road sites was desired, at Pipeline and Capricorn Roads, narrow tracks were required to access forest interior sites. It is not thought that track making had any significant effect on the overall habitat structure or complexity at, or approaching, forest interior sites. Additionally, any effect would have probably been to the advantage of the long-tailed bats.

The length of time taken to complete the Pipeline Rd investigation and the fact that not all pairs were monitored simultaneously, due to e.g. equipment failures and inclement weather, is thought to have contributed to the significant time effect. However, the effect of habitat type on bat activity was still significant.

It is doubtful that variation in the consistency of coding significantly influenced the results of this study.



*Ability to compare results between studies*

The difference in overall levels of activity at Pipeline and Kangaroo Rds is considered in Chapter 5.

***Development of methods for the study of long-tailed bats in plantation forests***

The results of this study suggest that in Kinleith Forest, the strategies of ABM placement at roadsides and the use of driving transects to identify bat presence and distribution (Chapter 3) were good ones. Given the practicality of these methods, they appear widely applicable in exotic plantation forests and roaded native forest. These methods focussed on habitats bats were likely to use, and were economic of time because roads offer easy access to monitoring sites. Given the similarity in bats' proportional use of road in both the young forest at Kangaroo Rd, and the mature forest at Pipeline Rd, there is also potential to use driving transects in evaluating the relative importance of different habitat types to bats (Jüdes 1989; Chapter 5), though further investigation is recommended.

The bat field in New Zealand is comparatively young. In many areas focus is on identifying bat presence or absence (Chapter 3). Forestry companies seem increasingly interested in surveying their estates for bats, particularly with the opportunity to gain environmental certification which may provide a competitive advantage in the marketplace. The development of standardised reliable, rapid-survey methods, like driving transects which required little equipment and prior training, can only help these efforts. Such methods will also be invaluable for studying population trends and assessing the effect of management regimes (O'Donnell 2000).

***Management implications***

In the interests of providing full and balanced discussion, the possible opportunities and threats that road creation presents to long-tailed bats and other management implications are considered in Chapter 8.

**6. CONCLUSIONS**

Long-tailed bats, predicted to be "edge" bats by their wing morphology and echolocation call structure, and observed using edge and road habitats in areas of native forest, preferentially used roads over forest interior habitat in Kinleith Forest (an exotic plantation forest), probably for reasons of habitat structure, though roads may also play a role in navigation. This behaviour may be used to researchers' advantage in presence-absence and distribution surveying.

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# 5

**BROAD-SCALE HABITAT USE BY LONG-TAILED BATS  
(*Chalinolobus tuberculatus*) IN KINLEITH FOREST,  
CENTRAL NORTH ISLAND, NEW ZEALAND**



# 5

## BROAD-SCALE HABITAT USE BY LONG-TAILED BATS (*Chalinolobus tuberculatus*) IN KINLEITH FOREST, CENTRAL NORTH ISLAND, NEW ZEALAND

### ABSTRACT

Patterns of broad-scale habitat use by long-tailed bats (*Chalinolobus tuberculatus*, Vespertilionidae) in a large exotic plantation forest were examined by 1) investigating the areas where bats were found, 2) comparing the rate of "bat encounters" in two contrasting areas of forest (Galaxy and Wainui) using driving transects, 3) relating habitat use to habitat availability, 4) assessing activity in young and mature pine forest, and 5) identifying areas with high activity. Long-tailed bats are present in all the main topography types, and use a range of habitats including harvested/unstocked land; *Eucalyptus* spp., *Pseudotsuga menziesii*, *Sequoia sempervirens*, young and mature *Pinus radiata* forest; wetlands; and native forest remnants. Bats appeared to select older pine forest and generally avoid unstocked land or younger forest, this was also supported by activity findings. Older pine forest retains more heat, has a different understorey, and may offer more shelter than younger forest, potentially influencing prey abundance and bat activity. Bats' differential use of habitat may partially explain the lower number of bat encounters in the Wainui area than the Galaxy area. Six sites, including a wetland, older pine forest, and areas in or adjacent to native forest, had high bat activity.

### 1. INTRODUCTION

New Zealand's native long-tailed bats (*Chalinolobus tuberculatus*, Vespertilionidae) are threatened (Molloy 1995; IUCN 2000). Typically tree roosting (O'Donnell 1994; Molloy 1995), and generally associated with indigenous forest (Dwyer 1960; Daniel 1990; Higham 1992; O'Donnell 1994; Molloy 1995), sightings in exotic plantation forest are surprising (Daniel 1981). However, bats are known from the Kinleith Forest area (Marsh and Blake 1997) and have been seen in the plantation forest itself (Chapter 1). The present study, focussing on the distribution and ecology of long-tailed bats in Kinleith Forest, is significant nationally as it is the first comprehensive study of bats' use of this habitat type. As such, it was initially unclear where to begin looking for long-tailed bats. This chapter considers the places where bats were detected, and examines habitat use and selection by long-tailed bats.

2. STUDY AREA

Carter Holt Harvey Forests' Kinleith Forest (centred around 38°17'S 175°53'E) is an exotic plantation forest of 131,000 ha in the South Waikato, central North Island, New Zealand (Figure 1; Chapter 2). *Pinus radiata* is the dominant commercial species, followed by *Eucalyptus* spp.

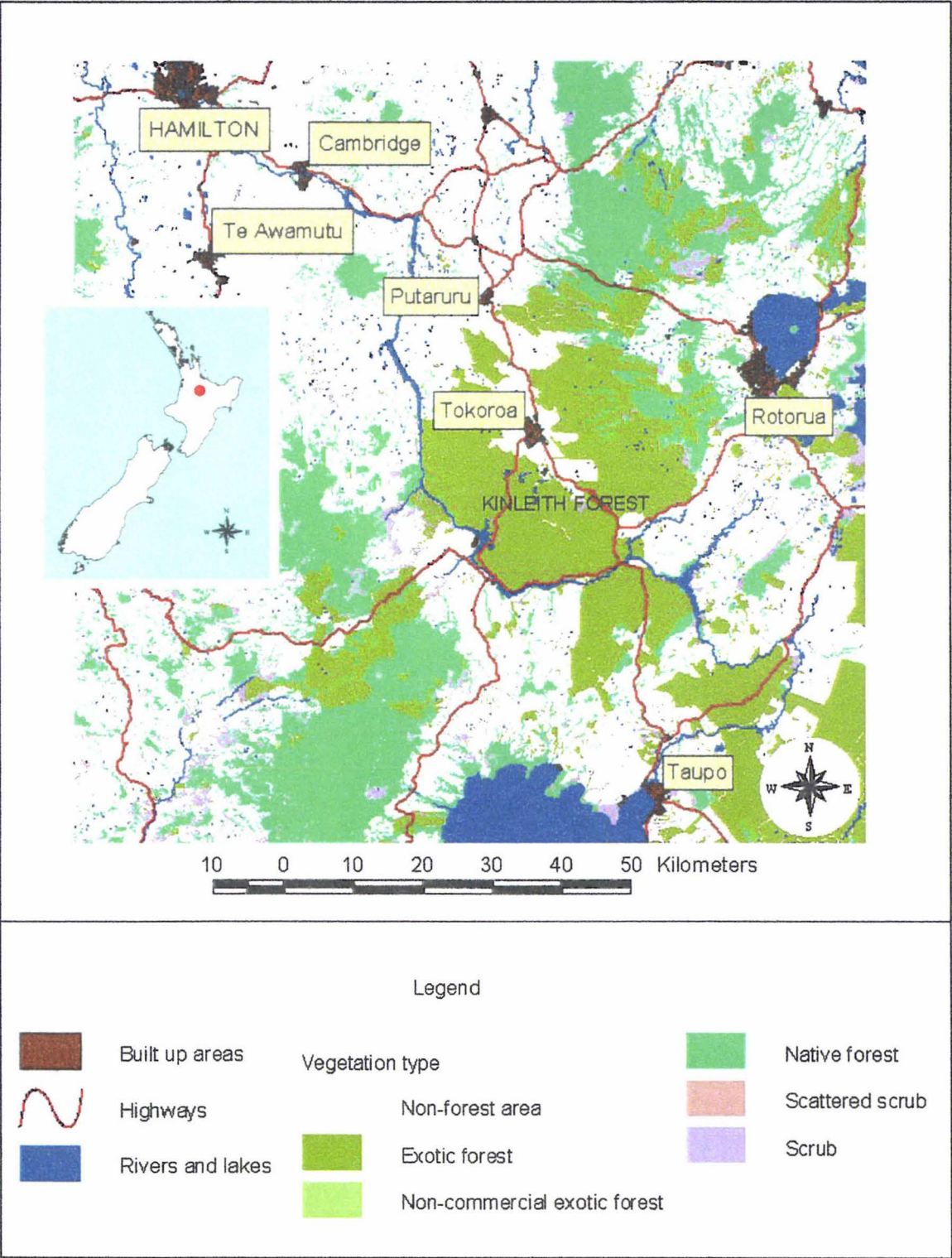


Figure 1 Location of Kinleith Forest



and Douglas-fir (*Pseudotsuga menziesii*). Areas vary from first to third rotation. At least 10% of Kinleith Forest is managed as (non-production) reserve land (R Black unreferenced personal communication 2001). Reserves include riparian vegetation, scrubland, fernland, wetlands, and gorges of podocarp broadleaf tawa forest descending from the Mamaku Plateau (R Black unreferenced personal communication 2001). The north-eastern Forest adjoins the Mokaihaha Ecological Area, a large area of podocarp broadleaf forest.

### 3. METHODS

Fieldwork was carried out between early 1998 and mid 2000.

#### ***General trends of habitat use***

Places where bats were active (bat sites) were identified using selective surveys (monitoring for bat calls at specific sites) and driving transects (monitoring continuously along a  $\approx 50$  km route) (Chapter 3). Details of bat sites including adjacent land use and vegetation, and presence of nearby streams or wetlands were recorded.

#### ***Comparison of encounter rate in two contrasting areas of forest***

Driving transects, driven on alternate nights, provided a preliminary comparison of the bat encounter rates in two contrasting areas of Kinleith Forest — Galaxy in the north-east with its large areas of indigenous forest, and Wainui in the west, an area with little indigenous forest (Chapter 3). The transects were also compared in terms of the proportional abundance of the various habitat types (forest species, age, or other land use). Habitat abundance was calculated from measurements of the road frontage length of each habitat around the route from forestry maps (see *Habitat selection*).

#### ***Habitat use by individual bats***

Radio-telemetry was a preferred method for investigating habitat use and range at a more specific level (Bradbury and others 1979; Wilkinson and Bradbury 1988). Two Austbat (Australia) harp traps ( $3.3 \text{ m}^2$  and  $4.2 \text{ m}^2$ ) (similar to Tidemann and Woodside 1978) and/or one  $6 \times 2.6 \text{ m}$   $1\frac{1}{2}$  inch mesh mist-net were used in April 1999 and January and February 2000, at seven locations in Kinleith Forest over  $> 29$  nights (Chapter 7). Harp traps were free-standing or suspended from trees, the mist-net was set up on a pulley system anchored on poles or ropes. Despite these efforts, unfortunately, no bats were caught.

#### ***Habitat selection***

Driving transects were undertaken as described in Chapter 3. For the Galaxy and Wainui transects, habitat selection was examined by comparing the habitats in which bats were



detected with their availability along the transect routes (Jüdes 1989). If bats were actively selecting certain habitats, we would expect bat sites to occur more often in those habitats than the habitats occurred along the transect. Such reasoning has been widely used by researchers investigating bat habitat or roost preferences (e.g. Crampton and Barclay 1996, 1998; Walsh and Harris 1996a; Vonhof 1996; O'Donnell 1999a, 2000b, Sedgely and O'Donnell 1999a, 1999b; Sedgely 2001). Habitat availability was assessed from forestry maps<sup>1</sup> corrected to October 1998 — the mid point of bat data collection. A measuring wheel (ASI, Switzerland) was used to measure the road frontage length of each distinct forest/land use block for both sides of the road along the transect routes. Measurements were made three times and then averaged (R Summers; D Williams unreferenced personal communication 2001). Means were then multiplied by the appropriate factor to get the distance represented on the ground. Data was sorted by habitat type and the total length of the transect in each habitat calculated.

The habitats in which bats were encountered were described in terms of the two adjacent forest types/land uses and then grouped as for the habitat availability data.

The data for the two transects was combined and the proportion of bat encounters in each habitat type calculated. The null hypothesis was that bats use Kileith Forest randomly, i.e. bat encounters per habitat would be proportional to the abundance of that habitat. Chi-square tests were used to evaluate this for areas of young pine forest (unstocked to 11-year-old trees) and older pine forest (ages 17–31 years). The expected number of bat encounters per habitat was calculated as the average number of bat encounters per kilometre multiplied by the number of kilometres occupied by each habitat.

### ***Comparison of bat activity in mature and young pine forest***

Research into the use of forest interior and roadside habitats in young and mature pine forest is described in Chapter 4. Bat activity appears lower overall in the young forest (five and six year old pines, Kangaroo Rd) than the mature forest (23-year-old pines, Pipeline Rd). Though the two areas were not monitored simultaneously, two controls — automatic bat monitoring units (ABMs) which operated at fixed sites during both studies — allow an indirect comparison of bat activity using a Chi-square test. The expected level of bat activity was calculated for the young forest as the ratio of activity in mature forest to control<sub>1</sub> at time<sub>1</sub>, multiplied by bat activity at control<sub>1</sub> at time<sub>2</sub> — the period when activity in the young forest was observed. This was repeated for the second control. Bat activity was represented by the total number of bat passes. For each of the young and mature forest, this was the summed mean nightly number of passes from the three roadside monitoring sites. Data from roadside sites rather than forest interior sites (or a combination of both) was used because bat activity was generally higher at roadsides.

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<sup>1</sup> of Kileith Forest and Fletcher Challenge Forests' Pt Horohoro Forest, located along Mamaku South Rd.

### ***Specific sites of importance***

Sites of high bat activity were identified from 885 ABM-nights' data (Table 1), and six sunset and opportunistic surveys, for 24 disparate areas. Field methods are detailed in Chapter 3. High activity was defined as  $\geq 60$  bat passes/hour, or  $\geq 100$  bat passes/night (incomplete hours of recording e.g. at the start and end of the night were omitted). A bat pass is "a set of two or more echolocation calls as a single bat [flies] past the microphone" (O'Donnell unpublished<sup>2</sup>, p 5).

**Table 1** Number of ABM-nights analysed per site

Area	n	Area	n	Area	n
Beale	3	Mercer	3	Renahan	5
Capricorn (several ABMs)	146	Neptune–Tunnel	3	Rewarewa	8
Hoiho–Tram	6	Ohakuri	5	Star	187
Hughes	9	Pipeline (several ABMs)	129	Tikitiki Bridge	2
Jack Henry–Waipa	33	Pohaturoa (4 ABMs)	19	Tunnel Rd west (2 ABMs)	9
Jade–Kowhai	11	Puriri–Te Ranga	4	Waihou	14
Kangaroo (several ABMs)	79	Rawhiti–Sambur	3	Wawa	2
Matahana	9	Redwoods, I5352	188	West Tikitiki Native	8

As bat activity can be affected by nearby active roosts (e.g. Krusic and Neefus 1996), it may be possible to locate areas containing active roosts by checking activity data (see also Chapter 7). C O'Donnell (unreferenced personal communication 2001) suggested communal roosts to have fairly constant activity throughout the night and roost-associated bat calls to be distinctive. Hence, ABM-nights with high activity but no feeding buzzes (Griffin and others 1960) were considered to possibly be associated with roost sites, and of these (four), those (two) with multi-hour activity peaks were scrutinised more closely.

## **4. RESULTS**

### ***General trends of habitat use***

#### ***Selective surveys***

Bats were present at most monitoring sites, and so the following findings largely reflect survey effort.

Long-tailed bats were mainly detected at roadsides in areas of mature ( $\geq 17$  years) pine forest. They were also found in some areas of mixed-age trees (e.g. mature pines adjacent to 2–4-year-old pines), and areas of mixed species, e.g.  $\geq 17$ -year-old eucalypts with pines (young or

<sup>2</sup> O'Donnell C. A Department of Conservation bat record scheme draft proposal. 8 p. Available from: Colin O'Donnell, Department of Conservation, Private Bag, Christchurch, New Zealand.

mature). Bats were present in the 17 ha Redwood Reserve (Frontispiece). Planted in 1927, this is one of the oldest blocks in the forest.

Bats were detected in four areas of 2–8-year-old pines.

Two wetlands had notable bat activity. Bat activity exceeded 60 passes/hour and 100 passes/night at Hoiho Rd wetland (see *Specific sites of importance*), and bats were regularly seen at Tikitiki Reserve lake. Bats were present at another two wetlands. High bat activity was also observed inside a native remnant. In another area of native forest, bats were detected in/above the forest interior, but there was much greater activity on the roadside (Chapter 6).

Bats were not detected in an area of 4–8-year-old pines at Fly Rd, in the forest interior of 23-year-old pines at Capricorn Rd, nor in exposed places around Pohaturoa in winter (though one call was heard from a roadside area in 21-year-old pines).

### *Driving transects*

Bats were encountered in a range of habitats during driving transects. The majority were in mature ( $\geq 17$ ) pines or Douglas-firs. Fewer bat calls were heard in areas of mixed age (mature and generally  $\leq 6$  years) pine forest, and even fewer again in young ( $\leq 7$ -year-old) pine forest. However, bats were observed at two harvested areas (near Skunk Rd and near Tank Rd), and again at one of these areas shortly after planting.

A couple of calls were heard in reserve areas adjacent to the Mokaihaha Ecological Area. One of these had low native forest, with emergent spars.

Bats were also detected on Mossop Rd just as we were setting up our equipment to begin a transect. This area has young pine trees bordered by pasture with a stream running through it.

### *Overall*

Long-tailed bats were present in all the main topography types of Kinleith Forest (Chapter 2), and were detected to an elevation of around 680 m asl.

### ***Comparison of encounter rate in two contrasting areas of forest***

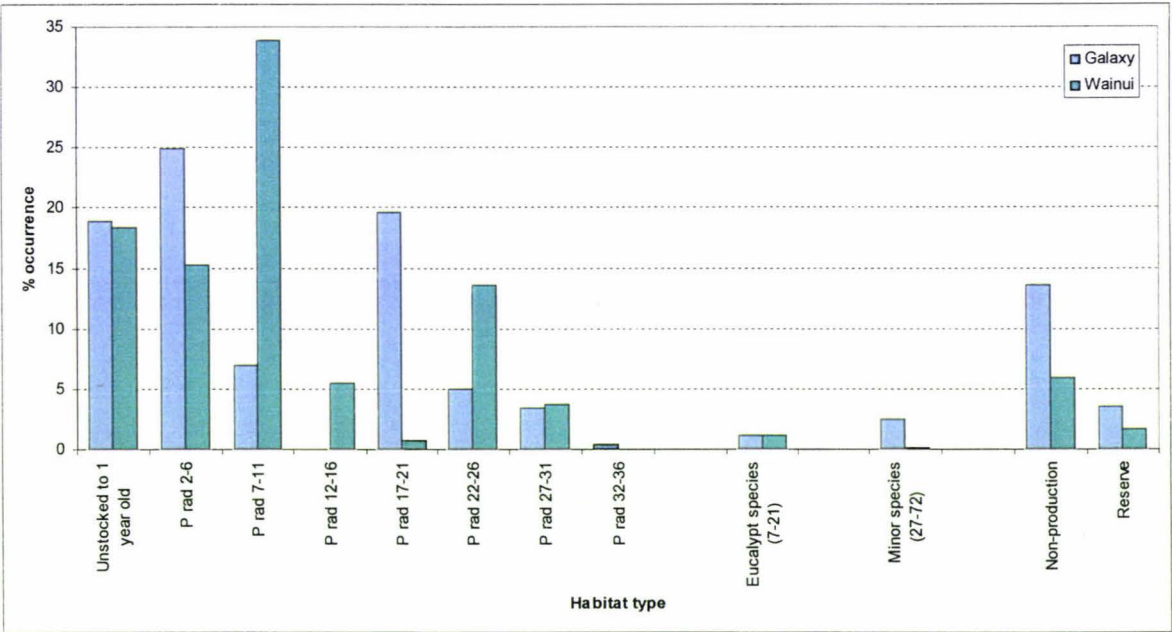
There were proportionately more bat encounters on the Galaxy transect than the Wainui transect during paired surveys (Table 2).



**Table 2** Bat encounters on paired Galaxy and Wainui transects

Date	Transect	Bat encounters	Bat encounters/km
11/02/1999	Wainui	4	
12/02/1999	Galaxy	1	
18/02/1999	Galaxy	3	
19/02/1999	Wainui	0	
12/04/1999	Galaxy	3	
13/04/1999	Wainui	0	
Total	Galaxy	7	0.13
Total	Wainui	4	0.09

A comparison of the habitat distribution of the Galaxy and Wainui transects is shown in Figure 2. Overall, the Wainui transect had a greater proportion of young (2–11-year-old) trees, while the Galaxy transect had comparatively more older (17–31-year-old) pines (Table 3) and minor species. The Galaxy transect had proportionately more reserve land — typically riparian vegetation, and areas of podocarp broadleaf forest, as well as a greater proportion of non-production land.



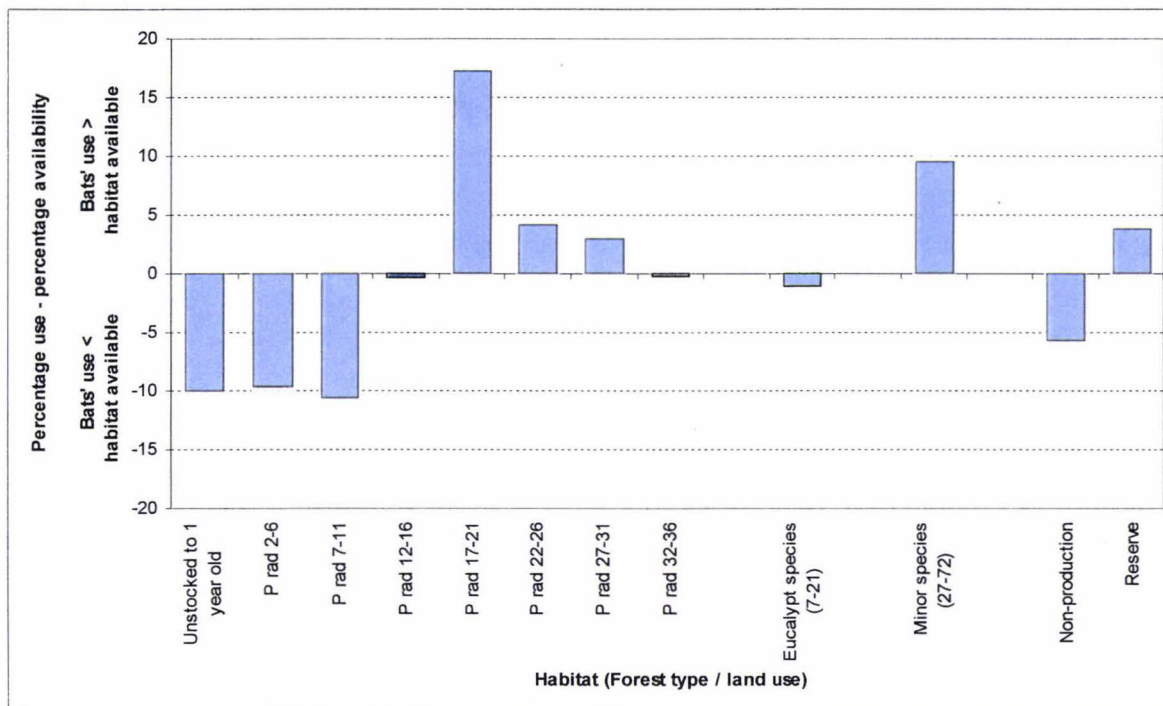
**Figure 2** Comparison of the habitats sampled by the Galaxy and Wainui transects. P rad: *Pinus radiata*, non-production land includes areas not part of Kinleith Forest and “non-forest area” but not reserves.

**Table 3** Comparison of the occurrence of key forest types along the Galaxy and Wainui transects

Habitat	Galaxy %	Wainui %
<i>Pinus radiata</i> 2–11 years	31.9	49.2
<i>Pinus radiata</i> 17–31 years	28.1	18.2

### Habitat selection

Overall, bats were encountered in 23 different locations along the Galaxy and Wainui transects. Habitats used by long-tailed bats is compared with habitat availability in Figure 3. Long-tailed bats appeared to select areas of older (17–31-year-old) pines ( $\chi^2_{1,1} = 14.30, P < 0.0005$ ) but avoid areas that were unstocked or in pines up to 11 years old ( $\chi^2_{2,1} = 7.33, P < 0.05$ ) (Appendix 5.1). They also seemed to favour areas of minor species (Douglas-firs and redwoods) and reserve areas.



**Figure 3** Habitat selection by long-tailed bats, Kinleith Forest, 1998–1999. Bat habitats are compared with their availability for Galaxy and Wainui transects. P rad: *Pinus radiata*, non-production land includes areas not part of Kinleith Forest and “non-forest area” but not reserves.

### Comparison of bat activity in mature and young pine forest

Bat activity was proportionally higher in the 23-year-old pines (Pipeline Rd), than in the five and six year old pines (Kangaroo Rd) (Table 4). The difference in activity was highly significant ( $\chi^2_{1,1} = 231.64, P < 0.0005$ ) (Appendix 5.2).

**Table 4** Comparison of bat activity in mature pines (Pipeline Rd, Oct–Nov 1999), and young pines (Kangaroo Rd, Nov–Dec 1999). Bat activity at control sites (Redwoods and Star) is used to calculate the expected level of activity in the young forest, had bats been as active there as in the mature forest.

Forest area	Observed total passes	Control site	Observed total passes	Number of nights (n)	Expected total passes
Pipeline	213	Redwoods	31	13	–
Pipeline	100	Star	208	4	–
Kangaroo	11	Redwoods	20	4	137
Kangaroo	16	Star	305	6	146

**Specific sites of importance**

Areas with high hourly levels of bat activity (≥ 60 passes) are shown in Table 5.

**Table 5** Areas of Kinleith Forest with high hourly long-tailed bat activity

Area	Date	Passes in 1 h (≥ 60)	Hour after sunset	Total nightly passes
Hoiho	25/08/1998	103, 79	9 <sup>th</sup> , 10 <sup>th</sup>	343
Redwoods	26/04/1999	≥ 63*	2 <sup>nd</sup>	Unknown
Star	12/07/1999	62	2 <sup>nd</sup>	65
Pipeline	20/08/1999	71, 165, 63, 119	3 <sup>rd</sup> , 5 <sup>th</sup> , 6 <sup>th</sup> , 7 <sup>th</sup>	510
	26/09/1999	90	8 <sup>th</sup>	205
	09/10/1999	72	7 <sup>th</sup>	≥ 97 <sup>†</sup>
West Tikitiki Native	22/01/2000	83	5 <sup>th</sup>	≥ 100 <sup>†</sup>
	07/02/2000	137	10 <sup>th</sup>	≥ 206 <sup>†</sup>
Capricorn	12/03/2000	67	9 <sup>th</sup>	225
	21/03/2000	62, 79	8 <sup>th</sup> , 9 <sup>th</sup>	195

\* 63 passes heard in 44 minutes during opportunistic bat monitoring  
† Recording incomplete

The Hoiho site backed on to a block of tall 43-year-old eucalypts and faced part of a substantial wetland along the Opareiti Stream. There were surrounding blocks of four year old pines, and an unstocked/just planted area. The Redwood Reserve, comprises 17 ha of tall 72-year-old trees. High bat activity was observed over a small grassed area directly outside this block and bordered also by young pine trees. The redwoods are the tallest trees for some distance, the surrounding area is mainly in young (≤ 6-year-old) pines. Star Rd is located in a narrow tongue of pine forest between the native forest clad valleys of the Takapuhurihuri and Onukutaurira Streams, and runs along part of the northern border of the Mokaihaha Ecological Area. The ABM was located at the junction of Star and Galaxy Rds, opposite the steep valley of the Takapuhurihuri Stream, but surrounded on other sides by 19 and 21-year-old pine forest. Pipeline Rd runs through a flat area of predominantly 23-year-old pines (Chapter 4). “West Tikitiki Native” is an area of riparian podocarp broadleaf forest along the Tikitiki Stream. The ABM was in forest of mainly low tawa (*Beilschmiedia tawa*) with *Pseudowintera axillaris* and tawari (*Ixerba brexioides*), and some rimu (*Dacrydium cupressinum*) including an impressive emergent tree. The Capricorn Rd sites were roadside sites in 13 and 23-year-old pines (Chapter 6).



The same areas, except for Redwoods, also featured as sites with high nightly bat activity. In all, there were 40 ABM-nights with  $\geq 100$  passes, some were the same as in Table 5, however the top 10 are shown in Table 6.

**Table 6** Areas of Kinleith Forest with high nightly long-tailed bat activity

Area	Date	Total nightly passes
Pipeline	20/08/1999	510
Hoiho	25/08/1998	343
Pipeline	08/10/1999	245
Capricorn	12/03/2000	225
West Tikitiki Native	07/02/2000	206
Pipeline	26/09/1999	205
Star	17/09/1999	195
Capricorn	21/03/2000	195
Capricorn	04/05/2000	192
Capricorn	30/04/2000	178

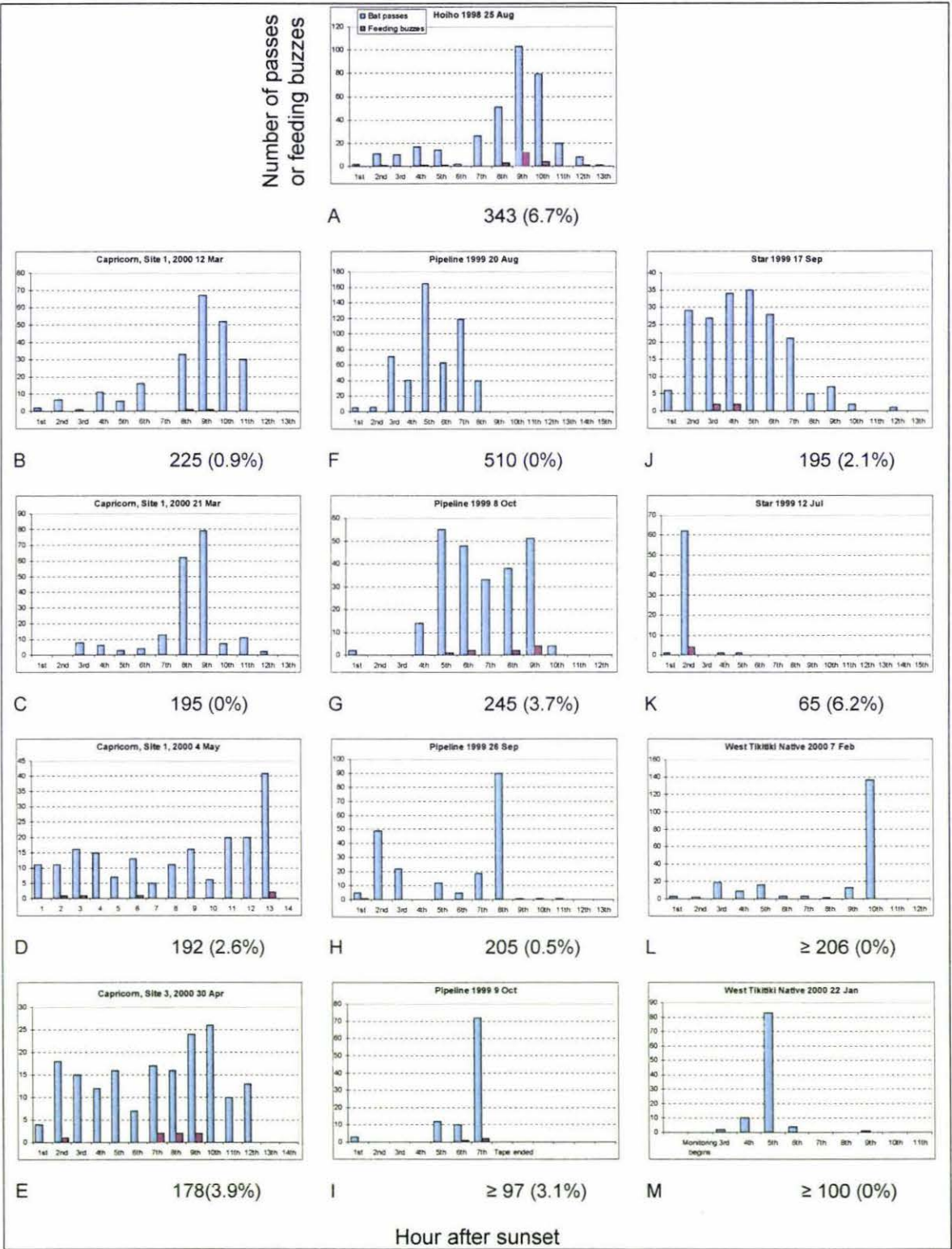
In order to examine why all these sites may be important to bats, activity profiles for the ABM-nights of high bat activity (Table 5 and 6) are shown in Figure 4. Feeding buzzes (Griffin and others 1960), indicating foraging attempts, are evident at most sites. Feeding activity was relatively high at Hoiho Rd wetland on 25 August, with 6.7% of all calls containing feeding buzzes, and up to 11.6% of calls in the ninth hour after sunset. At other sites, bat passes possibly indicate commuting activity. High bat activity, rapid passes and simultaneous calls from multiple bats observed at Capricorn Rd on 21 March, suggest this site may have been near an active communal roost (C O'Donnell unreferenced personal communication 2001).

## 5. DISCUSSION

### *General trends of habitat use*

Like long-tailed bats elsewhere (e.g. Griffiths 1996; O'Donnell 1999a, 1999b, 2000a, 2000b, 2001), long-tailed bats in Kinleith Forest use a range of habitats. While survey effort mainly focussed on roadside habitats, bats were found in most of these areas. Indeed, long-tailed bats preferentially use roads over the forest interior, probably for reasons of habitat structure although roads may also have a role in navigation and orientation (Chapter 4). Long-tailed bats make significant use roads elsewhere in New Zealand (e.g. Griffiths 1996; O'Donnell 1999a). In Kinleith Forest, long-tailed bats were also detected at forest edges e.g. where mature forest adjoined young forest. While all such areas also had roads (often one lane and unsealed) present, long-tailed bats are known to forage along forest edges (e.g. Daniel and Williams 1984; Daniel 1990; Molloy 1995) and select this type of habitat (O'Donnell 1999a).

Bats were active in many areas of older pines. O'Donnell (2000a) suggested that roads overtopped with evergreen trees of 25–40 m held temperatures  $1.0 \pm 0.8^\circ\text{C}$  higher than open areas possibly providing favourable conditions for invertebrates and bats. I observed similar



**Figure 4** Nightly activity profiles for areas with high bat activity. The total number of bat passes recorded for each night is shown beneath each graph, along with the percentage of calls containing feeding buzzes.

differences in temperature between open areas or areas of young trees and areas of mature pines in Kinleith Forest (G Moore unpublished data). I also suggest that some of the areas overtopped with pines offered a greater degree of shelter from the wind than more open areas,

affecting both invertebrate abundance (Williams 1940; Kunz 1988) and bat activity. Long-tailed bats elsewhere forage in sheltered clearings on windy nights, both in exotic forest and near beech forest (M Hansen unreferenced personal communication 2001). Overseas too there seems to be a relationship between degree of shelter, insect abundance and bat activity (Racey and Swift 1985; Mayle 1990; Limpens and Kapteyn 1991).

Long-tailed bats' presence at wetlands in Kinleith Forest is not surprising. Insectivorous bats commonly forage in wetland and riparian areas (e.g. Racey and Swift 1985; Thomas 1988; Mayle 1990; de Jong and Ahlén 1991; Walsh and Mayle 1991; Clark and others 1993; Grindal 1996; Hayes and Adam 1996; Krusic and Neefus 1996; Lunde and Harestad 1986; Parker and others 1996; Walsh and Harris 1996a, 1996b; Pierson 1998; Grindal and others 1999; Shiel and others 1999) and such areas may be very important to them (e.g. de Jong and Ahlén 1991; Grindal 1996; Parker and others 1996; Walsh and Harris 1996b; Grindal and others 1999). Long-tailed bats primarily feed over aquatic and riparian habitats in South Canterbury (Griffiths 1996; O'Donnell 2000b), including over a shallow pond in pasture adjacent to native forest (Griffiths 1996). Bat sightings are also frequently associated with water (Dwyer 1960, 1962; Daniel 1990; Chapter 3).

Bats were not detected in pine forest interior sites at Capricorn Rd. While they were detected in the interior of similar aged forest at Pipeline Rd (over a longer period), their activity was very low in this habitat. Long-tailed bats may be restricted in their ability to use the forest interior because of limited manoeuvrability and echolocation ability in highly cluttered habitats (Chapter 4). O'Donnell (1999a) found similarly low use of the forest interior by long-tailed bats in Fiordland beech forest.

Long-tailed bats were active in a couple of harvested areas, though these were near mature stands, and so could have been perceived as edge habitat by the bats (Grindal and Brigham 1998). While the driving transect method was not very sensitive to detecting feeding buzzes because each habitat was sampled for such a short period of time, I suggest the bats were probably foraging in at least one of these areas (around 15 passes were heard in six minutes). Invertebrate abundance appears to boom after harvesting (personal observations), and the bats may have been capitalising on this — many insectivorous bats are opportunistic feeders (e.g. Fenton and Morris 1976; Bell 1980; Vaughan 1980; Altringham 1996; Griffiths 1996; O'Donnell 1999a). Lunde and Harestad (1986) found greater insect abundance in a two year old cutover area than in coniferous forest or lacustrine habitat. However, Canadian research (Grindal 1996; Grindal and Brigham 1998) suggests coniferous forest may be an important source of prey and that prey abundance will be higher at forest edges but lower in the middle of clearcuts. It is interesting that there was still bat activity in this area a short time after planting, though it is not known whether the call heard represented a bat simply passing through or could have been indicative of more significant activity. Long-tailed bats have been observed in harvested areas



in other commercial coniferous forests in New Zealand (Garrick 1996a, 1996b) and have been recorded foraging in this habitat (M Hansen unreferenced personal communication 2001).

Bats were present in all the main topographies of Kinleith Forest and were detected to an elevation of around 680 m asl, consistent with other studies (Daniel and William's 1984; Daniel 1990).

### ***Habitat selection, differences in encounter rate, and differences in activity in mature and young pine forest***

That long-tailed bats appear to select older pine forest and avoid younger pine forest is interesting. Mature pine forest may be favoured over areas of younger forest because of its heat retention and shelter-providing properties and associated invertebrate abundance as discussed earlier. The younger forest was fairly open in structure — canopy closure occurs around age 9–11 (after one thinning) (Carter Holt Harvey Forests unreferenced personal communication 2001).

Older forest may also offer more habitat to potential prey species. Sierro (1999) found shrub layer cover, among other factors, to be significant in explaining habitat selection by barbastelle bats (*Barbastella barbastellus*, Vespertilionidae) in a *P. sylvestris* forest and suggested a possible link between this and prey diversity. There are certainly significant differences in understorey composition between young and mature pine forest (personal observations). Ogden and others (1997) observed adventive shrubs, predominating in stands under 20 years old in Kinleith Forest to subsequently give way to native species, and that older sites had more shade-tolerant species. Allen and others (1995) make similar observations.

