THE ECOLOGICAL REQUIREMENTS OF THE NEW ZEALAND FALCON (*Falco novaeseelandiae*) IN PLANTATION FORESTRY

A thesis presented in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Zoology at Massey University, Palmerston North, New Zealand

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Adult female New Zealand falcon. D. Stewart 2003.

"The hawks, eagles and falcons have been an inspiration to people of all races and creeds since the dawn of civilisation. We cannot afford to lose any species of the birds of prey without an effort commensurate with the inspiration of courage, integrity and nobility that they have given humanity…If we fail on this point, we fail in the basic philosophy of feeling a part of our universe and all that goes with it."

Morley Nelson, 2002.

ABSTRACT

Commercial pine plantations made up of exotic tree species are increasingly recognised as habitats that can contribute significantly to the conservation of indigenous biodiversity in New Zealand. Encouraging this biodiversity by employing sympathetic forestry management techniques not only offers benefits for indigenous flora and fauna but can also be economically advantageous for the forestry industry. The New Zealand falcon (*Falco novaeseelandiae*) or Karearea, is a threatened species, endemic to the islands of New Zealand, that has recently been discovered breeding in pine plantations. This research determines the ecological requirements of New Zealand falcons in this habitat, enabling recommendations for sympathetic forestry management to be made.

Plantation forests that create a mosaic of pine stand ages across a plantation, offer suitable habitat for breeding New Zealand falcons by providing abundant nest sites, promoting high abundances of avian prey and creating favourable conditions for hunting. The diet of falcons within pine forests consisted primarily of birds, of which the majority were exotic passerines. Prey abundances were highest along pine stand edges. Both sexes preferentially hunted along pine stand edges between stands less than four years old and stands more than 20 years old. Pairs also preferentially nested along these borders, particularly within and along the edges of pine stands less than two years old. Within pine stands, nest sites were always located on the ground. Introduced predators and some forestry operations negatively affected breeding success. Nevertheless, productivity was higher than recorded for other habitats and female falcons were recorded successfully breeding in their first year for the first time. High prey densities and availabilities are suggested as the primary explanation for this. The extent of juvenile dispersal strongly suggests that pine plantations supplement populations in surrounding areas where falcons are in decline. This research demonstrates that changes to the existing forestry operational practices can influence the success of the breeding population.

This research establishes that if commercial pine plantations are suitably managed, they can support extremely high falcon densities. Plantation forests therefore have a significant role to play in the future conservation of this species.

To my four parents
who have always encouraged me
to chase my dreams.
Thank you.

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CHAPTER 1.

INTRODUCTION

Fledgling female New Zealand falcon. D. Brill 2006.

"The true biologist deals with life, with teeming boisterous life, and learns something from it, learns that the first rule of life is living"

John Steinbeck, 1951.

1.1 Background

Increasingly the conservation of biodiversity cannot rely on protected areas of indigenous habitat alone (Norton 2000). Worldwide, the amount of land that is left unmodified by human activities is ever decreasing. For example, more than 70 percent of New Zealand's indigenous forest cover has been removed (McGlone 1989). As a result, one of the biggest challenges facing conservation biology today is how to encourage and manage biodiversity on private land (Knight 1999, Norton 2000). Conflicts of interest between industrial practices and biodiversity conservation are common. However, with global markets increasingly demanding environmentally friendly products, many industries are looking to implement environmentally sustainable practices. The plantation forestry industry is one such example. With the development of environmental certification standards (Nussbaum and Markku 2005) sustainable practices can be economically advantageous for the forestry industry while also benefiting biodiversity (Norton 1998).

As a result of forest clearance for agriculture, settlement and a high demand for wood products world-wide, more and more indigenous forest ecosystems are under threat (Sisk et al. 1994). Consequently, many bird species adapted to forest environments are threatened due to habitat loss (Stattersfield and Capper 2000). Plantation forests can reduce the need for indigenous forest logging, but are often still considered to be biological deserts (Maclaren 1996, Carnus et al. 2003). However, the value of plantation forests to biodiversity internationally is becoming increasingly recognised (Norton 1998, Hartley 2002). For example, in New Zealand, exotic pine plantations support a diverse range of indigenous flora and fauna (Gibb 1961, Jackson 1971, Clout and Gaze 1984, Ogden et al. 1997, Brockerhoff et al. 2003, Maunder et al. 2005). Internationally many species of raptor, including northern goshawk, *Accipiter gentilis* (Beier and Drennan 1997), black sparrowhawk, *Accipiter melanoleucus* (Malan and Robinson 2001), European sparrowhawk, *Accipiter nisus* (Newton 1996), merlin, *Falco columbarius* (Parr 1991) and Cooper's hawk, *Accipiter cooperii* (Moore and Henny 1984, Rosenfield et al. 2000), are known to use plantation forests, illustrating that the need for wood and the desire to conserve indigenous biodiversity need not be mutually exclusive land-use options (Norton and Miller 2000).

A species of particular interest in the plantation forests of New Zealand is the New Zealand falcon or karearea (*Falco novaeseelandiae*) (Stewart and Hyde 2004). Although the observation of New Zealand falcons in pine plantations is not a new phenomenon (Buddle 1940, Johnson 1940, Ryder 1948, Weeks 1948, Gibb 1961, Edgar 1963, Jackson 1971, Stewart and Hyde 2004), only one report of falcons breeding within this habitat prior to 1994 could be located (Ryder 1948, Stewart and Hyde 2004). This suggests that breeding pairs of falcon have only relatively recently begun to exploit this niche. The New Zealand falcon is the only extant, endemic species of raptor remaining in New Zealand (Marchant and Higgins 1993). As a result of habitat loss, predation from introduced predators and human persecution, the New Zealand falcon is classified as a threatened species by the Department of Conservation, New Zealand (Hitchmough et al. 2007). Yet, despite its threatened status, many aspects of New Zealand falcon biology are still poorly understood, including the ecology of the species in pine forests. The most recent population estimate put the number of falcons at 3,000 to 4,500 pairs (Fox 1977). However, these population estimates did not consider plantation forest as suitable breeding habitat. Since the 1970's, indications are that the falcon population may be in decline (Gaze and Hutzler 2004). It is therefore important to recognise and understand the use of plantation forests in planning a recovery program for the species.

The New Zealand falcon is described as a medium-sized falcon, with males ranging from 252g to 500g and females from 420g to 594g (Hoyo et al. 1994). The New Zealand falcon evolved as a forest dwelling falcon, and hence is different to that of a typical falcon, having a more accipiter-like rounded wing shape and long tail (Fox 1977). Three forms of the New Zealand falcon are recognised, the bush, eastern, and southern (Fox 1977). These forms are ecologically distinct and cover different regions of New Zealand. The bush falcon can be found over much of the North Island and north west South Island; the eastern falcon ranges over the eastern and central parts of the South Island; while the southern falcon is only found in the lower South West corner of the South Island in Fiordland, and on the Auckland Islands (Fox 1977).

The bush and southern forms are primarily forest falcons, which traditionally inhabit the indigenous podocarp and beech forests of New Zealand (Fox 1977, Barea 1995). The eastern form, however, is more typically an open country falcon and is most commonly recorded breeding in tussock grasslands and roughly grazed hill country (Fox 1977). Nevertheless, anecdotal reports suggest that all three forms of the New Zealand falcon may be breeding in pine plantations (Stewart and Hyde 2004). Thus, although this research concentrates on the bush form of the New Zealand falcon, the findings may apply to other forms of this species occurring in plantation forests.

Of the total forest cover in New Zealand, 20 percent is now made up of exotic plantation forest (Hartley 2002). The suitability of plantation forests for indigenous biodiversity depends on implementing plantation management practices that provide suitable conditions for individual species. Therefore, the successful management of plantation forests for indigenous biodiversity will depend on understanding the ecological requirements of species within them. The aim of this thesis is, to promote the conservation of New Zealand falcon by determining their ecological requirements in plantation forestry, and to recommend forestry management strategies based on these requirements.

1.2 Study area

This study was conducted in the Kaingaroa Plateau of the North Island of New Zealand in the pine plantation of Kaingaroa Forest (Fig.1.1). Kaingaroa Plateau is characterised by 250,000 ha of ignimbrite, typified by the white pumice soils from the eruption of the Taupo Caldera 1800 years ago (Boyd 1992). Kaingaroa Forest lies immediately west of the Te Urewera mountain ranges, between the cities of Rotorua to the north and Taupo to the south. During early Maori settlement of New Zealand, the area was entirely covered in indigenous forest (Nicholls 1990). However, before Europeans arrived most of this forest was burned (Nicholls 1990). When pine planting began in 1901, the vegetation mostly comprised monoao (*Dacrydium kirkii*), manuka (*Leptospermum scoparium*), tree fern (*Dicksonia* sp.), coarse grasses and remnant patches of indigenous podocarp and beech forest (Boyd 1992).

Kaingaroa Forest is the largest plantation forest in New Zealand comprising a single, 180,000 ha block of mostly radiata pine (*Pinus radiata*). This is bordered by dairy farms and indigenous podocarp forest to the east, and mostly dairy farm to the west.

Smaller pine plantations adjoin Kaingaroa Forest at the northern and southern extremes.

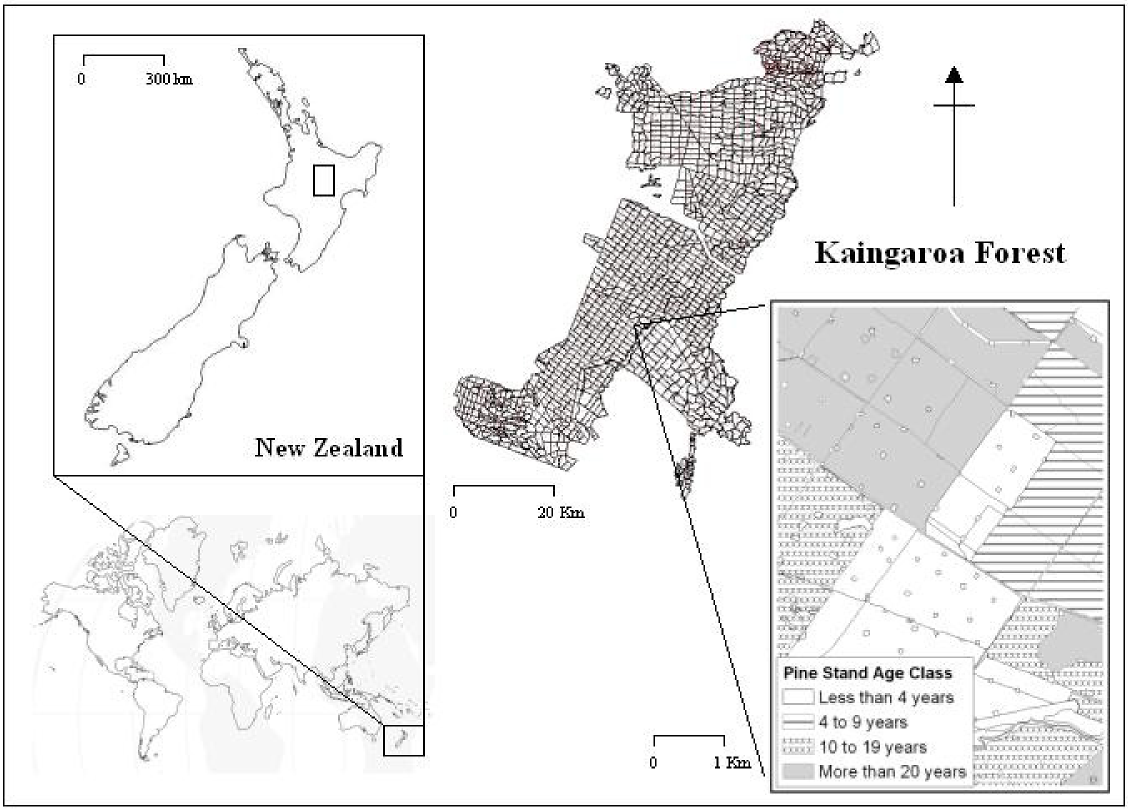

Figure 1.1. Map of Kaingaroa pine plantation illustrating its location in New Zealand and the size, compartment structure and mosaic of different aged pine stands in the forest.

1.3 Contribution of the research

This thesis illustrates the importance of private land use for the conservation of threatened species. In New Zealand, it highlights the contribution that pine plantations can make to indigenous biodiversity and how commercial use and biodiversity conservation need not be mutually exclusive land-use options.

The results from this study promote a better understanding of the biology of the New Zealand falcon and how the species interacts with the landscape. This information will allow a more accurate assessment of potential impacts to the species nationally and will enable pine plantation managers to encourage and support New Zealand falcon populations on their estates.

1.5 Thesis structure

The remainder of this thesis consists of seven chapters. Six of these chapters are written in the form of papers, each of which builds on the results of the previous chapter, the seventh is a general discussion of the results. Each chapter has been submitted to a peer-reviewed journal and while they stand alone they have been designed to combine and achieve the stated aim of the thesis. The journals chosen for submission have been chosen to cover varied disciplines including forestry, management, conservation and ecology. Each chapter provides the reader with the necessary background in order to put the research into its intended context, thus inevitably there is repetition of some material. The study site was the same throughout the study, therefore to reduce repetition this section has been removed from each chapter and is described above. References have been placed together in a section at the end of the thesis.

Chapter 2 describes the variation in the abundances of bird species throughout a plantation forest.

In **Chapter 3**, the diet of New Zealand falcons breeding in a plantation forest are related to prey abundances.

In **Chapter 4**, the habitat use of New Zealand falcons is investigated in relation to pine stand age, and home ranges are determined.

In **Chapter 5**, the factors influencing nest site selection of New Zealand falcons in a pine plantation are described in relation to habitat, forestry variables and breeding dispersal.

In **Chapter 6**, the productivity of New Zealand falcons in a plantation forest is described and investigated in relation to forestry management variables, in order to provide advice to forestry managers on avoiding any negative impacts of forestry operations.

In **Chapter 7** I describe the dispersal of New Zealand falcon fledglings within the study site.

In **Chapter 8**, the significance of the results and conclusions from each chapter are presented and specific management recommendations made. Recommendations for further work are discussed.

CHAPTER 2.

VARIATION IN BIRD SPECIES ABUNDANCE IN A COMMERCIAL PINE PLANTATION IN NEW ZEALAND

Stand of three-year-old *Pinus radiata*. R. Seaton 2003.

Chapter reference:
Seaton, R., E. Minot, J. D. Holland, and B. P. Springett. 2007. Variation in bird species abundance in a large-scale pine plantation in New Zealand. Submitted to journal.

2.1 Abstract

The abundance of bird species was investigated to determine how forestry characteristics affect birds in a commercial radiata pine plantation in New Zealand. In 2004 and 2005 we recorded bird species in Kaingaroa Forest using a belt transect method. In 2004, transects were chosen based on pine stand age, stand edge (the border between two age classes of pine stand) and pest control, and were repeated twice monthly from October to February. In 2005, transects were chosen to investigate the effect of the aspect and different classes of stand edge (different combinations of stand ages)

Bird density increased with age of pine stand. This trend was mostly driven by indigenous bird species, as exotic species were more evenly represented between different aged pine stands. Exotic bird species were found in greater numbers than indigenous species in young and intermediate aged pine stands, but both were recorded in similar abundances in mature stands. Stand edges had higher overall densities of birds than the interiors of stands. Eight of the 31 bird species observed made up 89 % of birds recorded. Chaffinches (*Fringilla coelebs*) were the most abundant species in every pine stand age category, but silvereyes (*Zosterops lateralis*) and whiteheads (*Mohoua albicilla*) were recorded in higher densities in some stand edge classes. The application of poison bait (1080) for pest control by the forestry company had no significant effect on bird density overall. The density of exotic bird species, however, was greatest where bait was applied from the ground over a small, localised area. Moreover, some indigenous species were recorded in their highest numbers in areas where bait had been aerially broadcast over a large area. Higher densities of birds were recorded at the start and end of the breeding season.

Our results indicate that in commercial pine forests, maximum avian diversity and density will result from a mosaic of pine stand ages with high local heterogeneity. Within this mosaic, stand edges and pine stands over 20 years old are important. If conservation of indigenous bird species is the management aim, then older stands must be well represented throughout, and broadcast application of pest control over a wide area may be beneficial.

2.2 Introduction

Plantation forest owners face increasing market pressures to incorporate management strategies sympathetic to indigenous biodiversity, as well as a worldwide demand for more environmentally sustainable products (Norton 1998). If these management strategies are to be effective the factors influencing biodiversity must be thoroughly understood. Several studies have documented the suitability of plantation forests in New Zealand to indigenous and exotic bird species (Gibb 1961, Jackson 1971, Colbourne and Kleinpaste 1983, Clout 1984, Clout and Gaze 1984). Plantation forests are more suited to some species than others. For example, insectivorous bird species are generally abundant, whereas nectar feeders and obligate cavity nesters are less well represented (Clout and Gaze 1984). Clout and Gaze (1984) recorded an increase in indigenous bird species density with increasing pine stand age, understorey height and complexity. Other factors determining bird species density and composition in plantation forests in New Zealand are less well understood.

Clear fell harvesting is used in both large-scale commercial and small-block farm forestry in New Zealand (Maclaren 1996). While the harvesting method is the same, the size of the operation can have a marked effect on the landscape. Commercial forestry creates a mosaic of different aged stands of plantation trees across the landscape. In contrast, small farm forestry blocks are usually felled all at once and thus do not have the different ages of stands across the plantation. Clear fell harvesting is perceived by some sectors as environmentally harmful, mostly due to aesthetics (Potton 1994). The size of clear fells in particular is controversial (Maclaren 1996), although little effect of clear fell size has been recorded on bird species abundance in New Zealand (Spurr and Coleman 2002) or overseas (Rudnicky and Hunter 1993, Krementz and Christie 2000). Edge habitats, relative to interior habitats, can have negative or positive effects on species abundance (Kroodsma 1984). However, the effect of stand edges (the border between two age classes of pine stand) in commercial pine plantations is rarely taken into account. Knowing the relative abundances of bird species between the edge and the interior of a pine stand is therefore a key factor when considering the effect of clear fell forestry.

Introduced predators (e.g. mustelids, feral cats, black and Norway rats) have caused the decline and extinction of many indigenous bird species in New Zealand (Tennyson and Martinson 2006). Forestry managers in New Zealand commonly use 1080 (sodium monofluoroacetate) poison bait to control plantation pests. This may also benefit bird populations by reducing potential predator numbers (Murphy et al. 1999). As a result pest control is generally termed predator control by conservation managers. Identifying the method of applying 1080 poison bait that is most beneficial to indigenous bird species is important when considering their management.

As part of a study assessing the ecological requirements of the New Zealand falcon in plantation forests, bird species abundance and composition was investigated in Kaingaroa Forest. These bird count data are used to investigate the effects of forestry variables on the composition of bird species and their density in a commercial plantation forest. By understanding these relationships, foresters will be better placed to make management decisions to enhance bird populations within plantation forests.

2.3 Method

Bird species abundance was assessed using a belt transect census method (Bibby et al. 1992). A single observer walked along predetermined transects recording species in two 50 m bands either side of each transect (0-50 m and 50-100 m). Inclement weather was avoided because of its negative effect on bird activity. Bird counts were carried out at least one hour after sunrise but before 10.00 am to reduce any effect of time of day and to allow direct comparison of counts. To further reduce the effect of time, transects were repeated and the time at which they were started within this period was cycled. 700m transects were marked out in straight lines running North-South and where vegetation became thick, lines were pre-cut at least one week before surveys so that they could be walked quietly. Counts along stand edges were restricted to 500 m because of the shape of the stands and the need to avoid the effects of neighbouring aged compartments.

Counts of individual birds were carried out in Kaingaroa Forest from October to February in 2004 and November to January in 2005. Study sites were chosen based on pine tree age and pest control treatment type. In 2004, four transect types were established, young (stands containing pine trees less than four years old), intermediate (stands containing pine trees between 10 and 14 years old) mature (stands containing pine trees greater than 20 years old) and edge (the boundary between young and mature stands). In New Zealand stands of radiata pine mature between 25 and 35 years old and are generally felled at this time (Maclaren 1996). The stand age classes were chosen to represent the greatest differences in stand structure and ages from a typical range of pine stand ages present in New Zealand's plantation forests (Table 2.1). Older stands of pine do also occasionally exist within these plantations. However, it has been illustrated that after pine stands reach 25 years old bird species density changes very little (Pierce et al. 2002). Thus, these older stands were not included in bird counts.

The four transect types were surveyed in each of three pest control treatment classes: localised ground control, aerial broadcast control and no-control (Table 2.1). In both ground and aerial control areas, 1080 bait was applied less than a year before the study. The no-control areas had not had bait applied for over three years. Localised control was restricted to just one or two compartments and bait was applied by hand, whereas with aerial broadcast control baits were applied from a helicopter or aeroplane over a large area covering many compartments. Understorey vegetation characteristics were also noted along each transect, including mean vegetation height, vegetation cover and the dominant vegetation class (Table 2.1). Each transect was repeated twice a month, from October to February, in each age class and each pest control treatment type.

Table 2.1. A summary table of the characteristics of the three study areas where bird counts were carried out in 2004.

Study area	1080 predator control type	Pine stand class	Pine age class (years)	Pine height (m)	Dominant vegetation class	Under storey vegetation height (m)	Vegetation cover (%)
1	Localised ground control	Young	Less than 4	0.5	Exotic grasses and fleabane	0.2	10
		Intermediate	10 to 14	8	Indigenous and exotic scrub	1	70
		Mature	More than 20	25	Indigenous shrub	1.5	80
		Edge	<4 vs 20+	1/ 25	Grasses/ indigenous shrub	0.3/ 1.5	20/ 90
2	Aerial broadcast control	Young	Less than 4	0.5	Exotic grasses and fleabane	0.3	30
		Intermediate	10 to 14	8	Indigenous and exotic scrub	1	90
		Mature	More than 20	25	Indigenous shrub	2	100
		Edge	<4 vs 20+	2/ 25	Grasses/ indigenous shrub	0.3/ 1.5	50/ 90
3	No control	Young	Less than 4	0.5	Exotic grasses and fleabane	0.3	20
		Intermediate	10 to 14	8	Indigenous and exotic scrub	1	100
		Mature	More than 20	25	Exotic grasses and indigenous scrub	0.3	70
		Edge	<4 vs 20+	2/ 25	Grasses/ indigenous shrub	0.3/ 1.5	50/ 90

In 2005, transects were selected in six types of edge habitat between pine stands of different ages (0-5 years, 0-10 years, 0-20 years, 5- 10 years, 5-20 years and 10-20 years). These transects were replicated in four different aspects: north, south, east and west (where aspect was the direction perpendicular to a transect, facing away from the older stand), were repeated twice in each aspect, twice a month from October to February. These transects were spread over the whole forest irrespective of pest control type.

The bird count data were converted into density per hectare by fitting a linear function. Data were divided into three classes for analysis: indigenous birds, exotic birds, and a combined data-set where all bird species were pooled. This was primarily done because forestry and conservation managers in New Zealand are particularly interested in indigenous species. Relationships between forestry variables and bird abundances in each class were investigated with a general linear model (GLM) using the statistical program SAS.

2.4 Results

2.4.1 Overall bird species abundance

Overall, chaffinches (*Fringilla coelebs*) were the most abundant species, making up 32 % of the bird species in Kaingaroa Forest (Fig. 2.1). Eight species out of the 31 species recorded during this study, made up 89 % of the bird species, including four indigenous species, silvereye (*Zosterops lateralis*), whitehead (*Mohua albicilla*), tomtit (*Petroica macrocephala*) and grey warbler (*Gerygone igata*) (see Appendix for full list). Rifleman (*Acanthisitta chloris*) were recorded only in mature stands here and although they have been recorded in pine forests before (Jackson 1971), are notably lacking from some other plantation forests (Clout and Gaze 1984). The New Zealand pipit (*Anthus novaeseelandiae*) was also recorded here but is often absent from other plantation forests (Clout and Gaze 1984).

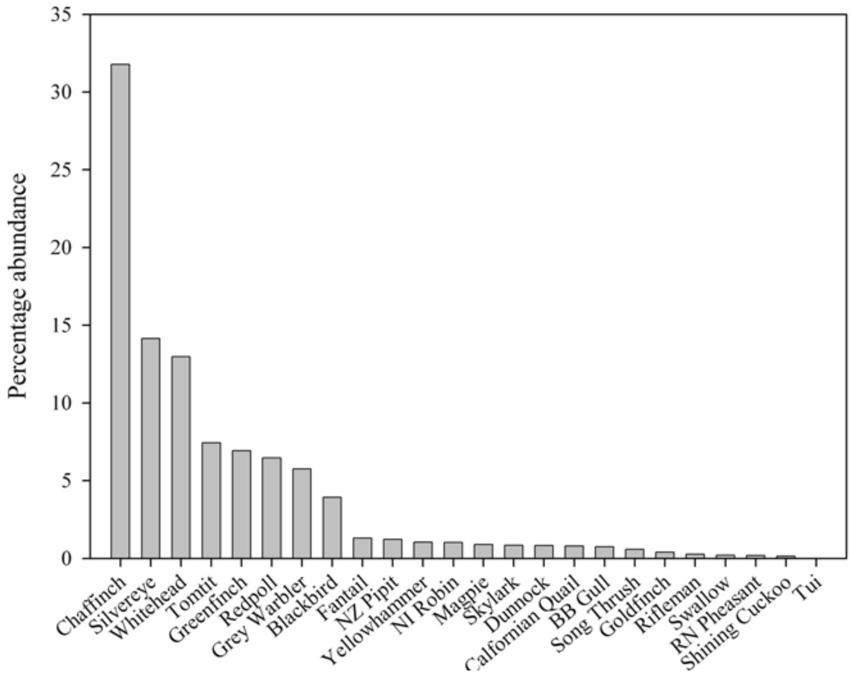

Figure 2.1. Percentage abundance of bird species in Kaingaroa Forest, all pine stand classes combined.

2.4.2 Variation of bird assemblage and abundance in different aged pine stands

The overall density of birds increased with pine stand age ($F_{2,90}$=19.06, *P*<0.0001), although there was no significant difference between intermediate and mature stands (Fig. 2.2). Indigenous species density increased with stand age ($F_{2,90}$=48.21, *P*<0.0001), while exotic bird density did not vary between stand age classes ($F_{2,90}$=0.54, *P*=0.59). The composition of bird species broadly changed from specialist open habitat species to forest dwelling indigenous species as pine stand age increased (Table 2.2). Chaffinches were the most abundant species recorded in all age classes (Table 2.2).

Table 2.2. Mean densities of bird species per hectare in each stand class, 2004. Young: stands containing pine trees less than four years old. Intermediate: stands containing pine trees between 10 and 14 years old. Mature: stands containing pine trees more than 20 years old. Edge: the boundary between young and old pine stands. **Bold**: Indigenous bird species.

	Pine stand class			
Bird species	**Young**	**Intermediate**	**Mature**	**Edge**
New Zealand pipit	**4.00**	**0**	**0**	**0.24**
Tomtit	**1.86**	**8.04**	**7.50**	**8.33**
Grey warbler	**1.21**	**7.58**	**3.82**	**7.30**
Silvereye	**0.69**	**7.62**	**6.16**	**34.40**
New Zealand falcon	**0.48**	**0**	**0**	**0.12**
Whitehead	**0.12**	**7.00**	**21.02**	**16.69**
Australasian harrier	**0.12**	**0**	**0**	**0.36**
Fantail	**0.12**	**1.07**	**1.67**	**1.67**
North Island robin	**0**	**0.48**	**2.20**	**0.91**
Shining cuckoo	**0**	**0**	**0.36**	**0.12**
Black-backed gull	**0**	**0**	**0**	**2.57**
Tui	**0**	**0**	**0**	**0.12**
Rifleman	**0**	**0**	**0.36**	**0.60**
Chaffinch	14.35	22.43	28.14	44.92
Redpoll	9.50	9.21	1.19	2.44
Greenfinch	7.05	3.85	5.73	7.31
Skylark	2.42	0	0	0.49
Yellowhammer	1.99	0.12	0	1.50
Goldfinch	1.19	0	0.12	0.12
Australian magpie	0.60	0.36	0	2.14
Dunnock	0.24	1.21	0.60	0.83
Welcome swallow	0.24	0	0	0.48
Blackbird	0.18	4.83	4.19	4.37
Songthrush	0.12	0.76	0.66	0.48
Californian quail	0.12	0.71	0	1.90
Ring-necked pheasant	0	0.12	0.07	0.48
Indigenous	**8.60**	**31.79**	**43.09**	**73.43**
Exotic	38.00	43.60	40.70	67.46
All birds	46.60	75.39	83.79	140.89

2.4.3 Variation in bird assemblage and abundance between the interior and edges of stands

In 2004, overall densities of birds were higher along stand edges than in the interior of pine stands ($F_{3,120}$=25.92, *P*<0.0001) (Fig. 2.2). When accounting for stand age, all stand edges show higher densities than interiors (Tables 2.2 & 2.3), and even when not accounting for age this was usually the case. Overall densities of bird species did not vary significantly between stand edge classes ($F_{5,47}$=1.07, *P*=0.40). Exotic and indigenous species, however, did significantly vary between stand edge classes ($F_{5, 47}$=4 42, *P*=0.006; $F_{5, 47}$=4.02, *P*=0.009). Exotic species were found at the highest densities along transects bordering unplanted stands, whereas indigenous species generally favoured stand edges that included mature stands (Table 2.3). Chaffinches were the most abundant species in all but three stand edge categories, where silvereyes and whiteheads were recorded as more abundant (Table 2.3).

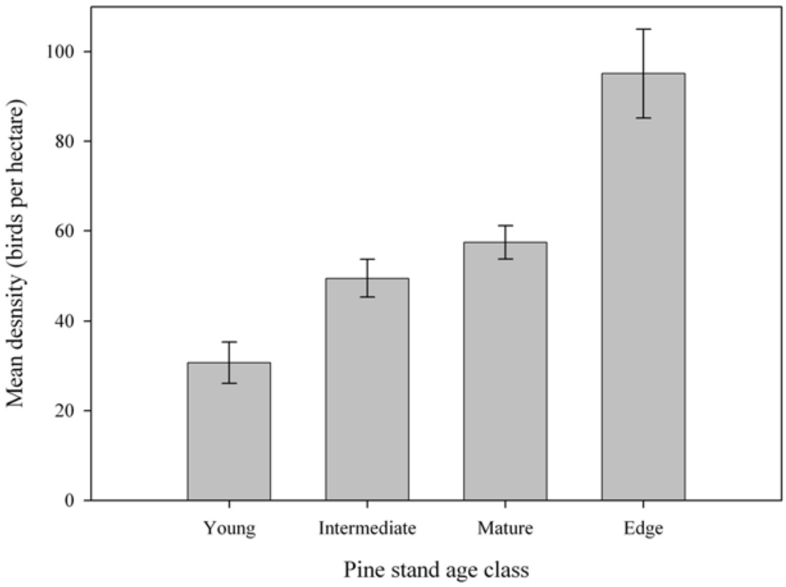

Figure 2.2. Mean density of bird species per hectare in each pine stand class, 2004 (±SE). Young: stands containing pine trees less than four years old. Intermediate: stands containing pine trees between 10 and 14 years old. Mature: stands containing pine trees more than 20 years old. Edge: the boundary between young and mature pine stands.

No difference was recorded in the assemblages of species between the centres or edges of pine stands, although North Island robins (*Petroica australis*) were slightly less well represented along stand edges containing mature pines, than in the centres of mature stands, suggesting they might prefer the interior of pine stands over edges (Tables 2.2 & 2.3).

Table 2.3. Mean densities of bird species per hectare in each stand edge class, 2005 (e.g. 5/20= a five year old pine stand bordering a 20 year old pine stand). **Bold**: Indigenous bird species

	Stand edge class					
Bird species	**5/20**	**5/10**	**10/20**	**0/5**	**0/20**	**0/10**
Silvereye	**30.50**	**15.34**	**18.83**	**13.00**	**6.09**	**22.53**
Whitehead	**19.75**	**6.13**	**31.50**	**0.63**	**17.31**	**1.92**
Tomtit	**7.93**	**5.29**	**7.79**	**3.00**	**6.79**	**6.79**
Grey warbler	**6.79**	**9.36**	**6.75**	**3.00**	**6.91**	**2.79**
Fantail	**2.63**	**0.50**	**1.00**	**1.00**	**2.50**	**3.00**
North Island robin	**1.00**	**0**	**0.55**	**0**	**0**	**0**
New Zealand pipit	**0**	**1.00**	**0**	**2.00**	**0**	**0**
Australasian harrier	**0**	**0.50**	**0**	**0.50**	**0**	**0**
Tui	**0**	**0.50**	**1.00**	**0**	**0**	**0.50**
Chaffinch	23.32	22.26	19.49	24.42	26.62	17.28
Greenfinch	6.00	6.38	2.00	2.84	9.30	6.13
Redpoll	3.78	5.18	3.57	10.85	9.42	13.77
Blackbird	1.50	2.69	5.29	2.43	5.09	9.38
Ring-necked pheasant	1.50	0	0	0.63	0.50	0
Dunnock	1.50	2.00	5.50	4.00	3.00	6.00
Song thrush	1.00	0.79	0	0	0.50	1.00
Australian magpie	1.00	0	0.50	2.50	0.79	3.00
Californian quail	1.00	5.00	1.00	5.18	5.59	5.50
Yellowhammer	0.50	0.63	0	3.29	0	1.34
Starling	0	0	0	0	0	3.50
Skylark	0	0	0	1.13	0	0
House sparrow	0	0	0	0	0.50	1.50
Goldfinch	0	0.50	0	0	0	4.00
Indian myna	0	0	0	1.00	0	1.00
Indigenous	**68.60**	**38.62**	**67.42**	**23.13**	**39.60**	**37.53**
Exotic	41.10	45.43	37.35	58.27	61.31	73.40
All birds	109.70	84.05	104.77	81.40	100.91	110.93

2.4.4 The influence of the aspect of a stand edge on bird species abundance

The aspect of an edge had no influence on the abundance of birds ($F_{3,47}$=1.01, *P*=0.41), which suggests that prevailing weather and shelter also had little effect (Fig. 2.3). However, bird counts were only carried out in fine weather to avoid bias in detection, therefore densities of bird species could potentially vary with aspect in different weather conditions.

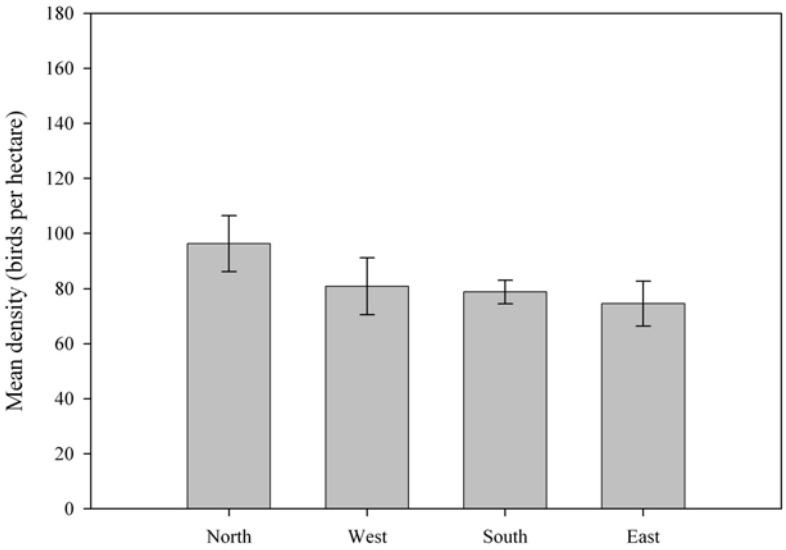

Figure 2.3. Mean density of bird species per hectare along pine stand edges facing north, west, south and east (±SE).

2.4.5 Variation in bird abundance between predator control (1080 poison bait) application types

There was no recorded difference in bird density between pest control (1080 poison bait) application types ($F_{2,120}$=2.02, P=0.14). However, the density of exotic birds was highest where pest control was localised ($F_{2,120}$=5.07, P=0.008), which was mostly attributable to the greater densities of chaffinches and greenfinches (*Carduelis chloris)* in this treatment area (Table 2.4). Indigenous birds, were found at similar densities in all three treatment types ($F_{2,120}$=0.02, P=0.98). Some indigenous species, however, were recorded at higher densities in pine stands where 1080 had been aerially broadcast over a large area, these included whitehead, grey warbler and tomtit (Table 2.4).

Table 2.4. Mean densities of bird species per hectare in each of three 1080 pest control application types. **Bold**: Indigenous bird species.

		1080 application type	
Bird species	**No control**	**Localised ground control**	**Aerial broadcast control**
Silvereye	**14.79**	**19.83**	**14.25**
Whitehead	**14.77**	**13.65**	**16.40**
Tomtit	**7.99**	**8.67**	**9.07**
Grey warbler	**6.14**	**4.96**	**8.80**
New Zealand pipit	**1.79**	**1.26**	**1.19**
North Island robin	**1.49**	**0.66**	**1.42**
Fantail	**1.19**	**2.14**	**1.19**
Rifleman	**0.83**	**0**	**0.12**
New Zealand falcon	**0.60**	**0**	**0**
Shining cuckoo	**0.36**	**0.12**	**0**
Welcome swallow	**0.24**	**0.48**	**0**
Australasian harrier	**0.12**	**0.24**	**0.12**
Black-backed gull	**0**	**2.45**	**0.12**
Tui	**0**	**0.12**	**0**
Chaffinch	32.25	43.64	33.96
Greenfinch	6.28	10.46	7.21
Redpoll	3.81	7.15	11.38
Blackbird	3.37	4.75	5.46
Australian magpie	1.17	0.78	1.14
Skylark	1.10	1.46	0.36
Dunnock	0.62	1.67	0.60
Californian quail	0.60	1.79	0.36
Yellowhammer	0.24	1.62	1.75
Song thrush	0.18	0.43	1.41
Goldfinch	0.12	0.60	0.71
Ring-necked pheasant	0	0.55	0.12
House sparrow	0	0.12	0
Indigenous	**50.31**	**53.58**	**52.68**
Exotic	49.74	75.02	54.46
All birds	100.05	128.60	107.14

2.4.6 Variation in bird abundance over the breeding season

Bird density was greatest at the start and at the end of the breeding season ($F_{4,120}$=23.71, P<0.0001) (Fig. 2.4). Both exotic and indigenous species followed this trend ($F_{4,120}$=12.34, P=0.0007; $F_{4,120}$=18.56, P<0.0001). But only a few species, (chaffinches, whiteheads and silvereyes) varied over the season, while most other species remained relatively stable (Table 2.5).