There could of course also be greater activity at the edge of older forest if it contained active bat roosts. While managed pines are not likely to provide the same abundance of roosting opportunities as unmanaged mature native forest (Daniel 1981; Hunter 1990; Gerell and Lundberg 1993; Newton 1994; Kirkby and others 1998; Sedgeley and O'Donnell 1999b), older forest probably offers more roosting opportunities than younger forest (Thomas 1988; Hunter 1990; Benzal 1991; Crampton and Barclay 1996; Erickson and West 1996; Parker and others 1996). Long-tailed bats have been found roosting in areas of older pines in Kinleith Forest and elsewhere (Chapter 1, 7).

Bats were only encountered in 12–16-year-old pines once, and there was comparatively little of this habitat type around the routes (around 4.5 km, or 5%). This habitat may have intermediate properties compared with young and older forest. Perhaps bats treat it neutrally, neither selecting it or avoiding it. However, further work is needed to investigate this.

Whilst, overall, long-tailed bats appeared to avoid unstocked areas and areas of young pine forest (Figure 3), bats were detected in a couple of harvested/just planted areas, and were probably foraging in at least one of these. It is unclear how important this habitat type is to long-tailed bats. Again, more data is needed. Possibly harvested and recently planted areas are only used over a short period when prey abundance is high, and use may be restricted to warm calm nights. All three encounters were on calm nights, but ambient temperatures varied (6.6°C, 13.6°C and 16.7°C) and this sample size is small. Even if this is the case though, such areas may still be more important to bats than my coarse analysis suggests. Significance may also change seasonally. Such changes are unlikely to have been detected by this study because of small sample size. Elsewhere long-tailed bats appear to move from their summer foraging grounds to feed more intensively over indigenous shrubland in late summer (O'Donnell 1999a, 2000b). Possibly bats in Kingleith Forest also move seasonally between habitat types. All bat encounters in harvested to just planted blocks in Kingleith Forest were in April (1998 and 1999), though this probably reflects survey effort. Other records of long-tailed bat activity in harvested areas are from September to November (Garrick 1996a, 1996b), and March (included foraging activity) (M Hansen unreferenced personal communication 2001).

Bats' apparent avoidance of young pine forest may explain the lower rate of bat encounters on the Wainui transect compared with the Galaxy transect, though sample size was small. The Wainui route passed through proportionately more young forest (Figure 2, Table 3), and there was a large area of 7–11-year-old trees. However, there were also other notable differences between the two areas which could not be controlled for, including rotation, elevation, topography and hydrology, and presence of native forest (Chapter 3) — a potential roosting habitat (Chapter 7). Bat presence/activity may be affected by a combination of these factors, though there may be other equally important unforeseen influences. I suggest my observation of greater bat activity in the Galaxy than the Wainui areas be regarded as an untested hypothesis.

The finding of significantly greater activity at Pipeline Rd in 23-year-old pines than at Kangaroo Rd in five and six year old pines lends support to the transect result that long-tailed bats tend to avoid areas of young pines and select areas of older pines. Although this result would be stronger had the two areas been able to be compared simultaneously, or had there been more data in common between the study areas and the controls (prevented by equipment breakdowns), the difference between observed and expected bat activity is of an order of magnitude in two separate calculations.

It is possible that the trends in habitat selection observed from the driving transect analysis reflect differential use of roads by long-tailed bats — tall forest may have a “funnelling effect” (Ahlén 1980–81; L Conole and G Baverstock unreferenced personal communication 2000), concentrating bats along the road and elevating apparent abundance, whereas in more open

areas bats may have been flying across the landscape, not along roads. However, though further examination is recommended (Chapter 4), investigations into bats' use of roads and forest interior habitats in young pines, mature pines and native forest (Chapter 4) showed bat activity to be greater along roads regardless of vegetation type. Overseas, bats make frequent use of linear landscape elements (e.g. Limpens and others 1989; Limpens and Kapteyn 1991; Krusic and Neefus 1996; Walsh and Harris 1996b) often following the same route to foraging areas (Limpens and others 1989; Limpens and Kapteyn 1991; Racey 1998). Long-tailed bats may behave similarly in Kinleith Forest regardless of surrounding vegetation. O'Donnell (1999a) found greater long-tailed bat activity along forest edges and roads than in grassland, and long-tailed bats followed similar movement patterns each night (O'Donnell 2000b). Together with the results from the Pipeline–Kangaroo Rd activity comparison, this suggests that the use of driving transects to examine habitat selection at a broad-scale was not inappropriate, and that the results are indeed meaningful. However, I must caution that overall my findings come from a limited data set. I did not seek to provide a picture of habitat use year round, but to identify preliminary trends.

### ***Important sites***

While there are no hard and fast rules regarding what is high bat activity and what is not, the thresholds I defined seem appropriate. Grindal (1999) suggests that rates of  $19.4 \pm 11.4$  (SE) passes/hour in *Myotis lucifugus* and *M. septentrionalis* are low, and implies that rates of 80.4, around 60 or around 150 passes/hour are reasonable to high. Though he considers activity in *Myotis* bats, both *Myotis* and long-tailed bats are temperate insectivorous bats of the family Vespertilionidae. O'Donnell (2000a) reports long-tailed bats in the Eglinton Valley, Fiordland National Park, to have an average pass rate of 31.7 passes/night during summer.

There are some similarities between sites where high bat activity was observed, though the pool of sites is small. All those in exotic forest were at least in part surrounded by  $\geq 19$ -year-old forest. Two sites were in or near native forest, three were near streams or wetlands. Four sites are currently designated reserve areas or are adjacent to reserves.

It is interesting that the same sites with the exception of the Redwoods, were amongst those with  $\geq 60$  passes an hour and among the top 10 ABM-nights in terms of total bat passes. A high hourly rate of bat passes is not always associated with a high nightly total, as found for Star (1999 12 Jul) and Pipeline (1999 9 Oct). That several sites featured on more than one occasion, and sometimes over a number of different months, suggests that these sites may be important to bats at more than just one time of year. However, this is not to say that other sites (surveyed or unsurveyed) are any less important to bats. Sample sizes in many cases were small (reflecting the presence-absence focus of much of the survey work), different habitats may be used at different times of year (O'Donnell 1999a, 2000b), and bat activity is highly variable (G Moore unpublished data; Gillingham 1996; Griffiths 1996; O'Donnell 1999a, 1999c, 2000b).



For example, activity from April through to September/October can be intermittent (G Moore unpublished data), with little to no activity for several days punctuated by a night of very intensive activity. Such nights are probably mild nights during which bats choose to come out and forage, before re-entering their “semi”-hibernation. Bat activity may peak at higher levels on these nights than in more favourable seasons (G Moore unpublished data). The graphs of high activity from Pipeline Rd, represent some of the peaks in such a pattern (G Moore unpublished data).

In most areas bats appear to have been foraging. The levels of feeding buzzes to passes at Hoiho are close to or exceed those reported by Griffiths (1996: 6.7% and 7.4%), and O'Donnell (1999a: 4.9%), though their rates are reported as overall rates from larger sample sizes. This is reassuring, because rates from other areas of the forest (Chapter 4, 6, and as illustrated by several other graphs) appear low and are possibly indicative of limited prey availability (Chapters 4 and 6). Prey may indeed be limited in those areas, and perhaps overall (though see discussion in Chapter 6), but is probably abundant in localised patches (e.g. Fenton and Morris 1976; Bell 1980; Vaughan 1980; Racey and Swift 1985), one hotspot being Hoiho wetland. The high bat activity outside the Redwood Reserve was probably also foraging activity. Bats were circling and several feeding buzzes were heard (G Moore unpublished data). There was very little activity there at the same time the next night.

The distinctive calls heard at Capricorn Site 1 (21 March), suggest the potential presence of a nearby communal roost (C O'Donnell unreferenced personal communication 2001). Kingfishers (*Halcyon santa vagans*) were nesting in a bank near the ABM, and it is possible that bats also roosted in this bank or in a nearby tree cavity. Cavity-bearing trees or snags (standing dead trees) were also found at West Tikitiki Native and in the forest adjacent to Pipeline, though it is uncertain whether bats were roosting in these areas (or indeed in the other areas of high activity). Though feeding buzzes were not recorded on some ABM-nights, possibly bats were hunting, but prey densities were low. Alternatively, bats may have just been passing through or the sites may have had some social significance.

### ***Scope and limitations***

The limitations of the data have largely been discussed in the appropriate sections already, and the reader is referred to Chapter 3 regarding field methods. However, a further four factors are considered here.

As described in Chapter 3, bat detectors may have a reduced range when attached to the wing-mirrors of a vehicle — as done for driving transects. It is not clear how this range may vary with tiny alterations in detector positioning (M Douglas unreferenced personal communication 2000) e.g. from night to night. Hence, it is possible that there were differences in the effective range of the bat detectors between the two transects compared. However, because the same vehicle

was used for each, researchers were thought to be fairly consistent in their setting up of bat detectors, two bat detectors were used on each transect, and both transects were travelled a number of times, there should not have been a systematic effect.

The analysis of habitat availability is likely to have been influenced by the accuracy achieved with the measuring wheel. The wheel was generally insensitive to measurements of under about 5 mm and so small blocks may have been under-represented. However, blocks were typically larger than this. Also, by measuring each length three times and taking the average, any measurement variation would have been evened out. For reference, the length of the Galaxy transect as calculated from the map was 47.5 km, driving round it averaged 53.2 km. Wainui transect was 40.1 km (map) compared to 43.8 km (ground).

Of course evaluating habitat availability for a given period from a map, especially in such a dynamic environment, is always going to provide an approximation. However, ground-proofing indicated that the forestry maps were reasonably accurate, comparatively few areas were noted to have changed over a period of three years, and the analysis comprised a large number of blocks and focussed on broad trends.

Ideally, sample sizes would have been larger. However, other research commitments constrained data collection. By combining the Galaxy and Wainui data sets in the analysis of habitat selection any problem was reduced — 23 bat encounters gave 46 habitat types for comparison with habitat availability over a route of effectively 194 km. However, the comparison of bat encounter rates between contrasting forest areas was limited to three paired transects. To this end, the observation of greater bat activity in the Galaxy area is presented as an untested hypothesis. No work of this nature appeared to have been previously undertaken in New Zealand, and so this section of research was always intended as a preliminary investigation. That activity analysis revealed a similar pattern of bat habitat use, suggests this method shows promise, and could be used further.

### ***Management implications***

Detailed consideration of the implications for forest management is given in Chapter 8.

### ***Future work***

It would be fascinating to follow up this work and to test the hypotheses presented, e.g. to consider habitat use and selection year round, to find out more about bats' use of harvested areas and of 12–16-year-old pines, to see whether there is indeed greater activity and hence potentially greater bat abundance in the Galaxy area than the Wainui area and examine contributing factors, and then possibly use these as predictors of bat distribution/abundance in other areas of Kinleith Forest and beyond.

## 6. CONCLUSIONS

Long-tailed bats use a range of habitats in Kinleith Forest, though they were frequently found at roadsides. Long-tailed bats appear to select areas of older pines and generally avoid areas which are unstocked or in young pines. This pattern is also supported by activity data. Such a preference may partially explain the lower rate of bat encounters in the western Wainui area compared with the north-eastern Galaxy area (though there are other physical differences between these areas besides forest composition). Six surveyed sites, including a wetland area, areas in or adjacent to native forest, and areas of older pine trees, seem important to bats, though other areas including unsurveyed areas may be equally important.

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# 6

THE USE OF EXOTIC PLANTATION FOREST AND  
NATIVE PODOCARP BROADLEAF FOREST BY  
FORAGING LONG-TAILED BATS (*Chalinolobus  
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## 6

## THE USE OF EXOTIC PLANTATION FOREST AND NATIVE PODOCARP BROADLEAF FOREST BY FORAGING LONG-TAILED BATS (*Chalinolobus tuberculatus*)

### ABSTRACT

This study investigates the importance of exotic plantation (*Pinus radiata*) forest and adjacent native podocarp broadleaf forest reserve land to foraging long-tailed bats (*Chalinolobus tuberculatus*, Vespertilionidae) in Kinleith Forest. Bat activity, insect abundance and ambient temperature were compared between forest types. Bat activity and foraging activity were far greater in the plantation forest than the native forest, possibly because of the greater abundance of moths — important prey. Forest type was the best predictor of bat activity.

### 1. INTRODUCTION

New Zealand's threatened long-tailed bats (*Chalinolobus tuberculatus*, Vespertilionidae) typically roost in trees (O'Donnell 1994; Molloy 1995), and are generally associated with indigenous forest (Dwyer 1960a; Daniel 1990; Higham 1992; O'Donnell 1994; Molloy 1995). However, they are widespread in Kinleith Forest (Chapter 3), a 131,000 ha exotic plantation, predominantly *Pinus radiata* forest in the central North Island. At least 10% of Kinleith Forest is managed as (non-production) reserve land (R Black unreferenced personal communication 2001). Reserves include wetlands, riparian vegetation, fernland and areas of native podocarp broadleaf forest (R Black unreferenced personal communication 2001). High bat activity was observed in one native forest remnant, possibly indicating the presence of a nearby roost (Chapter 5, 7) and driving transects revealed seemingly more bat sites in the north-east of the forest, an area noted for its large areas of indigenous forest, than the west, an area with very little indigenous forest (Chapter 5).

While coniferous plantation forest is unlikely to provide many roosts for bats (Daniel 1981; Hunter 1990; Newton 1994; Sedgely and O'Donnell 1999), bats may be roosting in indigenous forest and venturing into the exotic forest to forage. This may have important implications for

forest management and bat conservation. Regarding the suitability of different habitat types to long-tailed bats, farmland could be considered at one end of a continuum with virgin indigenous forest at the other (implied by the results from O'Donnell 1999a). O'Donnell (1999a) repeatedly stresses the importance of indigenous forest remnants in modified (farmland) areas to bats for foraging and roosting. However, the comparative value to bats of exotic plantation forest is uncertain, and has not been previously investigated in detail in New Zealand. This chapter examines the use of adjacent areas of "mature" exotic plantation forest and native podocarp broadleaf forest in Kinleith Forest by foraging long-tailed bats.

## 2. STUDY AREA

Carter Holt Harvey Forests' Kinleith Forest (centred around 38°17'S 175°53'E) is an exotic plantation forest of 131,000 ha in the South Waikato, central North Island, New Zealand (Figure 1; Chapter 2). *Pinus radiata* is the dominant commercial species, followed by *Eucalyptus* spp. and Douglas-fir (*Pseudotsuga menziesii*). At least 10% of Kinleith Forest is managed as (non-production) reserve land (R Black unreferenced personal communication 2001). Reserves include areas of podocarp broadleaf tawa forest, particularly along rivers. The area of focus was Capricorn Rd (480–520 m asl), situated in the north of the forest on the Mamaku Plateau, between Leslie Rd and State Highway 5 and running parallel to these (Figure 1: top right inset).

## 3. METHODS

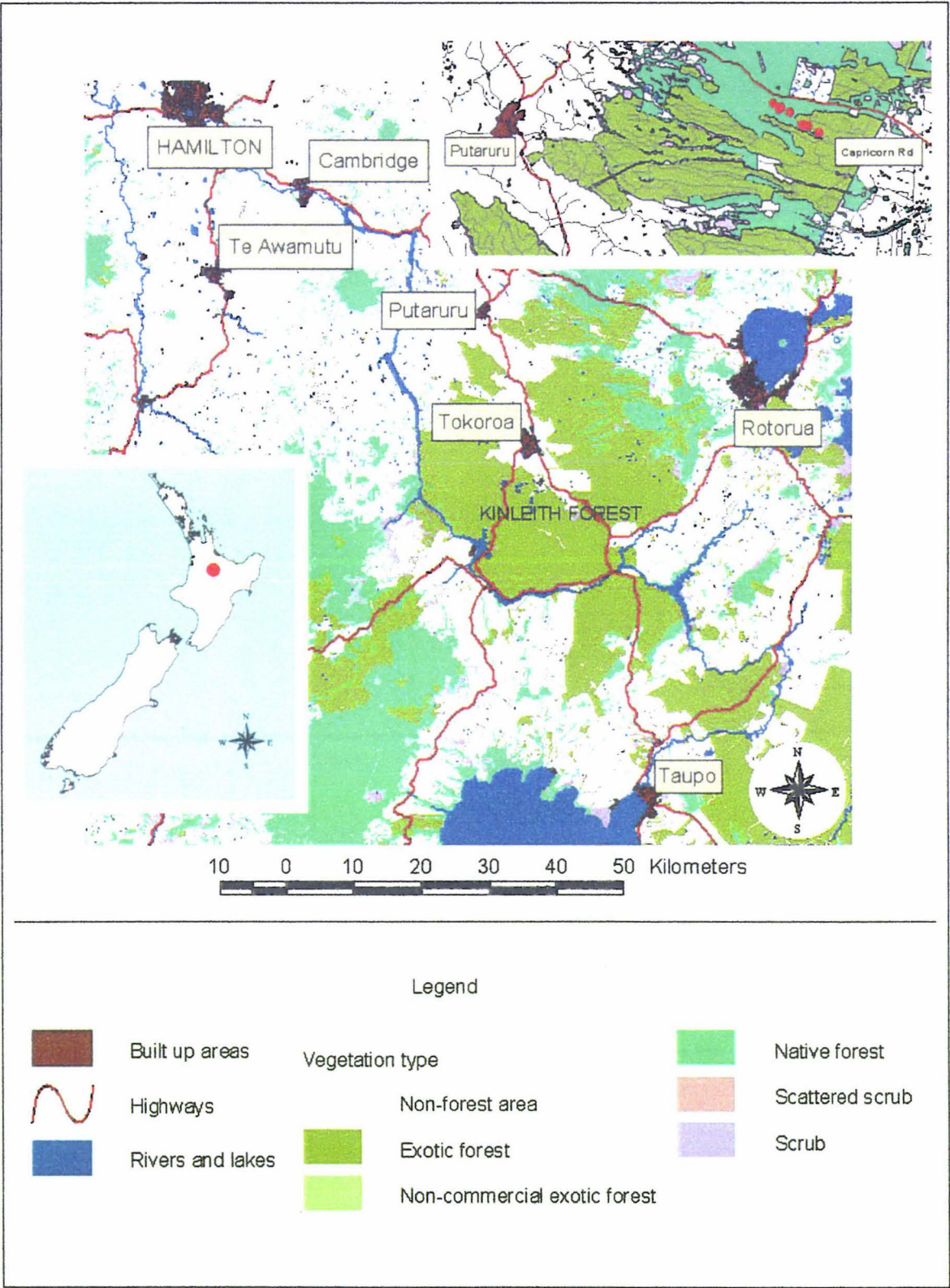
### ***Comparison of bat activity in exotic and native forest***

#### *Site selection*

Capricorn Rd was chosen because it was the only passable road in the forest travelling through sizeable areas of both "mature" pines (aged 23 and 13 years) and native forest. Bats were known from the area from anecdotal records (Chapter 3), and a pilot study confirmed there to be reasonable bat activity.

#### *Site description*

Much of Capricorn Rd runs along a high ridgeline between the Kuhatahi and Waipare Streams. The eastern end has been planted in *P. radiata* forest, and this extends some way along the ridge, while the river valleys below are in mature native podocarp broadleaf forest. The middle section of the road too is in native forest. The land is somewhat hilly. The road itself is one lane wide, unsealed, and rough in places. Bat activity monitoring sites are described in Appendix 6.1. Insects were sampled at sites between these in similar forest.



**Figure 1** Location of Kinleith Forest and of study site (top right inset)

*Bat detection*

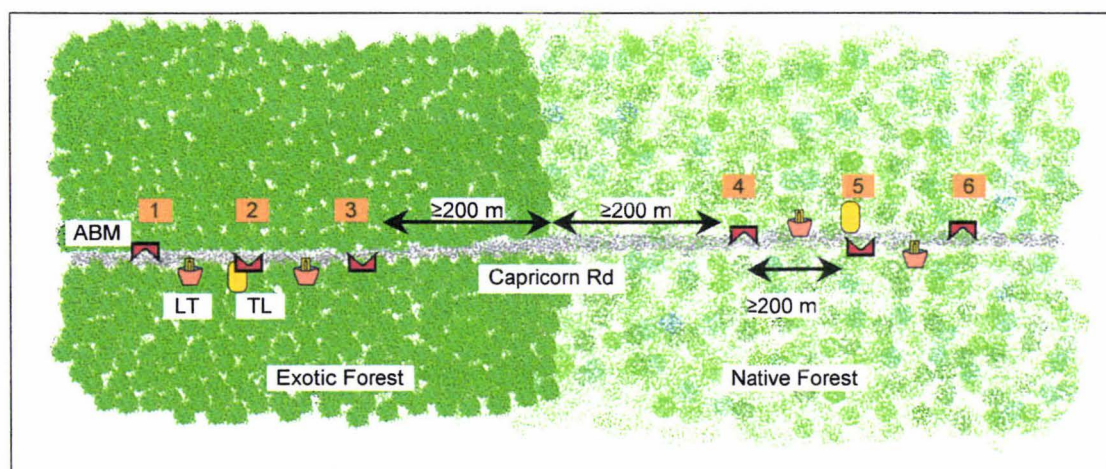
Bat calls were detected with automatic bat monitoring units (ABMs, 22, and 22b models Science and Research, Department of Conservation) (Chapter 3). The rainswitch feature of 22b models



was not used. Bat detectors were set to 40 kHz (Parsons 1997), and were calibrated with a frequency generator at the start of the study and rechecked as necessary. ABMs generally turned on half an hour before mean monthly sunset and off half an hour after mean sunrise, capturing the period of nightly bat activity (G Moore unpublished data). They were serviced daily — the cassette tape was changed or turned over, the battery was assessed and generally replaced with a fresh one to maximise performance, and the inner workings and other settings checked. Previous work indicated that individual ABMs may differ in their sensitivity to bat calls (G Moore unpublished data). This was addressed by the investigation design adopted.

### *Sampling bat activity*

Bat activity was monitored between March and May 2000 (most data coming from March) using six ABMs at roadside sites along Capricorn Rd — three in the exotic plantation forest, and three in the native forest (Figure 2). Monitoring sites were chosen to avoid features that may bias bat activity such as road junctions and vegetation boundaries. The two central monitoring sites were located outside a 200 m buffer zone on either side of the native-exotic forest boundary. ABMs were at least 200 m (mean 750 m) apart to ensure independence of sampling (based on O'Donnell and Sedgely 1994) and were positioned to face the road.



**Figure 2** Generalised investigation design. ABM: automatic bat monitoring unit, LT: light-trap, TL: temperature logger, #: site number.

ABMs were cycled among the six sites to 1) enable specific site effects to be separated out from ABM effects, 2) provide enough degrees of freedom to allow any ABM effect to be identified in the results, and 3) minimise the possible interaction between specific site and weather effects given that the weather on any two consecutive days is likely to be similar. ABM "A" started at Site 1 (the first exotic forest site) on Night 1 and was moved to Site 2 (the second exotic forest site) for Night 2 and so on. Night 6 saw it monitoring bat activity at the last native forest site, and for Night 7 it was moved back to Site 1 to repeat the cycle. The study was considered complete when good quality (no incomplete nights, and no ABM malfunctions) data, for all sites

simultaneously, had been obtained for each ABM in each site twice. This took 25 nights' monitoring to achieve.

### *Collecting environmental data*

#### Ambient temperature

Ambient temperature was recorded every half hour at ABM Sites 2 and 5, with SAPAC (SAR Ltd, Kent, UK) temperature loggers.

#### Insect abundance

Long-tailed bats are aerial insectivores (Daniel 1990; Higham 1992). Light-trapping was carried out on six nights (between March and April) at four locations (Figure 2) to assess potential prey availability in each forest type. Light-traps were located between bat activity monitoring sites to reduce the chance of recording artificially high bat activity should bats hunt the insects attracted to the lights (e.g. Fenton and Morris 1976; Bell 1980). Distances between bat monitoring and light-trapping sites ranged from 620 m (due to the desirability of putting the trap behind a security gate), to 50 m.

Each light-trap comprised a 17 L pale yellow plastic bucket, containing approximately 1.5 L of water with a little dishwashing detergent to reduce surface tension, and an ultraviolet (UV) fluorescent light (12 v, 8 W, Dick Smith Electronics, New Zealand) secured vertically to a depth of 10 cm (15 cm — when buckets had been fitted with light-holding brackets) inside the bucket. One tube of each light was run from approximately sunset, from a sealed gel lead-acid battery. Trapped insects were collected each afternoon before light-traps were reset. Insects were preserved in 70% ethanol.

ABM and light-trapping sites were described in terms of topography, flora, tree heights (measured with a clinometer), and general characteristics. The tree trunk to tree trunk distance across the road was measured at each site to quantify "openness".

### ***Investigation of bat activity at road and forest interior habitats in exotic and native forest***

A further study (described also in Chapter 4) was undertaken to test the underlying assumption of the previous investigation — that bats used roads in both forest types equally.

#### *Site selection*

Two roadside ABM sites, one in native forest and one in exotic forest were retained from the previous study (Sites 3 and 5). Forest interior sampling sites were to be located opposite up to



200 m into the forest, and so the roadside sites retained were chosen on the basis of the adjacent terrain. Several areas investigated were not wide enough to allow the positioning of ABMs before dropping steeply away to the rivers below.

### *Site description*

Site descriptions are provided in Appendix 6.1 and 6.2.

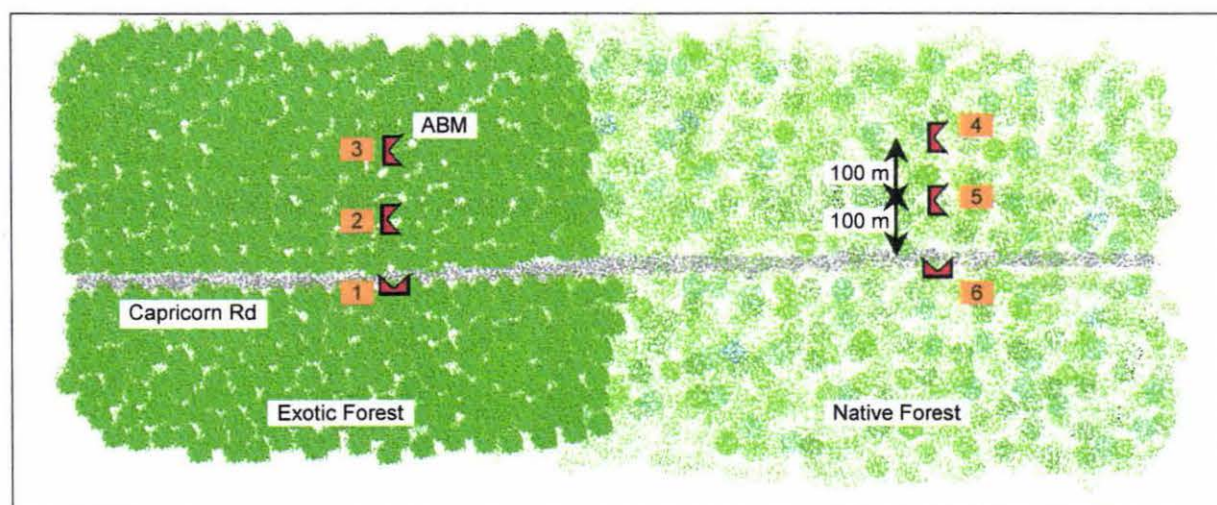
### *Bat detection*

Bats were detected as described previously using the same ABMs. ABMs were set to come on half an hour before mean monthly sunset and to turn off half an hour after mean sunrise. However, for the two final nights of the investigation, units were on only  $\geq 12$  minutes either side of the hours of darkness.

### *Sampling bat activity*

The method adopted was similar to that of the previous study. However, ABMs were set up in a group of three in each of the native and exotic forest blocks (Figure 3). One was located on the roadside, the others were placed perpendicular to the road, one at 100 m into the forest, the other at 200 m into the forest. This spacing was adopted to ensure independence of sampling (based on O'Donnell and Sedgeley 1994). The roadside ABM faced the road, while forest ABMs faced parallel to the road.

ABMs were serviced and checked as before, and cycled among sites (numbered as in Figure 3) until six clear nights' data had been obtained for all ABMs together, with each having sampled each site. This investigation was carried out between 13 April and 3 May 2000.



**Figure 3** Generalised investigation design. ABM: automatic bat monitoring unit, #: site number.



### *Collecting environmental data*

Each site was described and had three representative tree heights measured to provide a general idea of stand stature.

### ***Reliability checking***

For both investigations, after a period of training, an independent assistant helped check the reliability of coding of bat passes from the tapes (see next). This was done from a range of tapes encompassing most of the models of ABMs used in combination with various results e.g. tapes with little bat activity, bat calls interspersed with extraneous environmental noise and tapes with considerable bat activity. Reliability was calculated focussing on whether there was agreement in the number of bat passes for each hour sampled by the ABM using the formula:  $\text{Reliability} = \text{Agreements} / (\text{Agreements} + \text{Disagreements})$ .

### ***Data analysis***

#### *Comparison of bat activity in exotic and native forest*

##### Bat activity

Tapes were transcribed and bat passes totalled per ABM-night. Data from the 12 clear nights were considered for analysis. A log transformation was used to improve normality. Bat activity per treatment (exotic or native forest) was analysed in SAS (version 8.01, SAS Institute Inc, Cary, North Carolina, USA) using a general linear model. Factors in the model, in order of entry, were: date, ABM, treatment, site, and interaction term ABM x treatment. The mean number of bat passes per site and standard error was calculated for the log transformed data, then back transformed and graphed, hence, the error bars displayed are not symmetrical about the mean.

##### Foraging activity

The rate of feeding buzzes (Griffin and others 1960) to passes was calculated, and compared for exotic and native forest sites using a Chi-square test.

##### Possible influences

##### Ambient temperature

Temperature data were analysed for the 12 clear nights of bat activity data. Night was defined as the period from sunset to sunrise. Loggers recorded every half hour regardless of sunset and sunrise times, and so one temperature reading either side of "night" was included in the analysis, but readings for the intervening "day" were omitted. As there was a three minute difference between the times at which the loggers recorded ambient temperature, in one

instance two temperature readings before sunset were included for one logger, compared to one for the other — the data sets needed to be balanced for further analysis.

Overall means were compared between exotic and native forest sites using paired t-tests (Minitab version 13.1, Minitab Inc, Pennsylvania, USA) as were mean nightly minimum temperatures — an important predictor of bat activity (e.g. O'Donnell 2000a). For the latter, though sample size was considerably smaller, differences followed a normal distribution (Ryan-Joiner test,  $R = 0.9469$ ,  $P > 0.1000$ ) (Appendix 6.3).

### Insect abundance

Insects were identified to order, and counted. The bulk were Diptera (flies) and Lepidoptera (moths), key components of the diet of long-tailed bats (Gillingham 1996), and so analysis focussed on these. Comparatively little is known about the size range of insects taken by long-tailed bats, so the only omission from the data set was a large hepialid moth. Gillingham (1996) found no evidence that long-tailed bats eat insects this big, and the moth was bigger than the size range taken suggested by O'Donnell (2001). The variation in fly and moth numbers between replicate traps for each forest type was evaluated before means for each forest type were compared using paired t-tests (Minitab version 13.1, Minitab Inc, Pennsylvania, USA).

### *Modelling bat activity*

Analysis of correlations and modelling was used to find the main determinants of bat activity and see how these related to forest type. Ambient temperature (mean, maximum and minimum), moon phase and potential visibility (number of quarters of the night for which the moon was potentially visible), and bat activity data were examined along with insect abundance for those nights during which insects were sampled. Several reasons meant that two of these nights were not encompassed by the 12 nights' bat data used in the previous analyses. The variation in bat activity between replicates was considered before means were calculated. The relationship between environmental variables and mean bat activity was investigated using a Pearson correlation matrix, matrix plot, and stepwise (forward and backward, and forward) regression using Minitab (version 13.1, Minitab Inc, Pennsylvania, USA). As regression analysis is particularly sensitive to influential points, such points were subsequently removed, and the regression repeated. Bat activity data were analysed to make sure that ABM effect was not significant by calculating the median number of bat passes for the whole data set, then comparing the medians for each ABM to this using a Wilcoxon signed rank test (Minitab version 13.1, Minitab Inc, Pennsylvania, USA).

### *Investigation of bat activity at road and forest interior habitats in exotic and native forest*

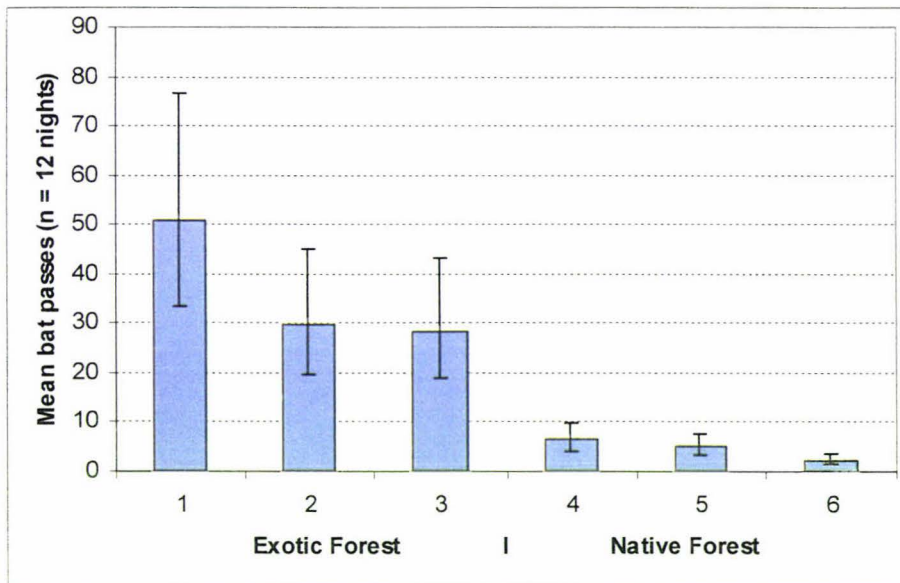
Results from tape transcripts were graphed. The small sample size precluded detailed statistical analysis.

## 4. RESULTS

### *Comparison of bat activity in exotic and native forest*

#### *Bat activity*

Long-tailed bat activity was significantly greater in the exotic plantation forest than in the adjacent podocarp broadleaf forest ( $F_1 = 96.13$ ,  $P < 0.0001$ ) (Figure 4), though there were also significant ABM ( $F_5 = 2.70$ ,  $P = 0.0322$ ) and site effects ( $F_4 = 2.61$ ,  $P = 0.0477$ ) (Appendix 6.4).

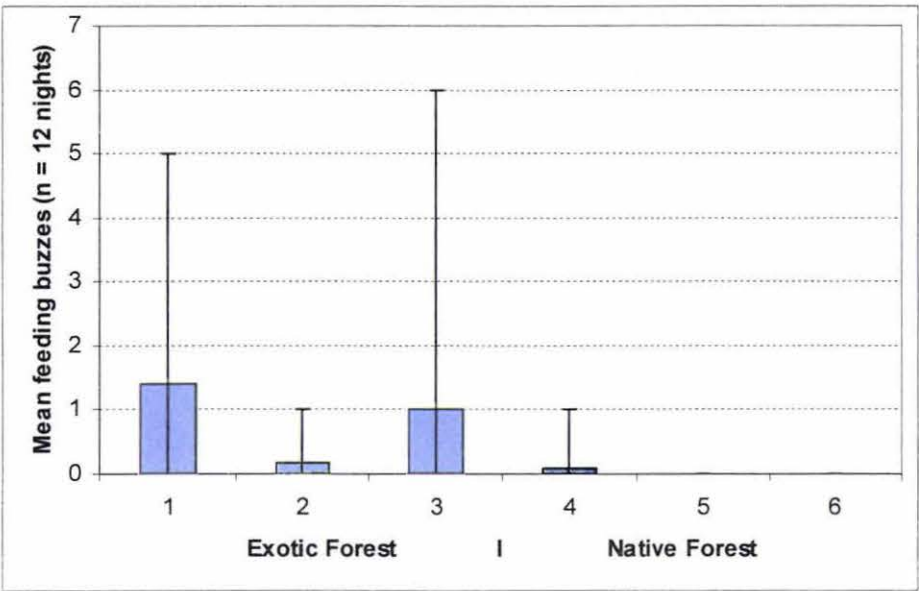


**Figure 4** Comparison of bat activity in exotic and native forest, Capricorn Rd, Mar–May 2000. Bars represent standard error.

#### *Foraging activity*

Foraging activity too was greater in the exotic forest than the native forest (Figure 5). In all, 31 feeding buzzes were recorded in the exotic forest compared with one in the native forest. However, there was no significant difference in the percentage of passes containing feeding buzzes in the exotic forest (1.74%) compared with the native forest (0.35%) ( $\chi^2_{1,1} = 3.022$ ,  $P = 0.082$ ) (Appendix 6.5) so pass data were used in further analysis.





**Figure 5** Foraging activity of long-tailed bats in exotic and native forest, Capricorn Rd, Mar–May 2000. The bars illustrate the maximum and minimum values.

*Possible influences*

Ambient temperature

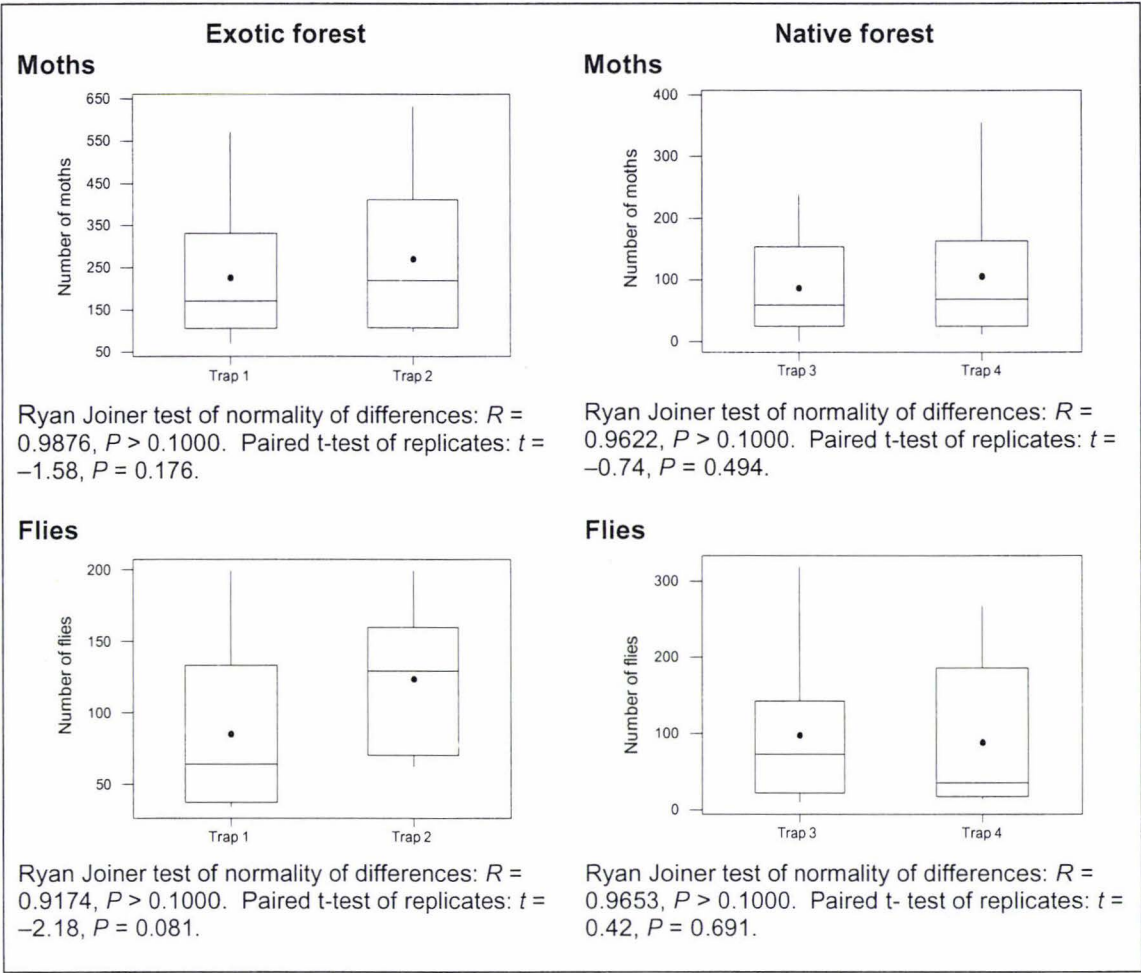
Overall, the native forest appeared significantly warmer than the exotic forest ( $t_{169} = -5.93$ ,  $P = 0.000$ ), and the mean nightly minimum temperature was also higher ( $t_{12} = -3.95$ ,  $P = 0.002$ ) (Table 1, Appendix 6.6).