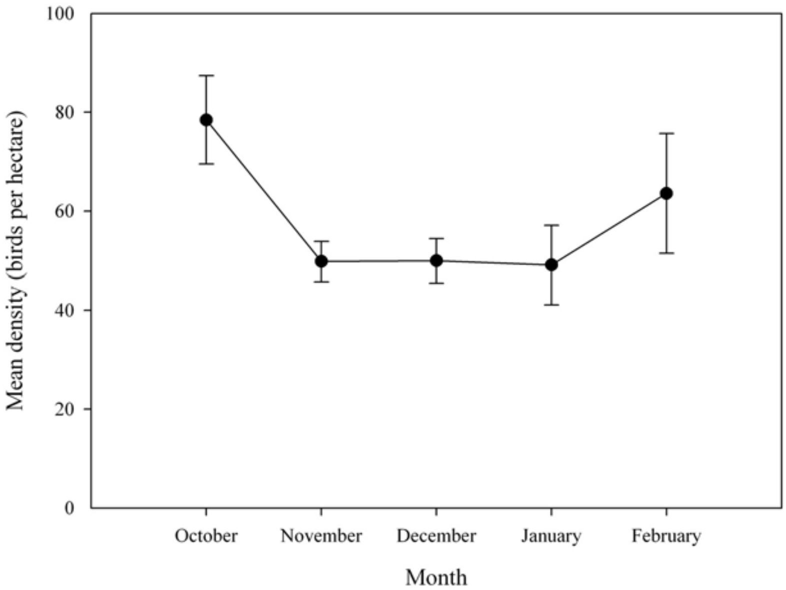

Figure 2.4. Mean density of birds per hectare in Kaingaroa Forest each month, October to February (±SE).

Table 2.5. Mean densities of bird species per hectare each month. **Bold**: Indigenous bird species

	Month				
Bird species	**October**	**November**	**December**	**January**	**February**
Silvereye	**15.48**	**2.62**	**1.90**	**13.79**	**15.09**
Whitehead	**14.44**	**10.60**	**8.79**	**4.96**	**6.03**
Grey warbler	**7.50**	**4.35**	**3.58**	**2.66**	**1.82**
Tomtit	**5.73**	**4.09**	**5.85**	**5.45**	**4.59**
New Zealand pipit	**1.43**	**0.71**	**0.83**	**0.95**	**0.31**
North Island robin	**1.14**	**0.33**	**0.34**	**0.87**	**0.90**
Fantail	**0.83**	**1.07**	**0.95**	**0.48**	**1.19**
Australasian harrier	**0.24**	**0**	**0.12**	**0**	**0.12**
Welcome swallow	**0.24**	**0**	**0.48**	**0**	**0**
Shining cuckoo	**0.12**	**0.24**	**0**	**0.12**	**0**
New Zealand falcon	**0.12**	**0.48**	**0**	**0**	**0**
Black-backed gull	**0**	**0.12**	**0.00**	**0.12**	**2.33**
Tui	**0**	**0.12**	**0.00**	**0**	**0**
Rifleman	**0**	**0**	**0.36**	**0.60**	**0**
Chaffinch	29.76	18.22	17.35	14.48	30.03
Greenfinch	4.65	5.05	6.51	3.95	3.78
Blackbird	3.24	2.52	3.19	1.30	3.33
Redpoll	2.80	6.19	4.48	5.91	2.96
Skylark	1.36	0.89	0.41	0.15	0.12
Yellowhammer	0.99	0.48	0.89	0.54	0.71
Australian magpie	0.93	0.07	1.07	0.60	0.42
Song thrush	0.93	0.48	0.38	0.12	0.12
Dunnock	0.60	0.73	0.24	0.95	0.36
Ring-necked pheasant	0.31	0.12	0.12	0.12	0
Californian quail	0.24	0.24	0.60	0.71	0.95
Goldfinch	0.12	0	0.24	0.71	0.36
House sparrow	0	0.12	0	0	0
Indigenous	**47.27**	**24.73**	**23.20**	**30.00**	**32.38**
Exotic	45.93	35.11	35.48	29.54	43.14
All Birds	93.20	59.84	58.68	59.54	75.52

2.5 Discussion

The edges of pine stands had greater densities of birds than the interiors of pine stands. These results are similar to those of Patterson *et al.* (1995) who observed that the edges of spruce stands in Scotland held higher densities of birds than the interiors of stands. Species inhabiting edge environments have the opportunity to increase the diversity of food available to them by using several habitat types, while remaining close to cover from predators (McCollin 1998). Chaffinches and silvereyes for example are generalist feeders (Heather and Robertson 1996), which would allow them to take advantage of several habitat and food types, and may explain their particularly high densities along stand edges.

Other studies have reported little effect of the size of a pine stand on the overall density of birds (Rudnicky and Hunter 1993, Donald et al. 1998, Krementz and Christie 2000). However, the greater densities of birds located along stand edges in our study suggests that smaller stands will promote higher densities of birds than larger stands. In contrast, some species may prefer interior habitat e.g. kiwi (Colbourne and Kleinpaste 1983) and North Island robin. The knowledge that stand edges promote overall species density must be tempered with the fact that maximum diversity requires the provision of interior habitat.

Overall, we found bird density increased with pine stand age, which concurs with the results of several other studies overseas e.g. (Suckling et al. 1976, Nilsson 1979, Friend 1982) and may be linked to an increase in the amount of understory vegetation. In contrast, in New Zealand, Clout and Gaze (1984) recorded no increase in overall bird density with pine stand age. This suggested that some exotic bird species preferred young pine stands, whereas indigenous species preferred mature stands. Our results concur with the increase in indigenous species density with stand age, but not with the trend for exotic species, which we found at similar densities in all stand age classes. The high abundances of chaffinches in mature pine stands (and along stand edges) further contradict the results of Clout and Gaze (1984) who record these in their highest abundances in young pine stands.

The discrepancy between the two studies may be due to variation in methodology. Clout and Gaze (1984) did not record species in stands less than six years old (which we class as young pine stands) and investigated a wider range of stand ages (six to 48 years). Also, they recorded bird species using five-minute bird counts which may produce different abundances of species compared to the transect method we employed. Finally, they counted birds at two times of the day, one in the early morning and one in the early afternoon. Because we did not aim to assess the effect of time of day, time was standardised by carrying out counts only in the early morning. Clout and Gaze (1984) do not report on the effect of time of day but the differences in their results may suggest that later in the day some exotic species forage differently, moving into young, open pine stands to feed. Although this requires further investigation the fact that, insect abundances are higher in young pine stands than in older stands (Beaudry et al. 1997, Fahy and Gormally 1998) and that insect abundances may be particularly high later in the day (due to higher temperatures promoting greater flying insect abundance and activity (Taylor 1963), may support this hypothesis. Large flocks of exotic finches were recorded in this study in young pine stands towards the end of the breeding season. This may be linked to ripening seed heads of grasses and other plant species at this time. Both hypotheses could also partially explain the particularly high abundances of birds along stand edges as flocking species forage out in the open but use stand edges for cover from predation.

From a management perspective, our results highlight the importance of the retention of mature stands in the landscape for shelter, protection, breeding sites and feeding grounds. Therefore to maintain overall species density, as well as high numbers of indigenous bird species, forestry managers should aim to consistently have mature stands over 20 years old located throughout a plantation.

In summary, high local heterogeneity of pine stand ages is key to maintaining high abundances and of both indigenous and exotic bird species in pine forests. High densities of indigenous bird species have inherent value in New Zealand, but high densities of some exotic species are also proving to be important in the landscape as they encourage high numbers of the endemic New Zealand falcon (*Falco novaeseelandiae*) (Stewart and Hyde 2004), a species that is thought to be in decline elsewhere in New Zealand (Gaze and Hutzler 2004).

Small-scale pest control can be less efficient than broadcast control, which is applied over a large area, as it reduces predator numbers for a shorter time period due to the shorter reinvasion distances involved (Warburton and Thomson 2002). Exotic birds, particularly finches, were denser in areas where bait was applied only on a small scale, on the ground, but the reason for this is not clear and may be unrelated to pest control. It has been shown that bird counts do not measure bird abundances on a fine enough scale to show the differences caused by pest control unless the effects are substantial (Atkinson et al. 1995). However, we recorded some indigenous bird species at their highest densities where 1080 poison bait was applied aerially and over a large area. Indicating that large-scale aerial application of bait is likely to be more beneficial to the conservation of indigenous species than more localised pest control.

In conclusion, maximum avian density and diversity will result from a mosaic of pine stand ages with high local heterogeneity and an abundance of edge habitat. If indigenous bird species conservation is the management aim, then older stands must be well represented throughout, and the broadcast application of pest control over a wide area will be beneficial.

2.6 Acknowledgements

This research was made possible by funding from Kaingaroa Timberlands, Timberlands Limited, Carter Holt Harvey, Hancock Forest Management Ltd., New Zealand Forest Managers and the Tertiary Education Commission in the form of an Enterprise Scholarship. We would also like to thank Massey University, The Department of Conservation New Zealand and Wingspan Birds of Prey Trust.

2.7 Appendix

Bird species recorded in Kaingaroa Forest during this study.

Common name	Scientific name	Common name	Scientific name
Australasian harrier	*Circus approximans*	New Zealand pipit	*Anthus novaesseelandiae*
Australasian magpie	*Gymnorhina tibicen*	North Island robin	*Petroica australis*
Bellbird	*Anthornis melanura*	Redpoll	*Carduelis flammea*
Black-backed gull	*Larus bulleri*	Rifleman	*Acanthisitta chloris*
Blackbird	*Turdus merula*	Ring-necked pheasant	*Phasianus colchicus*
Californinan quail	*Callipepla californica*	Shining cuckoo	*Chrysococcyx lucidus*
Chaffinch	*Fringilla coelebs*	Silvereye	*Zosterops lateralis*
Dunnock	*Prunella modularis*	Skylark	*Alauda arvensis*
Fantail	*Rhipidura fuliginosa*	Song thrush	*Turdus philomelos*
Goldfinch	*Carduelis carduelis*	Starling	*Sturnus vulgaris*
Green finch	*Carduelis chloris*	Tomtit	*Petroica macrocephala*
Grey warbler	*Gerygone igata*	Tui	*Prosthemadera novaeseelandiae*
House sparrow	*Passer domesticus*	Welcome swallow	*Hirundo tahitica*
Indian myna	*Acridotheres tristis*	Whitehead	*Mohoua albicilla*
Long-tailed cuckoo	*Eudynamys taitensis*	Yellowhammer	*Emberiza citrinella*
New Zealand falcon	*Falco novaeseelandiae*		

CHAPTER 3.

DIET AND PREY SELECTION OF THE NEW ZEALAND FALCON IN A PLANTATION FOREST

Juvenile male New Zealand falcon feeding on a mouse. S. McPherson 2006.

"Every now and then, it is as if someone had thrown a stick of dynamite into the place – a great rising fountain of birds and cacophonous din. And if you are quick, and lucky, you can see the falcon, sometimes with a dead thing dangling beneath, at other times empty taloned – but you can still imagine a rather smug look on his face, from causing all that havoc! "

Simon Barnes, 2005.

Chapter reference:
Seaton, R., N. Hyde, J. D. Holland, E. Minot, and B. P. Springett. 2007. Diet and prey selection of New Zealand falcon (*Falco novaeseelandiae*) in a plantation forest. Submitted for publication.

3.1 Abstract

The diet of the New Zealand falcon (*Falco novaeseelandiae*) in a plantation forest is described by identifying species occurring in pellets and prey remains collected from 37 nest sites during the 2003 and 2004 breeding seasons. Transects were set up in different aged pine stands and along stand edges to assess bird species abundance. Diet and prey abundance are compared to determine whether bird species were taken opportunistically or selectively. Bird species comprised the greatest proportion of the diet, 84% by frequency and 74% by biomass. Chaffinches (*Fringilla coelebs*) were taken most frequently, but blackbirds (*Turdus merula*) and rabbits (*Oryctolagus cuniculus*) contributed more by biomass, although rabbits were not recorded at every nest site. Bird species density increased with stand age but was even higher along stand edges ($F_{3,120}$=25.92, P<0.0001, r^2=0.54). Chaffinches were the most abundant species and were preyed upon opportunistically, while those that were either open habitat species (e.g. yellowhammers, *Emberiza citrinella*) or were of medium size (e.g. blackbirds) were selectively taken. Very small species (e.g. grey warbler, *Gerygone igata*), were taken in lower proportions than would be expected from their abundance. Proportions of bird species preyed upon were correlated most closely with bird species availability in young pine stands (P=0.02, R= 0.72). We conclude that the mosaic of different aged pine stands created by clear fell forestry is providing a high density and diversity of suitable prey for New Zealand falcon. Whether prey species are taken selectively or opportunistically depends on the abundance, size and the location of the prey species.

3.2 Introduction

The endemic New Zealand falcon (*Falco novaeseendiae*) exists in three ecologically distinct forms: the bush, eastern and southern falcons (Fox 1977). They breed in a variety of habitat types, from rough pasture and tussock lands to beech and podocarp forests (Fox 1977). Recently the bush form, which traditionally inhabits the indigenous forests of the North Island of New Zealand (Fox 1977, Barea et al. 1997), has been discovered breeding in exotic pine plantations (Stewart and Hyde 2004). The New Zealand falcon is classified as threatened by the Department of Conservation, New Zealand (Hitchmough et al. 2007). This increase in their range has significant implications for the conservation of the species. Very little is known of the biology of the New Zealand falcon in its forest habitat (Fox 1977, Barea et al. 1997), and quantified studies of their diet both in indigenous and exotic forest are lacking.

Previous research on New Zealand falcons has reported that they are primarily a bird catching falcon (Fitzgerald 1965, Fox 1977, Lawrence and Gay 1991, Barea 1995, Stewart and Hyde 2004), although they are also known to take reptiles, mammals and insects (Buller 1888, Fitzgerald 1965, Fox 1977). They will take a wide range of prey sizes, from insects, to prey up to six times their body weight (e.g. ring-necked pheasants, *Phasianus colchicus* and ¾ grown hare, *Lepus europaeus*) (Fox 1977, Hyde and Seaton 2007).

Research on prey selection in predators indicates that prey species are either taken opportunistically, in proportion to their relative abundances, or are selected for because of their relative profitability (Jaksic 1989). Some raptor species take most prey opportunistically, while others feed more selectively (Steenhof and Kochert 1988, Sodhi and Oliphant 1993, Joy et al. 1994, Quinn and Cresswell 2004, Figueroa and Corales 2005). Prey abundance is often a limiting factor in the breeding density of raptors (Newton 1979). Understanding how prey densities vary over the landscape and which prey species contribute the most to the diet, is therefore key to the effective management of raptor species.

Here we document the diet of the New Zealand falcon in an exotic pine plantation and determine the relationship between falcon diet and prey species abundance and size.

3.3 Methods

Pellets and prey remains were collected to describe the diet of the New Zealand falcon in a pine plantation. In order to assess prey availability transects were established within different aged pine stands and along stand edges. The assessment of prey availability was restricted to bird species because previous studies have shown that birds constitute the greatest proportion of the New Zealand falcon diet (Fitzgerald 1965, Fox 1977, Lawrence and Gay 1991, Barea 1995, Stewart and Hyde 2004). Avian prey in the diet of New Zealand falcon was compared with avian prey availability in Kaingaroa Forest in order to assess the relationship between falcon diet and prey abundance.

3.3.1 Pellet and prey remains

Falcon pellets and prey remains were collected from nest scrapes and adjacent plucking posts over two breeding seasons, September to March 2003 and 2004. Pellets were dissected and the remains identified against a reference collection. Using either pellets or prey remains alone causes bias in prey estimation, with pellets over representing small items and prey remains over representing large items (Mersmann et al. 1992, Real 1996, Redpath et al. 2001). To reduce this bias, the number of individuals of each prey species taken was calculated based on pellet and prey remains combined (Fox 1977). Pellets were assumed to contain one individual of the bird species identified within it, unless several pellets were collected from a nest containing the combined remains of a single large prey item within them (e.g. ring-necked pheasant, or rabbit, *Oryctolagus cuniculus*). In the latter instance such cases the combined pellets were assumed to represent one in individual of that species (Fox 1977). The biomass of each species was taken as the mean adult weight stated by Heather and Robertson (1996). For larger prey items, especially mammals such as hare, falcons may select only smaller individuals (Fox 1977). Thus to reduce the overestimation of the weight of prey, mammal weights were taken as the mean weights of actual prey items taken by New Zealand falcons in a study by Fox (1977). Insect weights were estimated to the nearest 0.5g. Biomass of unidentified prey items recorded in the diet was estimated as the mean weight of that taxonomic group.

3.3.2 Bird abundance

Bird counts were carried out in Kaingaroa Forest during the breeding season in 2004. Four transect types were established, young (stands containing pine trees less than four years old), intermediate (stands containing pine trees between 10 and 14 years old) mature (stands containing pine trees greater than 20 years old) and edge (the boundary between young and mature stands). These stand classes were chosen to represent the greatest differences in stand structure from the pine stand ages most commonly represented in New Zealand's plantation forests (Maclaren 1996). Bird species abundance was assessed using a belt transect census method and converted into density per hectare by fitting a linear function (Bibby et al. 1992). Biomass of bird species was estimated in the same manner as prey items.

3.3.3 Statistical analyses

The difference in bird species abundance between different pine stand classes was assessed using a general linear model. In this study, we used stepwise multiple linear regression to investigate which pine stand class contained bird species abundances most similar to the proportions of bird species recorded in the diet. Prey species that were present in low numbers in the diet and the forest were removed from the regression analysis.

3.4 Results

3.4.1 Pellet and prey remains

442 pellets and 275 prey remains from 37 nests were collected and analysed. Within these, 999 individual prey items, comprising 32 species of bird, mammal and insect were identified.

Birds comprised the greatest proportion of the diet, 87% by frequency and 74% by biomass (Table 3.1). Chaffinches (*Fringilla coelebs*) were taken most frequently, but blackbirds and rabbits contributed more by biomass. Mammals made up 26% of the diet by biomass and insects less than one percent. Rabbits made up the greatest proportion of mammal prey, 52% by biomass, while nearly all the insect biomass consisted of huhu beetles (*Prionoplus reticularis*). Other species that made up relatively large proportions of the diet included European hare, California quail (*Callipepla californica*), ring-necked pheasant, song thrush (*Turdus philomelos*), and yellowhammer. However, very large prey items such as rabbit, European hare and ring-necked pheasant were not recorded at every nest site. Passerines that could not be identified down to species level also contributed a significant proportion of the diet (18%).

Table 3.1. Prey species taken by New Zealand falcon during 2003 and 2004 breeding seasons in Kaingaroa Forest (see Appendix 1 for detailed results of each year separately).

Prey Species	Mass[a] (g)	% Frequency	Biomass Consumed (g)	% Total Biomass
Birds				
Chaffinch (*Fringilla coelebs*)	22	20.3	4364	9.40
Yellowhammer (*Emberiza citrinella*)	27	11.3	3051	6.57
Greenfinch (*Carduelis chloris*)	28	7.2	2016	4.34
Blackbird (*Turdus merula*)	90	6.9	6210	13.37
Song thrush (*Turdus philomelos*)	70	4.6	3220	6.93
Starling (*Sturnus vulgaris*)	85	2.0	1700	3.66
Skylark (*Alauda arvensis*)	38	1.9	722	1.55
Dunnock (*Prunella modularis*)	21	1.6	336	0.72
Californinan quail (*Callipepla californica*)	180	1.4	2520	5.42
House sparrow (*Passer domesticus*)	30	1.4	420	0.90
Silvereye (*Zosterops lateralis*)	13	1.1	143	0.31
Indian myna (*Acridotheres tristis*)	125	0.8	1000	2.15
Tomtit (*Petroica macrocephala*)	11	0.5	55	0.12
Whitehead (*Mohoua albicilla*)	17	0.4	66	0.14
New Zealand pipit (*Anthus novaeseelandiae*)	40	0.4	160	0.34
Redpoll (*Carduelis flammea*)	12	0.4	48	0.10
Ring-necked pheasant (*Phasianus colchicus*)	1300	0.3	3900	8.40
Goldfinch (*Carduelis carduelis*)	16	0.3	46	0.10
Shining cuckoo (*Chrysococcyx lucidus*)	25	0.3	75	0.16
Tui (*Prosthemadera novaeseelandiae*)	105	0.2	210	0.45
Grey warbler (*Gerygone igata*)	7	0.1	7	0.01
North Island robin (*Petroica australis*)	35	0.1	35	0.08
Bellbird (*Anthornis melanura*)	30	0.1	30	0.06
Kingfisher (*Halycyon sancta*)	65	0.1	65	0.14
Unidentified passerine	20	18	3500	7.53
Unidentified bird	20	2	480	1.03
Total Bird		**83.6**		**74**
Mammals				
European hare (*Lepus europaeus*)	1781	0.2	3562	7.67
Stoat (*Mustela erminea*)	270	0.1	270	0.58
Rabbit (*Oryctolagus cuniculus*)	607	1.0	6070	13.07
House mouse (*Mus musculus*)	17	0.1	17	0.04
Unidentified lagomorph	607	0.1	607	1.31
Unidentified mammal	150	0.9	1350	2.91
Total Mammal		**2.4**		**25**
Insects				
Huhu beetle (*Prionoplus reticularis*)	2.0	8.6	172.00	0.37
Giant dragonfly (*Uropetala carovei*)	2.0	0.1	2.00	0
Carabid beetle (*Carabidae spp.*)	0.5	0.2	1.00	0
Cockchafer beetle (*Scarabeus spp.*)	0.5	0.6	3.00	0.01
Unidentified beetle	0.5	4.1	20.50	0.04
Unidentified insect	0.5	0.3	1.50	0
Total Insect		**13.9**		**0.43**

[a] Mass estimates for birds from Heather and Robertson 1996, for mammals from Fox 1977.

3.4.2 Bird abundance

In total 29 potential avian prey species were recorded in Kaingaroa Forest from 2003 to 2005 (See Appendix 2). Bird density increased with pine stand age ($F_{2,90}$=19.06, P<0.0001, r^2=0.59), but was even higher along stand edges ($F_{3,120}$ =25.92, P<0.0001, r^2=0.54). Chaffinches were the most abundant species recorded in each stand class (Table 3.2). Silvereyes (*Zosterops lateralis*) were also recorded in high densities along stand edges. Whiteheads (*Mohoua albicilla*) were only recorded in high densities in mature pine stands. Yellowhammers, skylarks (*Alauda arvensis*) and New Zealand pipits (*Anthus novaeseelandiae*) were recorded in low densities and only in young, open stands.

Table 3.2. Relative bird abundance (% individuals) in each pine stand class, young (stands containing pine trees less than four years old), intermediate (stands containing pine trees between 10 and 14 years old), mature (stands containing pine trees greater than 20 years old), and stand edge (the boundary between young and mature stands) during the 2004 breeding season in Kaingaroa Forest.

	Stand class				
Species	Young	Intermediate	Mature	Stand edge	Combined
Chaffinch (*Fringilla coelebs*)	31.2	29.7	33.6	32.0	31.8
Redpoll (*Carduelis flamela*)	20.7	12.2	1.4	1.7	6.5
Greenfinch (*Carduelis chloris*)	15.3	5.1	6.8	5.2	6.9
New Zealand Pipit (*Anthus novaeseelandiae*)	8.7	0.0	0.0	0.2	1.2
Skylark (*Alauda arvensis*)	5.3	0.0	0.0	0.4	0.8
Yellowhammer (*Emberiza citrinella*)	4.3	0.2	0.0	1.1	1.0
Tomtit (*Petroica macrocephala*)	4.0	10.7	8.9	5.9	7.4
Grey Warbler (*Gerygone igata*)	2.6	10.1	4.6	5.2	5.8
Goldfinch (*Carduelis carduelis*)	2.6	0.0	0.1	0.1	0.4
Silvereye (*Zosterops lateralis*)	1.5	10.1	7.4	24.5	14.1
Australian Magpie (*Gymnorhina tibicen*)	1.3	0.5	0.0	1.5	0.9
Welcome Swallow (*Hirudo tahitica*)	0.5	0.0	0.0	0.3	0.2
Dunnock (*Prunella modularis*)	0.5	1.6	0.7	0.6	0.8
Blackbird (*Turdus merula*)	0.4	6.4	5.0	3.1	3.9
Whitehead (*Mohoua albicilla*)	0.3	9.3	25.1	11.9	13.0
Song Thrush (*Turdus philomelos*)	0.3	1.0	0.8	0.3	0.6
Fantail (*Rhipidura fuliginosa*)	0.3	1.4	2.0	1.2	1.3
Californian Quail (*Callipepla californica*)	0.3	0.9	0.0	1.4	0.8
Tui (*Prosthemadera novaeseelandiae*)	0.0	0.0	0.0	0.1	0.0
Shining Cuckoo (*Chrysococcyx lucidus*)	0.0	0.0	0.4	0.1	0.1
Rifleman (*Acanthisitta chloris*)	0.0	0.0	0.4	0.4	0.3
Ring-necked Pheasant (*Phasianus colchicus*)	0.0	0.2	0.1	0.3	0.2
North Island Robin (*Petroica australis*)	0.0	0.6	2.6	0.6	1.0
Black-backed Gull (*Larus dominicanus*)	0.0	0.0	0.0	1.8	0.7

3.4.3 Prey availability and selection

Eighty-three percent (24 out of 29) of potential prey bird species recorded in Kaingaroa Forest (Appendix 2) were recorded in the pellets and prey remains of the falcons. Four species of bird, starling, long-tailed cuckoo (*Eudynamys taitensis*), Indian myna (*Acridotheres tristis*) and house sparrow (*Passer domesticus*), were recorded as prey but were not recorded in bird counts. New Zealand falcons were occasionally observed hunting cicadas (*Kikihia spp.*), but these also, were not recorded in prey remains.

Stepwise multiple linear regression analyses was used to find the best fit of birds preyed upon to availability in each pine stand class. For the proportion of prey taken to prey available, young pine stands show the best fit (R^2=0.52, P =0.02, N =20). The explanation of prey selection was not improved by adding prey abundance from any other stand classes to the regression model.

Chaffinches were taken in proportion to their abundance, while yellowhammers, were taken in greater numbers than abundance would suggest (Fig. 3.1). Conversely, silvereyes, tomtits (*Petroica macrocephala*), whiteheads, redpolls (*Carduellis flammea*) and grey warblers (*Gerygone igata*) were taken less than expected. When accounting for biomass, some species were more important in the diet than frequency alone suggests (Fig. 3.2). California quail and ring-necked pheasant (*Phasianus colchicus*), were preyed upon relatively infrequently, but contributed significantly to the diet due to their relatively large mass. Song thrushes, blackbirds and greenfinches (*Carduelis flamela*) were also more important in the diet when accounting for their greater biomass.

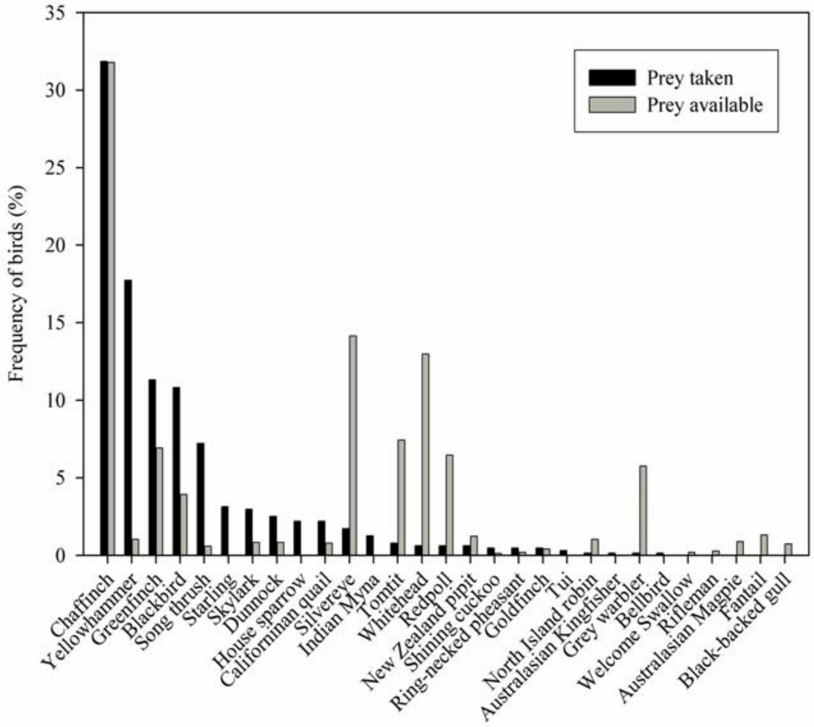

Figure 3.1. Frequency of bird species taken by nesting New Zealand falcon compared to prey abundances.

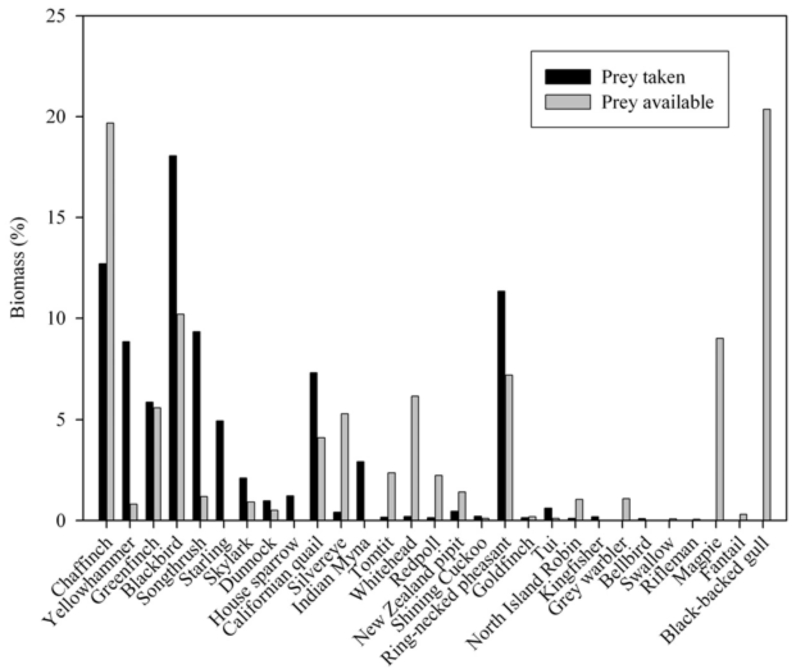

Figure 3.2. Biomass of prey species taken by nesting New Zealand falcon compared with the biomass of prey available.

3.5 Discussion

As in previous studies of nesting New Zealand falcons (Fitzgerald 1965, Fox 1977, Lawrence and Gay 1991, Barea 1995, Stewart and Hyde 2004), birds made up most of diet. Some prey were taken opportunistically, while others were apparently selected for. Chaffinches were the most abundant bird species present in all stand classes and were taken in proportion to their frequency in the environment, suggesting that they were preyed upon opportunistically. Other bird species that were recorded in high densities are more restricted in where they occur, which may have contributed to them being taken in relatively low proportions. Several of these species, including silvereyes, tomtits and grey warblers, are also very small, and may have been preyed upon infrequently because of their relatively low energy value, as stated by optimal foraging theory (Pyke et al. 1977).

Species that are taken more frequently than expected from their relative abundances include open habitat species (e.g. yellowhammers), and those that offer an energetic benefit because of their larger mass (e.g. blackbirds), and we suggest these species are selected. The hunting technique of New Zealand falcons are similar to those of sparrowhawks (*Accipiter nisus*) (Fox 1977), which prey on birds based on vulnerability rather than abundance (Quinn and Cresswell 2004). Open habitat species may be more vulnerable to predation from New Zealand falcons because young pine stands afforded relatively little cover (Suhonen et al. 1994).

Although large prey items can contribute significantly to the diet of some pairs, there is a trade off between increased size of prey and the risks involved in capture (Fox 1977, Newton 1986, Barea 1995). The smaller males (mean weight 264g) do most of the hunting during the breeding season (Fox 1977). Medium-sized prey such as blackbirds and song thrushes are important in the diet, even more so than chaffinches when considering biomass. Males more readily take these medium-sized prey than very large prey items such as ring-necked pheasant, rabbit and hare (Fox 1977). The larger females (mean weight 474g) hunt these larger prey, possibly at times with the help of males (Fox 1977). Some large species, including the Australian magpie and black-backed gull, have the added risk of congregating in large defensive groups during the breeding season (Heather and Robertson 1996). Although they have been recorded as items in the diet in other studies (Fox 1977), they were absent from our samples in Kaingaroa.

Mammals made up 25% of the diet by biomass in Kaingaroa Forest compared to 38% in the open hill country of the South Island (Fox 1977). This discrepancy may be explained because of the smaller bush falcons we studied are not able to tackle large prey items as easily as the larger eastern falcon in the South Island. Additionally this may reflect differences in mammal and bird prey abundance between sites. Insects, in contrast, contributed very little by way of frequency or biomass to the diet, with one species, the huhu beetle, constituting nearly all of the insects taken. Towards the end of the breeding season, huhu beetles were observed flying in large numbers. Thus, like with hobbies (*Falco subbuteo*), insects may not only provide food, but also relatively simple practise for fledglings learning to hunt (Chapman 1999).

Several bird species (starling, long-tailed cuckoo, Indian myna and house sparrow) were recorded as prey items but not in bird counts. Starling, Indian myna and house sparrow are associated with human settlements (Heather and Robertson 1996), and we suggest that these were taken outside of Kaingaroa Forest in adjacent farm blocks.

Few nests were located near the edge of the forest explaining the relatively low frequency of these species in the diet.

Bird species density increased with pine stand age and was higher still along stand edges, with overall bird species diversity being promoted by a landscape containing a variety of stand age classes (Chapter 2). This variety of stand ages and species provides New Zealand falcons with various opportunities for hunting, particularly along stand edges where prey species become more vulnerable as they forage out into more open areas (Suhonen et al. 1994). Barea (1995) noted the preference of forest dwelling New Zealand falcons for hunting in open areas. That hunting-habitat preference is highlighted here by the correlation between prey available in young stands and prey taken.

The composition of bird species differs between exotic and indigenous forests (Clout and Gaze 1984), making it unlikely that the diet recorded in pine forests resembles in proportion that of New Zealand falcons living in indigenous forests. Moreover, higher bird densities, particularly for exotic species, have been recorded in pine plantations than in indigenous forests (Gibb 1961, Kikkawa 1966, Clout and Gaze 1984). This indicates that pine forests may provide a more abundant food supply for New Zealand falcons than their more traditional indigenous forest habitat. As such, New Zealand falcon populations are less likely to be restricted by prey density in this novel habitat, suggesting that pine plantations potentially have a significant role to play in the conservation of this species.

3.6 Acknowledgements

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3.7 Appendices

3.7.1 Appendix 1.

Summary of the prey species taken by nesting New Zealand falcon for the two breeding seasons 2003/2004 and 2004/2005. Percentage includes all species whereas percentage bird biomass uses only the bird count data in calculating the percentage value.

		2003/ 2004					2004/ 2005				
Species	**Weight (g)**	**Frequency**	**Total % Frequency**	**Biomass**	**Total % Biomass**	**Bird % Biomass**	**Frequency**	**Total % Frequency**	**Biomass**	**Total % Biomass**	**Bird % Biomass**
Chaffinch	22	99	22	2129	10	13	104	19	2236	9	12
Yellowhammer	27	57	13	1539	8	10	56	10	1512	6	8
Green finch	28	34	8	952	5	6	38	7	1064	4	6
Blackbird	90	30	7	2700	13	17	39	7	3510	13	19
Song thrush	70	14	3	980	5	6	32	6	2240	9	12
Skylark	38	13	3	494	2	3	6	1	228	1	1
Starling	85	13	3	1105	5	7	7	1	595	2	3
Dunnock	21	8	2	168	1	1	8	1	168	1	1
House sparrow	30	7	2	210	1	1	7	1	210	1	1
Silvereye	13	6	1	78	0	0	5	1	65	0	0
Californinan quail	180	6	1	1080	5	7	8	1	1440	6	8
Tomtit	11	4	1	44	0	0	1	0	11	0	0
Indian myna	125	4	1	500	2	3	4	1	500	2	3
Ring-necked pheasant	1300	2	0	2600	13	16	1	0	1300	5	7
Goldfinch	16	2	0	31	0	0	1	0	16	0	0
Shining cuckoo	25	2	0	50	0	0	1	0	25	0	0
Whitehead	17	1	0	17	0	0	3	1	50	0	0
Grey warbler	7	1	0	7	0	0	0	0	0	0	0
Bellbird	30	1	0	30	0	0	0	0	0	0	0
Tui	105	1	0	105	1	1	1	0	105	0	1
New Zealand pipit	40	1	0	40	0	0	3	1	120	0	1
Redpoll	12	1	0	12	0	0	3	1	36	0	0
Fantail	8	0	0	0	0	0	0	0	0	0	0
North Island robin	35	0	0	0	0	0	1	0	35	0	0
Rifleman	7	0	0	0	0	0	0	0	0	0	0
Magpie	350	0	0	0	0	0	0	0	0	0	0
Long tailed cuckoo	125	0	0	0	0	0	0	0	0	0	0
Black backed gull	950	0	0	0	0	0	0	0	0	0	0
Swallow	14	0	0	0	0	0	0	0	0	0	0
Kingfisher	65	0	0	0	0	0	1	0	65	0	0
Passerine	20	56	13	1120	5	7	119	21	2380	9	13
Unidentified bird	20	9	2	180	1	1	15	3	300	1	2
Total Bird		**372**	**84.16**	**16169.5**	**79.37**	**100**	**464**	**83.30**	**18210**	**69.81**	**100**
Hare	1781	0	0	0	0		2	0	3562	14	
Stoat	270	0	0	0	0		1	0	270	1	
Rabbit	607	6	1	3642	18		4	1	2428	9	
Unidentified lagomorph	607	0	0	0	0		1	0	607	2	
House mouse	17	1	0	17	0		0	0	0	0	
Unidentified mammal	150	3	1	450	2		6	1	900	3	
Total Mammal		**10**	**2.26**	**4109**	**20.17**		**14**	**2.51**	**7767**	**29.78**	
Huhu beetle	2.0	41	9.28	82.00	0.40		45.00	8.08	90.00	0.35	
Giant dragonfly	2.0	1	0.23	2.00	0.01		0.00	0.00	0.00	0.00	
Carabid beetle	0.5	1	0.23	0.50	0.00		1.00	0.18	0.50	0.00	
Cockchaffer beetle	0.5	5	1.13	2.50	0.01		1.00	0.18	0.50	0.00	
Unidentified beetle	0.5	12	2.71	6.00	0.03		29.00	5.21	14.50	0.06	
Unidentified insect	0.5	0	0.00	0.00	0.00		3.00	0.54	1.50	0.01	
Total Insect		**60**	**13.57**	**93**	**0.46**		**79**	**14.18**	**107**	**0.41**	
TOTAL		**442**	**100**	**20371**	**100**		**557**	**100**	**26084**	**100**	

3.7.2 Appendix 2.

Potential prey bird species recorded in Kaingaroa Forest 2003 to 2005.