**Table 1** Comparison of ambient temperature in exotic and native forest

	Exotic forest	Native forest
Mean nightly temperature (°C)	10.480	10.925
Mean nightly minimum temperature (°C)	8.232	9.495

Insect abundance

In total, 4,124 moths and 2,366 flies were caught. There was no significant difference in insect abundance between replicates (Figure 6) and so replicates were pooled.



**Figure 6** Comparison of moth and fly abundance from replicate light-traps in exotic and native forest, Capricorn Rd, Mar–Apr 2000. Graphs show range, interquartile range, median — represented by the central horizontal line, and mean — represented by the solid circle.

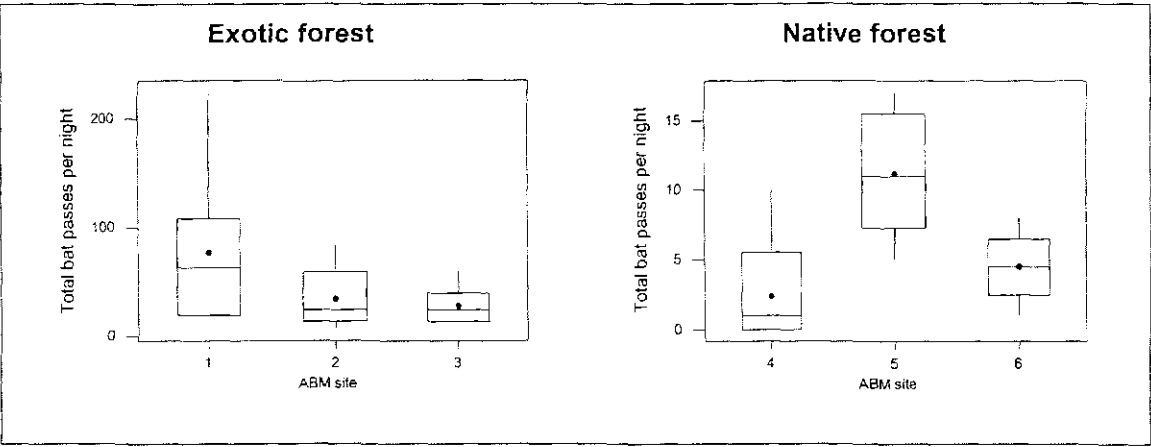
There were over twice as many moths in samples from the exotic forest than from the native forest, however fly numbers were not significantly different in the two forest types (Table 2).

**Table 2** Comparison of invertebrate abundance in exotic and native forest

	Exotic forest	Native forest	Significance ( $t$ , $P$ )
Mean number of moths	247.8	95.8	5.05, 0.000
Mean number of flies	104.1	93.1	0.53, 0.605

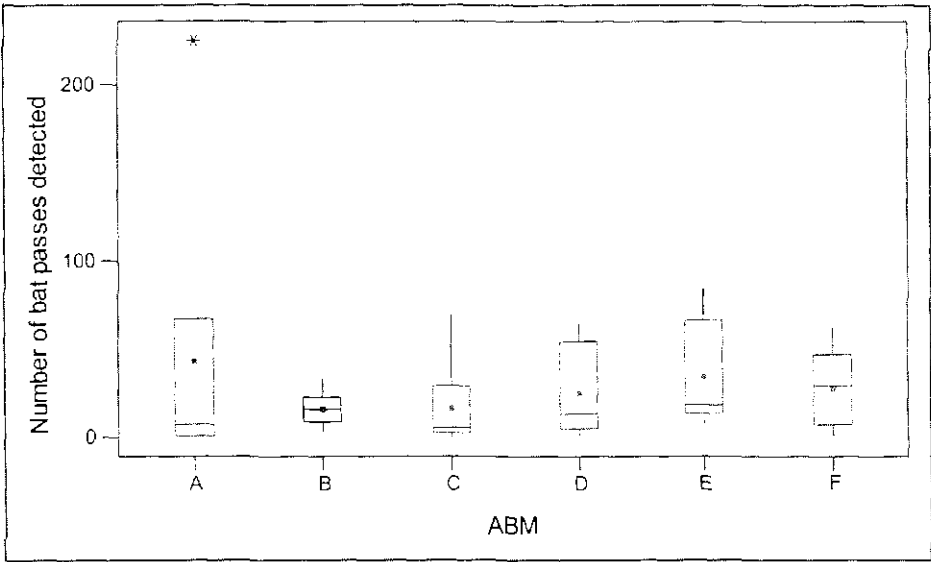
*Modelling bat activity*

There was some variation in bat activity between monitoring sites (Figure 7) particularly in the native forest. However, the difference in activity between forest types exceeded that between replicates. Hence, bat activity data for each forest type was pooled and mean activity per night calculated.



**Figure 7** Comparison of bat activity among monitoring sites, Capricorn Rd, Mar–Apr 2000. Graphs show range, interquartile range, median — represented by the central horizontal line, and mean — represented by the solid circle.

The median number of bat passes recorded overall was 14. Medians from individual ABMs were not significantly different to this (Figure 8; Table 3) indicating no large ABM effect.



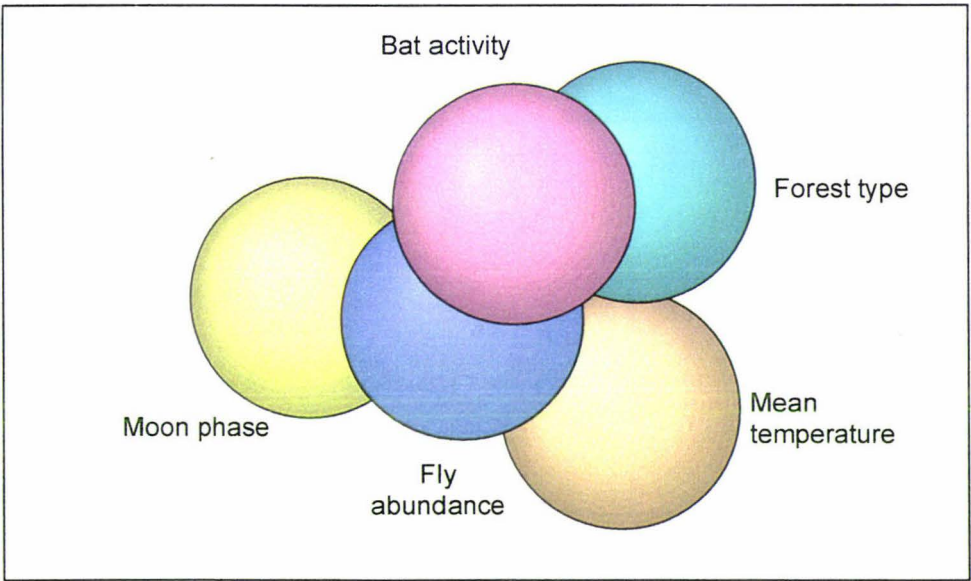
**Figure 8** Bat activity detected by each ABM, Capricorn Rd, Mar–Apr 2000. Each ABM monitored bat activity over six nights except for “F” which only recorded on five of these. Graphs show range, interquartile range, median — represented by the central horizontal line, and mean — represented by the solid square. An outlying value is shown by the asterisk.



**Table 3** Comparison of the median number of bat passes detected by each ABM with the overall median

Wilcoxon Signed Rank Test: A, B, C, D, E, F						
Test of median = 14.00 versus median not = 14.00						
ABM	N		N for	Wilcoxon	P	Estimated
	N	Missing	Test	Statistic		Median
A	6	0	5	5.0	0.590	7.500
B	6	0	5	9.0	0.787	15.50
C	6	0	6	7.0	0.529	8.000
D	6	0	6	12.0	0.834	26.00
E	6	0	6	17.5	0.173	34.00
F	5	1	5	12.0	0.281	29.00

Bat activity was strongly correlated with forest type ( $r = -0.751$ ,  $P = 0.005$ ) and the mean number of flies ( $r = 0.750$ ,  $P = 0.005$ ). Fly abundance was in turn associated, though less strongly, with moon phase ( $r = -0.567$ ,  $P = 0.054$ ) and mean temperature ( $r = 0.550$ ,  $P = 0.064$ ). These relationships are shown graphically in Figure 9. (See Appendix 6.7 for correlation matrix.)



**Figure 9** Representation of the relationships between bat activity and environmental variables based on correlation analysis. The degree of overlap of the spheres represents the strength of the relationship between the variables as defined by the P-value.

Though mean numbers of flies and moths were correlated ( $r = 0.735$ ,  $P = 0.006$ ), there was not a significant relationship between bat activity and moth numbers ( $r = 0.291$ ,  $P = 0.358$ ).

Stepwise regression (forward and backward) showed forest type (exotic or native) to be the best predictor of bat activity, followed by the mean number of flies (Table 4).

**Table 4** Forward and backward stepwise regression of mean bat activity. ExNat: forest type, MeanFlie: mean number of flies caught per forest type per night.

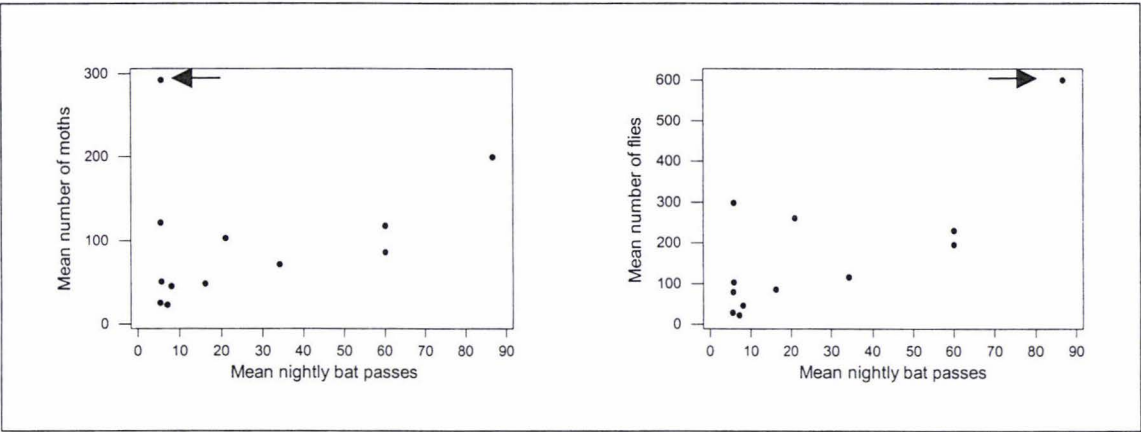
Alpha-to-Enter: 0.15 Alpha-to-Remove: 0.15			
Response is MeanBats on 9 predictors, with N = 12			
Step	1	2	
Constant	86.36	52.04	
ExNat	-40	-27	
T-Value	-3.60	-2.71	
P-Value	0.005	0.024	
MeanFlie		0.086	
T-Value		2.69	
P-Value		0.025	
S	19.3	15.1	
R-Sq	56.44	75.86	
R-Sq(adj)	52.08	70.49	
C-p	2.9	0.1	
PRESS	5356.81	4571.48	
R-Sq(pred)	37.27	46.47	

**Table 5** Forward stepwise regression of mean bat activity. ExNat: forest type, MeanFlie: mean number of flies caught per forest type per night, MaxTemp: maximum nightly temperature per forest type, MeanMoth: mean number of moths caught per forest type per night.

Forward selection. Alpha-to-Enter: 0.25				
Response is MeanBats on 9 predictors, with N = 12				
Step	1	2	3	4
Constant	86.36	52.04	116.17	108.26
ExNat	-40.1	-27.0	-27.2	-20.8
T-Value	-3.60	-2.71	-2.85	-1.99
P-Value	0.005	0.024	0.021	0.087
MeanFlie		0.086	0.099	0.149
T-Value		2.69	3.11	2.99
P-Value		0.025	0.014	0.020
MaxTemp			-4.9	-4.8
T-Value			-1.38	-1.41
P-Value			0.205	0.201
MeanMoth				-0.114
T-Value				-1.28
P-Value				0.243
S	19.3	15.1	14.4	13.9
R-Sq	56.44	75.86	80.50	84.18
R-Sq(adj)	52.08	70.49	73.19	75.14
C-p	2.9	0.1	0.9	2.0
PRESS	5356.81	4571.48	4686.90	4852.98
R-Sq(pred)	37.27	46.47	45.12	43.17

Forward stepwise regression identified maximum temperature and mean number of moths to add to the explanatory power of the model (Table 5).

Both the fly and moth data contained an influential point (Figure 10).



**Figure 10** Relationship between bat activity and moth and fly abundance. Influential points are arrowed. Means represent the nightly average per forest type, calculated from the two light-traps or three bat monitoring sites.

With these points removed, both methods of stepwise regression (forward and backward, and forward) identified forest type as the best predictor of bat activity (Table 6).

**Table 6** Forward and backward stepwise regression of mean bat activity with two influential data points omitted. ExNat: forest type.

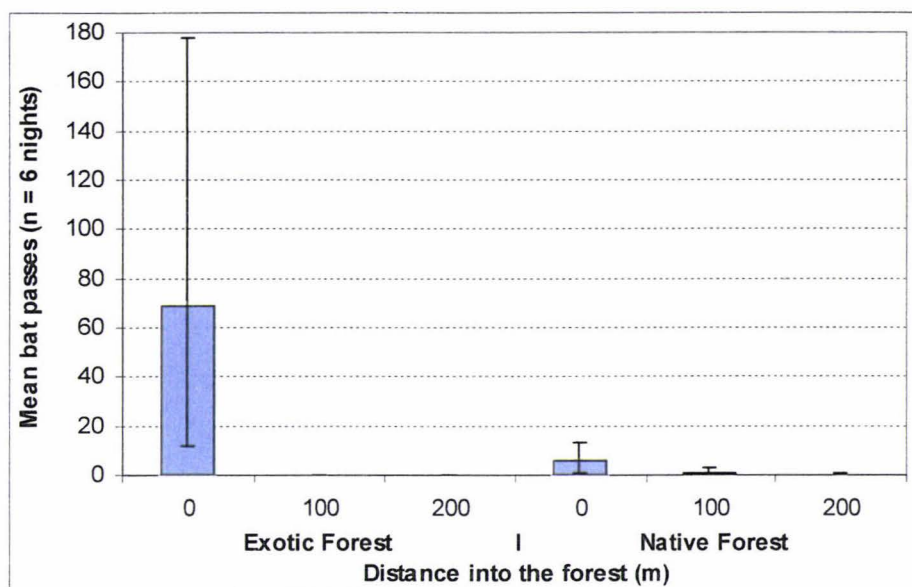
Alpha-to-Enter: 0.15    Alpha-to-Remove: 0.15	
Response is MeanBats on 9 predictors, with N = 10	
N(cases with missing observations) = 2    N(all cases) = 12	
Step	1
Constant	70.10
ExNat	-31.9
T-Value	-3.40
P-Value	0.009
S	14.8
R-Sq	59.08
R-Sq(adj)	53.96
PRESS	2753.37
R-Sq(pred)	36.06

However, there was still a significant correlation between fly abundance and bat activity ( $r = 0.726$ ,  $P = 0.017$ ), though the influences of moon phase and temperature on fly abundance were no longer significant (Appendix 6.8). The significance of the correlation between moth abundance and bat activity remained largely unaltered (Appendix 6.8).



### ***Investigation of bat activity at road and forest interior habitats in exotic and native forest***

Bat activity was greater at the roadside than in the forest in both the exotic and native forest (Figure 11).



**Figure 11** Comparison of bat activity at roadside and forest interior habitats in exotic and native forest, Capricorn Rd, Apr–May 2000. 0 m: roadside site. Bars illustrate maximum and minimum observations.

### ***Reliability of coding***

There was total agreement in coding ABM-nights with no bat activity, and so these were omitted from subsequent analysis. Coding reliability was hence conservatively calculated to be 85% ( $n = 213$  sampled hours).

## **5. DISCUSSION**

### ***Bat response to habitat type***

The significantly greater bat activity in the pine forest than the native forest, and finding that forest type was the best predictor of bat activity, is surprising, especially given 1) the seemingly widely held view in New Zealand that exotic pine forest is undesirable (Walsh 1995; Maclaren 1996) — partly because of its perceived lack of biodiversity (Chapter 3), and 2), the general association between long-tailed bats and native forest (Dwyer 1960a, 1960b, 1962; Daniel 1990; LEARNZ99 1999; O'Donnell 1999b, 2000b, 2000c, 2001). In the UK, a national bat survey found that bats selected semi-natural broadleaf woodland over mixed or coniferous woodland (Racey 1998). Elsewhere too, bat activity in areas of coniferous forest appears comparatively low (e.g. de Jong and Ahlén 1991; Krusic and Neefus 1996; Kalcounis and others

1999). In California, *Corynorhinus townsendii* (Vespertilionidae) ignored lush exotic vegetation to forage in native ironwood forest some 5 km away (Brown and others 1994). In contrast, Fawcett (1997, p 4) reports a study which found more bat activity in coniferous plantations than “overgrazed ancient woodlands” in the New Forest, England; and Rachwald (1992), in eastern Poland, detected more calls and feeding buzzes in coniferous forest than in deciduous forest.

There was no significant difference in the proportion of foraging calls in the two forest types. Feeding buzz rates have been found to parallel call rates in other studies (Furlonger and others 1987; Griffiths 1996; O'Donnell 2000a). However, the higher number of feeding calls in the exotic forest indicates greater foraging activity in that habitat. This could be considered surprising for the above reasons, and shows that long-tailed bats are not simply flying through the exotic forest to foraging grounds elsewhere. Given some insectivorous bats appear more specific in their tastes than previously thought (Pierson 1998), even flying further to forage in native vegetation (Brown and others 1994), it is exciting that long-tailed bats are feeding in exotic plantation forest. Indeed, Daniel (1981) suggested that long-tailed bats may have been feeding in plantation pine forest (Chapter 1). However, O'Donnell (1999a) stressed the importance of indigenous forest remnants in modified landscapes to provide both foraging and roosting sites for long-tailed bats.

The greater bat activity observed in exotic pine forest than native forest appears to be supported by recent work from Pureora Conservation Park. There, walking transects through native and exotic forest identified more long-tailed bat passes, and bat encounters, in pine forest than native forest (Moorcroft and others 2000), even accounting for the difference in length of the transect in each forest type. Insect abundance also appeared overall to be higher in the exotic forest (Moorcroft and others 2000).

## ***Possible explanations***

### *Investigation design*

That the bats were using the road fairly equally between forest types, indicates that the investigation design is not a key factor in explaining the big difference in bat activity between the exotic and native forest.

### *Habitat*

There were differences between the native and exotic forest in terms of the structure and species presence. The native forest showed far more variation in height partially reflecting the wide range of species present, from tree ferns to emergent rimu (*Dacrydium cupressinum*). However, the average height appeared not too dissimilar to that of the exotic forest. The native forest also had less easily defined edges. There was some unavoidable variation between monitoring sites in terms of topography. The first monitoring site in the exotic forest was in a

shallow valley, whereas the last site in the native forest was on a ridgeline. There were fewer differences between intermediate sites. Monitoring sites in the exotic and native forest appeared to have similar degrees of clutter. Overall, it is hard to know which factor or factors the bats may have found desirable. Also, my perceptions of the environment, and those of the long-tailed bats likely differ.

One possible difference between the forest types may have been in the degree of shelter offered from the wind. Perhaps the sites in the exotic forest were comparatively more sheltered than those in the native forest. Certainly long-tailed bats elsewhere forage in sheltered clearings on windy nights, both in exotic forest and near beech forest (M Hansen unreferenced personal communication 2001). Overseas too there seems to be a relationship between degree of shelter, insect abundance and bat activity (e.g. Racey and Swift 1985; Mayle 1990; Limpens and Kapteyn 1991). However, I have little data to support or refute this hypothesis.

Though forest type was selected in the models separately to measures of invertebrate abundance, another possibility is that the seemingly denser understorey of shrubs in the pine forest compared with the native forest, where the forest floor was more shaded, offered more habitat to prey species such as moths. Sierró (1999) found shrub layer cover, among other factors, to be significant in explaining habitat selection by barbastelle bats (*Vespertilionidae*) in a forest dominated by pines (*P. sylvestris*), and hypothesised this link.

There is support for the significance of habitat in influencing bat activity from the literature. Habitat was an important predictor of bat activity and foraging activity in O'Donnell's (2000a) study. Larger scale work in Britain found habitat availability to be the primary predictor of bat abundance (Walsh and Harris 1996). Lunde and Harestad (1986), in British Columbia, identified greater bat (*Myotis lucifugus*, *Vespertilionidae*) activity in lacustrine habitat than forest although there was no difference in insect abundance. However, they did not quantify other variables. *M. lucifugus* is a very manoeuvrable bat, well adapted for foraging in close forest habitats (Krusic and Neefus 1996). This suggests that the bats chose to forage in the lake area instead of the forest rather than did so out of morphological necessity. Lunde and Harestad (1986) suggested the bats' patterns of activity may reflect differential foraging success among habitat types. While there are larger differences in habitat type between lakes and forests than adjacent forest blocks, it could be that differential foraging success somehow played a role in long-tailed bats' use of exotic forest over native for foraging in Kinleith Forest.

### *Ambient temperature*

Differences in temperature between the two forest types, though significant, were small and could be largely attributable to variation between the two data loggers. Data loggers of the same brand used in a previous study differed in their readings by an average 0.26°C (Chapter 4). Generally, insect (Williams 1940; Taylor 1963) and bat activity (Erkert 1982; Avery 1985;



Walsh and Mayle 1991; Griffiths 1996; Walsh and Harris 1996; O'Donnell 2000a) increase with increasing ambient temperature and so we would expect greater insect abundance and bat activity in the native forest, but this was not observed.

### *Insect abundance*

My results are not very clear as to the significance of the relationship between bat activity and insect abundance. Bat activity was significantly correlated with fly abundance. This may indicate a causal relationship, or bats and flies could be active in the same sort of environmental conditions, or perhaps elements of both are involved. Bat activity was not significantly correlated with moth abundance. However, moth and fly abundance were correlated, though there were over twice as many moths in the exotic forest as the native forest while the numbers of flies were fairly similar between the forest types. Neither fly nor moth abundance featured in the regression models once influential points were removed. Despite these somewhat ambiguous findings, I hypothesise that insect, and particularly moth abundance is probably an important factor in explaining bat activity, and bats' preferential use of exotic forest.

I would suggest that bats "like" the exotic forest for some as yet unquantified reason, are active in similar conditions to flies, and prey on flies, but also capitalise upon the large numbers of moths in the exotic forest. That there was not a strong relationship between moth numbers and bat activity in the regression model could indicate that moths are always present. Indeed, some moths can thermoregulate (Heinrich 1993) and so may be active at times when bats may choose not to be active. Alternatively, this may be a reflection of the small sample size.

Long-tailed bats take a wide range of flying terrestrial and aquatic invertebrates (O'Donnell 2000d). However, their main prey are flies (Diptera), beetles (Coleoptera), and moths (Lepidoptera) (Gillingham 1996) — especially Noctuidae and Geometridae (O'Donnell 2000d), which were common in the pine forest. Dwyer (1960a) reported bat droppings at Orakei Korako (near Kinleith Forest) to consist almost entirely of moth and fly fragments. While the exact proportion of flies and moths taken by long-tailed bats is unknown (Gillingham 1996), related Australian species, *C. gouldii* and *C. nigrogriseus*, appeared to take Lepidoptera in the greatest abundance, followed by Diptera for *C. gouldii* (Vestjens and Hall 1977). Griffiths (1996) and O'Donnell (2000a) identified insect abundance to be an important factor in explaining the amount of foraging activity per night of long-tailed bats. At Pureora Conservation Park, there also seemed to be some relationship between insect abundance and relative bat activity (Moorcroft and others 2000).

Many insectivorous bats are opportunistic feeders (e.g. Fenton and Morris 1976; Bell 1980; Vaughan 1980; Altringham 1996; Griffiths 1996; O'Donnell 1999b), and given their need to satisfy complex energy demands (e.g. Erkert 1982; Avery 1985; Barclay 1989; Clark and others 1993; Rydell 1993; de Jong 1994; Grindal and others 1999; O'Donnell 1999b) it makes sense

for them to exploit areas of abundant prey (e.g. Clark and others 1993; Grindal and others 1999). That they do this is perhaps best illustrated by several species' use of streetlights for foraging (e.g. Furlonger and others 1987; Rydell 1992; Racey 1998), especially mercury-vapour lights which emit substantial UV radiation and attract large numbers of flying insects (Racey 1998). Other studies also showed bats to exploit areas of comparatively high prey abundance (e.g. Fenton and Morris 1976; Bell 1980; Vaughan 1980; Racey and Swift 1985). Studies in Sweden (de Jong and Ahlén 1991; de Jong 1994) found bat distribution in different habitats, and seasonal changes in habitat use, could be explained in terms of the abundance of insects.

This evidence, in combination with the high abundance of moths observed in the exotic forest, suggests that moth abundance may be biologically significant in explaining long-tailed bats' apparent preference for exotic forest.

### *Roosting opportunities*

A further factor that can influence the activity of bats in an area is proximity to roost sites (e.g. Furlonger and others 1986; Krusic and Neefus 1996). There could possibly have been an active roost at road Site 1 in the exotic forest on 21 March (C O'Donnell unreferenced personal communication 2001; Chapter 5, 7). However, this night's data was not included in analysis. The chance of roost sites inflating the bat activity observed was also reduced by using several replicates.

### *Predation*

Although two moreporks were seen leaving a roost tree near roadside ABMs in the native forest, it is not thought that there was differential predation between the two habitat types. Moreporks have also been seen on the edge of pine forest.

### *Competition*

It is unlikely that the high level of bat activity in the exotic forest reflects interspecific competition. Short-tailed bats are not evident in Kinleith Forest (Chapter 3), and appear to forage only within the interior of native forest (O'Donnell and others 1999), whereas long-tailed bats commonly forage along forest edges (Chapter 4, 5; O'Donnell 1999b).

### *Predicting bat activity*

There is support from the literature for the activity models given here. Several researchers found similar variables to be important in explaining bat activity, specifically long-tailed bat activity (e.g. Gillingham 1996; Griffiths 1996; O'Donnell 2000a), and Griffiths (1996) and O'Donnell (2000a) present similar models. Regarding the graphical model (Figure 9), bat activity has been related to habitat (e.g. Lunde and Harestad 1986; Walsh and Harris 1996;

O'Donnell 2000a) and insect abundance (e.g. Erkert 1982; Taylor and O'Neill 1988; de Jong and Ahlén 1991; Griffiths 1996; O'Donnell 2000a) in other studies. Insect abundance is known to be highly influenced by temperature (Williams 1940; Taylor 1963) and there are also interactions with moon phase (Williams 1940; Kunz 1988; and suggested by Griffiths 1996). Griffiths (1996) found similar factors — dusk temperature, minimum temperature, insect abundance, moon phase and visibility of moon face — to be important in describing the period during which long-tailed bats were active. It is interesting that in an earlier analysis, where the boundaries of “night” for temperature data were taken as the readings closest to sunset and rise times<sup>1</sup>, the variables represented in Figure 9 were also selected from the pool of environmental variables by stepwise (forward, and forward and backward) regression (though maximum temperature was selected over mean temperature).

While the models presented seem intuitively sensible, and there is support for them, I caution that the results are from a limited data set (in part due to problems encountered in light-trapping) of six nights from late summer–autumn. Hence, although forest type is undoubtedly important in explaining bat activity, other models should be regarded untested hypotheses.

While Gillingham (1996) considered the number of bat passes in the first hour after sunset to provide a better measure of bat activity than total nightly passes, this measure was not used here because peak bat activity generally occurred later in the night, and often there was no bat activity in the first hour.

### ***Proportion of foraging calls***

The proportion of feeding buzzes does not differ much from that observed in other areas of Kinleith Forest (Chapter 4), and is low compared to that found by Griffiths (1996) and O'Donnell (2000a). Possible explanations include: 1) the bats were mainly commuting to feeding areas elsewhere, but foraging a little as they went, 2) food was limited (as suggested by O'Donnell 1999b, 2000a), 3) bats were eating bigger insects and so did not need to hunt as much, and 4) our studies may not be comparable (Chapter 4).

Long-tailed bats have relatively large home ranges (O'Donnell 1999b) and habitat use can vary seasonally (O'Donnell 1999b, 2000d). Possibly the areas monitored in this study were peripheral to the bats' main foraging areas. Indeed, the proportion of buzzes at seemingly the best foraging site so far observed, reached 11.7% (of 103 calls in an hour) (Chapter 5). While this study may not have identified the key foraging areas of long-tailed bats in the Capricorn Rd area, that there was more foraging activity in the pine forest than the native forest would indicate that it is a comparatively important habitat type.

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<sup>1</sup> This method was discontinued because a balanced data set was required for some analyses.



The abundance of potential prey appeared less limited in the exotic forest than the native forest, and insectivorous birds do well in mature pine forest in New Zealand (e.g. Maclaren 1996). However, food availability in Kinleith Forest could still be limiting to long-tailed bats overall. Racey and Swift (1985) found in pipistrelles (*Pipistrellus pipistrellus*, Vespertilionidae) that the rate of attempted feeding was proportional to insect density within certain bounds. This implies also that the rate of feeding buzzes reflects insect density.

Opportunistically foraging bats have been found to select the largest appropriate prey items (Fenton and Morris 1976) and long-tailed bats appear to take insects of a range of sizes (Gillingham 1996; O'Donnell 2001). However, Swift and others (1985) found no evidence that pipistrelles selected their diet on the basis of insect size. It is unclear whether long-tailed bats may be taking bigger prey in exotic forest than native forest.

### ***Scope and limitations***

#### ***Bat activity data***

It is doubtful that there was any difference in the sensitivity of ABMs between forest types as all ABMs were located in similar positions, e.g. on banks and camouflaged by vegetation. Similarly, it is unlikely that bats varied in their call structure, and hence their detectability, between the exotic and native forest because the monitoring sites all appeared superficially similar. Bat activity was probably sampled above the canopy at all sites.

ABMs have a potential 50 m horizontal range directly in front and reduced range to the sides (O'Donnell and Sedgely 1994). Their range is further limited in forest (Parsons 1996). Hence, the spacing of ABMs is considered appropriate to have avoided recording overlap between sites and to have negated the chances of recording elevated bat activity due to proximity to light-traps. The use of a double replicate in the forest interior was justified because the scale at which long-tailed bats used this area was initially unclear.

Variation in coding consistency is not considered significant.

The individual ABMs used significantly influenced the results in the comparison of bat activity between the two forest types based on the 12-night data set. However, treatment (forest type), conservatively entered later into the general linear model, could still account for much of the variation observed, and was more significant. Some monitoring sites experienced greater bat activity than others creating a significant site effect, however, though partially related to treatment, treatment was more significant overall.

When modelling bat activity, the smallest data set was that for insect abundance. To make the most of this, bat data for those nights was analysed. Two of these nights' data had not been

used previously because of minor problems with individual ABMs. On one night, one ABM in the native forest failed. On this and a second night, the ABM for Site 1 in the exotic forest was put out slightly after sunset. These biases are not significant. The former was overcome by calculating the mean activity from the two remaining ABMs. The latter simply provided more conservative estimates of bat activity at actually the busiest site. For the six nights, most ABMs were used at most sites, and there was no significant effect of ABM bias in the results which largely mirrored those of the larger 12-night data set.

### *Insect abundance data*

While light-trapping has been criticised as a method for assessing the availability of potential bat prey (Kunz 1988) by comparing like data, collected simultaneously, and replicating traps, the concerns associated with the method are reduced. Light-trapping appeared sufficiently robust to reveal any large differences in potential prey abundance between the two forest types.

It is unfortunate that the amount of data collected was limited to six nights. Research was constrained by the limited field season, unavailability of more suitable batteries and/or timer units, and intermittent bad weather.

The proportion of day-flying insects caught was probably negligible because the batteries would have been flat by around 4:15 a.m. One tube of each light was used, and each tube was rated at 8 W. Run off a 12 v battery, this would have drawn a current of  $\frac{2}{3}$  A. The batteries were mostly rated at 6.5 Ah, and were therefore expected to last around 9.75 hours. Sunset in March 2000 was approximately 18:30 (regular time), and so the batteries would have been dead flat by 04:15, and the light very dim. The traps work by disorientating flying insects with their UV light. During the day the sun would have been a stronger source of UV light than the traps. Additionally, any possible effect would have occurred in both forest types.

Analysis of the insect data was limited to the observation of general trends. Further work may provide more insight into the nature of insect communities in the two forest types and the relative availability of potential prey species to long-tailed bats.

### ***Management implications***

Implications for forest management and bat conservation are considered in Chapter 8.

### ***Future work***

This work generates many further questions including why exactly long-tailed bats showed a preference for exotic forest over native forest, whether exotic forest is important year round, where key foraging sites are if the area investigated was peripheral to these, whether food is

limiting to long-tailed bats in Kinleith Forest, and the implications of these for forest management and bat conservation.

## 6. CONCLUSIONS

Insectivorous long-tailed bats foraged more in exotic plantation forest than native podocarp broadleaf forest, possibly because of the greater abundance of moths. Forest type was the best predictor of bat activity.

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# 7

**ROOSTING ECOLOGY OF LONG-TAILED BATS  
(*Chalinolobus tuberculatus*) IN KINLEITH FOREST,  
CENTRAL NORTH ISLAND, NEW ZEALAND**

"Pooh . . . . felt that the Heffalump was as good as caught already, but there was just one other thing which had to be thought about, and it was this. Where should they dig the Very Deep Pit?

Piglet said that the best place would be somewhere where a Heffalump was, just before he fell into it, only about a foot further on."

— Milne AA (1926, p 64–5)

# 7

## ROOSTING ECOLOGY OF LONG-TAILED BATS (*Chalinolobus tuberculatus*) IN KINLEITH FOREST, CENTRAL NORTH ISLAND, NEW ZEALAND

### ABSTRACT

Tree-roosting long-tailed bats (*Chalinolobus tuberculatus*, Vespertilionidae) appear to have specific roosting requirements and may be vulnerable to disturbance. This study investigates the roosting ecology of long-tailed bats in Kinleith Forest, a large exotic plantation forest, to identify the importance of production forest (which may have very few suitable cavities), and non-production indigenous forest reserves. Anecdotal accounts indicated several roosts to be in production *Pinus radiata*, including old crop trees. One record was of a roost in a barely noticeable crevice in a 30-year-old pine, others were from areas of native forest, rocky crevices and a cave. Four accounts were of communal roosts. Maternity roosts may also occur in production forest. Most observations were made during the process of habitat modification and so roosts no longer exist. At least one possible communal roost was identified from bat activity data. A review of roosting ecology suggests that while highly mobile, long-tailed bats use many roosts in a small area, often roost near forest edges, are highly selective of roosts, and may face inter- and intra-specific competition for roosts.

### 1. INTRODUCTION

Bats spend most of their lives in roosts (Altringham 1996). Roosts provide sites for mating, rearing young, and hibernation (Kunz 1982); they promote social interactions (Kunz 1982) including information exchange (Altringham 1996); and allow for food digestion (Kunz 1982). Sheltered roosts, predominantly used by microbats, are relatively permanent, offer microclimate stability, reduced risks of predation, good protection against the elements (Kunz 1982) and they

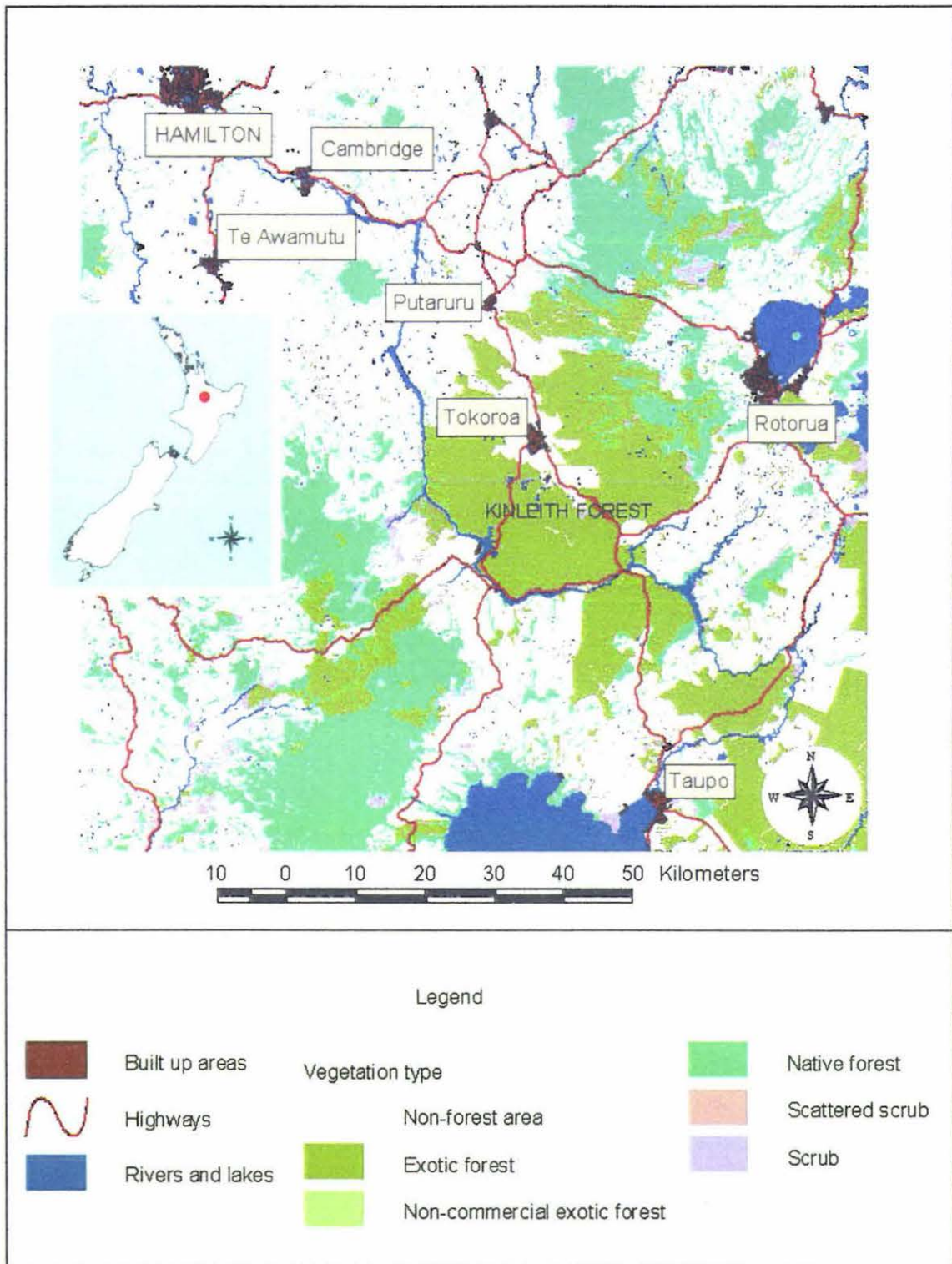


facilitate comparatively cheap thermoregulation (Altringham 1996) (Appendix 1.1). The availability and capacity of suitable roosts can limit species distribution and abundance (Findley and Wilson 1974; Humphrey 1975; Kunz 1982; Fenton 1992; Findley 1993) and bats may be exceedingly vulnerable to roost site disturbance (Fenton 1992). Bats are generally more sensitive about their roosting than their foraging sites (Fenton 1992).