Common name	Scientific name	Common name	Scientific name
Australasian magpie	*Gymnorhina tibicen*	North Island robin	*Petroica australis*
Bellbird	*Anthornis melanura*	Redpoll	*Carduelis flammea*
Black-backed gull	*Larus bulleri*	Rifleman	*Acanthisitta chloris*
Blackbird	*Turdus merula*	Ring-necked pheasant	*Phasianus colchicus*
Californinan quail	*Callipepla californica*	Shining cuckoo	*Chrysococcyx lucidus*
Chaffinch	*Fringilla coelebs*	Silvereye	*Zosterops lateralis*
Dunnock	*Prunella modularis*	Skylark	*Alauda arvensis*
Fantail	*Rhipidura fuliginosa*	Song thrush	*Turdus philomelos*
Goldfinch	*Carduelis carduelis*	Starling	*Sturnus vulgaris*
Green finch	*Carduelis chloris*	Tomtit	*Petroica macrocephala*
Grey warbler	*Gerygone igata*	Tui	*Prosthemadera novaeseelandiae*
House sparrow	*Passer domesticus*	Welcome swallow	*Hirundo tahitica*
Indian myna	*Acridotheres tristis*	Whitehead	*Mohoua albicilla*
Long-tailed cuckoo	*Eudynamys taitensis*	Yellowhammer	*Emberiza citrinella*
New Zealand pipit	*Anthus novaesseelandiae*		

CHAPTER 4.

HABITAT SELECTION AND HOME RANGES OF NEW ZEALAND FALCONS IN PLANTATION FORESTS

Fitting a backpack mounted radio transmitter to an adult male falcon. R. Seaton 2005.

Chapter reference:
Seaton, R., E. Minot, J. D. Holland, and B. P. Springett. 2007. Habitat selection and home ranges of New Zealand falcons (*Falco novaeseelandiae*) in plantation forests. Submitted for publication.

4.1 Abstract

We successfully radio tracked 13 New Zealand falcons (*Falco novaeseelandiae*) (8 males, 5 females) in Kaingaroa pine plantation over the 2004 and 2005 breeding seasons, in order to investigate home range size and habitat selection in plantation forests. Mean home range sizes were 9.2km^2 for males and 6.2km^2 for females, which are much smaller than previous estimates made for forest dwelling New Zealand falcons. Kaingaroa pine plantation is harvested in discrete blocks, creating a mosaic of different aged pine stands. Pine stands were categorised by tree age and further classified into stand edge (the border between two pine stands of different ages) and stand interior (the area within a pine stand of same aged trees). Based on habitat available and habitat used, both sexes strongly favoured the edges between pine stands less than four years old, and stands more than 20 years old. We suggest that this is a result of high prey density and availability along these stand edges. Males and females also favoured the interior of pine stands less than four years old, but only males favoured mature stands over 20 years old. We suggest that these results indicate variations in niche and prey suitability between the sexes, most likely resulting from differences in body size. In conclusion, it is recommended that in order to encourage high densities of New Zealand falcon in commercial pine plantations, forestry managers should aim to provide a mosaic of pine stand ages that regularly provide stand edge, particularly young stands less than four years old bordering mature stands over 20 years old.

4.2 Introduction

The New Zealand falcon (*Falco novaeseelandiae*) is a threatened species (Hitchmough et al. 2007) which is subject to habitat loss and degradation, persecution and predation by introduced predators (Fox 1977, Lawrence 2002, Gaze and Hutzler 2004). New Zealand falcons have recently been discovered breeding in exotic pine plantations (Stewart and Hyde 2004, Addison et al. 2006), increasing the range of management options for the species.

Three ecologically and morphologically distinct forms of the New Zealand falcon have been described, the bush, eastern and southern falcon (Fox 1977). The bush and southern forms are primarily forest falcons, which traditionally breed within indigenous podocarp and southern beech forests (*Nothofagus* spp.) (Fox 1977, Barea et al. 1997). Only 24% of New Zealand's indigenous forest cover remains since human settlement (Ewers et al. 2006). Currently 20% of New Zealand's forest cover, amounting to 1.8 million hectares (Statistics New Zealand 2004), is exotic plantation forest (Hartley 2002). Forestry, and particularly clear fell harvesting, which creates a mosaic of stand ages, is often criticised for its perceived detrimental environmental impact (Maclaren 1996). However, many species of raptors outside of New Zealand have been reported breeding in exotic plantation forests, including northern goshawk, *Accipiter gentilis* (Beier and Drennan 1997), black sparrowhawk, *Accipiter melanoleucus* (Malan and Robinson 2001), European sparrowhawk, *Accipiter nisus* (Newton 1996), merlin, *Falco columbarius* (Parr 1991) and Cooper's hawk, *Accipiter cooperii* (Moore and Henny 1984, Rosenfield et al. 2000). The contribution that pine forests can make to indigenous biodiversity in New Zealand is becoming well documented (Jackson 1971, Clout and Gaze 1984, Ogden et al. 1997, Brockerhoff et al. 2003, Maunder et al. 2005). The forestry industry therefore has the potential to contribute significantly to the conservation of indigenous species both in New Zealand, and elsewhere.

We examined the home range and habitat selection of New Zealand falcon in a pine plantation to determine patterns of habitat use. Understanding habitat selection in relation to pine stand age is essential if forestry managers are to create landscapes, which are sympathetic to New Zealand falcon conservation.

4.3 Methods

4.3.1 Telemetry

Using radio transmitters, we collated movement and hunting data on adult New Zealand falcons in relation to the age of pine stands and the location within them during two breeding seasons, December to March 2004 and 2005.

Adult falcons were trapped using a variety of methods, dependent on the situation, including Balchatri traps, noose hats and Dho-gaza nets (Fox 1977, Bloom 1987). Radio transmitters weighing 12g were attached to 16 adult New Zealand falcons, nine males and seven females, using backpack harnesses (Kenward et al. 2001). These birds were tracked over an eight-hour period once a week for 12 weeks, December to March. The network of forest roads enabled individual New Zealand falcons to be quickly and accurately located using triangulation. For each radiolocation we recorded the age of the stand in which an individual was located, whether it was within the interior of a stand (> 50m from a stand edge), or on the stand edge (within 50m of the border between two stands more than four years different in age), and the time spent in each location. Stand sizes were large enough to ensure a high confidence of the stand class an individual was located in using two triangulation points or more, and the road network allowed accurate assessment of whether an individual was located within a stand interior or along a stand edge.

Successful hunting locations were recorded as the last place an individual was located prior to making a food pass at the nest. Nest sites were continuously observed during the eight-hour radio tracking period in order to observe food passes. This technique presumes that when a falcon catches prey that they, either fly directly back to the nest, or pluck the prey close to where it was caught, and then fly back to the nest (both scenarios were observed in the field). Therefore, there is a degree of error when using this technique, owing to the fact that hunting was normally not observed, and it was not possible to determine whether an individual had in fact flown into a different pine stand class from where the prey was caught, plucked it, and then flown back to the nest. Thus the result is an index of hunting selection rather than an absolute measure. Unsuccessful hunting attempts were removed from the analysis as they were only recorded by observation, which were affected by the openness of the pine stand and biased in favour of young stands.

4.3.2 Home Range Calculations

Minimum convex polygon (95% MCP) home ranges were calculated to delineate the home ranges of individuals during the breeding season, using Hawth's analysis tools 3.17 (Beyer 2004) in ArcMap 9.0. MCP home ranges were calculated monthly and per breeding season for each individual. Differences between home range sizes between sexes and over the breeding season were evaluated using *t*-tests.

4.3.3 Analysis of Habitat Selection

The area of pine stand within each MCP home range was split into stand interior and stand edge and classified by pine stand age. The interiors of stands were classified as less than 4 years, 4 to 9 years, 10 to 19 years and more than 20 years old from the range of tree ages most commonly available in a *Pinus radiata* dominated forest (Maclaren 1996), and to represent the greatest diversity in stand structure. Stand edges were classified according to the age category of the stand on either side of the edge, e.g. a stand less than 4 years old bordering a stand more than 20 years old.

Within each individual's home range we calculated the areas of each stand age class using ArcMap 9.0 as well as the proportion of each pine stand class available. The area of stand edge was calculated as the length (m) of the edge multiplied by 100m (stand edge was defined as being the area up to 50m from the border between two stand classes). The proportion of time each individual spent in each pine stand class was calculated separately. Habitat use was compared to habitat availability to determine habitat selection of each sex using compositional analysis; paired *t*-tests were used to assess the degree of preference for a pine stand class (Aebischer et al. 1993).

4.4 Results

Radio transmitters were attached to 16 breeding adult New Zealand falcons. The nest of one pair was predated within one week of attaching the transmitters and another transmitter was lost after one week of tracking. Overall, home range and habitat use data were therefore only collected for 13 New Zealand Falcons, eight adult males and five adult females, from December to March 2004 and 2005.

4.4.1 Home range

Mean adult male home range size was 9.23 km^2 and mean adult female home range size 6.15 km^2 (Table 4.1). There was no significant difference in home range size between males and females overall (t=1.40, df 11, P= 0.19), but male home ranges were significantly larger than females in December (t=3.33, df 11, P= 0.007) and January (t=2.92, df 11, P= 0.01). Male home range size peaked in January, while female home range size generally increased over the breeding season. Where pairs were tracked in a close group there was very little overlap of 95% MCP home ranges (Fig. 4.1.).

Table 4.1. Home range size (km^2) of adult New Zealand falcons in Kaingaroa Forest during the 2004 and 2005 breeding seasons.

			95% MCP Home ranges		
Sex	Individual	December	January	February	Total
Male	1	2.41	11.25	2.67	9.51
	2	6.04	9.95	9.73	13.14
	3	1.46	7.74	4.98	5.71
	4	4.37	6.14	3.61	7.81
	5	3.36	5.62	2.39	6.18
	6	5.59	5.74	5.82	7.17
	7	3.60	5.88	2.64	6.53
	8	10.70	12.11	10.62	17.75
Female	1	0.03	5.40	8.40	10.56
	2	0.37	1.22	0.85	1.48
	3	0.35	3.06	7.45	6.08
	4	0.87	5.68	1.49	6.21
	5	0.04	4.83	5.70	6.42
	Mean Male	4.69	8.05	5.31	9.23
	Mean Female	0.33	4.04	4.78	6.15

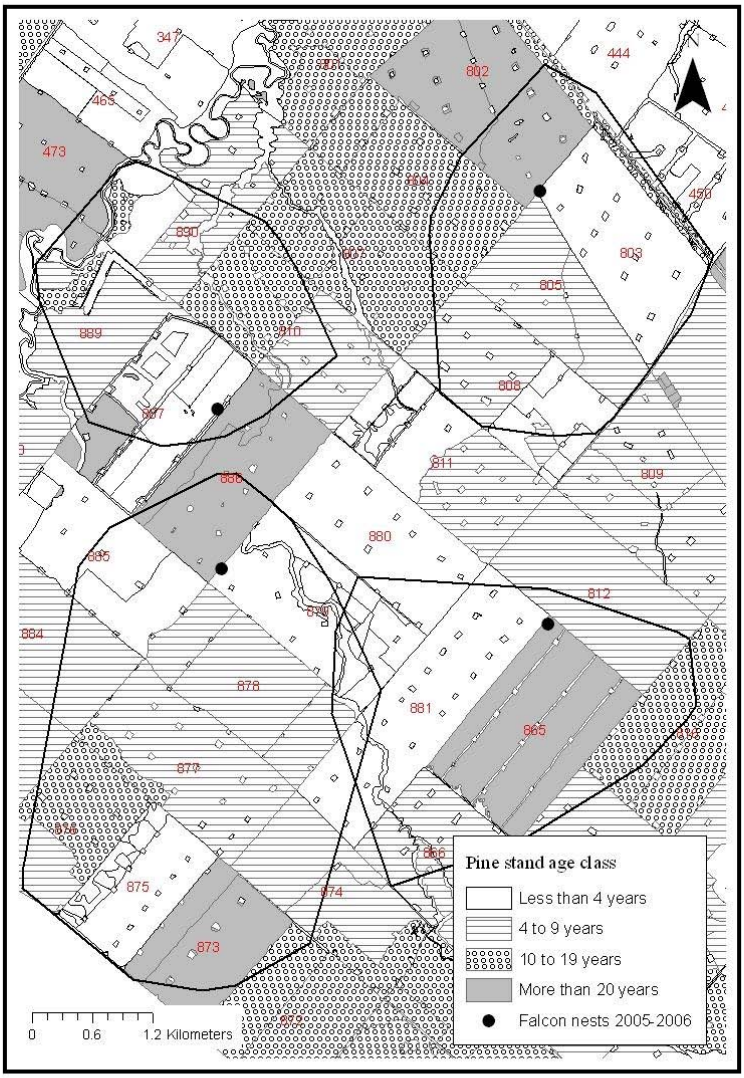

Figure. 4.1. A cluster of four neighbouring adult male New Zealand falcon home ranges during the 2005 breeding season showing the location of the nest sites, the 95% MCP home ranges and the composition of the pine stand age classes each home range comprises.

4.4.2 Habitat Selection

The area of each pine stand age-class within each home range varied between individuals (Table 4.2). Stands less than four years old made up the largest proportion of almost every New Zealand falcon home range, on average contributing 43% of the available area. Overall, male and female home range compositions were very similar.

Table 4.2. Percentage stand class availability within the 95% MCP home ranges of male and female New Zealand falcons radio tracked during the 2004 and 2005 breeding season in Kaingaroa Forest.

		Stand classes (years)									
Sex	Individual	Less than 4[a]	4 to 9[a]	10 to 19[a]	More than 20[a]	<4 / 4-9[b]	<4 / 10-19[b]	<4 / 20+[b]	4-9 / 10-19[b]	4-9 / 20+[b]	10-19 / 20+[b]
Male	1	56.83	10.81	6.39	3.31	1.42	4.02	12.37	0.91	1.66	2.30
	2	24.63	29.28	17.12	6.75	5.97	3.81	3.05	5.33	2.04	2.04
	3	38.13	19.72	7.04	24.63	0.69	0	2.61	1.40	4.55	1.24
	4	45.02	35.92	0	11.16	4.71	0	3.19	0	0	0
	5	27.51	41.89	7.60	13.35	2.96	0.93	2.90	1.49	0.78	0.59
	6	31.09	34.45	8.53	10.58	3.78	5.82	1.24	1.99	0.27	2.25
	7	44.60	0	43.06	0	0	8.63	2.00	0	0	1.70
	8	26.31	15.20	15.37	27.26	5.87	0.66	3.97	3.41	1.03	0.92
Female	1	33.39	9.12	10.96	19.82	1.39	3.25	15.88	0.89	2.88	2.41
	2	51.90	9.26	0	21.06	8.17	0	9.62	0	0	0
	3	59.10	0	0	27.12	0.69	3.26	6.43	0	0	3.40
	4	59.72	0	25.09	0	0	13.85	1.34	0	0	0
	5	58.96	10.87	0.60	14.90	7.15	0	6.60	0	0.92	0
	Mean	**42.86**	**16.66**	**10.90**	**13.84**	**3.29**	**3.40**	**5.48**	**1.19**	**1.09**	**1.30**

[a]stand interior classes, [b]stand edge classes.

New Zealand falcons do not use their home ranges in a random manner but favour certain age classes of pine stand, differing between males and females. Compositional analysis produces a rank order of relative preference for habitat use. Pairwise comparisons of rank indicated that pine stand edges between stands less than four years old and more than 20 years old were consistently preferred over all other stand classes by male and female New Zealand falcons (Tables 4.3 & 4.4). Females in general preferred stands less than four years old and the stand edges bordering these young stands (Table 4.4). Four stand edge classes ranked highly for males along with stand interiors less than four and more than 20 years old (Table 4.3).

Table 4.3. Results of compositional analysis of pine stand class use for **male** New Zealand falcons during the 2004 and 2005 breeding seasons. Rank scores indicate the relative preference of pine stand age-classes from highest (9) to lowest (0). Pine stand age-classes are split into two types of location; stand interior[a] and stand edge[b]. Pairwise *t*-tests indicate the relative preference of pine stand age-classes. Positive *t*-values indicate the row class ranked higher than the column class, and negative *t*-values indicate the row class ranked lower than the column class. A significant *P*-value indicates that the direction of the relationship was high.

Pine stand age class		Less than 4[a]	4 to 9[a]	10 to 19[a]	More than 20[a]	<4 bordering 4-9[b]	<4 bordering 10-19[b]	<4 bordering 20+[b]	4-9 bordering 10-19[b]	4-9 bordering 20+[b]	10-19 bordering 20+[b]	RANK
Less than 4[a]	*t*		1.47	9.65	0.07	-0.71	-0.83	-7.31	2.14	0.51	-0.13	5
	P		0.09	<0.001	0.47	0.25	0.22	<0.001	0.03	0.31	0.45	
4 to 9[a]	*t*	-1.47		-8.94	-2.96	-10.27	-9.84	-14.76	-1.54	-3.01	-3.59	0
	P	0.09		<0.001	0.01	<0.001	<0.001	<0.001	0.08	0.01	0.00	
10 to 19[a]	*t*	-9.65	8.94		-0.59	-5.04	-5.49	-10.15	1.41	-0.21	-0.86	3
	P	<0.001	<0.001		0.29	<0.001	<0.001	<0.001	0.10	0.42	0.21	
More than 20[a]	*t*	-0.07	2.96	0.59		-0.44	-0.52	-6.20	6.46	1.42	-0.78	5
	P	0.47	0.01	0.29		0.33	0.31	<0.001	<0.001	0.10	0.23	
<4 bordering 4-9[b]	*t*	0.71	10.27	5.04	0.44		-0.57	-9.65	2.76	0.96	0.25	6
	P	0.25	<0.001	<0.001	0.33		0.29	<0.001	0.01	0.18	0.40	
<4 bordering 10-19[b]	*t*	0.83	9.84	5.49	0.52	0.57		-8.67	2.75	1.02	0.35	6
	P	0.22	<0.001	<0.001	0.31	0.29		<0.001	0.01	0.17	0.37	
<4 bordering 20+[b]	*t*	7.31	14.76	10.15	6.20	9.65	8.67		11.64	8.41	7.03	9
	P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	
4-9 bordering 10-19[b]	*t*	-2.14	1.54	-1.41	-6.46	-2.76	-2.75	-11.64		-9.06	-13.56	1
	P	0.03	0.08	0.10	<0.001	0.01	0.01	<0.001		<0.001	<0.001	
4-9 bordering 20+[b]	*t*	-0.51	3.01	0.21	-1.42	-0.96	-1.02	-8.41	9.06		-6.40	2
	P	0.31	0.01	0.42	0.10	0.18	0.17	<0.001	<0.001		<0.001	
10-19 bordering 20+[b]	*t*	0.13	3.59	0.86	0.78	-0.25	-0.35	-7.03	13.56	6.40		5
	P	0.45	0.00	0.21	0.23	0.40	0.37	<0.001	<0.001	<0.001		

Table 4.4. Results of compositional analysis of pine stand class use for **female** New Zealand falcons during the 2004 and 2005 breeding seasons. Rank scores indicate the relative preference of pine stand age-classes from highest (9) to lowest (0). Pine stand age-classes are split into two types of location; stand interior[a] and stand edge[b]. Pairwise *t*-tests indicate the relative preference of pine stand age-classes. Positive *t*-values indicate the row class ranked higher than the column class, and negative *t*-values indicate the row class ranked lower than the column class. A significant *P*-value indicates that the direction of the relationship was high.

Pine stand class		Less than 4[a]	4 to 9[a]	10 to 19[a]	More than 20[a]	<4 bordering 4-9[b]	<4 bordering 10-19[b]	<4 bordering 20+[b]	4-9 bordering 10-19[b]	4-9 bordering 20+[b]	10-19 bordering 20+[b]	RANK
Less than 4[a]	*t*		9.36	6.25	2.69	4.46	2.50	-1.22	7.63	4.29	3.99	8
	P		<0.001	<0.001	0.01	0.001	0.02	0.13	<0.001	0.001	0.002	
4 to 9[a]	*t*	-9.36		-4.86	-1.59	-8.62	-9.95	-12.61	2.50	-0.41	-0.58	1
	P	<0.001		<0.001	0.08	<0.001	<0.001	<0.001	0.02	0.35	0.29	
10 to 19[a]	*t*	-6.25	4.86		-0.48	-4.50	-6.52	-9.68	4.38	1.06	0.82	4
	P	<0.001	<0.001		0.32	0.001	<0.001	<0.001	0.001	0.16	0.22	
More than 20[a]	*t*	-2.69	1.59	0.48		-0.64	-1.40	-4.31	10.07	4.56	3.83	4
	P	0.01	0.08	0.32		0.27	0.10	0.001	<0.001	<0.001	0.002	
<4 bordering 4-9[b]	*t*	-4.46	8.62	4.50	0.64		-4.74	-9.86	6.54	2.43	2.16	5
	P	0.001	<0.001	0.001	0.27		<0.001	<0.001	<0.001	0.02	0.03	
<4 bordering 10-19[b]	*t*	-2.50	9.95	6.52	1.40	4.74		-5.43	6.73	3.12	2.90	7
	P	0.02	<0.001	<0.001	0.10	<0.001		<0.001	<0.001	0.01	0.01	
<4 bordering 20+[b]	*t*	1.22	12.61	9.68	4.31	9.86	5.43		13.63	7.00	6.41	9
	P	0.13	<0.001	<0.001	0.001	<0.001	<0.001		<0.001	<0.001	<0.001	
4-9 bordering 10-19[b]	*t*	-7.63	-2.50	-4.38	-10.07	-6.54	-6.73	-13.63		-8.02	-7.10	0
	P	<0.001	0.02	0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	
4-9 bordering 20+[b]	*t*	-4.29	0.41	-1.06	-4.56	-2.43	-3.12	-7.00	8.02		-1.17	2
	P	0.001	0.35	0.16	<0.001	0.02	0.01	<0.001	<0.001		0.14	
10-19 bordering 20+[b]	*t*	-3.99	0.58	-0.82	-3.83	-2.16	-2.90	-6.41	7.10	1.17		3
	P	0.002	0.29	0.22	0.002	0.03	0.01	<0.001	<0.001	0.14		

4.4.3 Successful hunting locations

The number of successful hunting attempts by male and female New Zealand falcons was similar between stand edges and interiors (Table 4.5). Females made fewer successful hunting attempts during the breeding season than males. Males made most successful hunting attempts within stand interiors less than four years old, more than 20 years old and along stand edges between these two classes of pine stand. Females made the most hunting attempts in stands less than four years old and along stand edges between stands less than four years old and more than 20 years old, but in contrast to males had very few successful hunting attempts within stands over 20 years old.

Table 4.5. Locations of successful male and female New Zealand falcon hunting attempts in each pine stand class during the 2004 and 2005 breeding seasons in Kaingaroa Forest.

	Stand Classes (years)											
	Total Interior	Total Edge	Less than 4 years[a]	4 to 9 years[a]	10 to 19 years[a]	More than 20 years[a]	<4 / 4-9[b]	<4 / 10-19[b]	<4 / 20+[b]	4-9 / 10-19[b]	4-9 / 20+[b]	10-19 / 20+[b]
Female	16	10	15	0	0	1	1	1	8	0	0	0
Male	55	64	19	8	5	23	7	8	29	7	10	3
TOTAL	71	74	34	8	5	24	8	9	37	7	10	3

[a]stand interior classes, [b]stand edge classes.

Male New Zealand falcons made more successful hunting attempts in every stand age-class than females and hunted in a wider variety of pine stand age-classes. Both male and female delivery rates declined over the breeding season, while the number of prey deliveries made by males always remained far higher than those made by females (Fig. 4.2).

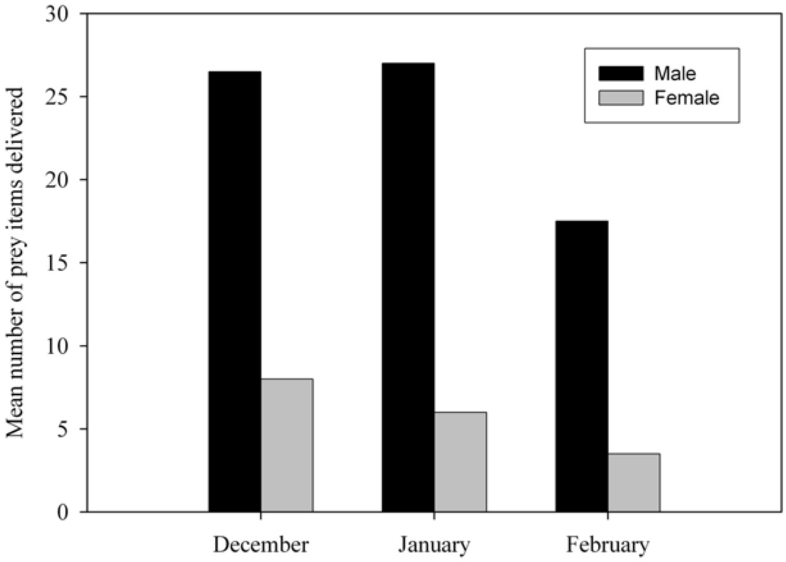

Figure 4.2. Mean number of prey items delivered to the nest by male and female New Zealand falcons during the 2004 and 2005 breeding seasons in Kaingaroa Forest.

4.5 Discussion

The New Zealand falcon home range size of 9 km^2 recorded in Kaingaroa Forest, is considerably smaller than the 75 km^2 previously estimated for New Zealand falcons in indigenous forest (Fox 1977). Although the accuracy of previous estimates is low because of a lack of available radio telemetry data, it remains likely that home ranges in indigenous forests are much larger than in pine plantations because prey is more abundant in the latter (Clout and Gaze 1984). If nest site availability is not limited, this suggests that the highest densities of this species could now be located in exotic pine plantations.

Prey species are more available to merlins (*Falco columbarius*) and black sparrowhawks (*Accipiter melanoleucus*) along plantation edges (Parr 1991, Malan and Robinson 2001). It has also been suggested that prey is more available to New Zealand falcons along habitat boundaries (Fox 1977, Barea 1995). In pine plantations prey availability is enhanced by very high densities of prey congregating along pine stand edges (Chapter 2). New Zealand falcon preferred several pine stand edge classes, suggesting that they are choosing areas characterised by high prey abundance, and that optimal hunting conditions are located along these habitat boundaries.

Prey availability is also high in open stands where prey is more vulnerable to predation (Suhonen et al. 1994), and open habitat species are commonly selected for in the diet of New Zealand falcon in pine forests (Chapter 3). Although habitat use will always be biased toward nest sites, (which are often located in pine stands less than four years old) (Stewart and Hyde 2004, Addison et al. 2006), a high proportion of prey was taken by both sexes in stands less than four years old. Indicating that young pine stands provide more than just potential nest sites. The selection by both sexes for stand edges bordering stands less than four years old, also indicates the suitability of these young stands, with the older stand providing the necessary cover for New Zealand falcons from which to launch hunting attempts out over younger more open pine stands. Large prey species such as rabbit (*Oryctolargus cuniculus*), which are only taken by females and can contribute significantly to the diet(Fox 1977), are more abundant in young open stands (Gibb 1961), which may also contribute to their selection.

Male New Zealand falcon also preferred pine stands that were more than 20 years old. This behaviour is similar to other raptor species, including European sparrowhawk (*Accipiter nisus*), grey goshawk (*Accipiter novaehollandiae*) and brown goshawk (*Accipiter fasciatus*) (Marquiss and Newton 1981, Burton and Olsen 2000b), where the males' smaller size makes them more adapted to hunting under a canopy than females. Male New Zealand falcons are more manoeuvrable than females (Fox 1977), and the broad variety of stand classes that males were successful hunting in indicates that males are better adapted to hunt in a wider variety of stand ages than females. The size and species of prey delivered by each sex is likely to differ accordingly (Fox 1977, Marquiss and Newton 1981, Burton and Olsen 2000b).

Raptor home ranges vary over the breeding season depending on a variety of factors, including food availability and the energy requirements of offspring (Village 1982, Bloom et al. 1993). The size of male New Zealand falcon home ranges peaked after all the chicks had fledged, and then declined along with prey deliveries, as fledglings became more independent (Chapter 6). Prey density increases at the end of the breeding season (Chapter 2), and this may allow males to forage over a smaller range (Village 1982, Bloom et al. 1993). Female home ranges increased over the breeding season as they became more independent of the nest, and the number of prey deliveries decreased as young became self sufficient. Throughout this time there is very little, if any, overlap in home range between adjacent pairs, which confirms that New Zealand falcon pairs are very territorial during the breeding season. However, we suggest that only a proportion of the overall home range is vigorously defended as very few aggressive territorial interactions were observed.

4.6 Management recommendations

Considering the broad scale loss of indigenous forest and their threatened status, the use of this exotic habitat by falcons is significant and represents a unique opportunity for the forestry industry to promote the conservation of a threatened species in New Zealand.

We suggest that a mosaic of stand ages, which creates a high overall proportion of stand edge resulting in high prey density and availability, is responsible for the relatively small home range size of New Zealand falcon in pine plantations. If forestry managers wish to enhance the suitability of their estates for New Zealand falcon, they should provide a mosaic of different aged stands, while ensuring that stands of less than four years old bordering stands over 20 years old are consistently available.

4.7 Acknowledgements

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CHAPTER 5.

NEST SITE SELECTION OF NEW ZEALAND FALCONS IN PLANTATION FORESTS

Typical New Zealand falcon nest location (under the log in the foreground). R. Seaton 2005.

"One day walking along near the margin of the forest, my hat was suddenly knocked off my head, and at the same time I heard a shrill cry. On looking up, I found it was one of these courageous little Sparrow-Hawks that had attacked me, and which, after sitting a moment or two on a branch, again pounced on me; and although I had a large compass-stick in my hand, with which I tried to knock it down, it repeated its attack several times."

Sir J. Von Haast, in Buller 1888

Chapter reference:
Seaton, R., J. D. Holland, E. Minot, and B. P. Springett. 2007. Nest site selection and breeding dispersal of New Zealand falcon (*Falco novaeseelandiae*) in plantation forests. Submitted for publication.

5.1 Abstract

Eighty-four New Zealand falcon nest sites were located in Kaingaroa pine plantation over three breeding seasons, 2003 to 2006. Habitat and forestry management variables were measured at nest sites and randomly selected hypothetical non-nest sites, in order to assess New Zealand falcon nest site selection. Additionally, 202 New Zealand falcons were colour banded to investigate the effect of breeding dispersal on nest site selection each year. Unplanted pine stands and stands one year old and less were preferentially selected for nesting, but nest sites were located in pine stands up to five years old. All nests located within Kaingaroa Forest were on the ground, in young pine stands or within the borders of mature pine stands adjacent to young stands. Where indigenous forest bordered young pine stands, however, New Zealand falcons nested in the epiphytes of emergent trees, in indigenous forest and not on the ground. Eighty percent of pairs remained together to breed in subsequent breeding seasons. Fifty-four percent of pairs nested in the same pine stand the following breeding season, while 44 percent moved to a younger pine stand or another stand of the same age, two percent moved into older stands. Nest sites differed significantly from randomly selected non-nest sites. Nest sites had more cover over the nest scrape, were closer to stand edges and had a greater area of pine trees over 20 years old within their home ranges. Smaller pine stands have the potential to increase breeding densities of New Zealand falcons by increasing prey density and availability, although there was no evidence that falcon pairs selected small over large stands as nest sites. Pine harvesting practices that clear fell forest in relatively small discrete stands, creating abundant edge habitat, benefit New Zealand falcon by continually providing suitable nest sites, and by promoting prey abundance and availability.

5.2 Introduction

In order to effectively manage landscapes for the conservation of a species it is important to understand what factors are most important in the selection of nest sites at a landscape, home range and nest site scale. Although there is a good understanding of the broad habitat requirements of the New Zealand falcon (*Falco novaeseelandiae*) on a landscape scale (Fox 1977), we still know little about what factors determine nest site selection at the finer scales (Barea et al. 1997, Lawrence 2002). The New Zealand falcon is a threatened species (Hitchmough et al. 2007) that has recently been recorded breeding in exotic pine plantations (Stewart and Hyde 2004, Addison et al. 2006). By determining the features of pine plantations selected by falcons, forestry companies will be able to implement management practices that encourage and support New Zealand falcon populations on their estates.

There are three forms of the New Zealand falcon, the bush, eastern, and southern falcon (Fox 1977). The bush falcon is a forest falcon, whose range spreads over much of the North Island and down into the north west of the South Island. It is ecologically distinct from the other forms of the New Zealand falcon (Fox 1977) and has been the subject of little research (Fox 1977, Lawrence and Gay 1991, Barea et al. 1997, Stewart and Hyde 2004).

Plantation forests provide important habitat for the New Zealand falcons, whose traditional forest habitat has been greatly reduced since human colonisation (McGlone 1989). The contribution of pine plantations to indigenous biodiversity in New Zealand is becoming well documented, with a wide diversity of indigenous flora and fauna existing in plantation forests (Jackson 1971, Clout and Gaze 1984, Ogden et al. 1997, Brockerhoff et al. 2003, Maunder et al. 2005). Forestry companies that implement management strategies which are sympathetic to this biodiversity stand to gain through an improved public perception of the industry, and the provision of tangible market advantages by meeting green certification requirements (Norton 1998, Maunder et al. 2005).

We describe New Zealand falcon nest sites in Kaingaroa pine plantation and describe how habitat, breeding dispersal and forestry management practices influence nest site choice. Using these results we outline how plantation forests can be managed to encourage and support New Zealand falcon populations.

5.3 Method

New Zealand falcon nest sites were surveyed over three breeding seasons, (September to March) from 2003 to 2006. Habitat variables were measured around each nest site and around randomly selected non-nest sites in order to compare the habitat around nest sites with habitat generally. Forestry management data relating to each nest and non-nest site were collated from forestry companies.

Individual falcons were colour banded and pairings recorded each year. This enabled breeding dispersal between years to be assessed.

5.3.1 Nest site location

Stands of pine trees aged less than four years old were identified as suitable nesting habitat because most previous records for falcons are from this habitat. These nest records come from Wingspan Birds of Prey Trust (Stewart and Hyde 2002, 2004), the Raptor Association of New Zealand, the Department of Conservation New Zealand and several forestry companies (Addison et al. 2006). New Zealand falcon nests have been found in pine stands older than four years old (Addison et al. 2006), but by far the greatest number of nests have been located within or on the borders of pine stands less than four years old.

All the pine stands in Kaingaroa Forest less than four years old were identified each breeding season. These young stands were walked to solicit defensive behaviour and to listen and watch for other characteristic falcon breeding behaviour. By using this two-step process, we aimed to survey and describe the majority of the breeding New Zealand falcon population in Kaingaroa Forest rather than the entire population. Forestry workers also provided sightings of falcons throughout the study.

The GPS location of each nest was recorded and the mean distance between nearest nests was calculated for each breeding season using the spatial statistics tool, ‘average nearest neighbour’ in ArcMap 9.0.

5.3.2 Nest stand age

In order to compare use with availability, and hence selection, we recorded the age of each pine stand where nests were located and the number of each age available each breeding season. Nests were sometimes located on the border between two stands in the transitional zone between stand ages. Where this was the case, the age of the younger stand was recorded as the nest stand age. The number of stands available was determined by counting the number of discrete areas planted at the same time. Use was compared with availability using a Kolmogorov-Smirnov two-sample test.

5.3.3 Compartment size

There are several ways to measure the area of clear fell harvest. For our purposes, we define the size of a clear fell compartment as the discrete area of trees of less than four years old surrounding a nest. The clear fell sizes used for nesting were compared to those available each season using a Kolmogorov-Smirnov two-sample test. To avoid bias associated with pseudo-replication, we used only data from the 2005-2006 breeding season (the season in which the most nests were located).