New Zealand's two remaining species of native bats, long-tailed bats (*Chalinolobus tuberculatus*, Vespertilionidae) and short-tailed bats (*Mystacina tuberculata*, Mystacinidae) are threatened (Molloy 1995; IUCN 2000a, 2000b). Typically tree-roosting (O'Donnell 1994; Molloy 1995), long-tailed bats appear to have specific roosting requirements (Gillingham 1996; Sedgeley and O'Donnell 1996a, 1998; O'Donnell 1997). They are very mobile (Chapter 1; O'Donnell 1997), and in indigenous forest, long-tailed bats move roosts frequently (Gillingham 1996; Sedgeley and O'Donnell 1996a; O'Donnell 1997), and use many different roosts within their range (O'Donnell 1997). While there are several records of bats roosting in exotic plantation forest, including two records of roosts in *Pinus radiata* in Kinleith Forest (1976, 1996, Chapter 1), it is unlikely that plantation forest trees provide many cavities suitable for bats given their short rotation times, and intensive management (Chapter 1) (Daniel 1981; Hunter 1990; Newton 1994; Pierson 1998). Also, conifers, dominant in Kinleith Forest (Chapter 2) and in New Zealand's forestry industry (Chapter 1), provide comparatively few tree trunk cavities (Hunter 1990, Newton 1994). Yet long-tailed bats are widespread in Kinleith Forest (Chapter 3), with high activity in places (Chapter 3, 5).

The roosting ecology of long-tailed bats in plantation forest has not been previously investigated in detail in New Zealand. It is hypothesised that long-tailed bats roost in production trees of Kinleith Forest to an extent, but that areas of mature indigenous forest (reserves within the Forest, and areas outside of the Forest) will be of greater importance to them for roosting. Long-tailed bats may also roost in rocky crevices and caves (Daniel and Williams 1984; Daniel 1990; Moore 1995; Griffiths 1996). In order for Carter Holt Harvey Forests Ltd to have regard for this threatened species when making forest management decisions, it is crucial to find out more about the importance of production and non-production areas of Kinleith Forest to the bats and whether tree felling operations (e.g. roading, thinning and clearfelling) pose a threat to roosting habitat and ultimately bat survival.

This chapter details investigations into the roosting ecology of bats — particularly long-tailed bats, in Kinleith Forest. It discusses the findings and briefly reviews our current knowledge of the roosting ecology and social structure of long-tailed bats. The implications of tree felling operations for long-tailed bats are considered in Chapter 8.



**Figure 1** Location of Kinleith Forest

## 2. STUDY AREA

Carter Holt Harvey Forests' Kinleith Forest (centred around 38°17'S 175°53'E) is an exotic plantation forest of 131,000 ha in the South Waikato, central North Island, New Zealand (Figure 1; Chapter 2). *Pinus radiata* is the dominant commercial species, followed by *Eucalyptus* spp. and Douglas-fir (*Pseudotsuga menziesii*). Areas vary from first to third rotation. At least 10% of

Kinleith Forest is managed as (non-production) reserve land (R Black unreferenced personal communication 2001). Reserves include riparian vegetation, scrubland, fernland, wetlands, and gorges of podocarp broadleaf tawa forest descending from the Mamaku Plateau. The north-eastern Forest adjoins the Mokaihaha Ecological Area, a large area of podocarp broadleaf forest.

### 3. METHODS

#### *Radio-telemetry*

Radio-telemetry was the preferred method for locating bat roosts (Bradbury and others 1979; Wilkinson and Bradbury 1988). A handling permit from the Department of Conservation (Spe 011, Authority No. 4/411, 21<sup>st</sup> January 1999) and approval from the Massey University Animal Ethics Committee (protocol No. 99/4, 22-1-99) were obtained before trapping of bats for attachment of radio-transmitters was begun.

Two Austbat (Australia) harp traps (similar to Tidemann and Woodside 1978; see Kunz and Kurta 1988 for review), of 3.3 m<sup>2</sup> and 4.2 m<sup>2</sup>, and/or one 6 x 2.6 m 1½ inch mesh mist-net were used in April 1999 and January and February 2000 (giving 29 complete trap-nights), at seven locations in Kinleith Forest. Suitable locations were identified with prior reconnaissance, and bat activity monitoring using automatic bat monitoring units (ABMs) (Chapter 3). Locations comprised stub roads, redwood forest, a native forest remnant, waterways, and the entrance of an old tram tunnel (accessible for a three day window before harvesting).

Harp traps were used free-standing or hung from trees (using a similar method to Sedgeley and O'Donnell 1996b). They were positioned to intercept potential bat flyways. Landscape features, vegetation and sometimes our vehicle were used to try to funnel bats into the traps, and at one location a curtain of shade cloth was erected around the traps for the same purpose. A bird caller (Audubon, Connecticut USA) was sometimes employed in an attempt to call bats into traps (A Arkins unreferenced personal communication 1995; Heaphy 1998), and at one site an ultraviolet fluorescent light was sited nearby to attract flying insects (potential bat prey), and thus bats, to the trap (Fenton and Morris 1976; Bell 1980; S Pilkington unreferenced personal communication 2000). Traps were generally checked for bats a couple of hours into darkness, and then an hour before sunrise and at sunrise. Traps were taken down during rain.

The mist-net was set up on a pulley system anchored on poles or ropes over branches (Kunz and Kurta 1988; Heaphy 1998), and used during the first couple of hours of darkness and on one occasion between 1 am and sunrise (the time activity monitoring suggested bats were most likely to be in the area). When open, it was checked once every 10 minutes.



### ***Review of anecdotal records***

Anecdotal records of bats in and near to Kinleith Forest (Chapter 3) were reviewed for roosting information.

### ***Review of activity data***

Areas with high bat activity were reviewed (Chapter 5). As bat activity can be affected by nearby active roosts (e.g. Krusic and Neefus 1996), it may be possible to locate areas containing active roosts by checking activity data (Chapter 5).

### ***Tunnel inspection***

In an effort to find bat roosts and/or potential bat trapping areas, old tram tunnels were identified from maps and with the help of locals. Two tunnels, the western-most tunnel on Tunnel Rd (later a trap site), and that between Mackney and Lower Crimp Rds, were located and checked for signs of bats. A further tunnel was known to be inaccessible by vehicle, and a fourth was given low priority for searching given the time it would have taken to find in the rough terrain.

## **4. RESULTS**

Despite much effort, no bats were caught, precluding the use of radio-telemetry. Of the two tunnels inspected, one tunnel was very wet, and flooded at one end, it is not thought to be used by bats. In the other no bats were seen although bats were active in the area (G Moore unpublished data), and bat-like droppings were found. However, these may have been from cave weta (Rhaphidophoridae) (present in the tunnel) or mice (*Mus musculus*). Regrettably no droppings were collected for analysis.

### ***Anecdotal evidence of bat roosts***

In addition to the two long-tailed bat roosts reported from *P. radiata* in Kinleith Forest by Daniel (1981): Waikato Block, and Wilke (1996) and Garrick (1997a, 1997b): near Upper Atiamuri (Chapter 1), there were seven anecdotal records of roosts (or suggesting their presence). These are summarised below.

#### ***Capricorn Rd***

Bats were seen in 1983 when patches of native forest were being burnt in land preparation (R Black unreferenced personal communication 1998) [a practice no longer continued in Kinleith Forest (L Cannon unreferenced personal communication 2001)]. Presumably they were roosting in the area.

### *Deer Rd*

About half a dozen bats were seen “fluttering around” when a first crop pine was felled between around 1986 and 1988 along Deer Rd (B Atkinson unreferenced personal communication 1999; G Newton unreferenced personal communication 2001). The tree was noted to have been previously broken in half, maybe in a storm, and the bats were in a small hollow in its core (G Newton unreferenced personal communication 2001).

### *Maroa*

When native forest was being cleared east of Maroa around 1968 — before the area was planted in pines, several bats were found when a native tree was felled (B Snowsill unreferenced personal communication 2000). One dead bat was sent to the Department of Internal Affairs (B Snowsill unreferenced personal communication 2000). Discussion of this record suggested the bats were probably short-tailed bats. (See also Chapter 3.)

### *Old State Highway*

A bat was found on radiata pine firewood being collected from the Old State Highway south of Tokoroa (J Boon unreferenced personal communication 1998), suggesting it had been roosting in a production tree which had been felled.

### *Paheke Rd*

A loader-driver found a bat on Paheke Rd around 1994 on a log that came to the skid (R Black unreferenced personal communication 1998), suggesting the bat had been roosting in a production tree that had been felled. The area appears to have been in pines planted in 1956, 1960 and 1962 (R Black unreferenced personal communication 2001). The silvicultural history is unclear though the trees appear to have been pruned at some time (R Black unreferenced personal communication 2001).

### *Sneddon Block*

A record of bats roosting in rocky crevices in Sneddon Block/Wiltsdown area is thought to have been held by the former Acclimatisation Society, though this may date back some 40 years (F Rodwell unreferenced personal communication 2000). Attempts to follow this up were unsuccessful. However, both F Rodwell and J Dodgson (unreferenced personal communication 1998) indicate that the steep gorge along the Pokaiwhenua Stream, which has some native riparian vegetation, may be a roosting habitat (see also Chapter 3 for bat sightings in this area).

*Orakei Korako*

There are several sightings of bats in Rautapu Cave at Orakei Korako (Scrimgeour 1991; Garrick 1994, 1995) including a suspected short-tailed bat. This area is approximately 2.3 km from Kinleith Forest.

***Areas of high bat activity***

High bat activity was observed at Capricorn Rd, Hoiho Rd, Pipeline Rd, Star Rd, and in a riparian area of native forest to the west of Tikitiki Reserve (Figure 2). Additionally, 63 bat passes were detected in 44 minutes immediately outside the Redwood Reserve (1999 26 Apr). Several feeding buzzes (Griffin and others 1960), indicating foraging, were heard. The high bat activity, rapid passes and simultaneous calls from multiple bats observed at Capricorn Rd on 21 March (2000), suggests the potential presence of a nearby communal roost (C O'Donnell unreferenced personal communication 2001). Site descriptions are given in Chapter 5.

**5. DISCUSSION*****The Kinleith results***

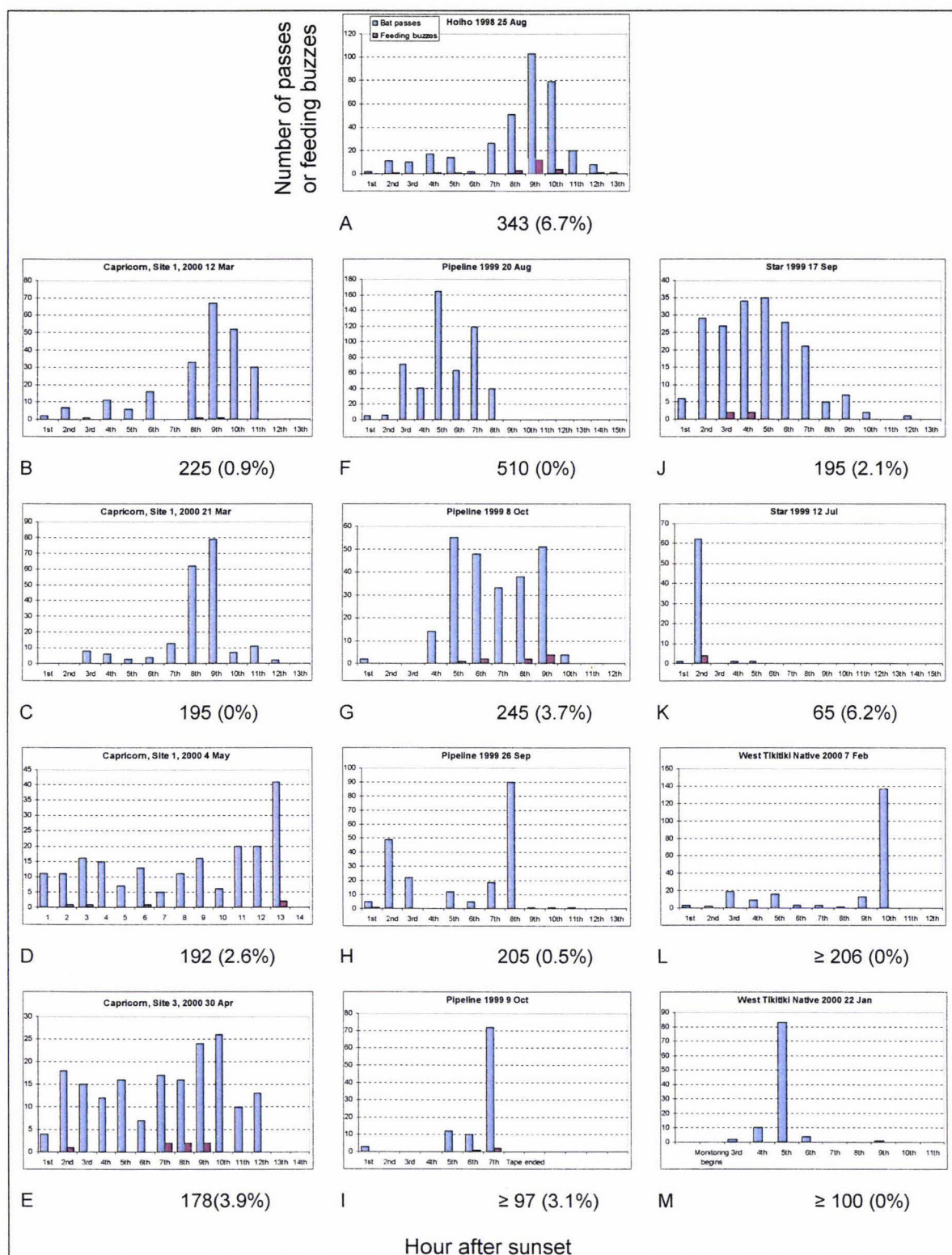
While the bat species seen is largely unclear from the anecdotal records, it is thought that many were probably long-tailed bats as this species is more likely to occur in exotic forest (e.g. Daniel 1981, 1990; Daniel and Williams 1984) and long-tailed bats are widespread in the Kinleith Forest area (Chapter 3).

Considering the nine records of bat roosts or potential roosts (Daniel 1981; Wilke 1996; Garrick 1997a, 1997b; and the seven presented here), most were in production trees (though this may reflect greater ease of observation), two were in native forest, one was in an area of rocky crevices and native forest, and one was in a cave near to Kinleith Forest. Long-tailed bats roost both solitarily and communally (O'Donnell and Sedgeley 1999; see also *Review of roosting ecology*). At least four records were of communal roosts. Most roosts/suspected roosts were identified during habitat modification and so no longer exist.

While the quality of anecdotal records is likely to vary, several were supported by a couple of people, and other observers seemed fairly certain in their recollections, being able to pinpoint the location or relate that the bats appeared to be torpid when found.

Several areas of Kinleith Forest had high bat activity (at least during part of the time they were monitored). The calls heard at Capricorn Site 1 (21 March) were distinctive, suggesting the potential presence of a nearby communal roost (C O'Donnell unreferenced personal communication 2001). Kingfishers (*Halcyon santa vagans*) were nesting in a bank near the ABM, and it is possible that bats also roosted in this bank or in a nearby tree cavity. Cavity





**Figure 2** Nightly activity profiles of areas with high bat activity. The total number of bat passes recorded for each night is shown beneath each graph, along with the percentage of calls containing feeding buzzes.

bearing trees or snags (standing dead trees) were also found at West Tikitiki Native and in the forest adjacent to Pipeline Rd, though it is uncertain whether bats were roosting in these areas (or indeed in the other areas of high activity). On most ABM-nights, bats appeared to be

foraging (Figure 2, Redwoods results) (Chapter 5), though nights with no feeding buzzes may indicate commuting or social activity.

I originally hypothesised that long-tailed bats roost in production trees of Kinleith Forest to an extent, but that areas of mature indigenous forest (reserves within the Forest, and areas outside of the Forest) will be of greater importance to them for roosting, and that long-tailed bats may also roost in rocky crevices and caves. The results presented, though from a small number of anecdotal reports, support the first part of this hypothesis. Five of nine records were from production forest. The record from Orakei Korako and possibly the record from Sneddon Block provide support for the last part. The exact Sneddon Block record however, was unable to be located, and so its accuracy could not be gauged. While long-tailed bats appear to have roosted at least in the past in native forest in the Kinleith Forest area, I have little information on the relative importance of this to them as roosting habitat. However, I still suspect it is at least equally important as the production forest and probably more so given managed pines are not likely to provide the same abundance of roosting opportunities as unmanaged mature native forest (Daniel 1981; Hunter 1990; Gerell and Lundberg 1993; Newton 1994; Kirkby and others 1998; Pierson 1998; Sedgeley and O'Donnell 1999b) even when trees are near the end of the rotation, and areas of young trees may not provide any suitable cavities at all. In South Canterbury, a primarily pastoral habitat mosaic, long-tailed bats selected indigenous forest remnants and secondary indigenous scrublands for roosting (O'Donnell 2000a). They avoided plantation pine forest (O'Donnell 2000a) which was mostly young (under 15 years, with most around 5 m in height) (C O'Donnell unreferenced personal communication 2001).

Managed forest is unlikely to provide the same roosting opportunities for cavity-dwelling bats as unmanaged forest in part because of intensive silviculture and short rotation times (Chapter 1; Daniel 1981; Hunter 1990; Newton 1994; Pierson 1998; Sedgeley and O'Donnell 1999b).

Undesirable trees are thinned out, and short rotation times mean that trees are felled generally before they have a chance to form cavities. However, this has not always been the case in Kinleith Forest. The initial planting boom of the late 1920s to mid-1930s (Allsop 1964; NZFOA 2000) was followed by WWII, and with a shortage of labour, money and few markets, there was little emphasis on forest management except for harvesting to supply the Penrose wallboard and case mills (Healy 1982; Sutton 1993). Given the size of the initial planting boom and this subsequent lack of resourcing, large areas of the first crop trees (known later as the "old crop") were left unharvested well beyond today's short rotation times (Forest Research 1997). This long period, general lack of silviculture [though an outbreak of *Sirex noctilio* horntail borer in 1949 effectively thinned out some of the poorer quality trees (Healy 1982)] and universally poor tree form with significant mortality rates (Sutton 1993), probably created an estate with comparatively more cavity-bearing trees — potential roosting sites for bats, than today's forest.

While this is difficult to test, several of the bat/roost sightings discussed here appear to have been from old crop trees. Daniel's (1981) reported the finding of a communal roost of long-tailed bats) in *P. radiata* forest being harvested in the Waikato Block in 1976 (Chapter 1, 3). The area was recalled as being near Commons Rd by a Carter Holt Harvey Forests staff member, who suggested the trees were first crop pines, planted around the 1930s (R Black unreferenced personal communication 1999). The roost reported from Deer Rd is also thought to have been in first crop pines, and the Paheke Rd bat sighting appears to be from 32–38-year-old pines though some silviculture had been carried out. Another record of a communal bat roost from central North Island pine forest was from an 86-year-old *P. strobus* tree (Garrick 1996, 1997a, 1997b).

There are several areas of old crop trees left in Kinleith Forest, mainly being present in the more inaccessible places (B Atkinson unreferenced personal communication 2000). Remaining blocks are generally small in size and scattered. One of the most substantial old crop areas, Pohaturoa, was recently harvested (Watkin 2001) though no bat roosts were found.

However, while old crop trees may have provided more roosting opportunities for long-tailed bats than more recent rotations, this is not to say that long-tailed bats do not roost in younger potentially less "scruffy" production trees. The communal roost reported by Wilke (1996) and Garrick (1997a, 1997b), near Upper Atiamuri, was in a 30-year-old pruned radiata pine in a deformity of the trunk several metres up the tree (M Wilke unreferenced personal communication 2000; Figure 3). M Wilke observed the trees of the forest block to be quite uniform, and that the crevice the bats were in was a blemish in the log that was barely noticeable.

While bats may roost in production trees, the question arises, do they also breed in production trees? Long-tailed bats give birth between mid November and mid December (Gillingham 1996; O'Donnell 2000a). They congregate in "maternity colonies" in late Spring–Summer (e.g. McCann and others 1996; O'Donnell 2000a), dominated by reproductive females and their young (O'Donnell and Sedgeley 1999). The question can hence be rephrased as: do maternity roosts occur in production trees? This question is important because long-tailed bats are K-strategists, breeding only slowly (O'Donnell 2000a); they have very specific requirements when it comes to maternity roosts e.g. in terms of microclimate (O'Donnell 2000a; Sedgeley 2001); and disturbance of maternity roosts e.g. through harvesting, may be detrimental to the viability of bat populations (Sasse and Perkins 1996; O'Donnell 2000a). Daniel (1981, p 110) says of his record that the colony "may have been a nursery colony consisting of mainly adult females and, if so, they would have given birth within 2 to 3 weeks if undisturbed"<sup>1</sup>. However, Garrick

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<sup>1</sup> It is recognised that in his 1990 summary (Daniel 1990, p 121) Daniel is more certain stating that the roost "contained only pregnant females and was obviously nursery colony". However, I tend to favour Daniel's (1981) original





**Figure 3** Communal long-tailed bat roost in 30-year-old *Pinus radiata*, near Upper Atiamuri, Kinleith Forest, 1996. Reproduced from Wilke (1996) with permission.

(1997a) noted that two dead bats collected from the Upper Atiamuri site were a juvenile and a female long-tailed bat, suggesting that that roost was indeed a maternity roost. Even if long-tailed bats do not regularly use production trees for maternity roosts, this evidence, scant as it is, does indicate that production trees may be used for maternity roosts.

### ***Other potential roosting substrates in Kinleith Forest***

While there is currently no direct evidence, long-tailed bats may also roost in other commercial species in Kinleith Forest including eucalypts and redwoods, as well as other substrates like rocky crevices.

Eucalypts are broadleaved trees and so may provide more cavities than coniferous trees (Hunter 1990; Newton 1994). The reason for this is that when a limb is lost from a broadleaf tree, "protective gum-filled cells form only in the living sapwood, round the edges of the wound", leaving the heartwood exposed to attack from pathogens (Newton 1994, p 267). However, resin released from the living tissue of a wounded conifer impregnates the heartwood thereby protecting it (Hunter 1990; Newton 1994). Eucalypt species appear more susceptible to attacks by wood-boring insects than radiata pine (Miller and Wilkinson 1995). However, Mackowski (1984) suggests that *Eucalyptus pilularis* grown for timber will not reach the size/age associated

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interpretation given he states that only five of some twenty odd bats were measured, and that no evidence is provided that their gender and reproductive status was assessed.

with the formation of hollows before the occurrence of harvesting as governed by economic constraints. Hollows suitable for possums and gliders, and presumably bats, start to form when trees reach between 100 and 125 cm dbh (between the ages of 144 and 194 years). *E. regnans* similarly does not start to form hollows until trees are more than 120 years old (Ambrose 1982, cited in Lindenmayer and others 1991). Grown commercially in New Zealand, rotations of around 35 years are suggested for these species for a target dbh of 75 cm (Miller and Wilkinson 1995). Rotations for the related *E. nitens* may be as short as 12–15 years for pulp (Miller and Wilkinson 1995). While New Zealand and Australia have very different ecologies, overall it would seem doubtful that eucalypts grown commercially here will provide many cavities for long-tailed bats through the natural processes of senescence and pathological decay. However, storm damage could facilitate cavity formation, providing some roosting opportunities for bats. Also, while rotations may be typically short, amenity plantings of eucalypts in Kinleith Forest are likely to reach older ages. Daniel and Williams (1984) report long-tailed bats and bats of unknown species to have been found roosting in eucalypt species, and long-tailed bats may roost under the bark of eucalypt trees as they do in other trees (Daniel and Williams 1984; Daniel 1990; Sedgeley and O'Donnell 1999b).

The redwoods of the Redwood Reserve on Galaxy Rd were noted to have relatively deeply fissured bark, an abundance of knots, several trees had multiple leaders and a number had lost their tops or were damaged. These features may provide roosting opportunities for long-tailed bats.

Parts of Kinleith Forest are characterised by steep rocky bluffs harbouring crevices. There are also various caves (personal observations), including tapu/sacred caves important to local Māori (B Cuff unreferenced personal communication 2000). One of these is protected from disturbance by a coarse grill, through which long-tailed bats could enter (B Cuff unreferenced personal communication 2000). There are also a couple of disused quarries in the Forest. Long-tailed bats roost in caves and rocky crevices elsewhere (e.g. Daniel and Williams 1984; Garrick 1995; Moore 1995; Gillingham 1996; Griffiths 1996, O'Donnell 2000a), and they may use such features in Kinleith Forest<sup>2</sup>, though tree-roosts are also likely to be important (O'Donnell 2000a).

### ***Review of the roosting ecology and social structure of long-tailed bats***

As detailed previously, roosts are crucial to bats, and bats are very sensitive to disturbance of their roost sites. While my study has been able to shed some light on roosting habits of bats in Kinleith Forest, more information is needed to better assess the likely implications of tree felling on bats. For example, we need to consider whether long-tailed bats could move to new areas if roosting habitat came up for felling. The following summarises what is known about the roosting

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<sup>2</sup> No surveys of cave areas were undertaken out of respect for tapu sites.



ecology and social structure of long-tailed bats before this question and others are considered (Chapter 8). In the interests of providing a holistic summary, some material touched on briefly before is repeated. Discussion mainly draws on the results of long-term research from the Eglinton Valley, Fiordland, which focused on the period of late spring to early autumn, during which long-tailed bats reproduce (e.g. O'Donnell 1999; Sedgeley 2001).

### *Where long-tailed bats roost*

Long-tailed bats are typically tree-roosting (O'Donnell 1994; Molloy 1995), roosting in cavities or under bark (Daniel and Williams 1984), but they are also known from caves, rocky crevices, bridges and buildings (Daniel and Williams 1984). Early work in South Canterbury showed there to be more bat roosts in limestone crevices than in trees (Griffiths 1996). However, more recent work has reversed this finding (O'Donnell 2000a). Long-tailed bats often roost near the forest edge. Sedgeley and O'Donnell (1999a) found 95% of 304 roosts to occur within 500 m of the forest-grassland edge and all of the 43 roosts Gillingham (1996) identified were between 10 and 280 m from the forest edge. Long-tailed bats roost in a variety of indigenous and exotic tree species (e.g. Daniel and Williams 1984) including pine trees (this study). Of a sample of 155 tree-roosts (used during the day by long-tailed bats) in beech (*Nothofagus*) forest, 54% were in live trunks, 21% in dead trunks, 21% in large branches, and 4% under loose bark (Sedgeley and O'Donnell 1999b).

### *Communal and solitary roosts*

Long-tailed bats may roost solitarily or communally, and move frequently between these roost types (O'Donnell 1999; O'Donnell and Sedgeley 1999). Over the October–March period in the Eglinton Valley, 62.7% (of 371) roosts were communal (O'Donnell and Sedgeley 1999). Work in Hawke's Bay, however, found only 30% (of 43 roosts) were communal (October–February) (Gillingham 1996). Communal roosts averaged  $34.7 \pm 23.4$  (SD) bats (O'Donnell and Sedgeley 1999), or 86 bats (Gillingham 1996), and were dominated by reproductive females (O'Donnell and Sedgeley 1999). Reproductive females mainly used communal (maternity) roosts during pregnancy and lactation, becoming more solitary post-lactation (O'Donnell and Sedgeley 1999). Males on the other hand often roosted solitarily but adults switched to communal roosts more frequently post-lactation, presumably to mate (O'Donnell and Sedgeley 1999).

### *Long-tailed bats are highly selective of roosts*

Long-tailed bats are highly selective of day roosts. Their preferences are examined here at a number of spatial scales, large through to small.

In predominantly pastoral land in South Canterbury, long-tailed bats showed a preference for native species, roosting in indigenous forest remnants and secondary indigenous vegetation over planted — generally young (C O'Donnell unreferenced personal communication 2001) —



exotic forest, exotic scrub and pastoral land (O'Donnell 2000a). However, long-tailed bats also selected riparian willows (O'Donnell 2000a). Willows (*Salix* spp.), along with kanuka (*Kunzea ericoides*), and older cabbage trees (*Cordyline australis*) were notable cavity-forming trees (O'Donnell 2000a). Bats favoured the largest cavity-bearing trees in the landscape for roosting and breeding (O'Donnell 2000a).

In the Eglinton Valley, long-tailed bats selected roosts on the basis of topography, forest composition and tree characteristics (Sedgeley and O'Donnell 1999a). Most roost-trees were in mature, open-structured lowland forest of the floor of the U-shaped valley, within 500 m of the forest edge (Sedgeley and O'Donnell 1999a). Gillingham (1996) also found long-tailed bat roosts to be located close to the forest edge (see previous). Bat roosts occurred in trees that were taller than randomly sampled trees, had relatively little canopy closure, larger diameters, larger trunk surface areas and greater numbers of cavities (Sedgeley and O'Donnell 1999a).

Except for the roosts under bark (Sedgeley and O'Donnell 1999b) all were in knot-hole cavities (Sedgeley 2001). These were comparatively high above the ground and uncluttered by surrounding vegetation (Sedgeley and O'Donnell 1999b). The cavities themselves had medium-sized entrances and were well insulated (Sedgeley and O'Donnell 1999b). Microclimates were relatively stable (Sedgeley 2001). Cavities were cooler during the day than the ambient temperature but warmer at night (Sedgeley 2001). Roost cavities differed from a sample of available cavities (implying selection by bats) in that they had higher minimum temperatures, temperature peaked later in the day and remained high for longer, and humidity levels were more buffered and remained high longer (Sedgeley 2001). These features are thought to confer substantial energetic benefits to breeding long-tailed bats (Sedgeley 2001).

### *There may be interspecific competition for roosts*

In the Eglinton Valley, there was evidence that parakeets (*Cyanoramphus auriceps*), starlings (*Sturnus vulgaris*), rats (*Rattus* sp.), and a gecko (*Hoplodactylus maculatus*) used cavities previously occupied by bats (Sedgeley and O'Donnell 1999b), indicating the potential for competition. Griffiths (1996) suggested that long-tailed bats may be excluded from potential roost sites in limestone crevices by nesting starlings and rock pigeons (*Columba livia*). In Kinleith Forest, fern fronds and moss, possibly gathered by nesting birds, were found in the base of the crevice of the Upper Atiamuri bat roost (Wilke 1996). Possums (*Trichosurus vulpecula*) may also compete with bats for cavities (O'Donnell 2000a). Competition for roost sites by introduced mammals, birds and wasps may have contributed to the decline in long-tailed bats (O'Donnell 2000b).

*Long-tailed bats use many roosts*

Various studies have found that they move (communal) roosts virtually everyday (Gillingham 1996; Griffiths 1996; O'Donnell and Sedgeley 1999; Sedgeley and O'Donnell 1999b; O'Donnell 2000a, 2000c; Sedgeley 2001), they abandon roosts as a group (O'Donnell and Sedgeley 1999; O'Donnell 2000a) with females carrying their young (O'Donnell and Sedgeley 1999; O'Donnell 2000a). Roost reuse is low (O'Donnell and Sedgeley 1999) and a large pool of roosts are used (O'Donnell and Sedgeley 1999; Sedgeley 2001). Solitarily roosting bats also move between roosts, but they may occupy the same roost for a longer period (O'Donnell and Sedgeley 1999).

*Long-tailed bats have a small core roosting area*

While long-tailed bats used a large number of roosts in the Eglinton Valley, and have large home ranges (O'Donnell 2001) they remained faithful to a relatively small roosting area, of median 20–129 ha (O'Donnell 1999, 2000a, 2001). Gillingham (1996), Hawke's Bay, found consecutive communal roosts to be relatively close together (min 110 m, max 770 m) though consecutive solitary roost sites were most often located on opposite sides of the 36 ha reserve.

*Long-tailed bats have a distinct social structure*

In Fiordland, the study "population" of bats in a fairly homogeneous habitat was actually found to consist of three cryptic social groups containing on average 72 to 132 bats (O'Donnell 2000c). While the foraging ranges of the three groups overlapped, roosting occurred in three geographically distinct adjacent areas (O'Donnell 2000c). Although not all bats of each group roosted together simultaneously (many roosts were present and these moved each day), bats remained loyal to their social group — there was very little switching between groups, and the switching that did occur was only for one night (O'Donnell 2000c). Nor was there dispersal of young to other groups, juveniles associated with their natal group as one year-olds, and also later when breeding (O'Donnell 2000c). The level of genetic exchange between groups, and the number of groups needed to maintain a viable population is currently unknown (O'Donnell 2000c).

A similar population structure appears to occur among long-tailed bats in South Canterbury (O'Donnell 2000a).

*Trapping bats*

My lack of success in trapping long-tailed bats for radio-telemetry work is unfortunate. However, other researchers too have experienced difficulty in catching long-tailed bats (Gillingham 1996; Griffiths 1996; O'Donnell 2000a). There appear to have been few attempts to trap bats in plantation forest in New Zealand and so there was little experience to draw upon. The ease with which bats are caught at Puketitiri, Hawke's Bay (Gillingham 1996; McCann

1996), where I had previous experience, was not translated to the Kinleith Forest situation. Long-tailed bats have keen senses and are agile fliers, easily avoiding traps (personal observations) and nets. Should trapping be undertaken in Kinleith Forest in the future, a higher level of resourcing and larger team of people would be recommended.

### ***Future work***

There are many questions to be answered. The key ones highlighted by this research are whether long-tailed bats have core roosting areas in Kinleith Forest, and if so, where — are these in mainly in production or non-production areas? Answering these will enable us to better assess the implications of larger scale felling operations.

## **6. CONCLUSIONS**

Long-tailed bats in Kinleith Forest have previously roosted in production trees, especially old crop trees, and probably continue to do so. Maternity roosts can also occur in this habitat. Indigenous forest reserve land may also be important for roosting.

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# 8

## MANAGEMENT INFLUENCES AND GENERAL DISCUSSION



# 8

## MANAGEMENT INFLUENCES AND GENERAL DISCUSSION

### ABSTRACT

Tree-roosting long-tailed bats (*Chalinolobus tuberculatus*, Vespertilionidae) are widespread in Kinleith Forest, a 131,000 ha exotic plantation forest in the central North Island. Tree felling operations could threaten long-tailed bats at an individual and a population level by causing injury or death, reducing available habitat, and isolating bat groups. However, tree felling could create foraging (e.g. edge) habitat and facilitate access for bats. Effects are likely to depend on the scale of operations. Other forestry operations which could negatively affect long-tailed bats include site preparation, pesticide use, infrastructure works, transportation and quarrying. Pest mammal control operations, and the conservation of cave, wetland and reserve areas, potentially benefit long-tailed bats. The complex habitat mosaic of Kinleith Forest may be favourable to long-tailed bats. However, there are many questions yet to be answered. Sensitive management may be needed to ensure bat survival in Kinleith Forest.

Long-tailed bats most probably eat a number of forestry pests including *Helicoverpa armigera* and may be an effective biocontrol agent. Artificial roosting boxes could be used to encourage bats in this role and reduce the number of bats potentially harmed in tree felling operations.

This study, the first in New Zealand to investigate native bats' use of exotic plantation forest in detail, has made many significant contributions to knowledge.

### 1. INTRODUCTION

New Zealand's vulnerable long-tailed bat (*Chalinolobus tuberculatus*, Vespertilionidae) and short-tailed bat (*Mystacina tuberculata*, Mystacinidae) are typically tree-roosting and generally associated with indigenous forest. Bats were seen at the edge of Kinleith Forest, a 131,000 ha exotic plantation forest, prompting this study into their use of the Forest, and the effects of forestry operations. Long-tailed bats were found to be widespread in Kinleith Forest occurring in all topographies and a range of habitats including harvested/unstocked land, young *P. radiata* forest, and mature ( $\geq 17$  years) *P. radiata*, *Eucalyptus* spp., *Pseudotsuga menziesii* and *Sequoia*

*sempervirens* forest, wetlands, and native forest remnants. In places activity was high. Long-tailed bats commonly used roads as flyways in young (without canopy closure) and mature *P. radiata* forest, and podocarp broadleaf forest, probably for reasons of habitat structure, though roads may also play a role in navigation. Areas of older pine forest appear to be selected within the landscape while unstocked land or younger forest is avoided. Long-tailed bats showed greater foraging activity in plantation forest than native forest, possibly because of the greater abundance of moths — important prey. Several communal roosts, including a maternity roost have occurred in production trees, and old crop trees may provide valuable roosting habitat, though indigenous forest is probably of equal or greater importance.

This chapter draws on the results of this study to examine the effects of forestry on long-tailed bats, with special focus on operations involving tree felling. The role of long-tailed bats in the forest ecosystem is also considered along with possible opportunities to maximise the benefits to forestry. This chapter closes with a summary of the main findings and contributions of this study, and presentation of the key recommendations and conclusions.

## **2. EFFECTS OF FORESTRY ON LONG-TAILED BATS**

### ***Tree felling operations***

The effects of tree felling are considered in some detail because the potential for negative effects on long-tailed bats is substantial. Tree felling is a significant part of forestry — thinning is essentially the felling of selected trees during the rotation to promote growth of remaining crop trees, infrastructure works (roading and making landings) e.g. in advance of harvesting can involve tree felling, and the crop is harvested by felling and extraction. Tree felling at a stand level may result in increased fragmentation of habitat. Tree-roosting long-tailed bats may be very vulnerable to roost site disturbance and habitat fragmentation. Bats spend most of their lives in roosts (Altringham 1996). The availability and capacity of suitable roosts can limit species distribution and abundance (Findley and Wilson 1974; Humphrey 1975; Kunz 1982; Fenton 1992; Findley 1993) and bats may be exceedingly vulnerable to roost site disturbance (e.g. Fenton 1992). Bats are generally more sensitive about their roosting than their foraging sites (Fenton 1992). While highly mobile (Chapter 1), long-tailed bats use many roosts in a small area, they often roost near forest edges, are highly selective of roosts, and may face inter- and intra-specific competition for roosts (Chapter 7). Some bats seem vulnerable to habitat fragmentation (Bright 1993; de Jong 1995; Walsh and Harris 1996; Pavey 1998; Cosson and others 1999; Law and others 1999; Schulze and others 2000), including long-tailed bats which appear rare or absent from highly fragmented landscapes (O'Donnell 1999a, 2000b). Long-tailed bats' tendency to use roads as flyways (Chapter 4) and to roost near forest edges (Chapter 7) also suggests that roading operations in advance of harvesting could open up new areas to bats, but that these could later be compromised by harvesting (Chapter 4).

Tree felling operations are briefly reviewed in advance of discussion of the likely effects on long-tailed bats. Discussions centre on operations involving *Pinus radiata*, the dominant commercial species of Kīnleith Forest (Chapter 2). The recently introduced Millennium Forestry regime is considered at the end of this section.

## Review

### Thinning

Tree felling, including harvesting (felling for production but not limited to clearfelling), is a significant part of commercial forestry. The first tree felling operation in a *P. radiata* rotation is thinning (though see *Millenium Forestry*). Typically, initial stocking is high to 1) encourage good tree growth and form — trees raised in tight stands will tend to be taller, straighter and have smaller branches (Maclaren 1993); 2) provide mutual protection e.g. against wind (Maclaren and Knowles 1995), 3) ensure even crop distribution — it is not worthwhile replacing trees which have died because the replacements usually cannot compete with the remaining crop (Maclaren 1993; Maclaren and Knowles 1995); and 4) allow later selection of superior trees for the final crop (Maclaren 1993). Initial stocking rates of 600–1000 stems/ha could be considered typical for non-specialist crop (Maclaren and Knowles 1995; FCF 2000)<sup>1</sup>. High initial stocking generates significant competition between trees for resources (water, nutrients, sunlight), keeping stem diameters small (Maclaren 1993). Thinning reduces this competition by selectively removing trees, especially those that are smaller and with poorer form (FCF 2000), promoting increased growth in the remaining crop (Maclaren 1993). Most plantation stands in New Zealand undergo at least one thinning during their life (Maclaren 1993).