5.3.4 Habitat and forestry management

Habitat variables were measured at each nest site during the 2004 and 2005 breeding seasons. These included broad measurements of habitat within 50 m of the nest and more detailed measurements within 1 m of the nest scrape (see Appendix for full list). In order to compare any differences between pine stands where falcons were nesting and those pine stands where they were not measurements were also made within pine stands where New Zealand falcons were not present. These non-nest sites were randomly selected within pine stands less than four years old where falcons had not been observed. Forestry management data were collected from forestry company databases on stands containing nests and non-nest sites. These data included details of machine operations, spray regimes and pest control application (see Appendices for full list).

In order to describe nest sites on a broader scale, hypothetical home ranges of 9.23 km^2 representing the mean adult male home range in Kaingaroa Forest (Chapter 4), were constructed centring on each nest and non-nest using ArcMap 9.0 (Fig. 5.1). Pine stand ages were classified (less than four years old, four to nine years old, 10 to

19 years old and more than 20 years old) and the area of each age class available within each home range was calculated.

Across all of the variables described, stepwise discriminant analysis was applied to the standardised data to assess whether there were any differences between nest and non-nest sites. Nominal and categorical variables were not included in the discriminant analysis. Separate Chi-square tests were applied to these to assess the differences between nest and non-nest sites.

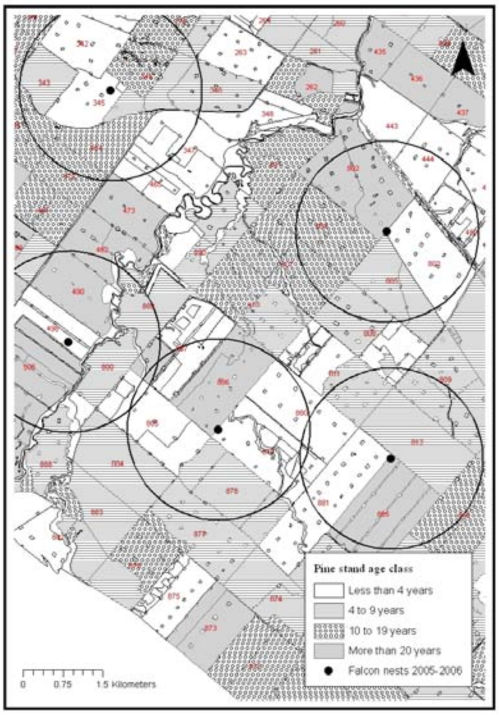

Figure 5.1. Hypothetical home ranges based on a mean adult male home range of 9.23km^2 (Chapter 4)

5.3.5 Breeding dispersal

In order to identify individuals and pairs, adult New Zealand falcons were trapped using Balchatri traps and Dho Gaza nets (Bloom 1987), and fitted with individual colour band combinations and a numbered metal band. Chicks, where possible, were banded on the nest; otherwise they were trapped after they were 50 days old (before this time fledglings were not interested in the traps). During subsequent breeding surveys, colour bands were recorded to assess individual movements and pairings between breeding seasons. Distances moved between subsequent breeding attempts were measured using ArcMap 9.0.

5.4 Results

5.4.1 Nest site location

The number of nesting New Zealand falcon pairs increased in the study site from 20 in 2003 to 36 in 2006 (Fig. 5.2). The mean distance between nearest nests decreased from 4.48 km in 2003, to 3.73 km in 2004, to 3.25 km in 2005. The closest nests recorded were only 0.97 km apart. In the third breeding season (2005-2006), two non-breeding pairs were located in the far north of Kaingaroa Forest, an area with no previous records of falcon activity.

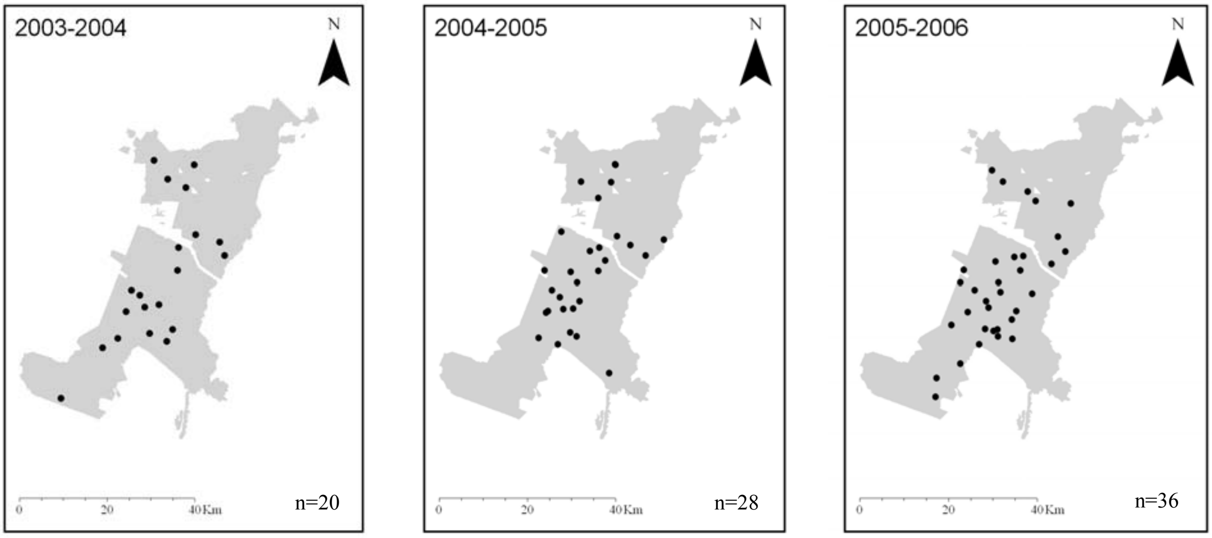

Figure 5.2. Nest attempt locations in Kaingaroa Forest each breeding season. Some nests are hidden due to overlapping location.

New Zealand falcon nest sites were all relatively similar to one another with most nests being located on the ground amongst pine slash. However, where stands less than four years old bordered indigenous forest (on the edge of Kaingaroa Forest), falcons nested in the large epiphytes high in emergent indigenous trees, and not on the ground. No falcon pairs were located breeding on the ground in pine stands less than four years old when the stand was bordered by indigenous forest.

5.4.2 Plantation stand age

The availability of stands less than four years old fluctuated spatially and temporally as stands became older and new stands were created by tree felling each year (Table 5.1). In 2005, falcons in Kaingaroa Forest had 172 discrete stands less than four years old available for nesting. From the available stands, Falcon pairs selected unplanted pine stands and those containing pines trees of one year old or less, over pine stands containing trees two and three years old (Kolmogorov two-sample test K=1.49, $P<0.05$) (Table 5.1).

Table 5.1. The percentage of nests found in each stand age category and the percentage of stands of that age class available, each breeding season in total.

	2003/ 2004		2004/ 2005		2005/ 2006		Total	
Age of stand (years)	% nests	% available	% nests	% available	% nests	% available	% nests	% available
Less than one	35	17	47	42	44	33	42	31
One	45	28	29	23	25	25	33	25
Two	15	29	14	18	19	24	16	24
Three	5	25	11	18	11	19	9	21
n=	20	205	28	328	36	312	84	845

5.4.3 Plantation stand size

New Zealand falcon nested in pine stands sized between 0.17 km^2 and 24.14 km^2. More falcon nests were located in small pine stands less than 4 km^2 than in larger pine stands. However, there were more small pine stands than large pine stands available in the forest (Fig. 5.3), which must be accounted for when considering selection. Small stands less than 1 km^2 were used less than expected considering their high availability (Fig. 5.3). When allowing for the difference in availability of pine stand sizes, there was no difference between the number of stands of each size available and the number of each size used for nesting by New Zealand falcons (Kolmogorov two-sample test K=0.77, n.s.) (Fig. 5.4), indicating that no particular sized pine stand was being selected.

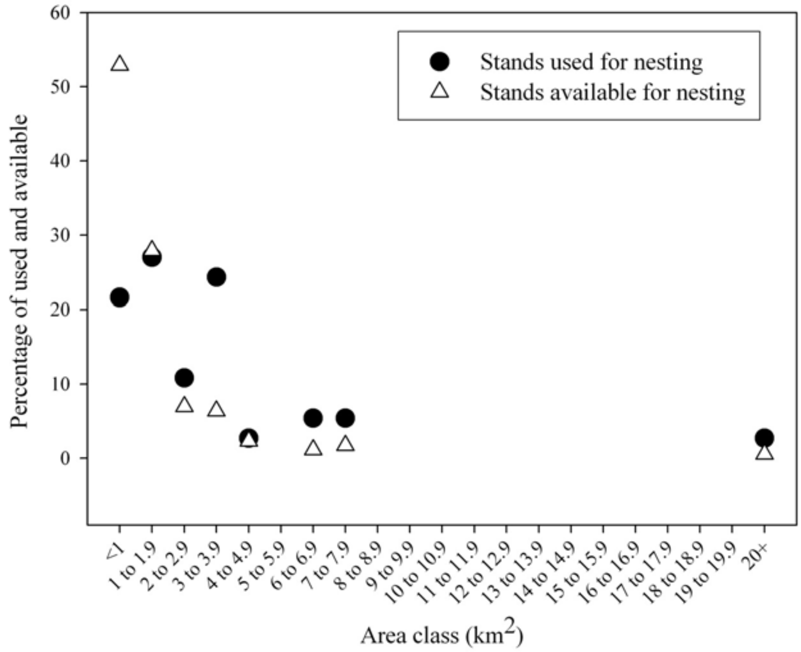

Figure 5.3. The percentage of nests located in each stand area class in 2005 and the percentage availability of stands less than four years old in each area class in 2005.

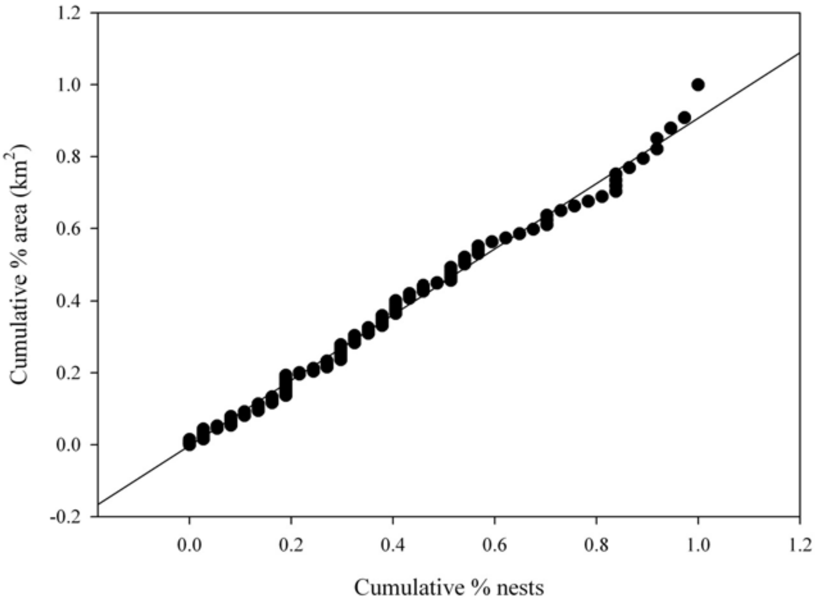

Figure 5.4. Plot showing cumulative percentage nests against cumulative percentage area (km^2) of all stands in Kaingaroa Forest (2005/2006 breeding season only). Where a stands is defined as a discrete area of less than four years old.

5.4.4 Habitat and forestry management

Despite the relatively low variation in many habitat and forestry management variables between nest and non-nest sites, discriminant analysis revealed several variables that explain differences between nest and non-nest sites (see Appendix 1). Nest sites had a lower pine height surrounding them, had more cover over the scrape, had taller pines at the stand edge nearest the nest (where a stand edge is the border between two pine stands differing in height by 4 m or more), and were significantly closer to stand edges than non-nests. Further, compared to non-nest sites the nest site home ranges had a larger area of pines aged 20 years old or more and a significantly smaller area of pines between 4 and 9 years old. Nest sites had a mean pine height of 1 m, the mean cover over the scrape was 65 percent (ranging from no cover to 100% cover), and the mean heights of the pines at the nearest stand edge were 20 m (see Appendix 1). Over 60 percent of nests were located 100 m or less from the nearest stand edge, and over 90 percent were located 200 m away or less (Fig. 5.5). The type of cover over nest scrapes varied from those over non-nest scrapes (χ^2 =43, d.f. 8, *P*<0.0001), (see Appendix 2). The most common cover types over nest scrapes were pine logs and tree fern trunks (*Dicksonia* sp. and *Cyathea* sp.), but included thin plants of various species, tree fern fronds, pine stumps, pine branches and in one case a small bluff.

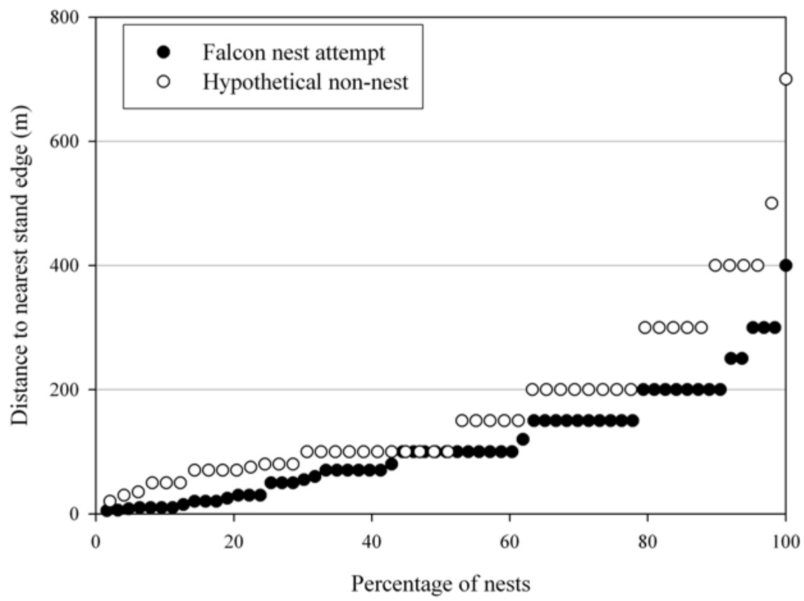

Figure 5.5. The distance to the nearest stand edge (a border of trees differing in height by at least 4 m) of the nests located in the 2004 and 2005 breeding seasons.

Pest control was carried out over most of Kaingaroa Forest during or before the study period. The most common control method employed was poisoning of plantation pests using 1080 poison (sodium monofluoroacetate). No significant difference was recorded between nest and non-nest sites in the time since 1080 was applied (*P*=0.29) (see Appendix 1). Nest sites and non-nest sites did differ significantly in the type of bait most commonly applied and the method of application. However, this difference was largely a result of including the northern part of Kaingaroa Forest in the sample of non-nest sites. No falcon nests were located in the north and pest control was applied differently there. In fact, the north of Kaingaroa Forest differed from the south in several of the recorded variables, including pest control application method, bait type, soil, relief and rotation number (see Appendices 1 & 2). All of these variables are therefore confounded with location. Non-breeding pairs were recorded in the north of Kaingaroa Forest later in the study, indicating that falcons are likely to breed there in the future. We suggest therefore, that none of these variables are affecting falcon nest site choice, and the significant results are a result of confounding variables related to location.

For the other management variables measured, we found no significant difference between nest and non-nest sites (see Appendix 1), including herbicide type (desiccant and release sprays), fertilizer type and time since these were applied before the breeding season.

5.4.5 Breeding dispersal

There were 174 New Zealand falcons colour banded in Kaingaroa Forest during this study, and 28 previously banded by Wingspan Birds of Prey Trust. This included 28 adult males, 27 adult females, 73 fledgling males and 74 fledgling females. During the study, 63 banding recoveries were made, including 19 males and 44 females.

The mean distance moved by individuals between subsequent nest attempts was 0.91 km (n=50), ranging from zero to 4.24 km. Only two pairs remained to nest in the same nest scrape the following breeding season. One pair was recorded laying in the same scrape for three subsequent breeding seasons.

Table 5.2. Breeding dispersal of pairs between pine stand age classes between subsequent breeding seasons 2003 to 2005.

	Stand age class movement (years)	%
Moved to another stand of the same Age	Zero to zero	19
	One to one	6
	Two to two	0
	Three to three	0
	TOTAL	**25**
Moved into a younger stand	One to zero	8
	Two to zero	6
	Three to zero	2
	Two to one	2
	Three to one	0
	Three to two	0
	TOTAL	**19**
Remained in same stand in subsequent seasons	Zero to one	25
	One to two	23
	Two to three	6
	TOTAL	**54**
Moved to an older stand	Zero to two	0
	Zero to three	0
	One to three	2
	TOTAL	**2**

Fifty four percent of pairs nested in the same pine stand the following year. Forty four percent moved to a younger stand or another of the same age (Table 5.2). Only one falcon pair was recorded moving into an older stand between breeding seasons. Of those that moved into younger stands, 35 percent moved into stands that had not been planted or were only just planted the previous winter. Of those pairs that remained within the same compartment between breeding seasons, 25 percent remained to breed in one year old pines, 23 percent remained to breed in two year old pines, but only six percent remained to breed in stands of three year old pines.

Eighty percent of pairs remained together to attempt to breed in subsequent breeding seasons. In 12 percent of nest attempts the male of the pair changed between breeding seasons and in eight percent the female changed. In all but one case, the location of the individual that left the pairing was unknown. In this one case both individuals of the pair were found breeding with new partners. In no cases were both individuals in a territory replaced by a completely new pair the following breeding season.

5.5 Discussion

5.5.1 Breeding densities

Our results indicate that pine plantations can hold greater densities of New Zealand falcon than other habitats. Mean distances between nests of the eastern form of the falcon, located in the open hill country of the South Island, range from 3.8 to 13.7 km with the closest nests being 1.5 km apart. Nesting densities of the bush form of the falcon are little known. Anecdotal reports however, suggest that in ideal conditions, mean distances between bush falcon nests in indigenous forests can be as low as 4.3 km apart (Guthrie-Smith 1927) and as close as 3.2 km apart (Fox 1977). Nevertheless, bush falcon densities in indigenous forests are thought to be far lower than this suggests (Fox 1977). In comparison, we recorded a smaller mean distance of 3.3 km between nests with the closest nests being less than 1 km apart.

We suggest that the high densities of New Zealand falcon in Kaingaroa pine plantation are primarily the result of high prey abundance (Clout and Gaze 1984) and availability (Chapter 3). Prey abundance is promoted by the highly heterogeneous landscape of different pine stand ages. Prey availability is high as a result of the abundant edge habitat, created by clear felling relatively small discrete blocks of forest. This provides ideal hunting conditions for falcon (Chapter 4).