There are two main options for thinning, thinning early in a rotation, and thinning late in a rotation. Early thinning, at age 5–6 (L Cannon unreferenced personal communication 2001) when the trees are around 7–8 m (FCF 2000), reduces competition early on allowing trees to develop larger diameters (Maclaren 1993). However, the culled trees are too small to be of commercial value and so are left to decompose (hence the term “thinning to waste”) (Maclaren 1993; FCF 2000). Late thinning, e.g. when trees reach 14–18 m (FCF 2000) or between 10–16 years (Maclaren 1993), allows culled trees to be extracted for commercial use (“production thinning”) e.g. as posts, poles, sawlogs, or for pulp (Maclaren 1993; Maclaren and Knowles 1995; FCF 2000). However, production thinning needs to be carefully timed — to occur when the cull trees are large enough for the operation to be profitable, but before the stand exceeds a height of around 18 m — due to the increased risk of windthrow (Maclaren 1993; Maclaren and Knowles 1995). Production thinning usually occurs on flatter land close to processing plants (FCF 2000). While late thinning means that branches in the crop trees will be suppressed,

<sup>1</sup> Note though that these levels are much lower than those used just two decades ago (within a rotation) due to improved genetics, nursery stock and techniques (e.g. Maclaren and Knowles 1995). Practices continue to change (e.g. see *Millennium Forestry*).



improving their form (Maclaren 1993), productivity of the final crop is reduced because of the prolonged period of competition associated with high stocking. Both thinning regimes were practiced in Kinleith Forest until recently (see *Millennium Forestry*), blocks either undergoing thinning to waste or production thinning resulting in a final stocking of around 350–400 stems/ha (L Cannon unreferenced personal communication 2001).

### Infrastructure works

The next operation involving tree felling is likely to be infrastructure works — roading and the creation of skid sites/landings in advance of harvesting. This ideally occurs some 6–18 months ahead of harvesting (R Black unreferenced personal communication 1998) though harvesting may follow immediately or begin before construction is complete (K Meredith unreferenced personal communication 2001). While Kinleith Forest has an extensive road network and some landings remain unplanted, harvesting usually entails additional construction. Landings are needed for stem handling (see *Harvesting*) and, where haulers are used, extraction. Roading is needed to link landings to the permanent road network which feeds the mills. Existing roads or tracks may need upgrading (Riddle 1995) to accommodate intensive use by heavy vehicles.

Swaths of 10–15 m width may be cut for the formation of new roads (K Meredith unreferenced personal communication 2001). Some adjacent areas may be felled, called “daylighting”, to allow the roadline to stabilise, vegetation on fill slopes to grow and areas to dry out (Robinson 1995). For example, a hillside could be harvested to allow the valley bottom to dry out (K Meredith unreferenced personal communication 2001). However, daylighting seldom occurs in Kinleith Forest (K Meredith unreferenced personal communication 2001). “Roadlining” involves felling a strip of trees to a depth of e.g. 5 m (K Meredith unreferenced personal communication 2001) along each side of an existing road or track (Riddle 1995). This may be undertaken as part of upgrading to facilitate widening and drying out (Riddle 1995; M Hansen unreferenced personal communication 2001). However, it may be sufficient to simply remove vegetation from the road surface (K Meredith unreferenced personal communication 2001). Landings are typically square or rectangular areas cut alongside roads, they can vary in size.

### Harvesting

The main tree felling operation is of course harvesting at the end of the rotation. Clearfelling is the standard method practiced in plantation forests in New Zealand (Lewis and Ferguson 1993; Maclaren 1996). It is economic, and appropriate to radiata pine which is naturally a pioneer species which grows in even-aged stands after disturbance (Maclaren 1996). Average coupe size is 25 ha (Maclaren 1996), though several coupes are likely to be felled in succession if adjacent stands are of similar age.

Harvesting systems encompass the processes of planning, felling, delimbing (at stump or landing), skidding (moving felled trees from stump to landing), log making (cutting trees to logs of customer specifications), fleeting (sorting the logs into stacks ready for loading), loading, and transportation, though these may not occur in this order (Riddle 1995). Wood extraction techniques include: felling and taking the full tree to a landing [superskid, or central processing yard (FCF 2000)]; felling, delimbing and topping at stump in preparation for extraction to the landing; and felling, delimbing and cutting to logs at stump (Riddle 1995). Choice of extraction techniques is dictated by topography and machinery capabilities, health and safety, environmental, and financial considerations (FCF 2000). For example, in flat and flat rolling country, a mechanical harvester may fell and delimb, with rubber-tyred skidders fitted with grapples removing stems (FCF 2000). On rolling to steep country, chainsaw (motor manual) clearfelling is most likely to be used with tracked machines and/or excavators fitted with logging grapples, aiding in extraction. Rubber-tyred skidders may be able to work on tracks or the less steep areas (FCF 2000). In steep areas where it is impractical to use ground-based equipment, haulers may be used to drag or lift stems, using a cable system, to landings (Maclaren 1993; FCF 2000).

### *Potential effects of tree felling on long-tailed bats*

#### Potential negative effects

##### Felling of roost-trees

The first potential effect of tree felling on long-tailed bats is that bats may be killed or injured if their roost-tree is felled. Daniel and Williams (1984) found tree felling to have caused the death of at least 13% (of 36) of long-tailed bats examined, (however, this proportion may be artificially high compared with other causes of death due to greater chances of observation). Two bats were found dead after a roost-tree was felled near Upper Atiamuri, Kinleith Forest, in December 1996 (Garrick 1997; Wilke 1996; Chapter 1, 7), and at least one bat appears to have been killed when a native tree was felled near Maroa (Chapter 3, 7). However, in three other accounts of roost-trees being inadvertently felled, no fatalities were reported (Daniel 1981; Garrick 1996, 1997).

It is unclear whether different extraction techniques have differing impacts on long-tailed bats. Perhaps less mechanised techniques e.g. motor manual (chainsaw) felling and delimbing offer a greater chance of observation of roosting bats and hence reduce the chances of potential injury.

Do bats move to safer roosts with the noise of approaching operations before roost-trees are felled? We do not know. O'Donnell (2000a) suggests research in a similar area — looking at the potential impacts of noise from people and machinery on feeding and breeding of bats — is urgently needed. The fact that many bat sightings have only been made once roost-trees have

been felled (Chapter 7) suggests that in these cases specifically, and perhaps more generally, long-tailed bats do not move in advance of harvesting. However, it could be that bats moving from an area ahead of tree felling are less likely to be observed. Long-tailed bats generally enter torpor during the day to conserve vital energy (Webb 1998; Appendix 1.1), and it can take them around 15 minutes to raise their body temperature and become active and able to fly (personal observations; Richardson 1985). This leaves them potentially vulnerable in situations requiring quick responses.

The next question is what happens to bats that move either before or after felling of a roost-tree? Being highly mobile, perhaps they can move to one of the other roosts of their potentially large pool of roosts (Chapter 7). Here is where we run into problems. We do not know if long-tailed bats in Kinleith Forest have a large pool of roosts. Further, if they do, this could be substantially limited in a number of ways (Chapter 7). Firstly, the availability of roosts in a predominantly coniferous production-orientated forest may be low (e.g. Sedgeley and O'Donnell 1999a). Secondly, given long-tailed bats' specific roosting requirements, even if they have a large pool to choose from, only a small subset of these may meet their thermodynamic and social needs at any one particular time (O'Donnell 1999a; O'Donnell and Sedgeley 1999; Sedgeley 2001). Thirdly, potentially available roosts may "belong" to adjacent social groups, and this may preclude their use by any displaced bats (Sedgeley and O'Donnell 1999a), or there could be interspecific competition for cavities (Griffiths 1996; Sedgeley and O'Donnell 1999b; O'Donnell 2000a, 2000b). Finally, felling operations, particularly end of rotation harvesting, could threaten a significant proportion, if not all, of a group's core roosting area (Sedgeley and O'Donnell 1999a; O'Donnell 2000c). Limited roost availability, whatever the cause, could threaten population viability (indicated by Findley and Wilson 1974; Humphrey 1975; Tuttle 1979; Kunz 1982; Fenton 1992; Findley 1993; O'Donnell 1999a).

The potential impact of disturbance of maternity roosts (which are dominated by reproductive females) (Chapter 7) is particularly large. Long-tailed bats, like bats in general (Chapter 1) breed very slowly (O'Donnell 2000a). They are not able to recover quickly from the effects of increased mortality (Boyd and Stebbings 1989; Law 1996), and populations may already be small (e.g. O'Donnell 2000a). Small populations are more vulnerable to extinction through chance events be these demographic (e.g. significant skewing of the sex ratio), environmental (e.g. a sudden decrease in available prey, or an event such as a storm), or genetic (loss of genetic diversity can occur through genetic drift and inbreeding resulting in reduced evolutionary potential — essentially the ability to population to adapt to changing conditions, and reduced fitness), or through a combination of these (Caughley 1994; Begon and others 1996).

Hibernating bats are also especially vulnerable to disturbance. In winter it may be particularly hard for bats to balance energy intake and energy consumption (Appendix 1.1). Prey are likely



to be less abundant and weather inclement (Appendix 1.1). Disturbance of a torpid or hibernating bat causes it to use up valuable energy reserves (Richardson 1985), which could threaten its survival (Fenton 1992).

Overall, tree felling, at its various scales, may not only have an immediate impact on bats at an individual level, potentially injuring or killing them, but it could also be detrimental [potentially even catastrophic (O'Donnell 2000c)] at a population level, jeopardising population viability (e.g. O'Donnell 1999a, 2000a, 2000c, 2001a; O'Donnell and Sedgeley 1999; Sedgeley and O'Donnell 1999a). Given long-tailed bats likely roost in production trees, though to an unknown extent (Chapter 7), the chance of negative effects would seem to increase with increasing scale of operation, and to a degree, tree age. The greater the area that is felled, the more likely it is that bat roosts will be encountered (whether occupied at the time or not). The chances of trees containing suitable cavities for bats is probably a function of tree age in that older trees have had more time for cavity development (e.g. Ambrose 1982, cited in Lindenmayer and others 1991; Mackowski 1984; Hunter 1990; Pierson 1998). However, this will also depend on silvicultural history. A final crop is likely to have undergone a previous thinning and so may have had many potential or developing roost-trees weeded out. A stand coming up for production thinning may possibly contain a number of potential roost-trees. It is unlikely that thinning to waste provides much of a threat to long-tailed bats. Long-tailed bats appear to avoid areas of young pines (Chapter 5) and it is doubtful that such trees would provide any roosting opportunities given their small diameter and height. Long-tailed bats' use of 12–16-year-old pines — those largely targeted for production thinning, is unclear (Chapter 5). However, such trees are of a size where they could possibly provide suitable roost sites. Records of bats roosting in production forest suggest many roosts were in trees older than this (e.g. aged 30+) (Chapter 7), but the number of mature trees clearfelled annually likely exceeds that harvested during production thinning, giving greater chance of observation. Roadlining and daylighting operations, which naturally target edge habitats — preferred roosting locations of long-tailed bats (Chapter 7), may or may not encounter bat roosts. Again, probabilities will depend on the scale of operation, and the extent to which long-tailed bats are roosting in production forest.

#### Tree felling and foraging and commuting bats

Long-tailed bats seemed to select areas of older pines in Kinleith Forest (Chapter 5), (though notably edge/road habitats), possibly because these remain warmer than open areas and offer greater shelter — potentially favourable conditions for invertebrates and bats, and because areas of older pines may provide important habitat for prey (Chapter 5). Long-tailed bats also used such areas for foraging, seemingly in preference to native forest (Chapter 6). They appeared to generally avoid unstocked areas and areas in pines up to the age of 11 years (Chapter 5). O'Donnell (1999a) similarly found an avoidance of more open areas by long-tailed bats. Long-tailed bats selected vertical forest edges and roads through the (*Nothofagus*) forest, but generally avoided open grassland despite invertebrates being as high there as in other

habitats (O'Donnell 1999a). Though they did commute through the grassland it did not appear to be a favourable foraging habitat (O'Donnell 1999a). O'Donnell (2001b) also found long-tailed bats to concentrate their activity in small core areas e.g. around 90 ha in size for individual adult male bats. Hence, in Kinleith Forest a reduction of vertical edge habitats and the creation of large open areas by clearfelling could significantly reduce foraging habitat for long-tailed bats. Food may already be limited (Chapter 4, 5, 6; O'Donnell 1999a), and the increased costs of foraging further afield, (or less efficiently), could reduce survival at an individual and population level (implied by Walsh and Harris 1996). Long-tailed bats in the Eglinton Valley were noted to have large home ranges and to forage for most of the night (O'Donnell 1999a), possibly as a response to limited prey availability. If prey availability is similarly limited in Kinleith Forest, and indications are that it may be (Chapter 4, 5, 6), it is not certain that long-tailed bats could easily accommodate further reductions through decreases in foraging habitat.

Edge habitats and roads may be used in navigation and orientation (Chapter 4). Overseas, many bat species "tend to fly from shelter to hunting area and back along a relatively regular route", using various linear elements like forest edges, roads and hedgerows (Limpens and others 1989, p 18). Certainly long-tailed bats make use of linear landscape elements (O'Donnell 1999a; Chapter 4). Long-tailed bats may use regular routes too. O'Donnell (2000a) notes long-tailed bats follow similar movement patterns each night. The scale at which long-tailed bats use the landscape in Kinleith Forest is unclear, and so the effect on long-tailed bats of the removal of forest edge used in navigation is unknown. It is possible that commuting or foraging bats would be disorientated. Perhaps they would be reluctant to cross large (intentionally undefined) cleared areas (e.g. de Jong 1995; Pavey 1998; Law and others 1999; though see O'Donnell 1999a, 2000a).

### Tree felling and sites of social significance

While little is known about the social interactions of long-tailed bats, it is likely that communal roost sites are important to these. Roosts promote social interactions, and provide sites for mating and rearing young (Kunz 1982). Moore (1995) and Ryan (1999) observed large numbers of long-tailed bats to fly into a sizeable limestone cave at night though only a few individuals roosted in the cave during the day, suggesting this site had some significance (Ryan 1999), possibly socially. O'Donnell (1999a, 2000c) found there to be three cryptic social groups of long-tailed bats in a relatively homogeneous area in the Eglinton Valley (Chapter 7). While the foraging ranges of the three groups overlapped, roosting occurred in three distinct areas (O'Donnell 2000c). Bats roosted with members of their social group and there was very little switching between groups (O'Donnell 2000c). Bats swarmed at roost sites at dawn possibly alerting other members to the new roost site (implied by O'Donnell 1999a) [although some individuals arrived after swarming had ceased suggesting some prior knowledge of new sites (O'Donnell 1999a)]. Young are left in crèches in roosts while their mothers forage (Webb 1997). Adult males join communal roosts more often once young are weaned, presumably to



mate (O'Donnell and Sedgeley 1999). Given long-tailed bats' frequent use of tree-roosts, tree felling operations (as described previously in relation to roost sites) may endanger sites of social significance to long-tailed bats.

#### Opening up new areas and then clearfelling

It is possible that the formation of new roads and landings opens up new areas to bats e.g. for roosting, foraging (see *Potential positive effects*), and social functions, which will later be compromised by harvesting (Chapter 4). The potential effects of felling roost-trees are outlined previously. Where harvesting closely follows construction, the chances of bats moving in to a new area before clearfelling, are potentially lessened.

#### Felling of prey habitat

Research in coniferous forest in Canada suggests that the forest may be an important habitat of prey of insectivorous bats, and that clearfelling may compromise this (Grindal 1996; Grindal and Brigham 1998, 1999). This may also be the case in Kinleith Forest with repercussions for long-tailed bats.

#### Isolation of groups of bats

Clearfelling may increase habitat fragmentation and reduce connectivity between groups of long-tailed bats. Connectivity (between subgroups of a population) already appears limited in long-tailed bats (O'Donnell 1999a) meaning that the effective population size is smaller than would be expected if all bats belonged to a single intermixing population (O'Donnell 1999a). Decreasing connectivity further would further reduce the effective population size, which would at best come to resemble the number of breeding individuals in each subgroup, but could be smaller than this again (Caughley 1994). Small groups are more vulnerable to extinction (as described previously). Hence, fragmentation of habitat could be detrimental to long-tailed bats at a subgroup level. However, given connectivity between subgroups appears already limited, it is possible that many intermixing groups may be required to maintain heterozygosity within a population (or metademe) (O'Donnell 1999a). Hence, fragmentation of habitat could have a larger population-level effect, potentially contributing to population extinction.

#### Potential positive effects

##### Access to roosting areas

Harvesting may create forest edge, a selected roosting habitat of long-tailed bats elsewhere in New Zealand (Chapter 7), potentially benefiting the bats [also suggested by Grindal (1999) in regards to *Myotis* bats, Vespertilionidae], or it may provide improved access to areas for roosting. Areas of mature forest of medium to low stocking, achieved through thinning, may be more conducive to commuting through to roost sites than areas of high stocking (discussion of



long-tailed bats' limitations and adaptations is provided in Chapter 4), also benefiting bats. Humes and others (1999) found greater *Myotis* activity in thinned than unthinned *Tsuga heterophylla* zone forest, and concluded that thinning may benefit bats by creating habitat structure that bats can use more effectively.

#### Tree felling and foraging and commuting bats

Waste thinning may affect invertebrate communities by providing a sudden surfeit of vegetation for decomposition (H Moore unreferenced personal communication 2001). This could potentially increase prey availability for long-tailed bats, but exact effects are unknown.

Clearfelling can benefit bats by increasing foraging habitat (Crampton and Barclay 1996; Grindal 1996; and indicated by Krusic and Neefus 1996; Perdue and Steventon 1996; Grindal and Brigham 1998, 1999), especially edge habitat (which may include roads bordered by tall forest) — often a preferred feeding area for bats (Walsh and Mayle 1991; Crampton and Barclay 1996; Grindal 1996; Krusic and Neefus 1996; Walsh and Harris 1996; Grindal and Brigham 1999). Long-tailed bats often forage along forest edges and roads (Chapter 4, 5, 6) and select these habitats (O'Donnell 1999a). Increasing the amount of edge and gap habitat through felling, by increasing available foraging habitat, could potentially increase the population carrying capacity of areas (O'Donnell 1999a; and implied by Walsh and Harris 1996). Indeed, O'Donnell (1999a, p 187) suggests that the formation of additional roads through the *Nothofagus* forest in the Eglinton Valley “may represent a net conservation gain” for long-tailed bats, and that such gaps may represent more attractive feeding habitats than natural forest gaps and edges because they remain overtopped by canopy trees. While it is unlikely that roads created or roadlined in advance of harvesting would remain overtopped by trees to the extent O'Donnell (1999a) indicates, road creation in tall forest may still increase available foraging habitat. Walsh and Harris (1996, p 516) suggest that corridors, which are analogous to edges and roads (Krusic and Neefus 1996), “may enhance the chances of long-term survival for a bat population in a fragmented landscape by linking patches, thereby providing access to additional feeding areas, or by providing an additional food supply that enables the bats to travel over a wider area in search of profitable feeding areas” (Chapter 4). While not all bats are restricted to using corridors (Limpens and others 1989; Limpens and Kapteyn 1991; Law and others 1999), long-tailed bats may benefit from clearfelling in this way. Certainly long-tailed bats were active in some harvested areas/recently created edge habitats in Kinleith (–Pt Horohoro) Forest and may have been capitalising on abundant prey (Chapter 5).

Roads and edges are used by commuting long-tailed bats (e.g. Chapter 4, 5, 6). New bat “highways” (Krusic and Neefus 1996) created by clearfelling, as well as providing new opportunities for foraging, may reduce the energetic costs associated with commuting (Grindal and Brigham 1998), also benefiting survival (implied by Walsh and Harris 1996). Such features may also be used in orientation and navigation (Chapter 4), and so the formation of gaps,

edges and roads may aid bats in finding their way around, especially in otherwise fairly homogeneous habitat (Chapter 4).

The benefit to long-tailed bats of the creation of forest openings and edges through tree felling again likely depends on operation scale. Linear features and small openings will present comparatively more favoured edge habitat than larger openings. To illustrate, a long-tailed bat may perceive edge habitat to some 17 m (based on echolocation call range — Chapter 4) from the true forest edge, and so the centre of a 34 m clearing would still just be “edge” and may be used for foraging; however, the centre of a 100 m clearing, “open habitat” may be avoided (see *Potential negative effects*) (as discussed by Grindal and Brigham 1998). The harvested/just planted areas where bats were found during driving transects (Chapter 5) were not far from forest edges. The benefits of clearfelling for long-tailed bats are also likely to depend upon the “residence time” of features. A road made into mature forest which is felled a week later is not likely to benefit long-tailed bats as much as a forest edge created by harvesting one mature block, but leaving a younger adjacent stand to grow for another couple of years.

While discussion has largely concentrated on clearfelling operations, it is possible that thinning, while facilitating access to forest interior roost sites (see previous), would also benefit bats travelling to foraging areas or areas of social significance.

#### Change of edge habitat orientation

Long-tailed bats may regularly forage and commute above the canopy (Griffiths 1996; O'Donnell 1999a) as do related Australian *Chalinolobus gouldii* (de Oliveira 1998). Hence, the creation of openings in the forest by clearfelling may simply change the location of the edge habitat used from horizontal to vertical (Grindal and Brigham 1998). The significance of this for long-tailed bats is not clear, though it is possible that vertical edges may be preferred in windy conditions.

#### *Striking a balance*

At a landscape scale, two important themes emerge from this discussion, that of habitat improvement/creation and that of habitat degradation/destruction. The underlying process — tree felling at a landscape scale, could be considered “fragmentation”. Fragmentation concerns both a reduction in the size of habitat available and an increase in the isolation of habitat patches (Bright 1993; Bright and Morris 1996). Whether fragmentation benefits long-tailed bats will depend on the balance achieved between: 1) creating foraging habitat, 2) reducing roosting and prey habitat, and 3) isolating habitat patches from one another (these are discussed at least in part by Grindal 1996; Walsh and Harris 1996; Grindal and Brigham 1998; O'Donnell 1999a, 1999b, 2000c).

Many bats appear vulnerable to fragmentation (Bright 1993; de Jong 1995; Walsh and Harris 1996; Pavey 1998; Cosson and others 1999; Law and others 1999; Schulze and others 2000). Some do not occur in smaller habitat remnants (Cosson and others 1999; Law and others 1999; Schulze 2000). Others avoid, or appear reluctant to cross intervening matrix habitat (Limpens and others 1989; Limpens and Kapteyn 1991; de Jong 1995; Pavey 1998; Law and others 1999). Those that seem most vulnerable to fragmentation are bats with low wing-loading and low aspect ratio, adapted to slow manoeuvrable flight (de Jong 1995; Pavey 1998) i.e. clutter-adapted bats which commonly forage in the forest interior (Pavey 1998). Conversely, bats which appear tolerant of fragmentation tend to have high aspect ratios, and are fast flying and forage above the canopy and in open areas, at edges and in gaps between trees (Law and others 1999). Law and others (1999) found *Chalinolobus morio*, which has a low aspect ratio, to be sensitive to fragmentation, while *C. gouldii*, with a high aspect ratio, was more tolerant of fragmentation.

Long-tailed bats have moderate wing-loading and aspect ratio associated with moderate to fast flight speeds and limited manoeuvrability (O'Donnell 1999a), and so may be predicted to be moderately vulnerable to (or tolerant of) habitat fragmentation. Long-tailed bats appear common in the forested Eglinton Valley of Fiordland National Park (O'Donnell 2001b), but seem rare or absent in highly fragmented landscapes (O'Donnell 1999a, 2000b), though there appears to be a large population near Te Kuiti (O'Donnell 1999c) — a karst area with native forest remnants in a matrix of farmland. The evident decline of long-tailed bats nationally (O'Donnell 2000b) would seem at least partly attributable to decreasing forest cover accompanying settlement and development of many regions (O'Donnell 2000b).

So how much fragmentation is beneficial, and how much is harmful? Increasing the amount of edge and gap habitats, favoured foraging habitats of long-tailed bats, could potentially increase the population carrying capacity of areas (O'Donnell 1999a). For example, in the situation of the Eglinton Valley, which has a large area of contiguous forest with a single narrow road running along the valley floor, O'Donnell (1999a, p 187) suggests that the construction of additional roads through the forest "may represent a net conservation gain" for long-tailed bats. O'Donnell (1999a) goes on to predict that "extensive and complex forest-edge mosaics would support more foraging bats than sites dominated by continuous forest". Krusic and Neefus (1996, p 196), make a similar prediction, that "forest openings, water sources, linear elements, such as trails and forest roads, and overmature hardwood forest stands, may provide the mosaic of habitats that encourage bat use and diversity". Fragmentation beyond this state however, may compromise the availability of roosting and prey habitat, raise the energetic cost of commuting to distant habitat patches, and reduce connectivity between subgroups, resulting in reduced population viability and potentially extinction.



It is possible that Kinleith Forest, with its wealth of roads and numerous habitat patches of differing species, density, and age, along with its reserve areas, wetlands and streams, and caves, currently represents a very favourable habitat mosaic, or that it could do in the future with sensitive management. Commercial forest is dynamic, there is a constant turnover of stands, management regimes continue to evolve (e.g. Healy 1982; *Millennium Forestry*), and to remain competitive, it is vital to be able to respond quickly to changing markets and economic conditions. Kinleith Forest is no exception. Even if a favourable mosaic currently exists, sensitive management may be needed to maintain this. Such management is likely to involve managing the forest at a variety of scales (Hunter 1990). For example, within the Forest long-tailed bats from e.g. three subgroups might range over an area of around 11,700 ha (O'Donnell 2001a). Sustainable management at the scale of Kinleith Forest itself (131,000 ha) or at the larger scale of the forest estate (some 332,000 ha), may not provide for their continued survival. Management at the level of individual stands e.g. of 25 ha may be useful in maintaining roosting habitat, but is unlikely to be sufficient in maintaining foraging habitat or accommodating any movements of the bats. If maintaining the bat population is the aim, it is doubtful that this could be achieved by either conserving roosting habitat or conserving foraging habitat (Pierson 1998; O'Donnell 2000a; and implied by Fenton 1992; O'Donnell 2001a). Conserving one will not necessarily conserve the other (O'Donnell 2000a), management strategies will need to take both into account (Pierson 1998; Pierson and Racey 1998).

### ***Other forestry operations and management influences***

Tree felling is a significant part of forestry, but there are many other processes involved in the journey from seedling to timber. This section investigates some of these, and their possible effects on long-tailed bats, as well as some broader management influences.

#### *Potential effects of other forestry operations on long-tailed bats*

##### Site preparation

##### Mechanical

Harvesting leaves an amount of debris ("slash") behind — branches, bark, tree tops, unmerchantable logs, uprooted stumps and broken trees (Maclaren 1993). This can significantly impede planting (Hall 1995). In Kinleith Forest, where debris exceeds 2 m in depth (as occurs over about 4% of the available planting area — around 6,500 ha annually) it is generally crushed (L Cannon unreferenced personal communication 2001). At the end of harvesting, or later in site preparation, any native trees and tree ferns over the height of 2 m may also be felled or crushed, though this is limited to individual trees of small areas (less than 1 ha) as restricted by the Kinleith Forest Resource Consent (R Black unreferenced personal communication 2001). Burning is no longer used as a site preparation technique (L Cannon unreferenced personal communication 2001).

Soil cultivation is undertaken in the rehabilitation of landings. Ripping (L Cannon unreferenced personal communication 2001) is used to counter the effects of compaction — improving tree growth, survival and stability by promoting better root development (Maclaren 1993). Landings form less than 1% of the plantable area in any one particular year (L Cannon unreferenced personal communication 2001). V-blading is used in frost-prone areas to create a ridge and furrow system to keep the growing tips of the newly planted trees above the frost layer (Hall 1995). Around 4% of the annual plantable area of Kinleith Forest is v-bladed (L Cannon unreferenced personal communication 2001).

Mechanical site preparation could affect long-tailed bats through changes in availability of insect prey. However, there appears little relevant work in this area, and that which is available largely concerns the response of individual Northern Hemisphere pest species (e.g. Ross 1989; Orlander and Nilsson 1999; Lof 2000; though see Beaudry and others 1997). Reported results are mixed.

The removal of native trees during site preparation or at the end of harvesting may be more significant to long-tailed bats (see *Potential effects of tree felling*). O'Donnell (2000a) found several bat roosts in indigenous trees in first rotation (C O'Donnell unreferenced personal communication 2001) plantation forest, though these were used to a lesser extent than their abundance. While most of Kinleith Forest is second and third rotation, there are still some significant areas of first rotation forest which could contain roost-bearing native trees. The majority of native trees occurring in second and third rotation pine forest are likely to be early successional species of under 30 years old which have established where production trees have died or been damaged (R Black unreferenced personal communication 2001). While less likely to provide suitable roosting habitats, the risk to long-tailed bats of felling these trees remains to be quantified (suggested by C O'Donnell unreferenced personal communication 2001).

### Chemical (weed control)

"In New Zealand, weed competition is often considered to be the single most important factor when establishing a tree crop. Many introduced scrub weed species are more aggressive here than in their natural habitat, and in drier parts of the country, grass and herbaceous species compete very strongly for moisture and nutrients" (Davenport 1995, p 79). In Kinleith Forest aerial spraying using glyphosate and metsulfuron (L Cannon unreferenced personal communication 2001) is carried out before planting to reduce competition and to eliminate wildings of unknown stock. Weeds if large, may also be crushed after spraying. Such work may take place some 10 months after harvesting, though this time may be reduced with a move to year-round planting (L Cannon unreferenced personal communication 2001).

There are several potential impacts of pesticides on wildlife including direct poisoning (Hurst and others 1991), secondary poisoning (Hurst and others 1991; O'Donnell 2000a), loss of food (Hurst and others 1991) and loss of habitat (Hurst and others 1991; O'Donnell 2000a). Wildlife within treatment areas are most likely to be affected, however, wildlife in adjoining habitats may be exposed through overspray, drift during and/or volatisation after application and through contact with affected vegetation or prey (Freemark and Boutin 1995).

For long-tailed bats, the chances of direct poisoning from herbicide use in Kinleith Forest would appear very low. Long-tailed bats are exceedingly unlikely to be roosting within clearcut treatment areas (though they could potentially be present in adjacent forested areas) and modern herbicides generally have low toxicity (Hurst and others 1991; Freemark and Boutin 1995; O'Donnell 2000a). The more toxic herbicides like paraquat (Hurst and others 1991; Freemark and Boutin 1995) [a bipyridylum (Ware 1994)] do not appear to be used in Kinleith Forest. Glyphosate is considered "practically non-toxic" to mammals (Freemark and Boutin 1995, p 76).

There is potential however for secondary and tertiary effects of herbicide use (Freemark and Boutin 1995). Long-tailed bats could potentially suffer secondary poisoning through consuming affected insect prey. However, this risk could be low (Freemark and Boutin 1995 — though research appears very limited in its scope). Edwards (1973) indicates that herbicides do not generally have a propensity for bio-accumulation.

Herbicide use could also affect long-tailed bats through impacts on the abundance or diversity of invertebrate prey. While Mayack and others (1982) suggested that the application of hexazinone (see *Post-planting weed control*) pellets did not appear to affect terrestrial invertebrate species composition, the results of other studies have been mixed (reviewed by Freemark and Boutin 1995). Some species appear to increase in abundance, others decrease, and diversity may decrease following herbicide application (Freemark and Boutin 1995). Some effects may be associated with a reduction in abundance and diversity of plant species (Freemark and Boutin 1995). For example, Brust (1990) observed carabid beetles to respond to the destruction of plant material rather than toxic or repellent effects of glyphosate and Santillo and others (1989) found small terrestrial mammals to be less abundant for at least three years after treatment of a clearcut with glyphosate, paralleling reductions in invertebrates and plant food and cover. The influence of herbicides on above-ground insect abundance and diversity may extend beyond treatment areas to adjacent habitats (Freemark and Boutin 1995).

Given long-tailed bats are unlikely to be roosting directly within treatment areas, loss of habitat is considered in a later section detailing potential effects of unintentional environmental change brought about by forestry operations.



The significance of all these potential effects for long-tailed bats in Kinleith Forest is unknown. There appears to be very little literature on the effects of herbicide on bats, and no studies have been undertaken in this area for long-tailed bats (O'Donnell 2000a). The mammals for which Freemark and Boutin (1995) considered the acute oral toxicities of various herbicides were not named, and may not have included bat species. Similarly, their review of the risks of secondary poisoning seem to be based on the extrapolation of findings for large domestic mammals.

### Planting

The act of planting is unlikely to have much direct effect on long-tailed bats, though associated operations may. When trees are older they may provide roosting or foraging habitat (e.g. at their edge) and accommodate populations of prey species.

### Post-planting weed control

Post-planting release is done as a ground-based spot-spraying operation using valzine hexazinone and terbuthylazine, or glyphosate (L Cannon unreferenced personal communication 2001). This is carried out before trees reach two years old. Occasionally follow-up aerial spraying is required if weed growth is still vigorous when the pine crop is 2–3 years old. This is done as a last resort usually using a clopyralid picloram mix.

Post-planting weed control could have similar effects on bats as pre-planting weed control, though the magnitude of these is likely to be less for ground-based operations (Freemark and Boutin 1995). Hexazinone appears to have low toxicity to invertebrates (e.g. Mayack and others 1982; Michael and others 1999).

### Disease control

*Dothistroma pini* is the most significant fungal disease of pine trees in Kinleith Forest (L Cannon unreferenced personal communication 2001). Infection causes pine needles to die, affecting first the lower crown of the tree (Maclaren 1993). Tree growth is reduced in direct proportion to the amount of foliage affected (Gadgil and others 1995). Blocks between the ages of two and 15 [when trees develop natural resistance (Maclaren 1993; Gadgil and others 1995)] are treated for *Dothistroma* on an as-required basis by aerial application of copper oxychloride (L Cannon unreferenced personal communication 2001). Some 25–30,000 ha may be treated annually, and some blocks could conceivably receive three (L Cannon unreferenced personal communication 2001) to five treatments during a rotation (Maclaren 1993).

The effects of copper oxychloride on long-tailed bats may be similar to the effects of herbicides, though no research has been carried out in this area (O'Donnell 2000a). Copper oxychloride is considered to be of low toxicity (Green and others 1987; Jalali and Singh 1995). However,

there is potential for secondary effects on long-tailed bats. While overseas research found low mortality in *Aphytis* spp. (Hymenoptera: Aphelininae) exposed to copper oxychloride, the fungicide reduced the ability of *Aphytis* to parasitize host *Quadraspidiotus perniciosus* (san jose scale), potentially leading to increased abundance of this organism (Jalali and Singh 1995). Though just one example, this indicates that use of copper oxychloride in Kinleith Forest could potentially influence the abundance and diversity of insect species, including bat prey species, which may affect the bats.

### Insect pest control

There is very little insecticide use in Kinleith Forest and insecticide has not been used in the last four years (L Cannon unreferenced personal communication 2001). While *Paropsis charybdis* (eucalyptus tortoise beetle) has previously been a problem, causing defoliation of *Eucalyptus nitens*, it was considered most economic to replace these eucalypts with *P. radiata* rather than apply insecticide (S Downs unreferenced personal communication 2001). However, Decis (deltamethrin), a synthetic pyrethroid (Ware 1994) was applied over a 20–30 ha area (near Tatua Rd) in the mid 1990s to control *Helicoverpa armigera* (Heliothis), but only one application was needed (S Downs unreferenced personal communication 2001).

Insecticides are generally more toxic to wildlife than herbicides or fungicides (Hurst and others 1991). There are various references in the literature as to the toxicity of deltamethrin to non-target species (e.g. El-Sebae and others 1985; WHO 1989; Hurst and others 1991; Hodgson and others 1998; Samways 2000) and synthetic pyrethroids generally (e.g. Green and others 1987; Hurst and others 1991). Several are conflicting. For example, Hodgson and others (1998) suggest deltamethrin has low vertebrate toxicity but overlook the fact that it is highly toxic to fish (WHO 1989). Hurst and others (1991) suggest synthetic pyrethroids generally have low acute mammalian and bird toxicity except for deltamethrin, while Green and others (1987), though they describe the development of deltamethrin, do not suggest it to be any more toxic than other synthetic pyrethroids. The situation however is clarified by WHO (1989) — the toxicity of deltamethrin depends on whether the compound is applied in a non-aqueous solvent (acute oral toxicity LD<sub>50</sub> values of 31–139 mg/kg for rats, or 19–34 mg/kg for mice) or suspended in water (LD<sub>50</sub> > 5,000 mg/kg rats). For reference, a long-tailed bat may weigh half as much as a mouse (Chapter 1 compared with Murphy and Pickard 1990). In a non-aqueous solution [as used in Kinleith Forest prior to this study (S Downs unreferenced personal communication 2001)], deltamethrin is considered to be highly toxic to mammals (WHO 1989; see also Freemark and Boutin 1995).

As for other pesticides there could potentially be several effects of insecticide on long-tailed bats — direct poisoning, secondary poisoning, and loss of food. Deltamethrin is “the most potent insecticide available” (Hodgson and others 1998, p 144), and is effective against a wide range of insects (Green and others 1987; Hodgson and others 1998). Hurst and others (1991)

suggest the main affect of synthetic pyrethroids on mammals is likely to be that of reducing insect prey abundance. Long-tailed bats are widespread in Kinleith Forest and were detected near the treatment area (Chapter 3). While long-tailed bats typically forage along forest edges or roads (O'Donnell 1999a), and appear to select edges associated with older pine trees (Chapter 4, 5, 6), if the area sprayed was part of a favoured foraging area, the reduction in prey availability could have possibly had a significant negative effect. Synthetic pyrethroids typically do not accumulate *in vivo* or in the environment (Hodgson and others 1998). However, given the lack of research on the effects of pesticides generally on long-tailed bats (O'Donnell 2000a), it would be premature to rule out the risk of secondary poisoning, and even of direct poisoning. Any future pesticide application in Kinleith Forest is likely to be in or near areas where long-tailed bats occur.

### Animal control

Possums *Trichosurus vulpecula* (Maclaren 1993), deer *Cervus elaphus scoticus* (Maclaren 1993), wild pigs *Sus scrofa* (McIlroy 1990), hares *Lepus europaeus* (Flux 1990; Maclaren 1993) and rabbits *Oryctolagus cuniculus cuniculus* (Flux 1990; Maclaren 1993) cause significant damage in plantation forests, eating the leaders out of young trees (Maclaren 1993), uprooting young trees (McIlroy 1990), and damaging bark causing core defects (Maclaren 1993). Carter Holt Harvey Forests (CHHF) use a range of pest control methods primarily targeting possums, hares and rabbits, including night shooting, possum trapping (especially when fur prices are favourable) and poisoning (B Middleton unreferenced personal communication 2001). Use of poison bait is particularly effective and 1080 (sodium monofluoroacetate) is favoured for economic reasons. 1080 bait may be aerially broadcast, target areas including native forest remnants as well as plantation forest to stem reinvasion. It may be distributed from motorbikes, or used in bait stations. Pest control operations are carried out pre-planting, but also target 2–12-year-old pines. Recreational hunting of deer and pigs also occurs in Kinleith Forest.

Possums (suggested by O'Donnell 2000a), stoats *Mustela erminea* (Daniel and Williams 1984; Molloy 1995), rats *Rattus* spp. (Daniel and Williams 1984; Molloy 1995), and feral cats *Felis catus* (Daniel and Williams 1984; Molloy 1995) are all potential predators of long-tailed bats. Possums (O'Donnell 2000a) and rats (Sedgeley and O'Donnell 1999b) may possibly compete with long-tailed bats for roost-trees. Possums, deer, and goats *Capra hircus* can threaten the health of indigenous forest, likely an important habitat of long-tailed bats (O'Donnell 2000a, 2001b, and suggested in Chapter 5, 6, 7), by eating, damaging or trampling plants and reducing regeneration (Porteous 1993). Prolonged herbivory can alter species composition (possums: Cowan 1990; deer: Challies 1990; goats: Rudge 1990), may reduce seed production (Cowan 1990), and may make the forest more vulnerable to other perturbations (Cowan 1990). Feral pigs eat tawa (*Beilschmiedia tawa*) and hinau (*Elaeocarpus dentatus*) drupes, and tawari (*Ixerba brexioides*) leaves (McIlroy 1990) potentially also impacting on forest health. Tawa is a dominant species in the Kinleith Forest area, and tawari and hinau are also present.



While pest control operations in Kinleith Forest do not especially target stoats, rats, feral cats, or goats, some reduction in these species likely occurs directly through the use of 1080 poison bait operations (B Middleton unreferenced personal communication 2001), or indirectly through secondary poisoning (Gillies and Pierce 1999; Heyward and Norbury 1999; Murphy and others 1999; Alterio 2000). As well as being the target of recreational hunters, some pigs and deer may also be killed by 1080 operations.

Animal control operations in Kinleith Forest likely benefit long-tailed bats directly by reducing the densities of potential predators and competitors, and indirectly through enhancing bat habitat (whether indigenous or plantation forest). In the Eglinton Valley an increase in bat numbers has been observed with predator control operations, though as yet this is not statistically significant (Lyll 2000). However, some caution is urged as the potential for secondary poisoning by 1080 in long-tailed bats is largely unassessed (Spur and Powlesland 1997). Other forest insectivores appear vulnerable to secondary poisoning e.g. robins *Petroica australis* (Powlesland and others 1999; Alterio 2000; Lloyd and McQueen 2000), tomtits *P. macrocephala* (Alterio 2000; Lloyd and McQueen 2000; Powlesland and others 2000), and short-tailed bats (Lloyd and McQueen 2000), though unlike long-tailed bats these generally forage on or close to forest floor (Lloyd and McQueen 2000).

#### Fertiliser application

Fertiliser is rarely used for pines in Kinleith Forest, though urea phosphate is applied manually when eucalypts are being planted (L Cannon unreferenced personal communication 2001). Fertiliser application seems unlikely to affect long-tailed bats.

#### Pruning

Various *P. radiata* blocks in Kinleith Forest are high pruned, i.e. pruned to a height of around 6.5 m in two lifts (S Perrett unreferenced personal communication 2001). These likely provide a comparatively more open habitat structure more conducive to use by long-tailed bats (refer Chapter 4) especially once blocks reach maturity.

It is unclear whether there would be a significant difference for long-tailed bats between prey availability in unpruned areas where there may be a constant “rain” of falling branches, and pruned areas where there is a sudden increase in fallen vegetation available for decomposition (H Moore unreferenced personal communication 2001).

#### Infrastructure works

The construction of stream crossings could potentially reduce the quantity and quality of foraging areas of long-tailed bats. Long-tailed bats forage in wetland areas in Kinleith Forest

(Chapter 5), and forage over rivers (Griffiths 1996; O'Donnell 2000a) and streams (Gillingham 1996) elsewhere. Such areas are likely to be an important source of prey (Chapter 5; and indicated by O'Donnell 2000a). Stream crossings may reduce the available stream area, and could potentially increase flow and turbulence should water be channelled through culverts. Long-tailed bats do not appear to favour areas of fast flowing or turbulent water which may impede their echolocation abilities (Griffiths 1996). However, large culverts are very rarely required and many smaller culverts are of a temporary nature (R Black unreferenced personal communication 2001). Further, effects may be very localised and not significant overall.

### Transportation

There may be "competition" between bats and vehicles for road habitat (Chapter 4). The significance of this is uncertain. Bats have not only been seen in the headlights of vehicles (Chapter 4), but there have been collisions between bats and vehicles in the Kinleith Forest area (B Atkinson personal communication 2001; S Garner unreferenced personal communication 2001), an occurrence also noted in other areas of New Zealand (e.g. long-tailed bat: National Bat Database<sup>2</sup>; unknown species: Anonymous 2000). It is not known whether bats prefer different types of roads, e.g. stub roads, which tend to be narrow and overall, infrequently used; compared with general roads, of intermediate width and usage; and arterial logging roads, which are typically wider and more frequently used. Such a preference could indirectly act to separate vehicles and bats in space. Nor is it apparent whether bats may directly select road habitats by vehicle usage, carefully avoiding busy areas, or preferentially foraging in busy areas because of the invertebrates stirred up by passing traffic. Bats may or may not, at certain times of year, separate their road use from that of vehicles in terms of time of night. During the hours of night-driving associated with this project, only one bat was ever seen in the headlights of the vehicle, and there were no observed collisions with bats, though the vehicle in question was smaller than many forestry vehicles.

### Quarrying

It is not known whether long-tailed bats are roosting in rocky crevices associated with active quarries and what effect quarrying operations may have on them, though the disturbance or destruction of roost sites would probably be detrimental. Bat roosts appear to have been disturbed in quarrying operations elsewhere in New Zealand (O'Donnell 2000a).

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<sup>2</sup> Electronic version available from: John Lyall, Department of Conservation, Private Bag 701, Hokitika, New Zealand.

*Potential effects on long-tailed bats of unintentional environmental change brought about by forestry operations*

While CHHF have systems in place to avoid, minimise, mitigate or remedy adverse environmental effects associated with forestry operations (e.g. CHHF 1997; 2000), from time to time adverse environmental effects likely occur, and these may potentially impact on long-tailed bats. These include changes to water quality, wetlands, soil and to native vegetation.

#### Water quality

Roading and landing construction in particular, but also harvesting (especially ground-based operations), site preparation practices, as well as road use, can result in increased levels of sediment, nitrogen and phosphates in waterways (Maclaren 1996). Siltation can adversely affect aquatic invertebrates (Tuttle 1979; ARA 1983; Maclaren 1996) and could consequently reduce habitat quality for foraging bats (Tuttle 1979; O'Donnell 2000a). Nutrient input could, in some situations, possibly benefit long-tailed bats — overseas work suggested eutrophic lakes to be important foraging habitats for bats (de Jong 1994; Racey 1998), however, there has been no apparent research on this here.

Maclaren (1996) suggests the risk to water quality of herbicides used in forestry is low. Modern herbicides generally have low toxicity (Hurst and others 1991; Freemark and Boutin 1995; O'Donnell 2000a; hexazinone: Mayack and others 1982; Michael and others 1999) and copper sprays used to control *Dothistroma* are also unlikely to have a significant effect on stream quality (Fish 1968, cited in Maclaren 1996). However, in the event that water quality was compromised by one of these or another substance such as diesel or oil, long-tailed bats may be adversely affected by reduced prey availability. Several overseas studies indicate that water pollution (of various sources) may adversely affect bats (e.g. Tuttle 1979; Gerell and Lundberg 1993; Walsh and Harris 1996).

#### Wetland drainage

Accidental wetland drainage during infrastructure works could detrimentally affect long-tailed bats by reducing available foraging habitat. Wetlands are likely to be important foraging areas (Chapter 5).

#### Soil deterioration

Soil deterioration may occur through compaction e.g. associated with use of heavy machinery during harvesting particularly at landings (Maclaren 1996); loss of topsoil; and loss of nutrients e.g. through leaching and crop harvest (Maclaren 1996). This may result in reduced productivity of crop trees (Maclaren 1996), but also potentially of undergrowth species. This



could in turn have consequences for invertebrate prey species and for long-tailed bats (in terms of foraging habitat, but also recruitment of potential roosting habitat). De Jong (1994) and Sierro (1999) found a positive relationship between bat activity and biological productivity of the environment. However, the nature and magnitude of potential effects for long-tailed bats remain to be quantified. Further, good forestry practice minimises lasting soil damage, and CHHF is clearly very aware of the value of the soil to production (e.g. CHHF 1997).

### Damage to vegetation

Native shrubland, small areas of forest or riparian vegetation may be potentially, but unintentionally, damaged during some forestry operations e.g. hauler-based harvesting (R Black unreferenced personal communication 2001). This could adversely affect roosting or foraging habitat of long-tailed bats. However, such impacts may be rare and comparatively small.

Spray drift from herbicide application could potentially kill trees used by bats for roosting, reducing their potential longevity as suitable roosting sites (O'Donnell 2000a). It could also detrimentally affect non-target vegetation and invertebrate prey (Freemark and Boutin 1995), reducing the quality of bats' foraging habitat.

### *Other management influences*

#### Caves and rocky overhangs

There has been a mixed history regarding the influence of forestry on caves in Kinleith Forest. In the past, some entrances have been at least partially blocked as an unintentional result of forestry operations (P Fletcher unreferenced personal communication 2001), others have been deliberately blocked to protect cultural sites from disturbance (R Black unreferenced personal communication 2001), at one, a grille was installed (B Cuff unreferenced personal communication 2000). There is now much more emphasis on identifying sites of cultural significance (which include some caves and rocky overhangs) and protecting them from possible adverse effects of forestry operations (e.g. P Fletcher unreferenced personal communication 2001). This may also benefit long-tailed bats should they use such features for roosting.

#### Wetlands

Two wetland areas appeared to be valuable foraging areas of long-tailed bats in Kinleith Forest and other wetlands in the Forest may also be very important to them (Chapter 5). Maintaining wetlands, especially against a background of national (Taylor and Smith 1997) and regional (Environment Waikato 1999) decline, has probably benefited long-tailed bats. One of the wetland areas where bats were commonly observed foraging was at Tikitiki Reserve. This was

developed primarily as a recreational area around 1973 with the creation of a lake on the Tikitiki Stream, though the lake is also a source of water if needed for fire fighting (L Downes unreferenced personal communication 2001). Several other wetlands were also created in Kinleith Forest. While Kinleith Forest is now well established and generally has all the water storage facilities it needs, and it is doubtful that further wetland areas will be created (L Downes unreferenced personal communication 2001), those present will likely continue to benefit long-tailed bats.

### Reserve areas

The maintenance of reserve areas and creation of new reserves may benefit long-tailed bats by protecting important foraging and roosting habitat. However, there is potentially another benefit, if an indirect one. Very few people in New Zealand know that we have native bats, and even fewer have seen them. Reserve areas may offer the opportunity for forest-users including school groups to learn more about long-tailed bats (a threatened species) and begin to appreciate them. Education and public awareness are key to conservation. Indeed, the Tikitiki Reserve offers a reasonable chance of seeing bats, especially from the "viewing platform" as they forage over the lake. However, currently unless visitors have prior knowledge, they may remain totally unaware of bats' presence.

### Conversion to farmland

Recently several blocks of Kinleith Forest have been sold, and several more, including in the Wiltsdown area, are becoming available for sale (R Black unreferenced personal communication 2001). Most of these areas are in prime dairy country and are unlikely to be kept in trees. However, if significant natural areas present, these would be covenanted before sale.

The probable conversion of these blocks to grass or crop land, while resulting in more edge habitat, may overall be detrimental to long-tailed bats which are generally less active in open grassland than forest edge and forest road habitats (Griffiths 1996; O'Donnell 2000a). Open grassland appears to be rarely used by long-tailed bats for foraging (O'Donnell 1999a).

### ***The Millennium Forestry regime***

While the effects of pruning, and thinning as a tree felling operation, have been considered for long-tailed bats in Kinleith Forest, during the course of this study the Millennium Forestry regime was introduced. With the vast improvements that have taken place in stock quality (e.g. Maclaren and Knowles 1995), thinning as a selection process is no longer considered necessary by CHHF. Blocks under the new regime will have a lower initial stocking: 500 stems/ha (5x4 m spacing) in low altitude areas, and 667 stems/ha (5x3 m) spacing in high

(around 600 m asl and above) altitude areas, and will not be thinned (L Cannon unreferenced personal communication 2001). Natural mortality is expected to result in final stockings similar to those previously achieved by thinning. Blocks planted under the old regime with a stocking of 667 stems/ha or higher will still undergo waste thinning at around age 5–6, but no blocks require production thinning. Additionally, advances in wood processing techniques reduce the need for pruning to produce clearwood. Pruning will only be carried out in a small number of areas such as Crown, Māori lease or joint venture blocks where there is a current obligation (S Perrett unreferenced personal communication 2001) (though these are not in the main Kinleith Forest area), or along some edges and roads e.g. as part of road maintenance (L Cannon unreferenced personal communication 2001).

While this regime centres on *P. radiata*, small areas of eucalypts are still being planted, around 500 ha per year of mostly *Eucalyptus fastigata* (L Cannon unreferenced personal communication 2001).

The Millennium Forestry regime may affect long-tailed bats in a number of ways, though the magnitude of effects remains to be quantified. Regarding roosting habitat, the lack of production thinning reduces the chances of roost-trees being felled, potentially benefiting long-tailed bats. However, also, it is likely that for at least part of the rotation [22–27 years (P Thomson unreferenced personal communication 2001)] there will be comparatively more standing dead trees (snags). Under the previous regime an artificial mortality rate was imposed at a certain time in the rotation (selected trees were thinned) freeing up resources for the remaining crop. Under the Millennium regime, there will be effectively the same mortality rate as trees compete for the available space (refer the  $-3/2$  power law e.g. Chapman and Reiss 1992; Begon and others 1996), but dead trees will not be felled nor taken away, and may remain standing for some time [though most are expected to have toppled over by the time of harvesting (P Thomson unreferenced personal communication 2001)]. Further, trees will die at a variety of ages during the rotation [though mainly before age 15, and most will be quite young (P Thomson unreferenced personal communication 2001)] instead of mainly at one age — the time of thinning, creating a range of snags. *P. radiata* sapwood is very susceptible to fungal attack, and heartwood can become severely decayed in five years (Butcher and Drysdale 1991). Snags and dying trees will be vulnerable to pathogens and potentially wind damage, potentially leading to cavity formation. Though most snags are likely to be relatively small and very short-lived, some may offer cavities or crevices suitable to long-tailed bats for roosting, though the longevity of these trees is also likely to be limited.

Previously, stands reached close to their final stocking comparatively early in the rotation through waste thinning, and pruning may have also decreased the density of vegetation in stands. Under the Millennium Forestry regime, which anticipates self-thinning and generally does not involve pruning, stands could be comparatively less open for at least part of the



rotation. This may make them somewhat less accessible to long-tailed bats e.g. for roosting and commuting. However, natural thinning may occur in a more patchy fashion than the previous selective thinning, effectively creating some gap habitats. These may facilitate bat access and could potentially offer foraging opportunities. Sedgely and O'Donnell (1999a) found long-tailed bat roosts in more open-structured areas of *Nothofagus* forest.

One of the reasons long-tailed bats may have shown a preference for areas of older rather than younger pines is that the understorey contains more shade-tolerant native species which may provide favoured prey habitat (Chapter 5). Under the Millennium Forestry regime, canopy closure is expected to effectively occur earlier in the rotation, around age 6–7 (L Cannon unreferenced personal communication 2001). The associated succession of undergrowth species from weedy exotic species to shade-tolerant native species will also likely occur earlier, potentially making stands attractive to foraging long-tailed bats at a comparatively younger age.

It is unclear what effect there will be on invertebrate communities and hence prey availability for long-tailed bats without inputs of thinning and pruning waste under the Millennium regime (H Moore unreferenced personal communication 2001).

### **Overall**

Long-tailed bats have declined in distribution and are now rare or absent in many areas in New Zealand (O'Donnell 2000b), from some areas they appear to have vanished in the last 20–30 years (O'Donnell 1997). Yet long-tailed bats are widespread in Kīnleith Forest and activity is high in places (Chapter 3, 5, 7). Though the status of the population is uncertain, it is possible that the reforestation of areas of anthropogenically-induced scrubland (Chapter 2) — along with protection of areas of native forest (e.g. Chapter 2, 6), retention and creation of wetlands, provision of edge and gap habitats in a complex habitat mosaic, and operations to control pest animals — has been beneficial, contributing to the continued presence of long-tailed bats in the Kīnleith Forest area today.

### **The unknowns**

This discussion has had to remain somewhat hypothetical. While the present study has increased our knowledge on many fronts (see also *Findings and contributions of this study*), there are still many questions. We do not know exactly where the long-tailed bats are roosting, whether this is in production forest, whether they have a large pool of roosts, nor whether they are faithful to a small core of roosting areas. Possibly roosting opportunities are limited, but this has not yet been able to be assessed in the field. We similarly have little knowledge of long-tailed bats' foraging areas, and whether these or indeed prey availability are limited.

Presumably long-tailed bats are using the landscape at a large scale, though core areas of activity may be small. Long-tailed bats' adaptability to landscape modification is uncertain. Long-tailed bats may exploit new clearings, but it is unclear how quickly they may respond to

gap creation. We do not know whether the level of collisions between bats and vehicles on roads is significant, and the potential effects of pesticides (herbicides, fungicides, insecticides, 1080) on bats remains to be quantitatively assessed. While this study has identified various trends of habitat use these may not necessarily represent fixed habitat requirements (O'Donnell 1999a).

More generally, although long-tailed bats are widespread in Kinleith Forest, are present in some areas from which they were known historically, and activity is high in places, we have little information on the size or health of the population. It could be stable, decreasing or increasing. Population-level responses to environmental change may be very hard to detect given our limited knowledge of the baseline population, the cryptic nature of long-tailed bats, their slow rate of reproduction and probable longevity. That an animal appears common does not necessarily preclude its vulnerability to environmental change (e.g. Law and others 1999). There could currently exist a sustainable balance between the use of resources by forestry and the use of similar resources by long-tailed bats, but this too is not readily observable.

### 3. BENEFITS TO FORESTRY OF LONG-TAILED BATS

"What use are bats?" is a question I encountered many times during the current study. Insectivorous bats are "natural insecticides" (Robertson 1990; O'Donnell unpublished<sup>3</sup>), individuals can consume over 600 insects in a night (O'Donnell unpublished), or astoundingly 10 mosquitoes or 14 fruit flies per minute (Griffin and others 1960). Webb (1996) estimated insectivorous bats in Britain to effectively prevent the fatal blood loss due to mosquito bites of 710,000 people annually (Chapter 1). Long-tailed bats are solely insectivorous, preying on moths (particularly Noctuidae and Geometridae), beetles, and flies among other prey (Gillingham 1996; O'Donnell 2000a, 2001b).

For Kinleith Forest, perhaps of greatest significance is long-tailed bats' probable role in predating the moth *Helicoverpa armigera* (Heliothis). This moth is a noctuid, it is within the size range taken (see DEFRA 2001 compare O'Donnell 2001b), it is nocturnal, and it is most numerous, and hence troublesome, during the summer (Herman 1995) — a time when bat activity is high (Chapter 1; G Moore unpublished data). *H. armigera* appears widespread in Kinleith Forest (e.g. Herman 1997; Forest Health Dynamics Ltd 2000) just as long-tailed bats are (Chapter 3) and bats have been detected near areas where it has been observed (Chapter 3 in relation to Forest Health Dynamics Ltd 2000, and Herman and Davidson 2000).

*H. armigera* is a widespread pest of commercial crops including fruits and vegetables (DEFRA 2001), maize (Herbison-Evans and Crossley 2001), cotton (Herbison-Evans and Crossley

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<sup>3</sup> O'Donnell C. Conserving long-tailed bats in South Canterbury. [Department of Conservation information sheet]. Available from: Department of Conservation, Private Bag, Christchurch, New Zealand.



2001) ornamentals (DEFRA 2001) and young pine trees (Herman 1995; Maclaren 1996). Occurring in Europe, Asia, Africa, Australia and the South Pacific, it is well established in New Zealand (Herman 1997). *Helicoverpa* spp. is also the “number-one agricultural pest in America” (McCracken 1996, p 2).

*H. armigera* reached damaging proportions in central plateau forests including Kinleith Forest in the mid 1990s (Herman 1995, 1996a; Herman and Davidson 2000), causing serious defoliation and some stripping of trunks and tip death in two year old pines (Herman 1995). CHHF had only recently begun oversowing of establishing blocks with grasses and legumes (Herman 1995). This potentially offered many benefits e.g. reduced weed growth, decreased fire risk, and significant gains in tree growth (Maclaren 1993) and was becoming an increasingly popular practice in the forestry industry (Maclaren 1993, 1996). However, lotus proved to be a suitable species for oviposition by *H. armigera*. *H. armigera* larvae feed on foliage near where they emerge, but as they grow they move further afield in search of more nutritious plant parts like flowers and fruit (Herman 1997). With mild weather, which allowed high survival of overwintering pupae and first generation larvae, and caused the early die-off of lotus and pasture species, burgeoning numbers of larvae moved to feeding on young pine trees, causing significant damage.

Research was quickly mounted to assess control options (Herman 1995). This developed into a two year programme involving several forestry companies (Herman 1996a). Objectives were to introduce a biocontrol agent, *Microplitis croceipes* (previously released elsewhere in New Zealand) (Herman 1996a) and to recalibrate the well established tomato industry integrated pest management programme for forestry (Herman 1996a). Caution is needed in the control of *H. armigera* because it is known to develop resistance to many insecticides (Cameron and others 1995; Gunning and others 1998; Hassan 1999; Herbison-Evans and Crossley 2001).

The introduction of *M. croceipes* has been successful (Herman 1997; Herman and Davidson 2000) and with other natural enemies (Herman 1997), less favourable weather conditions (Herman 1997), and cessation of oversowing using lotus (L Cannon unreferenced personal communication 2001), populations have not since reached damaging levels in Kinleith Forest (S Downs unreferenced personal communication 2001). However, population monitoring and prediction work is ongoing (e.g. Forest Health Dynamics Ltd 2000; D Hammond unreferenced personal communication 2001) — albeit at a low level [but one which can be stepped up if required (D Hammond unreferenced personal communication 2001)], and the threat of further serious damage by this pest has not entirely gone away.

Although the research undertaken pre-dates this study, it is interesting to note that at no time were long-tailed bats ever identified as a potential natural enemy of *H. armigera* (see Herman 1995; 1996a; 1996b, 1997), although they may have indeed been preying on *H. armigera* moths



at monitoring sites. Further, predators (as opposed to parasitoids) were seemingly discounted early on as having an inconsistent impact on *H. armigera* populations (Herman 1995). However, there is mounting evidence of the important role bats can play in consuming agricultural and forestry pests (e.g. Advani 1983; Whitaker 1993; Long and others 1998; Pierson 1998), including *Helicoverpa* spp. (Murphy 1993; McCracken 1996). Mexican free-tailed bats (*Tadarida brasiliensis*, Molossidae) from Bracken and nearby caves almost certainly eat *Helicoverpa*, and they do so by the tonne, capitalising on the large northward migrations of these moths from Mexico into central North America (McCracken 1996). At an organic farm in Oregon, a quantifiable reduction in the occurrence of *H. armigera* occurred with increases in the resident bat (*Myotis lucifugus*, Vespertilionidae) population (facilitated by providing roost boxes) (Murphy 1993).

While many insectivorous bats including long-tailed bats (e.g. Gillingham 1996; O'Donnell 2000a; 2001b) eat a range of insects, many are opportunistic feeders (e.g. Fenton and Morris 1976; Bell 1980; Vaughan 1980; Altringham 1996; Griffiths 1996; O'Donnell 1999a), exploiting areas of high prey abundance (but not necessarily diversity) (e.g. Fenton and Morris 1976; Bell 1980; Vaughan 1980; Racey and Swift 1985; Furlonger and others 1987; de Jong and Ahlén 1991; Rydell 1992; de Jong 1994; Racey 1998; McCracken 1996). Hence, insectivorous bats may play a very important role in helping to control pest populations (see also Marcot 1996; Pierson 1998). Indeed, the Mexican free-tailed bats showed a dramatic dietary shift during the course of the night — early on, before *Helicoverpa* spp. arrived, moths formed only 37% of the prey taken (McCracken 1996). However, during a second feeding bout, which coincided with *Helicoverpa* spp. arrival, moths comprised 96% of their diet (McCracken 1996). While Gillingham (1996, p 70) did not observe long-tailed bats to exclusively target any specific prey items, he suggests it “would be surprising if they never do so”.

The evidence presented suggests that long-tailed bats may (or could) be an effective biocontrol agent of *H. armigera* in Kinleith Forest, complementing current hymenopteran biocontrol agents *M. croceipes* and *Cotesia kazak* (e.g. Herman and Davidson 2000) which target larval stages (e.g. Herman 1995, 1997). Long-tailed bats are not known to eat Hymenoptera (Gillingham 1996; O'Donnell 2000a, 2001b).

Other pest species of which long-tailed bats could be important predators include the smaller Cerambycidae (longhorn beetles), which they definitely eat (C O'Donnell unreferenced personal communication 2001). Long-tailed bats may prey on burnt pine longhorn beetles (*Arhopalus ferus*) which fly at dusk and during the early part of the night (Emberson 1984). Burnt pine longhorn beetles are a potential pest in Kinleith Forest (S Downs unreferenced personal communication 2001). Females lay their eggs in the bark of dead and dying trees, the larvae tunnelling towards the inner phloem and cambium to feed (Forest Research 2001a). The presence of burnt pine longhorn beetles can severely reduce the time available for successful

salvage after fire or windthrow (Emberson 1984). However, perhaps a greater problem is that the presence of adult beetles sheltering in sawn timber can necessitate the fumigation of large quantities of wood before it can be exported (Forest Research 2001a). The possibility of long-tailed bats taking small huhu beetles (*Prionoplus reticularis*), cannot be discounted (C O'Donnell unreferenced personal communication 2001) — various culled elytra were found at known bat sites including open areas in Kinleith Forest (personal observations), suggesting the presence of a nocturnal flying predator. Huhu beetles present similar problems to foresters as burnt pine long-horn beetles, but larvae can sometimes also damage the heartwood of living trees (Emberson 1984).

Eucalyptus tortoise beetles (*P. charybdis*), a significant defoliator of *Eucalyptus nitens* in Kinleith Forest (S Downs unreferenced personal communication 2001; see earlier), can similarly not be ruled out as a potential prey species. Although seemingly not renowned for its flying ability (P Barrett unreferenced personal communication 2001), swarms have been washed up on beaches and found on Mt Taranaki (M Kay unreferenced personal communication 2001). Tortoise beetles have been caught in light traps (M Kay unreferenced personal communication 2001), suggesting their activity coincides at least partly with that of long-tailed bats. In size, tortoise beetles (Forest Research 2001b) are very similar to grass grub beetles (*Coselytra zealandica*) (e.g. Chapman 1984) a prey species of long-tailed bats (e.g. O'Donnell 2000a).

Other moth species e.g. the common forest looper (*Pseudocoremia suavis*, Geometridae), though not presenting much problem in Kinleith Forest (S Downs unreferenced personal communication 2001), with its small amount of Douglas-fir forest, are also likely to be taken by long-tailed bats. Long-tailed bats may benefit forestry by eating many other pest or potential pest species as well, however our current knowledge of their diet is still limited (O'Donnell 2000b).

Bats worldwide are an important part of the nutrient cycle (Chapter 1). Bats have extremely high throughput, producing nutrient rich guano (Pierson 1998). Often travelling considerable distances between roosting and foraging areas, they possibly “act as ‘nutrient pepper shakers’, redistributing nutrients over the landscape and creating nutrient ‘hotspots’ within roosts” (Pierson 1998, p 317). Long-tailed bats in Kinleith Forest may aid in the dispersal of nutrients from productive wetland areas to less productive forested areas (after Pierson 1998).

There are no obvious negative ecological effects of long-tailed bats to plantation forests. Long-tailed bats are not among the small number of bats known to modify their physical environment to create suitable roosts (Kunz 1982) and so do not directly harm the trees they choose to roost in.

#### 4. OPPORTUNITIES TO WORK TOGETHER

In Kinleith Forest, long-tailed bats may play a valuable role as biocontrol agents for a range of pests, including *H. armigera* which has caused significant defoliation of young trees. While knowledge of the roosting ecology of long-tailed bats in Kinleith Forest is limited, tree felling operations potentially threaten bat roosts, and roosting opportunities may already be scarce, thereby restricting (possibly endangering) populations and the associated level of benefit to be gained from ecosystem services provided by long-tailed bats.

The opportunity exists to trial artificial roosting boxes in Kinleith Forest to further encourage bats into areas vulnerable to pest damage — potentially helping to limit pest populations so that they do not reach outbreak proportions (Pierson 1998), and to reduce the number of bats potentially harmed in tree felling operations both directly (through injury) and indirectly (through habitat loss). Providing additional roosting opportunities could increase bat survival [if the roosts offer superior conditions (discussed by Sedgeley 2001)], population carrying capacity, and population size (Boyd and Stebbings 1989; Murphy 1993; and by implication Findley and Wilson 1974; Humphrey 1975; Kunz 1982; Findley 1993), increasing the benefits of pest control and nutrient dispersal, as well as significantly aiding the conservation of this nationally threatened species.

Artificial roost boxes have been widely used overseas (e.g. Kunz 1982; Boyd and Stebbings 1989; Mayle 1990; Robertson 1990; Racey 1992; Gerell and Lundberg 1993; Murphy 1993; Irvine and Bender 1995; Dourson 1997; Pierson 1998; Altringham 1998; O'Donnell 1999b), especially as a means of attracting bats into conifer plantations to control insect pests (Stebbing and Walsh 1988, cited in Sedgeley 1995; Mayle 1990). Long-tailed bats would likely adapt to using roost boxes given their occasional use of wooden bridges and buildings (Daniel and Williams 1984) for roosting, and M Daniel's (unreferenced personal communication 2001) observation of long-tailed bats roosting in holes drilled into pine trees for thinning<sup>4</sup>. Related *C. gouldii* has been observed using roost boxes in Australia (Irvine and Bender 1995). Initial trials of roost boxes for long-tailed bats are being undertaken in South Canterbury (O'Donnell 1999c; Cullen 1999).

Such a project, if set up as an ecological "experiment", among other benefits, could also help answer the crucial question presented by this study and posed by O'Donnell (1999a) and O'Donnell and Sedgeley (1999) of whether roosts are limiting. If roosts are limiting, reducing their availability further e.g. by tree felling could threaten population viability (O'Donnell and Sedgeley 1999). With a threatened species, investigation along these lines is precluded, however, one could observe the response to the provision of supplementary roosts (Newton 1994; O'Donnell 1999a).

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<sup>4</sup> These trees were thinned out by administering arsenic — this practice is very dated (R Black unreferenced personal communication 2001).



## 5. FINDINGS AND CONTRIBUTIONS OF THIS STUDY

Looking at how far we've come, at the beginning of this study, our knowledge of New Zealand bats was in its infancy. Few long-term studies had been completed (Higham 1992) and very little was known of the status, stability, limiting factors and ecology of either species (O'Donnell 1994; O'Donnell and Sedgeley 1994; Molloy 1995). While emphasis had previously been on short-tailed bat research, in 1997 the conservation status of long-tailed bats was becoming of increasing concern (O'Donnell 1997). Long-tailed bats appeared rare or absent from areas where they were previously widespread, but limited information was available from the North Island. Internationally, relatively little was known about forest-dwelling microbats (O'Donnell 1995; Brigham and Barclay 1996), let alone of the impacts of anthropogenic habitat modification (e.g. Grindal 1996; Hayes and Adam 1996; Lacki 1996). This study, looking at bats' use of Kinleith Forest and effects of forestry operations, was significant in three main regards: in being the first comprehensive study of native bats' use of commercial exotic forest in New Zealand; in considering bat distribution and habitat use at a scale previously unattempted in the South Waikato; and in focussing on an area outside of the estate of the Department of Conservation (DoC).

Objectives were:

1. To determine the presence and distribution of bats in the Kinleith Forest
2. To assess bats' use of the forest
  - To investigate bats' use of roads as flyways in different forest types
  - To ascertain habitat preferences and locate important foraging areas
  - To determine home range sizes
  - To locate and describe communal, maternity and solitary roosts
3. To assess the effects of forestry operations on bats.

This section summarises the findings of this study and describes its main contributions in terms of these objectives.

### ***Presence and distribution of bats in Kinleith Forest***

Long-tailed bats were confirmed to be present in Kinleith Forest and were found to be widespread (Chapter 3). They occurred in a range of habitats and topographies (Chapter 5), in places activity was high (Chapter 3, 5, 7). This is significant in itself, given the perception of plantation pine forests as sterile monocultures, the fact that production forests are unlikely to provide many cavities suitable for bat roosts, and that long-tailed bats are generally associated with indigenous forest (Chapter 3). With the decline of this species elsewhere, it is noteworthy that long-tailed bats were confirmed present in some areas from which they were known historically (Chapter 3).

An unexpected outcome was that I was able to graphically represent the results of this study in relation to the observed distribution of bats in the central North Island (Chapter 3: Figure 6). Comparison with Molloy's (1995) map which shows an absence of sightings in the Kinleith Forest area, highlights the important contribution this study makes to current knowledge. This research suggests that long-tailed bats may have a fairly continuous distribution in the Central North Island (Chapter 3), and that instead of approaching unsurveyed commercial exotic forests with the expectation that long-tailed bats are probably absent, long-tailed bats should be assumed present until proven otherwise (Chapter 3).

Two short-tailed bat populations occur within 15 km of Kinleith Forest, and sightings of short-tailed bats and *Dactylanthus taylorii* — a plant they naturally pollinate, both in Kinleith Forest and nearby suggests the presence of this species cannot be ruled out (Chapter 3).

### ***Bats' use of the forest***

Investigations focused on the widespread long-tailed bats.

#### *Roads as flyways*

In all forest types (young and mature *P. radiata*, and native podocarp broadleaf forest), bat activity was higher at roadsides than in the forest interior, even where the forest had not yet developed canopy closure (Chapter 4). Bats probably used roads as flyways for reasons of habitat structure, though roads may also play a role in navigation (Chapter 4). Many of the habitats in which long-tailed bats were found throughout this study were also associated with roads (Chapter 5). These results are important in that it was previously unknown whether long-tailed bats used roads in exotic plantation forest (Chapter 4). Further, support is provided for the use of road-based survey methods in exotic plantation forest (Chapter 4). Additionally, being well-roaded, Kinleith Forest may offer advantages to long-tailed bats over areas of more continuous forest (Chapter 4, this chapter).

#### *Habitat preferences, important foraging areas*

Long-tailed bats used habitats including harvested/unstocked land, young *P. radiata* forest, mature ( $\geq 17$  years) *P. radiata*, *Eucalyptus* spp., *Pseudotsuga menziesii* and *Sequoia sempervirens* forest, native forest remnants, and wetlands (though roads were associated with most of these) (Chapter 5). Long-tailed bats occurred in all the major topographies of Kinleith Forest (Chapter 5). Greater bat activity was observed in mature pine forest than young pine forest, and long-tailed bats appeared to select older pine forest and avoid unstocked land or younger forest (Chapter 5). This apparent preference may partially explain the greater bat activity observed in the north-eastern Galaxy area than the western Wainui area (Chapter 5). Six sites, including a wetland, older pine forest, and areas in or adjacent to native forest, had high bat activity, and mostly appear to be used by foraging long-tailed bats (Chapter 5). In a

comparison of foraging activity in exotic plantation and native forest, there was greater foraging activity (and activity in general), in the exotic plantation forest (Chapter 6) possibly due to the greater abundance of moths, an important dietary component of long-tailed bats (Chapter 6). However, forest type was the best predictor of bat activity (Chapter 6). The observed rate of foraging calls was generally relatively low (Chapter 4, 5, 6), however, on two ABM-nights rates equalled or exceeded those observed elsewhere in New Zealand (Chapter 5). Possibly prey were limited (Chapter 4, 5, 6) and/or patchily distributed (Chapter 5), and/or the areas observed may not represent core foraging areas (Chapter 4, 5, 6).

These results represent a significant contribution to knowledge. Firstly, it was unclear at the beginning of this study where to begin looking for long-tailed bats in exotic plantation forest. Now we have a basis from which to start in future studies. Secondly, with a better understanding of how bats are using the forest, and what habitats are important to them, we can begin to assess the likely impacts of forestry operations and management (this chapter). Thirdly, these results may help us build up a picture of the limiting factors operating on long-tailed bat populations New Zealand-wide. This will be crucial for species conservation. To this end, it is extremely interesting that long-tailed bats appeared to prefer exotic plantation forest for foraging over native forest — this certainly warrants further investigation.

### *Home range sizes*

Unfortunately, difficulties in trapping bats precluded the use of radio-telemetry and so investigation to meet this objective was unable to take place (Chapter 5).

### *Communal, maternity and solitary roosts*

Anecdotal records indicated several bat roosts were in production trees (*P. radiata*), including old crop trees. One record was of a roost in a barely noticeable crevice in a 30-year-old pine (Chapter 7). There is evidence that maternity roosts may occur in production forest (Chapter 7). Other roost records were from areas of native forest, rocky crevices and a cave (Chapter 7). Four accounts were of communal roosts (Chapter 7). Most observations were made during the process of habitat modification and so roosts no longer exist (Chapter 7). Six sites, including a wetland adjacent to tall trees, older pine forest, and areas in or adjacent to native forest, had high, possibly roost-associated, bat activity (Chapter 7). The distinctive calls at one of these in particular suggested the potential presence of a nearby communal roost (Chapter 5, 7).

This study has brought together a number of roost sightings which were previously little known, and distinguishes some areas of possible bat roosts. It identifies several patterns in the sightings including that a number of roosts were in old crop trees, and illustrates that maternity roosts may occur in production forest. Although there are many questions left to answer, these contributions are useful, aiding our understanding of the ecology of native long-tailed bats in



exotic plantation forest and allowing preliminary assessment of the likely affects of tree felling operations on long-tailed bats.

### ***The effects of forestry on bats***

Tree felling operations could on the one hand potentially benefit long-tailed bats e.g. by creating foraging habitat and facilitating access, but on the other, could threaten long-tailed bats at an individual and population level e.g. by causing injury or death; loss of foraging, roosting, and prey habitat; and decreasing connectivity between groups. Overall, effects are likely to depend on the scale of operations, and sensitive management may be needed to ensure bat survival in Kinleith Forest. Other forestry operations also have potential to negatively affect long-tailed bats e.g. site preparation, pesticide use, infrastructure works, transportation and quarrying. However, the magnitude and significance of effects is unknown. Pest mammal control operations may benefit long-tailed bats by reducing numbers of potentially competing and predatory organisms. The conservation of cave, wetland and reserve areas potentially benefits long-tailed bats, but conversion of forest blocks to grassland may be detrimental. The Millennium Forestry regime will likely see changes in snag numbers, stand density and understorey development. Effects for long-tailed bats could be mixed, but may overall be positive. The complex habitat mosaic provided by Kinleith Forest may be favourable to long-tailed bats. However, there are many questions yet to be answered.

This section has brought together findings from throughout this study and from across the globe to address the effects of forestry operations in Kinleith Forest on long-tailed bats. Being the first to do this, the first to look at the interactions between plantation forestry and long-tailed bats generally, and also considering various areas for which there is seemingly little knowledge globally e.g. effects of habitat fragmentation on temperate bats, it makes a valuable contribution to our knowledge. This study also contrasts with previous studies (e.g. Gillingham 1996; Griffiths 1996; O'Donnell 1999a; Webb 1999; Sedgeley and O'Donnell 1999a) which have largely focused on the morphology, physiology, demography and behaviour of long-tailed bats without considering external anthropogenic influences on their environment [though see recent work by O'Donnell (2000a)].

### ***Other outcomes***

This study has made two other significant contributions. It is the first in New Zealand to look at the possible benefits to plantation forestry of having long-tailed bats. The potential usefulness of long-tailed bats as biocontrol agents is only starting to be considered in New Zealand (e.g. O'Donnell 2000a, unpublished), and was overlooked in recent work adjusting an integrated pest management programme for *Helicoverpa armigera* for forest use. However, with a diet that includes beetles and moths (especially Noctuidae of which *H. armigera* is a member) long-

tailed bats may offer substantial benefits in forest pest control. They also play a role in nutrient dispersal.

A further outcome has been the development of driving transects. Previously little known in New Zealand, though used overseas, especially in Europe (Chapter 3), this method proved to be a successful rapid-survey method appropriate to the plantation forestry environment (Chapter 3, 4, 5) and with potential for use elsewhere (Chapter 4). Driving transects were particularly efficient in identifying bat presence (Chapter 3). They showed promise in comparing relative bat activity between two disparate areas of forest (Chapter 5; see also Ahlén 1980–81) and were successfully used to evaluate habitat selection (Chapter 5) contributing valuable knowledge.

Driving transects may be a useful tool for New Zealand in undertaking basic bat survey work — a current focus (Chapter 3), especially with the increasing emphasis on conservation outside of protected areas (Chapter 3) and the growing interest in bat survey work among forestry companies (Chapter 4). Driving transects may also be valuable in monitoring population trends over time (Chapter 3, 4) and assessing the effect of various management regimes (Chapter 3, 4). The method has certain advantages over the more widely used walking transect method, though the two could be complementary (Chapter 3).

### ***Aiding conservation***

Overall, this research has increased our knowledge and made contributions in several areas important to the conservation of New Zealand bats, as discussed in the 1995 Bat Recovery Plan (Molloy 1995). Objective 1 of this plan is to “undertake .... research on bats which will assist in their management” (p 11). This study has firstly increased our knowledge of the distribution of long-tailed bats — also highlighted as important by Lyall (2000). Secondly, it has contributed to our ecological knowledge e.g. by identifying patterns of habitat use. Thirdly, it has increased our knowledge of the potential threats facing long-tailed bats in a plantation forestry environment. Fourthly, a “new” monitoring technique, which is successful in this environment and shows promise for use elsewhere was developed. Objective 2 concerns evaluation of the status of bats. This study has furthered our knowledge of the distribution of long-tailed bats, and is the first to consider this at a broad scale in relation to vegetation type (rather than just indigenous forest), helping to meet this objective. It has also brought together and evaluated the evidence for the presence of short-tailed bats in Kinleith Forest. Objective 4 stresses the need to protect and monitor populations of bats throughout their geographic range. The current study is useful to this end in that it contributes information on long-tailed bats from a comparatively unstudied area and habitat type, providing valuable data which can be built on in future. Finally, Objective 5 is to “raise public awareness of bats and to involve the public in bat conservation”. During its course, this study touched many people, a large number of who were previously unaware we had bats in New Zealand. Many showed a keen interest when

given a little information. A large pool of enthusiastic volunteers were actively involved in fieldwork.

## 6. RECOMMENDATIONS

### **CHHF**

Several specific areas of importance to long-tailed bats were identified by this study. It is recommended that 1) caution be exercised when considering any operations which may affect habitat quality for long-tailed bats at sites on Capricorn Rd, Hoiho Rd, Pipeline Rd, Star Rd, at Redwood Reserve and in the riparian area along the Tikitiki Stream; and that 2) the specific value to long-tailed bats of old crop forest and forest at Capricorn Rd (where a potential roost is located) be assessed prior to undertaking any tree felling operations in these blocks, including roadlining. Long-tailed bats are present in Sneddon Block, Wiltsdown, and could potentially be roosting in the gorge of the Pokaiwhenua Stream. It is recommended that the value of this area to bats be assessed and provided for in any agreement regarding the sale of this land.

Should an occupied roost tree be felled during an operation (or should bat(s) be found in or on a log brought to a skid), it is recommended that felling operations cease until a bat survey has determined the significance of the area to bats and identified how potential negative impacts of felling can best be avoided, minimised, mitigated or remedied. The value to bats of non-production trees and spars (over the height of 2 m) should also be assessed before such trees are removed, and where possible, important trees should be protected.

That long-tailed bats are widespread in Kingleith Forest, show high activity in places, and are present in some areas from which they were known historically does not mean that the population is secure. Management decisions should be made with caution, and may need to consider the effects of operations at a range of scales. To "maintain" this species (CHHF 2000), further research is recommended to clarify the status of the population; to better identify and define areas of "significant habitat" (Resource Management Act 1990), especially core roosting areas, but also foraging areas; and to address how these can best be provided for during forestry operations. Further information is also needed on the scale at which bats are using the landscape and long-tailed bats' vulnerability/tolerance of fragmentation (see also *The Bat Recovery Group*). There may be opportunity for a co-operative research project with the local Department of Conservation, who is the steward of a significant area of land within the Kingleith Forest area and has similarly displayed an interest in finding out about the long-tailed bat population (e.g. Griffiths 1999). The results of the present study provide valuable base-line information.

The awareness of long-tailed bats in Kingleith Forest is growing, however, their presence and importance within the ecosystem needs to be recognised so that they are not overlooked in



assessment and decision-making processes. For example, the possible effects on long-tailed bats should be assessed when considering using pesticide, or introducing a new biocontrol agent to the Forest. If in future a cave requires protection from disturbance, it is suggested that a bat-friendly grille be installed rather than blocking up the entrance.

The significance of collisions between bats and vehicles in the forest requires assessment.

The presence of long-tailed bats in Kinleith Forest suggests long-tailed bats may also be present in other areas of Carter Holt Harvey Forests' estate. Survey work in other areas for long-tailed bats and potentially short-tailed bats is recommended. There is potential for short-tailed bats to be present in Kinleith Forest.

This study highlights several opportunities. Regarding insect pest control operations, it is suggested that consideration be given to the potential role of long-tailed bats as biocontrol agents in the implementation of current integrated pest management programmes and in the formulation of new ones. In particular, long-tailed bats may be a very effective predator of *Helicoverpa armigera*. The beneficial action of long-tailed bats as "natural insecticides" in the Forest could potentially be enhanced with the provision of artificial roosting boxes, these could also act to reduce the number of bats potentially harmed in tree felling operations (both directly and indirectly), offering benefits to forestry and bats alike.

The opportunity also exists to increase the public profile of long-tailed bats in Kinleith Forest. This could enhance the company's environmental image and increase the understanding of bats in the community, potentially aiding their conservation.

### ***Plantation forest managers***

Long-tailed bats are widespread in Kinleith Forest, and in places activity is high. The results of this work, particularly in relation to other survey work recently undertaken in commercial exotic forest, suggests that in the central North Island at least, long-tailed bats should be assumed to be present in unsurveyed exotic plantation forest until proven otherwise. Long-tailed bats may play important roles in insect pest control in plantation forests.

### ***The Bat Recovery Group***

Long-tailed bats are widespread in Kinleith Forest, they are still present in areas from which they were known historically despite a background of national decline, they seem to forage in pine forest over native forest (in autumn), activity is high in places and Kinleith Forest may present a very favourable habitat mosaic. Long-tailed bats are expected to be present in other exotic plantation forests, and may have a fairly continuous distribution in the central North Island. It is recommended that strategies for the conservation/recovery of this threatened

species recognise the potential importance of exotic plantation forest to long-tailed bats, and that this habitat type be considered during the development of population monitoring techniques. Any work in this area could build on the findings of this study.

Research into the tolerance of long-tailed bats to habitat fragmentation (as also suggested by O'Donnell 1999a) is definitely required. Kinleith Forest may provide a useful study opportunity offering a different degree of fragmentation to areas of recent or ongoing study (e.g. Fiordland National Park, South Canterbury, King Country). There may be opportunity for a joint research project.

### ***General***

I observe that many different parties with an interest in native bats e.g. Carter Holt Harvey Forests, the Bat Recovery Group, the Department of Conservation, World Wide Fund for Nature, and other forestry companies, appear to have some common goals. Open discussion, sharing ideas and experience, and contributing to joint research projects, could provide many benefits all round.

## **7. CONCLUSIONS**

Long-tailed bats are widespread in Kinleith Forest. Given the decline in this species elsewhere it is significant that long-tailed bats are present in some areas from which they were known historically. They occur in all topographies and a range of habitats from harvested land to mature production trees, wetlands and native remnants. In places activity is high. Capricorn Rd, Hoiho Rd, Pipeline Rd, Star Rd, at Redwood Reserve and riparian forest along the Tikitiki Stream seem particularly important to long-tailed bats.

Long-tailed bats commonly use forestry roads, even in young forest, probably for reasons of habitat structure, though roads may be important in navigation. This behaviour may be used to advantage in bat surveys.

Long-tailed bats appear to select areas of older pines and avoid areas of younger pines. Older pine forest retains more heat, has a different understorey, and may offer more shelter, potentially favourable conditions for insect prey and foraging bats.

Long-tailed bats seem to forage in plantation pine forest over native podocarp broadleaf forest, possibly because of the greater abundance of moths — important prey. Forest type is the best predictor of bat activity.

Long-tailed bats appear to roost in production trees, especially old crop trees, and may even use them for breeding, though indigenous forest is likely to be of equal or greater importance.

Forestry operations involving tree felling may threaten long-tailed bats at an individual and a population level by causing injury or death, reducing available habitat and isolating bat groups. However, at the right scale, tree felling may be beneficial, creating foraging habitat and facilitating access. Operations including pesticide use, transportation and quarrying may negatively affect bats. Pest mammal control and the conservation of cave, wetland and reserve areas potentially benefit them. Kinleith Forest may represent a favourable habitat mosaic to long-tailed bats, however, the net effect of forest management is uncertain. To ensure the continued survival of long-tailed bats in Kinleith Forest sensitive management may be required at a number of scales. There are many questions yet to answer.

Opportunities exist for bats and foresters to work together. Long-tailed bats are potentially very efficient biocontrol agents of a range of significant forest pests. They may be able to be encouraged in this role with increased roosting opportunities.

Overall, not only do long-tailed bats occur in exotic plantation forest, a previously overlooked habitat, but they may be widespread in such forest. There is a need for a paradigm shift: instead of anticipating long-tailed bats to be absent from unsurveyed exotic plantation forest, they should be assumed present until proven otherwise. Long-tailed bats' distribution in the central North Island may be fairly continuous.

There is potential for short-tailed bats to be present in Kinleith Forest.

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# 9

## APPENDICES

# 9

## APPENDICES

### 1. GENERAL INTRODUCTION

#### 1.1 *Further information about bats*

##### *The origin of bats*

Bats' scientific name, Chiroptera, is derived from the Greek meaning "hand wing" (Yalden and Morris 1975). The order is divided into two suborders, the Microchiroptera — true bats (782 described species) and the Megachiroptera — the flying foxes (175 described species) (Neuweiler 2000). Our knowledge of the origin and evolution of bats is limited (Daniel 1990) because the fossil record is very poor (Hill and Smith 1984). However, the earliest known fossils date back to the early Eocene (about 60 million years ago), and so the first bats (which were classed as Microchiroptera) may have arisen in the mid to late Cretaceous (70–100 million years ago) (Daniel 1990). Their ancestor is thought to have been insectivorous with webbed fingers and glider-like (Hill and Smith 1984) or shrew-like (Yalden and Morris 1975; Fenton 1983) with possible rudimentary echolocation ability (Fenton 1983; Hill and Smith 1984). The oldest known Megachiropteran fossil, is from much later [Oligocene, 35 million years ago (Hill and Smith 1984) or Miocene, 26 million years ago (Yalden and Morris 1975)]. The Megachiroptera are thought to have evolved independently of the Microchiroptera, possibly from a primate ancestor (Hill and Smith 1984).

##### *Microchiroptera*

The microbats, as their name suggests, are generally small, weighing from 5 to 20 g (Neuweiler 2000) although the smallest known bat is the bumble-bee bat (*Craseonycteris thonglongyai*) at 1.7 g (Daniel 1990), and a few species weigh over 50 g as adults (Fenton 1983). All use echolocation (Neuweiler 2000) for orientation and many use it in finding food (Schnitzler and Moss 1998). As well as specialised ears (Dawkins 1986; Daniel 1990), some microbats also have nose-leaves (leaf-like protuberances of skin associated with the nose region), thought to aid in echolocation (Hill and Smith 1984). Microbats are generally insectivorous (Neuweiler 2000) but some eat small vertebrates such as fish, frogs, lizards, birds, mice and other bats. The vampire bats are sanguivores, and others, like many of the Phyllostomidae, are facultative



or obligate frugivores and flower feeders (Neuweiler 2000). There are 17 families of Microchiroptera (Neuweiler 2000) found almost worldwide (Daniel 1990).

### *Megachiroptera*

The megabats consist of only one family, the fruit bats or flying foxes (Pteropodidae). They are found in the tropics and subtropics of Australia, Asia and Africa (Hill and Smith 1984). Most are large, ranging from 100 g (Neuweiler 2000) to the 1.2 kg giant flying fox (*Pteropus giganteus*) which has a wingspan of 1.7 m (Daniel 1990). They feed on fruit, nectar and pollen, and generally spend the days in their tree colonies. An important difference between the megabats and the microbats is their primary reliance on vision to navigate. The exception is *Rousettus*, a cave-dwelling megabat genus which uses the tongue (not the larynx as in microbats) to produce echolocation clicks (Neuweiler 2000).

### *Other features characteristic of bats*

#### Roosting habits

Bats spend most of their lives in roosts (Altringham 1996). Roosts provide sites for mating, rearing young, and hibernation (Kunz 1982); they promote social interactions (Kunz 1982) including information exchange (Altringham 1996); and allow for food digestion (Kunz 1982). Some species even use roosts for prey ambush (Kunz 1982). The variety of roosting habits is almost as varied as the bats themselves (Fenton 1983). Bats use foliage, and hollows and crevices in trees, rocks, caves and anthropogenic structures. At least 15 species make leafy tents (Fenton 1992). Sheltered roosts are relatively permanent, offer microclimate stability, reduced risks of predation, good protection against the elements (Kunz 1982) and facilitate cheaper thermoregulation (Altringham 1996) (see following). External roosts may be more ubiquitous and abundant but offer less protection and are more temporary (Kunz 1982). Bats commonly show greater fidelity to the more stable roost sites although fidelity is influenced by many factors (Kunz 1982). Temperate forest tree-roosting bats generally move roost sites frequently (O'Donnell 1999; O'Donnell and Sedgely 1999).

Generally the further from the equator, the greater the use of internal shelters (Kunz 1982; Altringham 1996; Neuweiler 2000). These are predominantly used by microbats, aided by their echolocation ability (Kunz 1982). Also, in the higher latitudes, bats tend to roost together in larger groups (Altringham 1996). Bats that roost in the open tend to be physically large (Kunz 1982; Altringham 1996). Megabats are the only foliage roosting bats that form large aggregations, most foliage roosting bats are solitary or form small groups (Kunz 1982).

Among the bats, roosting habits vary from obligatory, in some cases with highly specialised requirements, to opportunistic (Kunz 1982). The opportunistic species tend to be more widespread (Kunz 1982; Altringham 1996). The availability and capacity of suitable roosts can



limit species distribution and abundance (Findley and Wilson 1974; Humphrey 1975; Kunz 1982; Fenton 1992; Findley 1993) and bats may be exceedingly vulnerable to roost site disturbance (Fenton 1992). Bats are generally more sensitive about their roosting than their foraging sites (Fenton 1992).

### Solutions to the constraints of energy balance

Energy is the lowest common denominator in animals' lives. Every day requires that the energy intake from food or fat reserves meets that expended in day to day living, including getting the next meal (Altringham 1996). For bats, flying is very energetically expensive (Altringham 1996). The work of the flight muscles generates large amounts of heat (waste energy), which is dissipated through the specialised radiator-like wings (Fenton 1992). Crudely, bats need to eat to fly and fly to eat. Yet there is another major drain on energy. Being mammals, bats are endothermic — they metabolise food to maintain high body temperatures (Altringham 1996). This requires a high metabolic rate, and large food intake (Altringham 1996). These energy demands could prove problematic where food supply is seasonal, or where the animal is very small (Altringham 1996) — like most bats. Bats have the highest surface area to volume ratio among vertebrates (Yalden and Morris 1975), and so lose a high proportion of their body heat to the surrounding air (Altringham 1996) even when their wings are wrapped tightly around them (Fenton 1992). They therefore require proportionately larger amounts of food to generate sufficient energy to stay warm and remain active (Altringham 1996).

Temperate bats, which are generally small, and face seasonal variability in food supply and inclement weather, have come up with a novel solution. They can become heterothermic (Altringham 1996). That is, they can actively regulate their body temperature to minimise their energetic requirements (Altringham 1996). This state, where the body temperature is lower than its active homeothermic level and may be close to or at the ambient temperature (Neuweiler 2000), but is maintained within narrow limits and can be raised again without the external stimulus of rising air temperature (Altringham 1996), is known as torpor (Altringham 1996). Torpor may be used on a daily basis to conserve energy. While most bat species select roosts within their thermoneutral zones (where exertion of energy is not needed to keep warm or cool down) to minimise energy consumption (Fenton 1983), members of the Vespertilionidae (Altringham 1996), Rhinolophidae (Altringham 1996), and Mystacinidae (Webb 1999), are less restricted in their roosting requirements for most of the year because of their ability to become torpid (Fenton 1983).

Hibernation is “an extended form of torpor, lasting for days, weeks or months, which occurs on a seasonal basis, in response to a prolonged fall in ambient temperature or reduction in food supply” (Altringham 1996, p 117). About 10% of the known bat species hibernate (Findley 1993), including New Zealand's two species (long-tailed bats: Daniel 1990; MacKenzie 1995; short-tailed bats: Daniel 1979; MacKenzie 1995; Lloyd and McQueen 1998). Bats enter

hibernation with about a quarter of their body weight as fat and must conserve energy (Fenton 1992). This means finding a secure location cold enough to allow optimum metabolic shut-down, but not too cold to require the use of energy to keep from freezing. A humid environment may also be important to reduce water loss (Fenton 1992). Many caves and mines provide good hibernation sites, because temperatures remain stable and just above freezing (Fenton 1992). Bats may migrate long distances to suitable wintering quarters (Neuweiler 2000). However, most bats change their roost several times during winter (Neuweiler 2000) to optimise their energy savings (in relation to the weather and their remaining fat reserves) (Neuweiler 2000). Hibernation in hollow trees is possible where winters are less severe (Fenton 1992). Temperatures are less buffered than in deep caves, requiring exertion of energy to remain from freezing during cold snaps (Fenton 1992). However, these more exposed roosts offer bats the advantage of being able to arouse and forage during warmer nights (Fenton 1992). Indeed, in maritime climates, bats may be more or less active throughout a mild winter (Altringham 1996).

### Reproduction and life history strategies

Climate and feeding habits play a significant role in determining timing of reproduction (Altringham 1996). Mating, gestation and birth in most bats occur over a brief and well defined period (Fenton 1983). In the tropics, births usually coincide with the start of the rainy seasons (Fenton 1983). In many temperate bats and some tropical Vespertilionidae and Rhinolophidae, delayed fertilisation occurs (Fenton 1992). Bats mate in the late summer and autumn — when they are in peak condition (Fenton 1992) — and the females store the sperm delaying fertilisation so that young are born in the spring (Fenton 1992) or at the start of the rains (Fenton 1983). Thus lactation, which is very energy demanding, coincides with the time of abundant food supply (Fenton 1983; Neuweiler 2000). This strategy of sperm storage seems well suited to hibernating species, the period of storage coincides with hibernation (Fenton 1992) and birth in the spring time leaves sufficient time for full development of the young before the next winter (Altringham 1996).

Most bat species have one litter each year, of usually one or two young (Fenton 1992). All temperate bats are monestrous (have one reproductive cycle per year) (Findley 1993). Tropical bats are monestrous or polyestrous and commonly give birth to one infant per litter (Findley 1993). Bats are unique among small mammals, and vertebrates (other than the larger mammals) respectively, in their small litter sizes and low annual productivity (Findley 1993). However, relative to other mammals, bats produce proportionately larger offspring in terms of mother:pup weight ratio (Altringham 1996; Neuweiler 2000).

Bats also have comparatively long periods of gestation and nursing (Findley 1993). Most bats nurse from one to three months (Hill and Smith 1984). However, growth rates of young, though lower in megabats than microbats, are fast relative to other mammals (Altringham 1996). Some bats may be competent fliers in as little as 24 days [e.g. *Rhinolophus ferrumequinum*, a typical

microbat, (Altringham 1996)]. This rapid development is essential in a temperate environment where there is limited time to prepare for the approaching winter (Findley 1993; Altringham 1996). Reproductive maturity in most temperate bats is not reached until the age of nine months to a year, this may be similar in tropical bats (Findley 1993).

Bats are also remarkable in their longevity for their size (Findley 1993; Altringham 1996). An 8 g bat may be expected to live to an age of 4½, but many temperate (micro)bats have been recaptured at 20 years and even older (Findley 1993). Tropical bats too are long-lived (Findley 1993). Both tropical and temperate bats suffer lower mortality than many other vertebrates (Findley 1993). A typical microbat has a 40–80% chance of reaching an age of 7 or 8 years if it survives its first year [a particularly critical time in hibernating species (Findley 1993)], and many wild megabats and microbats have been recorded living between 10 and 31 years and beyond (Altringham 1996).

These features confer stability in bat populations (Findley 1993). Bats are outstanding K-strategists and seem best suited to life in stable communities in equilibrium (Findley 1993). Against conventional wisdom, bat communities appear to be structured largely by responses to the availability of crucial resources and to historic and geographic factors rather than by interactions with each other (Findley 1993).

#### Scale of habitat use

Bats are highly mobile and exploit feeding and roosting resources over large areas (Fenton 1992; O'Donnell 1995; Brigham and Barclay 1996). Although comparatively little is known about their range (Hill and Smith 1984) and the technique of radio-tagging small bats is relatively new (O'Donnell 1999), bats' nightly foraging expeditions may take them 10km (*Eptesicus fuscus* — Vespertilionidae), or closer to 20km (Vespertilionidae: *Eudermma maculatus*, *Nyctalus noctula*, *Lasiurus cinereus*, *Myotis myotis*) (Fenton 1992). Large mollossids (free-tail bats) may cover much greater areas (Fenton 1992). Megabats too appear to fly long distances between their roosts and fruiting trees (Hill and Smith 1984). Many temperate and tropical bat species make regular migrations (Fenton 1992) in response to changing climate and food availability (Neuweiler 2000).

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## 2. STUDY AREA

There is no supplementary material for this section.

## 3. BAT PRESENCE AND DISTRIBUTION

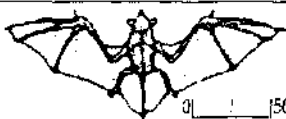
### 3.1 Bat sighting form distributed to recreational hunters

Refer following page.

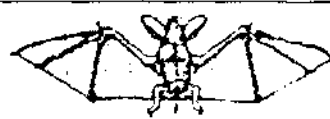
### 3.2 Revisions made to the National Bat Database data set before mapping

DoC_ID (CARD)	Change made
105948	Deleted record duplicate.
105977	Deleted all record duplicates.
106054	" <i>Mystacina tuberculata</i> " changed to "species unknown" because record states "The bats were reported to be in a hollow beech tree to the north of the reserve. No proof of identity".
106360	Deleted record duplicate.
106401	" <i>Chalinolobus tuberculatus</i> " changed to "species unknown" because record states "Farmer found a bat dead in a swimming pool. Though it was a short tailed bat, but this is not agreed upon".
106433	Deleted record duplicate.
107307	Both deleted because appear to be the same record but give different grid references. Both record a bat with large ears landing on a fisherman's hat along the Waiau River in January 1983.
106423	
107321	Deleted record duplicate.
107347	Deleted record because grid reference put location in the sea not the stated location of Rotoehu Forest.
107364	Retained grid reference but note location description and date are incorrect. Having talked to P Jansen (recorder) (unreferenced personal communications 2001) I am confident this is a legitimate record and one different to that described by M Wilke (unreferenced personal communication 2000).
108607	Deleted record duplicate. One entry recorded bat species as " <i>Chalinolobus tuberculatus</i> ", the other was classified as "species unknown". The latter was retained.
108613	Deleted record duplicate.
108618	Deleted record duplicate.
108645	Deleted record duplicate.
111583	" <i>Chalinolobus tuberculatus</i> " changed to "species unknown" because record states "An unidentified bat, presumed to be a long-tail was observed chasing moths in an open pasture situation".

# BAT SIGHTING RECORD



Long-tailed bat



Short-tailed bat

Information will be used in Masters research into bats' use of Kinleith Forest for  
Carter Holt Harvey Forests Ltd, and shared with Department of Conservation.

Please return to: Recreation Co-ordinator, CHH Forests, Grayburn House, Leith Pl, Tokoroa.

## LOCATION

## DATE & TIME

Map name and sheet number:

Grid reference:

Date (day-month-year):

Details eg near what roads, rivers, natural/ cultural features:

Time (24 hr):

Dawn/ Day/ Dusk/  
Night  
(Please circle)

## BAT INFORMATION

SPECIES	NUMBER	Circumstances in which bats were found:
Unknown		
Long-tailed		
Short-tailed		
BAT ACTIVITY		
Flying	Dead/ injured	
Feeding near the ground	Other (please specify):	
Roosting		

## HABITAT

Exotic forest - Radiata pine/ Eucalypt/ Other (please specify):

Approx. age:

and/or Area recently harvested

Beech forest

Description:

Broadleaf forest

Podocarp forest

Scrub

Farmland

Stream/ lake/  
swamp

Road edge

Other (please specify):

## OBSERVER DETAILS

Name:

Address and phone:

Affiliation:

Please use the back of this form if there is any further information you wish to contribute. Many thanks for your time.



## 4. USE OF FOREST ROADS BY LONG-TAILED BATS

### 4.1 Site description (exotic forest of two contrasting ages)

#### *Mature forest (Pipeline Rd)*

The forest in the area of study at Pipeline Rd was around 33.7 m in height and generally planted in 1976, though one block had been planted in 1977. Production thinning to a density of 375 stems/ha occurred between 1988 and 1995 (with the bulk in 1993). The block of "1977" trees had been pruned to 6 m fixed height in three operations between 1982 and 1985. There was a dense undergrowth of species including blackberry (*Rubus fruticosus*), Himalayan honeysuckle (*Leycesteria formosa*) in places, ferns, tree ferns and coprosmas (*Coprosma* spp.). Clematis (*Clematis* sp.) was also seen at one site.

Pipeline Rd is an unsealed one lane road of between 5 and 6.1 m width (measured at the monitoring sites). However, the water pipeline running along one side makes the distance between the forest blocks either side of the road quite large, at between 20 m (measured from tree trunk to tree trunk) and around 22 m. J906240 Rd, off Pipeline Rd, is also unsealed, and a single lane wide. Used less frequently than Pipeline Rd, it had saplings, ferns and blackberry growing along its edge. The tree trunk to tree trunk distance across this road was 10.8 m, however, the foliage of opposite trees was separated by a distance of only around 4 m.

#### *Young forest (Kangaroo Rd)*

The forest in the study area at Kangaroo Rd was planted in 1993 and 1994. It was around 6.3 m in height, unpruned, and largely unthinned. Most of the area had an actual stocking rate of 660.5 stems/ha and 695 stems/ha, while a smaller planting trial near one pair of sampling sites was at 800 stems/ha. A block of "1993" trees immediately east of this was thinned to waste just before this study began and had a density of 477 stems/ha. Some wildings were present and the stumps from the previous crop were evident. The vegetation between trees mainly consisted of tall grass, toetoe/pampas (*Cortaderia* sp.), bracken (*Pteridium aquilinum*), Spanish heath (*Erica lusitanica*) and Himalayan honeysuckle (*Leycesteria formosa*).

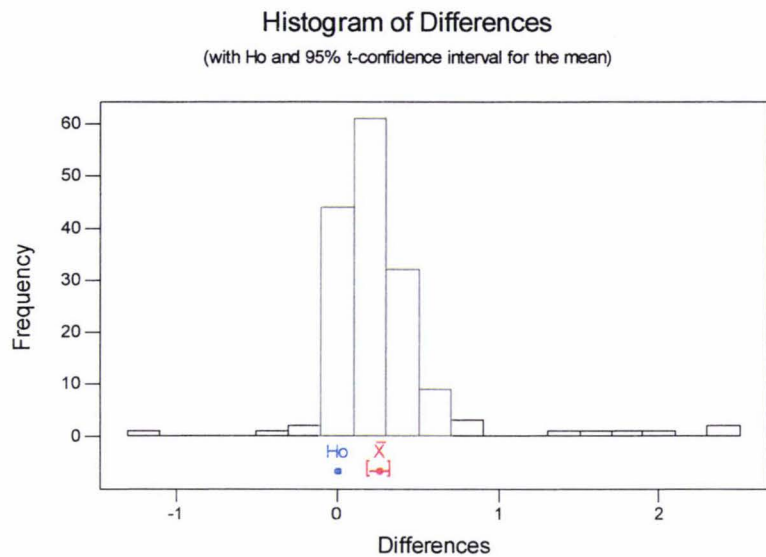
Both Kangaroo Rd and adjoining stub road F905285 are single lane unsealed roads. Road widths at sampling sites varied between 5.4 and 6.0 m. Tree trunk to tree trunk distances across the road were 14.3 to 19.7 m.

### 4.2 Pre-study comparison of temperature loggers

Paired T for Logger 1 (Road sites logger) - Logger 2 (Forest sites logger)

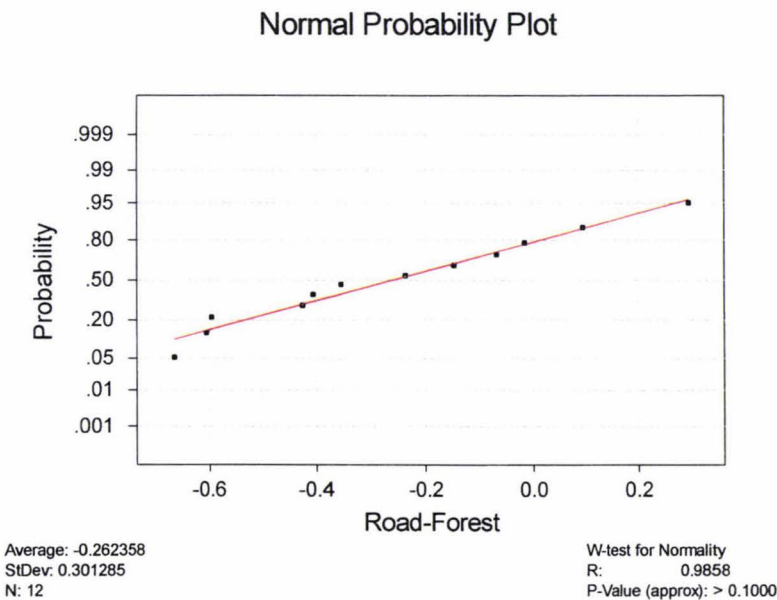
	N	Mean	StDev	SE Mean
Logger 1	159	17.636	1.962	0.156
Logger 2	159	17.378	1.793	0.142
Difference	159	0.2574	0.4043	0.0321

95% CI for mean difference: (0.1940, 0.3207)  
T-Test of mean difference = 0 (vs not = 0): T-Value = 8.03 P-Value = 0.000

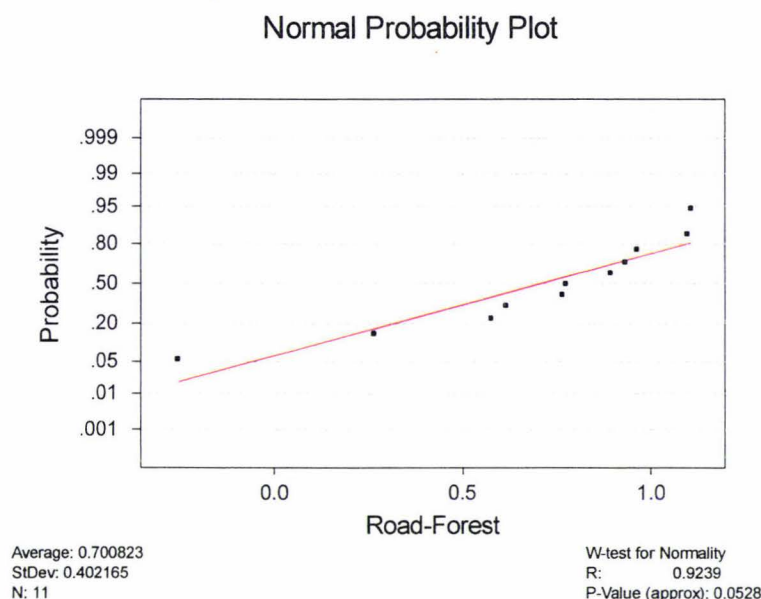


4.3 Assessment of normality of differences of nightly minimum temperatures for road and forest sites

Pipeline Rd



## Kangaroo Rd



#### 4.4 Site description (exotic and native forest)

##### Exotic forest

The *P. radiata* forest in the area of study at Capricorn Rd was of two different ages. That on the northern side of the road was 13 years old (planted in 1987), around 19.1 m in height, unpruned and had an actual stocking density of 326 stems/ha having been thinned to waste in 1993. The pines of the uphill southern side, in which two monitoring sites were located, were 23 years old (planted in 1977), around 25.7 m tall, unpruned, and had been thinned to waste to 337 stems/ha in 1991. The undergrowth of these trees was mainly native saplings up to around 7–10 m height. Species included coprosmas (*Coprosma* spp.), wineberry (*Aristotelia serrata*), pigeonwood (*Hedycarya arborea*), hangehange (*Geniostoma rupestre*), mahoe (*Melicytus ramiflorus*), pate (*Schefflera digitata*), tawari (*Ixerba brexioides*), kamahi (*Weinmannia racemosa*), and kaikomako (*Pennantia corymbosa*). There were also toadstools, ferns, some grasses, and areas of bush lawyer (*Rubus cissoides*) and supplejack (*Ripogonum scandens*). The undergrowth of the sparser younger pines was lower in stature, and had more exotic weedy species such as Himalayan honeysuckle (*Leycesteria formosa*) and buddleia (*Buddleja davidii*). Toetoe/pampas (*Cortaderia* sp.) was also present. The distance between the opposite blocks of forest across the road was 17.8 m.

##### Native forest

It was unclear whether the native forest of the study area had been logged, though logging had occurred in the general area. There was some evidence of past tramways (used in log extraction) to either side of the study area, but some magnificent rimu (*Dacrydium cupressinum*) remained, and there were no noticeable tree stumps.



The forest is mainly tawa (*Beilschmiedia tawa*) broadleaf podocarp forest. The roadside area of the study site was bordered on one side by a cutting covered in ferns, saplings e.g. rewarewa (*Knightia excelsa*), kamahi, pate, toetoe/pampas (*Cortaderia* sp.) and forest cabbage trees (*Cordyline banksii*), adjoining the mature tawa rewarewa forest. The other margin was pampas/toetoe, buddleia, kamahi and saplings, large tree ferns and tawa. The area was fairly open, with the distance between trees on opposite sides of the roads being around 21 m. The land on the southern side of the road, where two monitoring sites were located, was flattish near the road then sloped down steeply before flattening out then dropping down again in an enormous and very steep gorge. At the foot of the first slope, the forest was very tall with a tawa canopy of 30–40 m and several emergent rimu. There were more tiers to the forest than in the pine forest, however, the understorey was comparatively sparse given the low light levels reaching the forest floor. Species included rata (*Metrosideros* sp.), hangehange, miro (*Podocarpus ferrugineus*), pate, pigeonwood, coprosma, mahoe, tawari, supplejack, bush lawyer, and a wealth of ferns and epiphytes. The area was quite sheltered. At the edge of the gorge the forest was more exposed and generally shorter in stature e.g. between 7.8 m and 22.2 m. Additional species included totara (*Podocarpus* sp.), kamahi, puka (*Griselinia lucida*), lancewood (*Pseudopanax crassifolius*), hinau (*Elaeocarpus dentatus*), horopito (*Pseudowintera axillaris*), toro (*Myrsine salicina*) and red matipo (*Myrsine australis*). In both areas there were abundant seedlings.

#### **4.5 Bat activity at road and forest interior habitats in mature and young forest**

##### *Mature forest (Pipeline Rd)*

##### General linear model procedure

```
data Pline;
input Date $ ABM$ Treatment Site LogPass;
cards;
14/10/1999 D 1 1 0.17609
15/10/1999 C 1 1 -0.30103
16/10/1999 B 1 1 1.19033
18/10/1999 F 1 1 1.55023
19/10/1999 E 1 1 1.02119
20/10/1999 D 1 1 1.78888
21/10/1999 C 1 1 -0.30103
23/10/1999 A 1 1 1.13033
24/10/1999 F 1 1 1.46982
25/10/1999 E 1 1 1.81624
13/11/1999 A 1 1 1.0607
14/11/1999 B 1 1 1.43933
14/10/1999 E 2 2 -0.30103
15/10/1999 D 2 2 -0.30103
16/10/1999 C 2 2 0.81291
18/10/1999 A 2 2 0.17609
19/10/1999 F 2 2 0.54407
20/10/1999 E 2 2 0.81291
```

21/10/1999	D	2	2	-0.30103
23/10/1999	B	2	2	1.16137
24/10/1999	A	2	2	0.74036
25/10/1999	F	2	2	1.0607
13/11/1999	B	2	2	0.74036
14/11/1999	C	2	2	-0.30103
13/10/1999	A	1	3	0.17609
14/10/1999	F	1	3	-0.30103
16/10/1999	D	1	3	1.26717
17/10/1999	C	1	3	0.39794
18/10/1999	B	1	3	1.21748
19/10/1999	A	1	3	0.81291
22/10/1999	D	1	3	1.33244
23/10/1999	C	1	3	1.24304
24/10/1999	B	1	3	1.31175
30/10/1999	E	1	3	1.16137
1/11/1999	E	1	3	0.81291
14/11/1999	F	1	3	0.74036
13/10/1999	B	2	4	0.54407
14/10/1999	A	2	4	-0.30103
16/10/1999	E	2	4	0.39794
17/10/1999	D	2	4	-0.30103
18/10/1999	C	2	4	0.17609
19/10/1999	B	2	4	0.17609
22/10/1999	E	2	4	0.97772
23/10/1999	D	2	4	1.16137
24/10/1999	C	2	4	0.39794
30/10/1999	F	2	4	0.81291
1/11/1999	F	2	4	0.81291
14/11/1999	A	2	4	0.54407
13/10/1999	C	2	5	0.17609
14/10/1999	B	2	5	0.17609
15/10/1999	A	2	5	-0.30103
16/10/1999	F	2	5	1.16137
17/10/1999	E	2	5	1.19033
18/10/1999	D	2	5	0.92942
19/10/1999	C	2	5	-0.30103
20/10/1999	B	2	5	1.13033
13/11/1999	E	2	5	1.13033
15/11/1999	D	2	5	0.81291
26/11/1999	F	2	5	0.97772
27/11/1999	A	2	5	0.74036
13/10/1999	D	1	6	1.26717
14/10/1999	C	1	6	-0.30103
15/10/1999	B	1	6	-0.30103
16/10/1999	A	1	6	1.19033
17/10/1999	F	1	6	1.58546
18/10/1999	E	1	6	1.31175
19/10/1999	D	1	6	0.54407
20/10/1999	C	1	6	0.54407
13/11/1999	F	1	6	0.17609
15/11/1999	E	1	6	1.21748
26/11/1999	A	1	6	0.92942
27/11/1999	B	1	6	1.78176

```

;
run;
proc glm;
class Date ABM Treatment Site LogPass;
model LogPass = Date ABM Treatment Site ABM*Treatment;
means Site / LSD tukey;
run;
```

## Results

## Class Level Information

Class	Levels	Values
Date	20	1/11/199 13/10/19 13/11/19 14/10/19 14/11/19 15/10/19 15/11/19 16/10/19 17/10/19 18/10/19 19/10/19 20/10/19 21/10/19 22/10/19 23/10/19 24/10/19 25/10/19 26/11/19 27/11/19 30/10/19
ABM	6	A B C D E F
Treatment	2	1 2
Site	6	1 2 3 4 5 6
LogPass	25	-0.30103 0.17609 0.39794 0.54407 0.74036 0.81291 0.92942 0.97772 1.02119 1.0607 1.13033 1.16137 1.19033 1.21748 1.24304 1.26717 1.31175 1.33244 1.43933 1.46982 1.55023 1.58546 1.78176 1.78888 1.81624
Number of observations		72

## The GLM Procedure

Dependent Variable: LogPass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	34	23.07603749	0.67870698	5.90	<.0001
Error	37	4.25870462	0.11510012		
Corrected Total	71	27.33474211			



R-Square	Coeff Var	Root MSE	LogPass Mean
0.844202	48.63455	0.339264	0.697578

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Date	19	15.94143290	0.83902278	7.29	<.0001
ABM	5	2.86526669	0.57305334	4.98	0.0014
Treatment	1	2.75829762	2.75829762	23.96	<.0001
Site	4	1.18279123	0.29569781	2.57	0.0539
ABM*Treatment	5	0.32824905	0.06564981	0.57	0.7221

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Date	19	13.29543207	0.69975958	6.08	<.0001
ABM	5	2.89297485	0.57859497	5.03	0.0013
Treatment	0	0.00000000	.	.	.
Site	4	1.02415080	0.25603770	2.22	0.0851
ABM*Treatment	5	0.32824905	0.06564981	0.57	0.7221

*Young forest (Kangaroo Rd)*

## General linear model procedure

```

data Kroo;
input Date $ ABM$ Treatment Site LogPass;
cards;
29-NovA      1      1      0.17609
1-Dec E      1      1      0.17609
2-Dec D      1      1      0.17609
3-Dec C      1      1      -0.30103
5-Dec A      1      1      0.54407
6-Dec F      1      1      0.17609
8-Dec D      1      1      0.17609
14-DecE      1      1      -0.30103
15-DecF      1      1      -0.30103
17-DecB      1      1      0.39794
18-DecC      1      1      1.02119
22-DecB      1      1      0.17609
29-NovB      2      2      0.17609
1-Dec F      2      2      -0.30103
2-Dec E      2      2      -0.30103
3-Dec D      2      2      -0.30103
5-Dec B      2      2      0.17609
6-Dec A      2      2      -0.30103
8-Dec E      2      2      -0.30103
14-DecF      2      2      -0.30103
15-DecA      2      2      -0.30103
17-DecC      2      2      0.17609
18-DecD      2      2      -0.30103
22-DecC      2      2      -0.30103
1-Dec A      1      3      0.65321
2-Dec F      1      3      -0.30103
3-Dec E      1      3      0.54407
4-Dec D      1      3      -0.30103
7-Dec A      1      3      -0.30103
8-Dec F      1      3      -0.30103
9-Dec E      1      3      0.17609
10-DecD      1      3      -0.30103
14-DecC      1      3      -0.30103
15-DecB      1      3      -0.30103
16-DecC      1      3      0.54407
19-DecB      1      3      -0.30103
1-Dec B      2      4      -0.30103
2-Dec A      2      4      -0.30103
3-Dec F      2      4      0.39794
4-Dec E      2      4      -0.30103
7-Dec B      2      4      -0.30103
8-Dec A      2      4      -0.30103
9-Dec F      2      4      -0.30103
10-DecE      2      4      -0.30103
14-DecD      2      4      -0.30103
15-DecC      2      4      -0.30103
16-DecD      2      4      -0.30103
19-DecC      2      4      -0.30103
30-NovD      2      5      0.17609
1-Dec C      2      5      -0.30103
2-Dec B      2      5      0.17609
3-Dec A      2      5      0.54407
4-Dec F      2      5      0.17609

```

5-Dec E	2	5	-0.30103
6-Dec D	2	5	0.17609
7-Dec C	2	5	0.39794
10-DecF	2	5	-0.30103
14-DecA	2	5	-0.30103
16-DecE	2	5	-0.30103
20-DecB	2	5	-0.30103
30-NovE	1	6	0.17609
1-Dec D	1	6	0.17609
2-Dec C	1	6	-0.30103
3-Dec B	1	6	0.17609
4-Dec A	1	6	-0.30103
5-Dec F	1	6	0.65321
6-Dec E	1	6	0.17609
7-Dec D	1	6	-0.30103
10-DecA	1	6	-0.30103
14-DecB	1	6	-0.30103
16-DecF	1	6	-0.30103
20-DecC	1	6	-0.30103

```

;
run;
proc glm;
class Date ABM Treatment Site LogPass;
model LogPass = Date ABM Treatment Site ABM*Treatment;
means Site / LSD tukey;
run;
```



## Results

## Class Level Information

Class	Levels	Values
Date	20	1-Dec 10-Dec 14-Dec 15-Dec 16-Dec 17-Dec 18-Dec 19-Dec 2-Dec 20-Dec 22-Dec 29-Nov 3-Dec 30-Nov 4-Dec 5-Dec 6-Dec 7-Dec 8-Dec 9-Dec
ABM	6	A B C D E F
Treatment	2	1 2
Site	6	1 2 3 4 5 6
LogPass	6	-0.30103 0.17609 0.39794 0.54407 0.65321 1.02119
Number of observations		72

## The GLM Procedure

Dependent Variable: LogPass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	34	4.45816489	0.13112250	1.44	0.1410
Error	37	3.37631968	0.09125188		
Corrected Total	71	7.83448457			

R-Square	Coeff Var	Root MSE	LogPass Mean
0.569044	-496.7966	0.302079	-0.060805

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Date	19	2.89933573	0.15259662	1.67	0.0888
ABM	5	0.10150852	0.02030170	0.22	0.9505
Treatment	1	0.52197121	0.52197121	5.72	0.0220
Site	4	0.54819971	0.13704993	1.50	0.2216
ABM*Treatment	5	0.38714972	0.07742994	0.85	0.5244

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Date	19	2.73314571	0.14384977	1.58	0.1158
ABM	5	0.06407946	0.01281589	0.14	0.9817
Treatment	0	0.00000000	.	.	.
Site	4	0.59058911	0.14764728	1.62	0.1903
ABM*Treatment	5	0.38714972	0.07742994	0.85	0.5244

4.6 Proportionate use of habitat

Chi-Square Test: Road, Forest

Expected counts are printed below observed counts

	Road	Forest	Total
Pipeline	575	183	758
	574.10	183.90	
Kangaroo	40	14	54
	40.90	13.10	
Total	615	197	812

$$\text{Chi-Sq} = 0.001 + 0.004 + 0.020 + 0.062 = 0.087$$

$$\text{DF} = 1, \text{ P-Value} = 0.768$$

4.7 Ambient temperature by habitat in mature and young forest

Mean nightly temperature

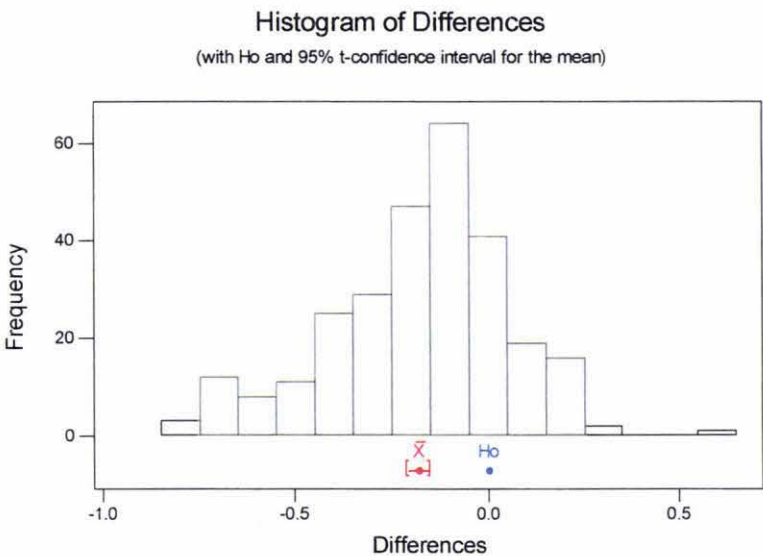
Mature forest (Pipeline Rd)

Paired T for Road - Forest

	N	Mean	StDev	SE Mean
Road	278	8.429	3.409	0.204
Forest	278	8.609	3.470	0.208
Difference	278	-0.1803	0.2316	0.0139

95% CI for mean difference: (-0.2077, -0.1530)

T-Test of mean difference = 0 (vs not = 0): T-Value = -12.98 P-Value = 0.000



Young forest (Kangaroo Rd)

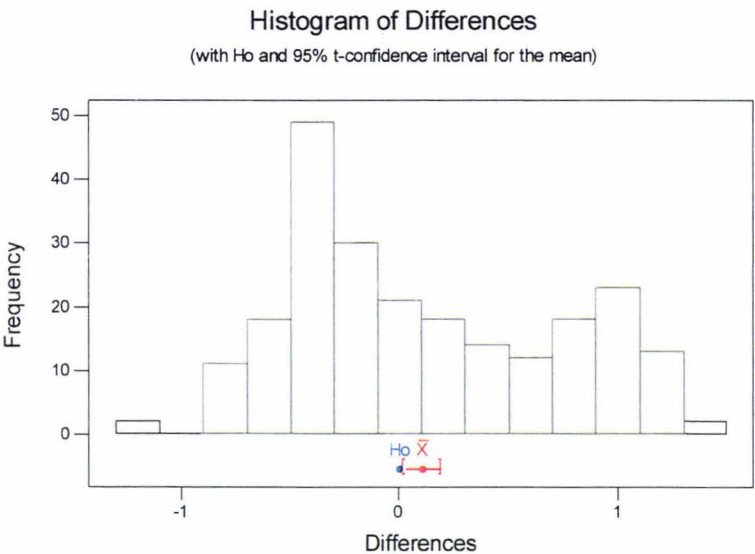
Paired T for Road - Forest

	N	Mean	StDev	SE Mean
Road	231	9.684	3.668	0.241
Forest	231	9.579	4.098	0.270



Difference            231        0.1055        0.6163        0.0405

95% CI for mean difference: (0.0256, 0.1854)  
T-Test of mean difference = 0 (vs not = 0): T-Value = 2.60    P-Value = 0.010



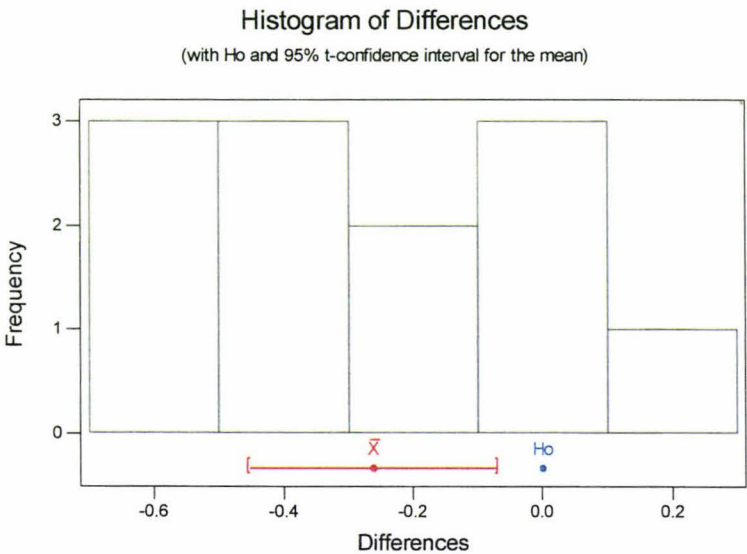
*Mean minimum nightly temperature*

**Mature forest (Pipeline Rd)**

Paired T for Road - Forest

	N	Mean	StDev	SE Mean
Road	12	5.93	3.87	1.12
Forest	12	6.20	4.03	1.16
Difference	12	-0.2624	0.3013	0.0870

95% CI for mean difference: (-0.4538, -0.0709)  
T-Test of mean difference = 0 (vs not = 0): T-Value = -3.02    P-Value = 0.012

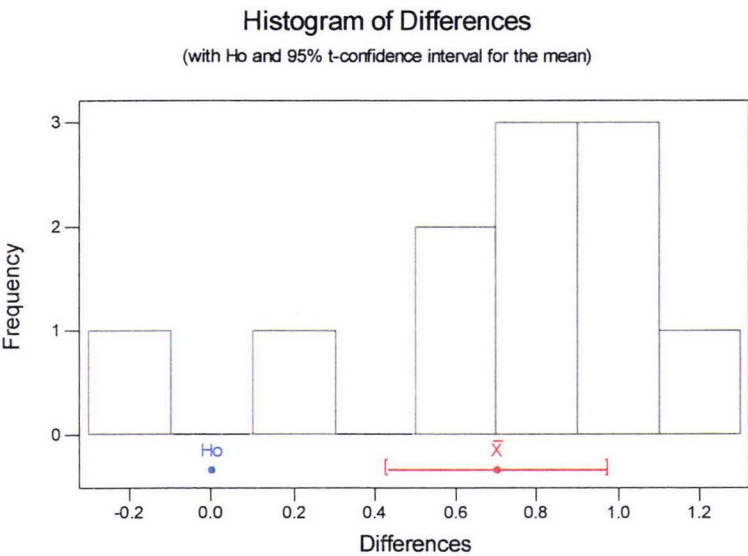


Young forest (Kangaroo Rd)

Paired T for Road - Forest

	N	Mean	StDev	SE Mean
Road	11	6.23	4.04	1.22
Forest	11	5.53	4.19	1.26
Difference	11	0.701	0.402	0.121

95% CI for mean difference: (0.431, 0.971)  
T-Test of mean difference = 0 (vs not = 0): T-Value = 5.78 P-Value = 0.000



4.8 Proportion of foraging calls by habitat in mature forest (Pipeline Rd)

Chi-Square Test: Passes, Buzzes  
Expected counts are printed below observed counts

	Passes	Buzzes	Total
Road	575	8	583
	575.41	7.59	
Forest	183	2	185
	182.59	2.41	
Total	758	10	768

Chi-Sq = 0.000 + 0.022 + 0.001 + 0.069 = 0.093  
DF = 1, P-Value = 0.761  
1 cells with expected counts less than 5.0

5. HABITAT USE BY LONG-TAILED BATS

5.1 Assessment of habitat selection

		Unstocked to 1-year-old pines		2–6- year-old pines		7–11- year-old pines		17–21- year-old pines		22–31- year-old pines	
Habitat available (km)	(% of route)	32.7	(18.7)	35.9	(20.5)	33.8	(19.3)	19.3	(11.0)	21.9	(12.5)
Observed number of bat encounters (%)		4	(8.7)	5	(10.9)	4	(8.7)	13	(28.3)	9	(19.6)
Expected number of bat encounters		9		9		9		5		6	
Total route length (km)		175.07									
Total number of bat encounters		46									
Number of bat encounters per km		0.26									

Table 1 Observed and expected rates of bat encounter in various habitats, Kinleith Forest



**Table 2** Chi-square test of bats' use of young pines compared with expected use

Habitat	Observed, O	Expected, E	O-E	(O-E) <sup>2</sup>	(O-E) <sup>2</sup> / E
Unstocked to 1-year-old pines	4	9	-5	25	2.78
2-6-year-old pines	5	9	-4	16	1.78
7-11-year-old pines	4	9	-5	25	2.78
				$\chi^2 =$	7.33
				DF =	2, 1
Critical values			<i>P</i>	0.05	0.025
			$\chi^2$	5.99	7.38

**Table 3** Chi-square test of bats' use of mature pines compared with expected use

Habitat	Observed, O	Expected, E	O-E	(O-E) <sup>2</sup>	(O-E) <sup>2</sup> / E
17-21-year-old pines	13	5	8	64	12.80
22-31-year-old pines	9	6	3	9	1.50
				$\chi^2 =$	14.30
				DF =	1, 1
Critical values			<i>P</i>	0.001	0.0005
			$\chi^2$	10.83	12.12

## 5.2 Comparison of bat activity in mature and young pine forest

**Table 1** Chi-square test comparing observed bat activity in young pine forest with that expected had activity been similar to that in mature pine forest

Observed, O	Expected, E	O-E	(O-E) <sup>2</sup>	(O-E) <sup>2</sup> / E
11	137	-126	15876	115.88
16	146	-130	16900	115.75
				$\chi^2 =$ 231.63
				DF = 1, 1
Critical values		<i>P</i>	0.001	0.0005
		$\chi^2$	10.83	12.12

## 6. USE OF EXOTIC/NATIVE FOREST BY FORAGING BATS

### 6.1 Description of bat activity monitoring sites (comparison of bat activity in exotic and native forest)

#### Pine forest

Trees on the northern side of the road were 13 years old, those on the southern side were 23 years old. None had been pruned, but all had undergone thinning (to waste) between 1991 and 1993, to between 326 and 339 stems/ha.

## Site 1

Site 1 was located in a shallow valley, the ABM facing the 13-year-old pines across the road and a gentle hill. The area appeared quite open. There was a steep bank to the right of the ABM which had kingfishers (*Halcyon santa vagans*) nesting in it, and a hill behind the ABM. The 13-year-old pines were around 12 m high and less bushy than those above the ABM which were 23–25 m tall. The distance between tree trunks across the road was 12 m. Undergrowth included buddleia (*Buddleja davidii*), Himalayan honeysuckle (*Leycesteria formosa*), toetoe/pampas (*Cortaderia* sp.), and native saplings. Mountain cabbage trees (*Cordyline indivisa*) were present nearby.

## Site 2

The ABM at Site 2 was located on a bank in the 13-year-old pines (standing at 14–15 m) facing the opposite road cutting and older pines (of 21–22 m). The road presented a fairly open potential flyway, though some pine branches extended above the road. The distance between tree trunks across the road was around 16 m. Other vegetation included toetoe/pampas, buddleia and Himalayan honeysuckle, as well as low ferns, coprosmas (*Coprosma* spp.), kamahi (*Weinmannia racemosa*), bracken (*Pteridium aquilinum*), wineberry (*Aristotelia serrata*), five finger (*Pseudopanax arboreus*), snowberry (*Gaultheria antipoda*), bush lawyer (*Rubus cissoides*) and cabbage trees (mountain, and forest — *C. banksii*).

## Site 3

The 13-year-old pines were around 19.1 m high with a low undergrowth of weedy species such as Himalayan honeysuckle and buddleia. Toetoe/pampas was also present. The 23-year-old pines of the uphill southern side were around 25.7 m tall. These overtopped a tier of mainly native saplings. Species included coprosmas and wineberry. The distance between the opposite blocks of forest across the road was 17.8 m.

## *Native forest*

The native forest is tawa (*Beilschmiedia tawa*) broadleaf podocarp forest. It was unclear whether the study area had been logged, though logging had occurred in the general area. There was some evidence of past tramways (used in log extraction) to either side of the study sites, but some magnificent rimu (*Dacrydium cupressinum*) remained, and there were no noticeable tree stumps as can be seen in other remnants in the South Waikato.

## Site 4

The ABM was located on the southern side of the road on a bank. The vegetation was low and scrubby near the roadside including toetoe/pampas, hangehange (*Geniostoma rupestre*),

buddleia and Himalayan honeysuckle, but bounded by emergent trees including rewarewa (*Knightia excelsa*), rimu, totara (*Podocarpus* sp.) and tawa. On the opposite side were tall tawa, tawari (*Ixerba brexioides*), and rimu, but also low possibly regenerating vegetation including tree ferns, coprosma, kamahi, toetoe/pampas and bushlawyer. The area was fairly exposed to the wind.

### Site 5

Site 5 was bordered on one side by a cutting covered in ferns, saplings e.g. rewarewa (*Knightia excelsa*), kamahi, pate (*Schefflera digitata*) and forest cabbage trees, as well as toetoe/pampas, adjoined by mature tawa rewarewa forest. The other margin comprised pampas/toetoe, buddleia, kamahi, saplings, and large tree ferns backing on to tawa. The area was fairly open, the distance between trees on opposite sides of the roads was around 21 m.

### Site 6

Site 6 was noticeable for its rata (*Metrosideros* sp.) enveloping both a rimu (approximately 31 m in height) and tawa (around 25 m). The vegetation of the road margins consisted of ferns, tree ferns, and toetoe/pampas, Himalayan fairy grass (*Miscanthus nepalensis*) and cutty grass (*Gahnia* sp.) The tawa forest was around 26 m high, with an understorey including ferns, tree ferns, lancewoods (*Pseudopanax crassifolius*), kamahi, tanekaha (*Phyllocladus trichomanoides*), red matipo (*Myrsine australis*), pate, coprosma, and hangehange. The trees across the road were approximately 15 m apart.

## **6.2 Description of bat activity monitoring sites (investigation of bat activity at road and forest interior habitats in exotic and native forest)**

### Pine forest

The roadside site, Site 3 of the previous study, is described in Appendix 6.1. Forest interior sites were located on the uphill southern side in 23-year-old pines. The undergrowth was mainly native saplings of up to around 7–10 m in height. Species included coprosmas, wineberry, pigeonwood (*Hedycarya arborea*), hangehange, mahoe (*Melicytus ramiflorus*), pate, tawari, kamahi, and kaikomako (*Pennantia corymbosa*). There were also toadstools, ferns, some grasses, and areas of bush lawyer and supplejack (*Ripogonum scandens*).

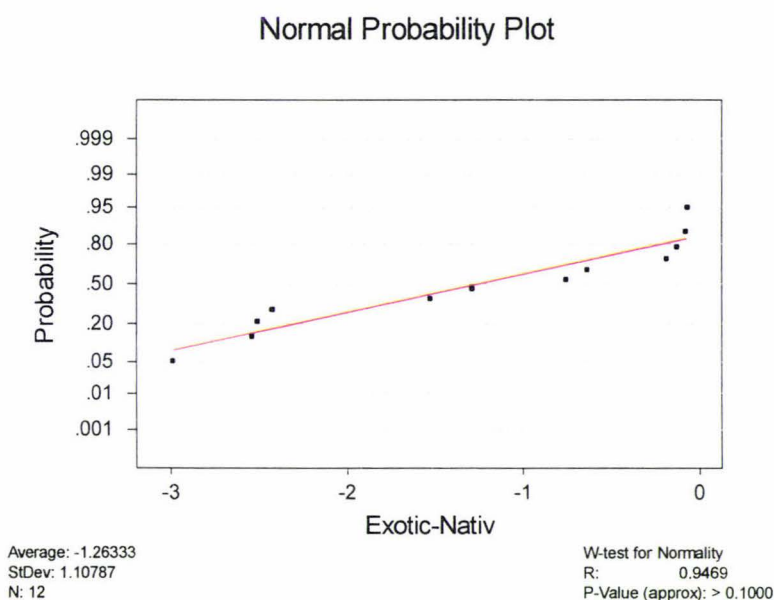
### Native forest

The roadside site, Site 5 of the previous study, is described in Appendix 6.1. Forest interior monitoring sites were situated on the southern side of the road. This sloped down steeply before flattening out then dropping down again in an enormous and very steep gorge. At the foot of the first slope, the forest was very tall with a tawa canopy of 30–40 m and several



emergent rimu. There were more tiers to the forest than in the pine forest, however, the understorey was comparatively sparse given the low light levels reaching the forest floor. Species included rata, hangehange, miro (*Podocarpus ferrugineus*), pate, pigeonwood, coprosma, mahoe, tawari, supplejack, bush lawyer, and a wealth of ferns and epiphytes. The area was quite sheltered. At the edge of the gorge the forest was more exposed and generally shorter between 7.8 m and 22.2 m. Additional species included totara, kamahi, puka (*Griselinia lucida*), lancewood, hinau (*Elaeocarpus dentatus*), horopito (*Pseudowintera axillaris*), toro (*Myrsine salicina*) and red matipo. In both areas there were abundant seedlings.

### 6.3 Assessment of normality of differences of nightly minimum temperatures for exotic and native forest sites



### 6.4 Comparison of bat activity in exotic and native forest

#### General linear model procedure

```
data Cap1;
input Date $ ABM $ Treatment Site LogPass;
cards;
12/03/2000 A 1 1 2.353146546
14/03/2000 E 1 1 1.484299839
15/03/2000 D 1 1 1.290034611
17/03/2000 B 1 1 1.525044807
18/03/2000 A 1 1 1.217483944
19/03/2000 F 1 1 1.596597096
20/03/2000 E 1 1 1.311753861
23/03/2000 B 1 1 1.469822016
1/04/2000 D 1 1 1.809559715
2/04/2000 F 1 1 2.15075644
3/04/2000 C 1 1 2.02325246
4/05/2000 C 1 1 2.284430734
12/03/2000 B 1 2 1.290034611
```

## Appendices

14/03/2000	F	1	2	1.371067862
15/03/2000	E	1	2	1.217483944
17/03/2000	C	1	2	1.648360011
18/03/2000	B	1	2	1.525044807
19/03/2000	A	1	2	1.243038049
20/03/2000	F	1	2	1.469822016
23/03/2000	C	1	2	1.537819095
1/04/2000	E	1	2	1.926856709
2/04/2000	A	1	2	1.423245874
3/04/2000	D	1	2	1.190331698
4/05/2000	D	1	2	1.694605199
12/03/2000	C	1	3	1.217483944
14/03/2000	A	1	3	1.161368002
15/03/2000	F	1	3	1.130333768
17/03/2000	D	1	3	1.829303773
18/03/2000	C	1	3	1.469822016
19/03/2000	B	1	3	1.130333768
20/03/2000	A	1	3	1.161368002
23/03/2000	D	1	3	1.469822016
1/04/2000	F	1	3	1.511883361
2/04/2000	B	1	3	1.980003372
3/04/2000	E	1	3	1.648360011
4/05/2000	E	1	3	2.043362278
12/03/2000	D	2	4	0.176091259
14/03/2000	B	2	4	-0.301029996
15/03/2000	A	2	4	0.176091259
17/03/2000	E	2	4	0.740362689
18/03/2000	D	2	4	0.653212514
19/03/2000	C	2	4	-0.301029996
20/03/2000	B	2	4	1.021189299
23/03/2000	E	2	4	0.653212514
1/04/2000	A	2	4	-0.301029996
2/04/2000	C	2	4	0.397940009
3/04/2000	F	2	4	1.190331698
4/05/2000	F	2	4	1.130333768
12/03/2000	E	2	5	1.190331698
14/03/2000	C	2	5	1.371067862
15/03/2000	B	2	5	1.243038049
17/03/2000	F	2	5	0.653212514
18/03/2000	E	2	5	1.311753861
19/03/2000	D	2	5	0.740362689
20/03/2000	C	2	5	0.740362689
23/03/2000	F	2	5	0.653212514
1/04/2000	B	2	5	1.161368002
2/04/2000	D	2	5	-0.301029996
3/04/2000	A	2	5	0.653212514
4/05/2000	A	2	5	0.653212514
12/03/2000	F	2	6	0.176091259
14/03/2000	D	2	6	0.653212514
15/03/2000	C	2	6	0.812913357
17/03/2000	A	2	6	0.176091259
18/03/2000	F	2	6	1.217483944
19/03/2000	E	2	6	0.740362689
20/03/2000	D	2	6	0.812913357
23/03/2000	A	2	6	-0.301029996
1/04/2000	C	2	6	0.544068044
2/04/2000	E	2	6	1.217483944
3/04/2000	B	2	6	1.190331698
4/05/2000	B	2	6	1.607455023

;  
run;

```
proc glm;
class Date ABM Treatment Site LogPass;
model LogPass = Date ABM Treatment Site ABM*Treatment;
means Site / LSD tukey;
run;
```

Results

Class	Levels	Values
Date	12	1/04/200 12/03/20 14/03/20 15/03/20 17/03/20 18/03/20 19/03/20 2/04/200 20/03/20 23/03/20 3/04/200 4/05/200
ABM	6	A B C D E F
Treatment	2	1 2
Site	6	1 2 3 4 5 6
LogPass	35	-0.301029996 0.176091259 0.397940009 0.544068044 0.653212514 0.740362689 0.812913357 1.021189299 1.130333768 1.161368002 1.190331698 1.217483944 1.243038049 1.290034611 1.311753861 1.371067862 1.423245874 1.469822016 1.484299839 1.511883361 1.525044807 1.537819095 1.596597096 1.607455023 1.648360011 1.694605199 1.809559715 1.829303773 1.926856709 1.980003372 2.02325246 2.043362278 2.15075644 2.284430734 2.353146546
Number of observations		72

The GLM Procedure

Dependent Variable: LogPass

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	26	21.35326703	0.82127950	5.67	<.0001
Error	45	6.51483796	0.14477418		
Corrected Total	71	27.86810498			



R-Square	Coeff Var	Root MSE	LogPass Mean
0.766226	34.26120	0.380492	1.110562

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Date	11	2.48719588	0.22610872	1.56	0.1435
ABM	5	1.95576871	0.39115374	2.70	0.0322
Treatment	1	13.91648698	13.91648698	96.13	<.0001
Site	4	1.51282571	0.37820643	2.61	0.0477
ABM*Treatment	5	1.48098974	0.29619795	2.05	0.0902

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Date	11	2.55618520	0.23238047	1.61	0.1300
ABM	5	1.95576871	0.39115374	2.70	0.0322
Treatment	0	0.00000000	.	.	.
Site	4	1.51282571	0.37820643	2.61	0.0477
ABM*Treatment	5	1.48098974	0.29619795	2.05	0.0902

6.5 Comparison of foraging activity in exotic and native forest

Chi-Square Test: Exotic, Native  
Expected counts are printed below observed counts

	Exotic	Native	Total
Buzzes	31	1	32
	27.66	4.34	
Passes	1778	283	2061
	1781.34	279.66	
Total	1809	284	2093

Chi-Sq = 0.404 + 2.572 +  
0.006 + 0.040 = 3.022  
DF = 1, P-Value = 0.082  
1 cells with expected counts less than 5.0

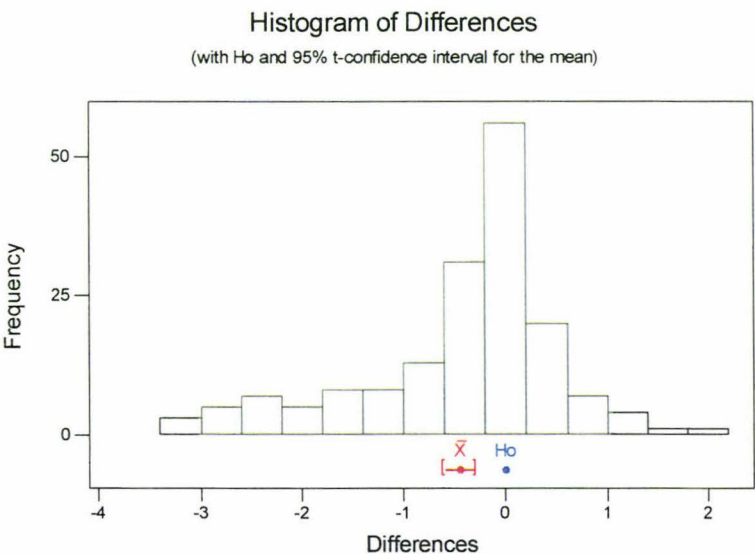
6.6 Comparison of ambient temperature between exotic and native forest

Mean nightly temperature

Paired T for Exotic - Native

	N	Mean	StDev	SE Mean
Exotic	169	10.480	2.548	0.196
Native	169	10.925	2.022	0.156
Difference	169	-0.4449	0.9758	0.0751

95% CI for mean difference: (-0.5930, -0.2967)  
T-Test of mean difference = 0 (vs not = 0): T-Value = -5.93 P-Value = 0.000

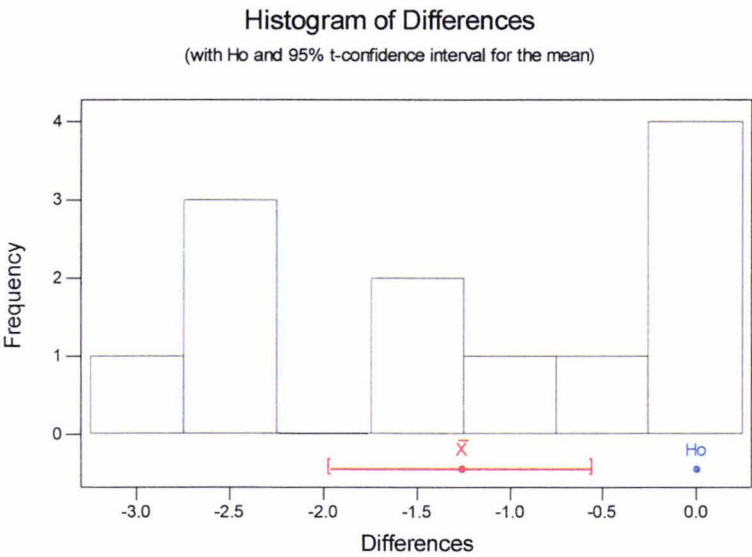


Mean nightly minimum temperature

Paired T for Exotic - Native

	N	Mean	StDev	SE Mean
Exotic	12	8.232	2.725	0.787
Native	12	9.495	2.115	0.611
Difference	12	-1.263	1.108	0.320

95% CI for mean difference: (-1.967, -0.559)  
T-Test of mean difference = 0 (vs not = 0): T-Value = -3.95 P-Value = 0.002



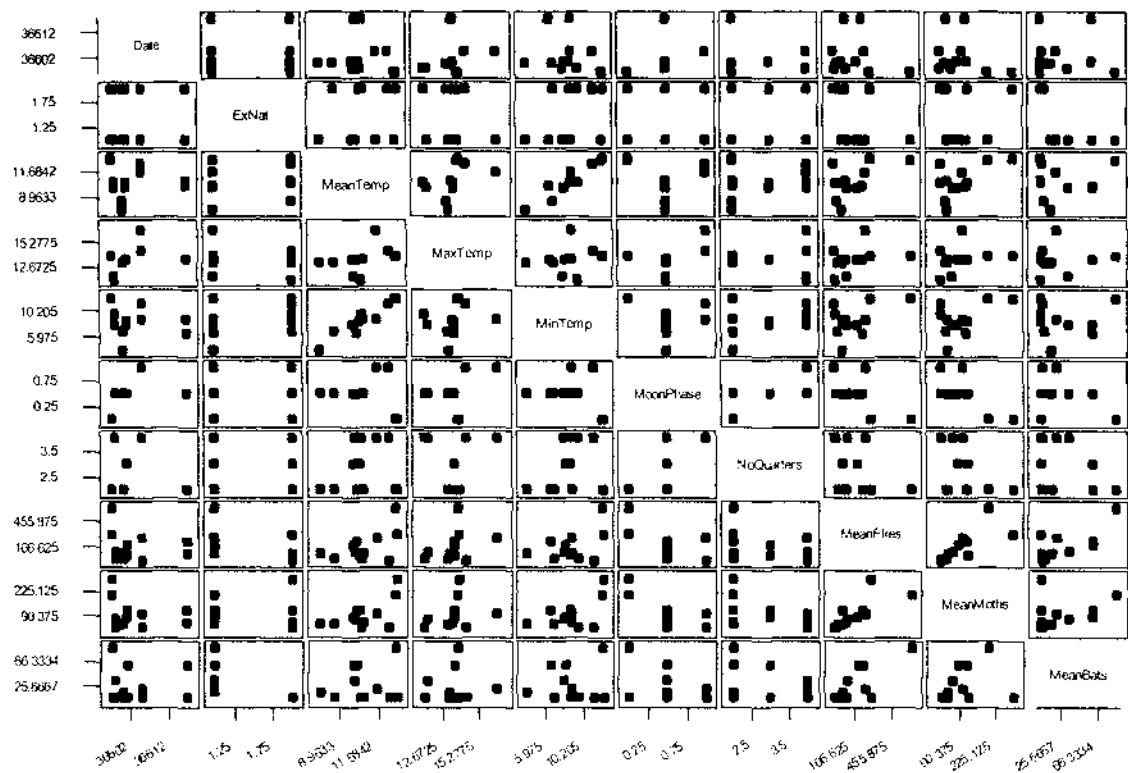


6.7 Correlations between bat activity and environmental variables

Table 1 Correlation matrix of bat activity in relation to environmental variables

	Date	ExNat	MeanTemp	MaxTemp	MinTemp	MoonPhas	NoQuarte	MeanFlie	MeanMoth
ExNat	0.000 1.000								
MeanTemp	-0.063 0.845	0.186 0.563							
MaxTemp	0.259 0.417	-0.178 0.581	0.390 0.210						
MinTemp	-0.234 0.463	0.362 0.248	0.948 0.000	0.189 0.556					
MoonPhas	0.342 0.277	0.000 1.000	-0.173 0.590	0.379 0.224	-0.276 0.386				
NoQuarte	-0.220 0.492	0.000 1.000	0.178 0.579	-0.004 0.991	0.177 0.583	0.643 0.024			
MeanFlie	-0.145 0.654	-0.485 0.110	0.550 0.064	0.348 0.268	0.456 0.136	-0.567 0.054	-0.350 0.264		
MeanMoth	-0.249 0.435	-0.073 0.822	0.589 0.044	0.262 0.412	0.528 0.078	-0.700 0.011	-0.410 0.185	0.735 0.006	
MeanBats	0.010 0.975	-0.751 0.005	0.153 0.635	0.063 0.845	0.065 0.841	-0.348 0.268	-0.216 0.499	0.750 0.005	0.291 0.358
Cell Contents: Pearson correlation P-Value									

**Figure 1** Matrix plot of bat activity in relation to environmental variables



## 6.8 Correlations between bat activity and environmental variables (with influential points omitted)

**Table 1** Correlation matrix of bat activity in relation to environmental variables with influential points omitted

	Date	ExNat	MeanTemp	MaxTemp	MinTemp	MoonPhas	NoQuarte	MeanFlie	MeanMoth
ExNat	0.000 1.000								
MeanTemp	-0.063 0.845	0.186 0.563							
MaxTemp	0.259 0.417	-0.178 0.581	0.390 0.210						
MinTemp	-0.234 0.463	0.362 0.248	0.948 0.000	0.189 0.556					
MoonPhas	0.342 0.277	0.000 1.000	-0.173 0.590	0.379 0.224	-0.276 0.386				
NoQuarte	-0.220 0.492	0.000 1.000	0.178 0.579	-0.004 0.991	0.177 0.583	0.643 0.024			
MeanFlie	0.140 0.681	-0.439 0.177	0.383 0.245	0.505 0.114	0.169 0.619	-0.283 0.399	-0.220 0.516		
MeanMoth	-0.068 0.842	-0.509 0.110	0.420 0.198	0.306 0.360	0.306 0.360	-0.547 0.082	-0.319 0.339	0.743 0.014	
MeanBats	0.219 0.543	-0.769 0.009	-0.103 0.776	0.038 0.916	-0.297 0.405	-0.199 0.582	-0.120 0.741	0.726 0.017	0.529 0.116
Cell Contents: Pearson correlation P-Value									



**Figure 1** Matrix plot of bat activity in relation to environmental variables



## 7. ROOSTING ECOLOGY OF LONG-TAILED BATS

There is no supplementary material for this section.

## 8. MANAGEMENT INFLUENCES AND GENERAL DISCUSSION

There is no supplementary material for this section.