Historically, New Zealand falcons have been observed in pine plantations (Buddle 1940, Johnson 1940, Ryder 1948, Weeks 1948, Gibb 1961, Edgar 1963, Jackson 1971, Stewart and Hyde 2004). Only Ryder (1948), however, reports falcons nesting prior to 1994. We therefore suggest that high densities of falcons are a relatively recent phenomenon in Kaingaroa Forest. The New Zealand falcon population in Kaingaroa Forest appears to be increasing. Considering the large amount of suitable breeding habitat remaining in Kaingaroa Forest, further increase seems likely. How much they may increase is likely to be related to clear fell size, the levels of local heterogeneity of stand ages and continued prey availability. Although falcon pairs did not select for small clear fell size, large areas of similar aged pine trees are unlikely to hold high densities of falcons because they have little edge habitat. We are unable to define an optimal stand or clear fell size, but suggest that maintaining high local heterogeneity of stand ages over the whole plantation is crucial for high densities of New Zealand falcon to exist in pine plantations.

5.5.2 Nest site location

Optimal foraging theory predicts that individuals should nest close to their food source (Pyke et al. 1977) and this may account for nest sites being located along the borders between young and mature pine stands. Male and female hunting preferences differ due to the differences in body size (Fox 1977), yet both are highly suited to this environment. Being more manoeuvrable, the smaller males specialise in catching small, agile prey (Fox 1977) that are most abundant within and along the edges of mature pine stands (Chapter 2). In contrast, the larger females, are better at tackling larger, more aggressive prey items such as hares and pheasants (Fox 1977, Hyde and Seaton 2007), which frequent young open stands (Gibb 1961, Jackson 1971). Locating nest sites along the borders between young and mature pine stands therefore places both sexes in close proximity to ideal hunting conditions. Perhaps most importantly, this allows females to take advantage of any hunting opportunities that may arise while still being able to brood and defend the nest.

While providing an abundance of prey and optimal hunting opportunities, the edges of mature stands may also aid in nest defence by providing a vantage point from which to observe the approach of potential predators. Additionally, stand edges may act as shelter from bad weather, although the position of older stands relative to nest sites and the prevailing weather does not seem to indicate this.

Nesting opportunities in plantation forests are limited to the ground because plantation trees lack the epiphytes, tree cavities and snags found in indigenous podocarp forests (Barea et al. 1997, Lawrence 2002, Stewart and Hyde 2004). Kaingaroa Forest also lacks suitable cliff nesting sites, which are used in other habitats (Fox 1977). Vegetation cover increases with pine stand age as plants colonise the bare ground between the pine trees (Allen et al. 1995). This reduces the availability of ground nesting space, making older stands unsuitable for nesting. Pine stands of one year old or less have very little vegetation cover after desiccant spray operations (Maclaren 1996) and were preferentially selected for nesting over those only a year or two older. The increased vegetation cover in these slightly older stands could explain this preference. Hunting conditions may be more difficult with increased vegetation as prey are more able to seek cover (Suhonen et al. 1994) and nests may be more prone to predation as increased vegetation provides cover for potential predators to approach without risk of being preyed upon themselves.

5.5.3 Forestry management

Forestry operations that leave pine slash are more favourable to New Zealand falcons because they provide suitable cover for nesting. This pine slash may provide not only cover for nests but, more importantly may increase prey abundance by providing more foraging opportunities and food for falcon prey (Freedman et al. 1996). Although there was no opportunity to test this, alternative land preparation practices such as burning off or removing pine slash, may make sites less suitable for falcon nesting. Burning or removing pine slash would remove potential nest cover, may reduce prey abundance (Hartley 2002), and the ash left after burning may not provide a suitable substrate for falcon nests. This could partially explain why New Zealand falcons were not recorded breeding in pine forests historically, as previously it was common practice to burn pine slash before tree planting (Roberts 1994).

The recent colonisation of pine forests by New Zealand falcons may also be linked to the large-scale use of 1080 poison bait for plantation pest control. 1080 baits have only been applied aerially over large areas since 1994 (Thomas and Taylor 2002). Pest control, as well as controlling plantation pests, is effective in controlling several introduced predators (Alterio 2000) that negatively impact upon falcon survival (Chapter 6). Control of these predators may be more beneficial to falcons inhabiting pine forests than in more traditional habitats where they nest off the ground and are less susceptible to predation (Fox 1977, Lawrence and Gay 1991, Barea 1995). This may explain the preferential selection of tree nest sites where indigenous forest bordered pine forest, but may also be linked to conservatism in nest site choice (Newton 1979). The high density of falcons in Kaingaroa Forest suggests that the application of 1080 poison bait for pest control is not detrimental to falcon survival and is more likely to be beneficial to them by reducing introduced predator numbers and increasing prey abundance (Powlesland et al. 1999). However, 1080 poison is only partially successful in controlling potential predators such as mustalids and wild cats (Gillies and Pierce 1999). Control programs that are more specifically targeted at falcon predators, rather than just plantation pests, should benefit New Zealand falcon even more. Nevertheless, caution should be maintained when using other forms of poison, especially those that are known to be bioaccumulative (Stephenson et al. 1999).

5.5.4 Breeding dispersal

Like other species of raptor New Zealand falcons showed strong pair bonds between subsequent breeding seasons (Newton 1979). Remaining with the same mate and territory may ensure fitness benefits including territory defence and advantages associated with increased familiarity with a home range (Warkentin et al. 1991). For falcons in pine plantations, this may include assessing the advantages of freshly created pine stands over other potential nest sites within a home range. In pine plantations, falcon breeding dispersal was restricted to the mean adult home range (9.23 km^2) (Chapter 4), they preferred nesting in very young pine stands, and they tended to remain within the same stand or move to a younger stand in subsequent breeding seasons. Thus, it seems likely that if a younger stand is created between breeding seasons, falcon pairs will move to breed in this stand. If not, they are more likely to breed in the same stand for another season.

5.6 Management recommendations

In summary, clear fell harvesting that creates a mosaic of stand ages across a plantation is beneficial to New Zealand falcon populations because it provides both suitable nest sites and an abundance of available prey. In contrast, pine plantations that are made up entirely of similar aged trees are unlikely to support breeding populations of falcons, as suitable aged stands for nesting are not always available and edge habitat is minimal.

There are three factors that forestry managers can influence to support New Zealand falcon populations. Firstly, by maximising the temporal and spatial availability of stands less than four years old bordering stands more than 20 years old by maintaining a high local heterogeneity of stand ages throughout a plantation. Secondly, by leaving pine slash after harvesting operations to provide nesting cover and foraging opportunities for both falcons and their prey species. Finally, by employing pest control techniques that specifically target the predators of New Zealand falcons.

5.7 Acknowledgements

This research was made possible by funding from Kaingaroa Timberlands, Timberlands Limited, Carter Holt Harvey, Hancock Forest Management Ltd., New Zealand Forest Managers and the Tertiary Education Commission in the form of an Enterprise Scholarship. Richard Seaton acknowledges the additional support of a Morley Nelson Fellowship from the Conservation Research Foundation and a Valder grant from the Waikato branch of the Royal Forest and Bird Protection Society. We thank volunteers Mathew Clement, Shane McPherson and David Brill for their hard work in the field. We are also grateful for the contributions of the New Zealand Department of Conservation and Massey University, and for advice and guidance from Wingspan Birds of Prey Trust and the Raptor Association of New Zealand.

5.8 Appendices

5.8.1 Appendix 1.

Mean, minimum and maximum values of variables put into the stepwise discriminant analysis and their associated univariate significance values.

	Nest			Non-nest					Nest			Non-nest			
Variables	Mean	Min	Max	Mean	Min	Max	P	Variables	Mean	Min	Max	Mean	Min	Max	P
Area of pines less than four years old within 50m of the nest (m^2)	92	30	100	95	52	100	0.177	Height of nest up slope (m)	11	0	60	1	0	60	0.721
Percentage of the ground covered in dead wood/ slash	31	5	70	23	5	50	0.010	Percentage height of nest up slope	44	0	100	49	0	100	0.545
Size class of dead wood/ slash	4	1	6	4	1	6	0.771	Angle of slope (degrees)	17	0	45	15	0	40	0.482
Percentage of bare ground within 50m of the nest	30	0	80	31	1	60	0.929	Distance to nearest perch (m)	4	0	5	3	0	15	0.324
Percentage of the ground covered in vegetation (non pine) within 50m of the nest	33	1	95	44	0	95	0.039	Height of nearest perch (m)	3	0.3	20	3	0.3	50	0.663
Mean height of vegetation (non pine) within 50m (m)	0.5	0.20	1	0.7	0.20	1.5	0.101	**Distance to the nearest edge (m)**	**113**	**5**	**400**	**175**	**20**	**700**	**0.005**
Percentage cover of dead vegetation within 50m	7	0	70	6	0	35	0.319	Class of the vegetation at the nearest edge	4	0	5	4	0	5	0.673
Height of pines in the youngest stand by the nest (m)	**1**	**0**	**5**	**2**	**0**	**5**	**0.009**	Height of the associated vegetation (non pine) at the nearest edge (m)	1.8	0	4	2	0	4	0.794
Class of vegetation (non pine) type	1	1	4	1	1	5	0.854	**Height of the pines at the nearest edge (m)**	**20**	**0.2**	**30**	**13**	**0**	**30**	**0.0001**
Percentage road within 50m	1	0	15	1	0	13	0.918	Distance to the edge at 90 degrees to the nearest edge (m)	721	70	3000	655	100	3000	0.537
Percentage skid within 50m	1	0	19	3	0	24	0.074	Class of the vegetation at 90 degrees to the nearest edge	3	1	5	4	1	5	0.030
Area of continuous pines less than four years old surrounding the nest (Km^2)	3	0.18	24	3	0.08	16	0.486	Height of the associated (non pine) vegetation at 90 degrees to the nearest edge (m)	1.3	0	7	2	0.3	20	0.046
Area of pine less than 4 years old within 1.72km of nest (Km^2)	3	0.53	7	3	0.78	7	0.811	Height of the pines at 90 degrees to the nearest edge (m)	14	0.4	30	12	0	30	0.146
Area of pine between 4 and 9 years old within 1.72km of nest (Km^2)	**2**	**0**	**4**	**3**	**0**	**7**	**0.006**	Distance to the edge at 180 degrees to the nearest edge (m)	962	200	5000	745	150	1900	0.097
Area of pine between 10 and 19 years old within 1.72km of nest (Km^2)	2	0	6	2	0	6	0.635	Class of vegetation at 180 degrees to the nearest edge	3	1	5	4	0	5	0.026
Area of pine more than 20 years old within 1.72km of nest (Km^2)	**2**	**0**	**5**	**1**	**0**	**6**	**0.001**	Height of the vegetation at 180 degrees to the nearest edge (m)	1.28	0.2	10	3	0	20	0.016
Time since the last pest control application (months)	15	0	50	13	0	39	0.294	Height of the pines at 180 degrees to the nearest edge (m)	13	0	30	12	0	30	0.406
The time since line raking (mechanical preparation) occurred (months)	2	1	2	3	1	2	0.306	Distance to edge at 270 degrees from the nearest edge (m)	786	20	3200	789	100	2800	0.978
Time since fertilizer was applied (months)	3	0	58	0.02	0	1	0.056	Class of the vegetation at 270 degrees from the nearest edge	3	1	6	3	0	5	0.162
Time since release spray was applied (months)	7	0	35	8	0	24	0.364	Height of the vegetation at 270 degrees from the nearest edge (m)	2	0.3	12	2	0	30	0.150
Time since desiccant spray applied (months)	13	0	65	17	0	44	0.253	Height of the pines at 270 degrees from the nearest edge (m)	14	0	30	12	0	30	0.563
Time since Dothystroma spray applied (months)	0.41	0	13	0.51	0	12	0.784	Mean height of the vegetation less than one metre from the nest scrape (m)	0.3	0	1	0.7	0	10	0.052
Rotation number	**2.83**	**2**	**3**	**2.51**	**2**	**3**	**0.0001**	Height of nest up slope (m)	11	0	60	1	0	60	0.721
Percentage cover over scrape	**66**	**0**	**100**	**19**	**0**	**100**	**0.0001**								

5.8.2 Appendix 2.

Results of Chi-square tests of differences between nest and non-nest sites on the categorical variables omitted from the discriminant analysis.

Variable	P	Variable	P
Relief class	**0.006**	**Class of the main cover over the scrape**	**<0.0001**
Type of fertilizer applied	0.05	Nest aspect	0.37
Release spray type	0.01	Perch type	0.27
Desiccant spray type	0.11	Bearing to the nearest edge	0.27
Scrape substrate	**<0.0001**		

CHAPTER 6.

DO PINE PLANTATION MANAGEMENT PRACTICES AFFECT THE BREEDING SUCCESS OF NEW ZEALAND FALCON?

Four to seven day old New Zealand falcon chicks in the nest scrape. D. Brill 2005.

"During the breeding season it is more than usually bold and fearless, assailing with fury all intruders upon its nest or young."

W.L. Buller, 1888

Chapter reference:
Seaton, R., E. Minot, J. D., Holland and B. P. Springett. 2007. Do pine plantation management practices affect the breeding success of New Zealand falcon (*Falco novaeseelandiae*)? Submitted for publication.

6.1 Abstract

Productivity data on New Zealand falcon (*Falco novaeseelandiae*) were collected from 87 nest sites in Kaingaroa pine plantation during three breeding seasons, 2003 to 2006. A mean of 1.81 chicks were successfully fledged per nest, with 71 percent of nests successfully raising young. Breeding occurred between August and March, with most eggs laid before December and most chicks fledged by February. Fifteen percent of nests were depredated, nine percent were infertile and four percent failed due to forestry operations disturbing or destroying nests. No negative impact of 1080 bait, or of desiccant or release spray application was recorded on falcon productivity. Considering that the greatest cause of falcon nest failure was predation by introduced predators, and the effects of pest control on prey density, we recommend 1080 pest control be continued. Although impacts from forestry operations were low and restricted to land preparation and harvesting operations, there is potential for adverse impacts to increase. We outline a management framework for mechanical forestry operations to follow to ensure negative impacts are avoided.

6.2 Introduction

Breeding success is commonly used as an indicator of the health of a population. As such, productivity can be useful for assessing the effects of land management practices. The New Zealand falcon (*Falco novaeseelandiae*) is a threatened species (Hitchmough et al. 2007) that has recently been discovered breeding in exotic pine plantations, outside of its traditional indigenous habitat, (Stewart and Hyde 2004). Some commercial forestry management practices, including mechanical operations and the application of various chemicals, have the potential to negatively impact on falcon productivity (Avery and Leslie 1990) and hence long-term population viability. Mechanical operations such as land preparation (windrowing and mounding) and harvesting pose a physical threat to individual falcon nests, and may disturb incubation and brooding behaviour. Herbicides and poisons used for mammal pest control, may have a negative impact on the productivity of falcon, either through direct toxicity or by more indirect, secondary effects (Spurr 1979, Avery and Leslie 1990, Eisler 1995, Blus and Henny 1997).

The contribution of pine plantations to New Zealand's native biodiversity are increasingly well documented with a wide diversity of indigenous flora and fauna existing in plantation forests (Jackson 1971, Clout and Gaze 1984, Ogden et al. 1997, Brockerhoff et al. 2003, Maunder et al. 2005). Elsewhere, some raptor species have been found in similar, or even higher, densities in plantation forests than within more traditional habitats (Rosenfield et al. 2000, Sergio and Bogliani 2000). Despite this, the forestry industry is still generally perceived as being environmentally destructive (Maclaren 1996). Consequently, the forestry industry stands to gain by implementing environmentally sustainable forestry management practices and by highlighting the positive effects of forestry on biodiversity.

There are three forms of the New Zealand falcon, the bush, eastern, and southern falcon (Fox 1977). The bush falcon is the only form of the New Zealand falcon found in the North Island of New Zealand, and is ecologically distinct from the eastern falcon (Fox 1977). The bush falcon is a forest falcon and has been the subject of relatively little research (Fox 1977, Lawrence and Gay 1991, Barea et al. 1997, Stewart and Hyde 2004).

Since the human colonisation of New Zealand, indigenous forest cover has been greatly reduced from its former extent (McGlone 1989). Artificially created forests cover 1.8 million hectares in New Zealand today (Statistics New Zealand 2004). Plantation forests therefore offer important potential habitat for the New Zealand falcon. These, plantation forests provide a unique opportunity to assess the breeding success of the bush form of the species. Understanding how plantation forests can be managed to support New Zealand falcon populations is therefore beneficial to both the forestry industry and the conservation of the species.

The aim of this study was to describe the productivity of the New Zealand falcon within a plantation forest, to investigate the impact of forestry practices on falcon productivity, and suggest how negative impacts may be mitigated.

6.3 Method

Surveys for New Zealand falcon nest sites were undertaken over three breeding seasons, September to March 2003-2004 and 2005-2006. Individual nests were located and productivity recorded. Forestry management data relating to each nest compartment were collated from forestry databases and using field observations.

6.3.1 Nest site surveys

Stands aged less than four years old were identified as suitable nesting habitat by looking at previous records of nesting falcon in pine forests recorded by Wingspan Birds of Prey Trust (Stewart and Hyde 2002, 2004), the Raptor Association of New Zealand, the Department of Conservation New Zealand and several forestry companies (Addison et al. 2006). Nest sites have been located in stands older than four years old (Addison et al. 2006), including during this study, but by far the greatest number of nests have been located within or on the borders of stands less than four years old.

In pine plantations, New Zealand falcons nest on the ground (Stewart and Hyde 2004). Nest sites were located by first identifying all pine stands less than four years old in Kaingaroa Forest each breeding season. These stands were surveyed on foot in order to listen and watch for characteristic falcon breeding behaviour. By using this two-step process, we aimed to survey and describe the majority of the breeding falcon population in Kaingaroa Forest. Forestry workers also provided sightings of falcon throughout the study.

6.3.2 Productivity

Nest site visits were timed so that lay, hatch and fledging dates could be accurately assessed, and to investigate mortality. A pair was considered to have initiated a nest attempt once an egg had been laid. In order to limit disturbance, the time spent at each nest site was kept to the minimum necessary to assess productivity. If a nest was located late during a breeding attempt, laying, hatching and fledging dates were back-calculated using a mean incubation time of 30 days and a mean fledgling time of 33 days for males and 35 days for females (Fox 1977). Back calculations of the number of eggs laid and chicks hatched were not included in analyses. The relationships between the time of the breeding season, the year, and productivity data was investigated using one-way ANOVAs.

6.3.3 Forestry management

Forestry management data were collated from forestry databases. Forestry management practices comprised extensive mechanical operations, mammal pest control and herbicide operations. Mechanical operations included land preparation for planting (windrowing and mounding) and harvesting. In Kaingaroa Forest the windrows (of pine slash) are 5 m apart, between which mounds are formed for trees to be planted in. These operations can be carried out at the same time using a mechanical excavator. An alternative method is for a bulldozer to plough the ground, moving slash aside and creating space for planting between the slash piles. The distance of mechanical operations from the nest at different stages of the breeding cycle was recorded in order to determine the effects of forestry operations on falcon breeding success.

Data describing pest control, herbicide (release and desiccant sprays) use, tree age and the number of rotations of planting and harvesting a nest stand had been through, were also collected.

The relationship between forestry management operations and productivity was investigated using a general linear model. Bonferroni adjustments were made to account for multiple testing of productivity variables. One-way ANOVAs were used to analyse categorical data not included in the general linear model.

6.4 Results

6.4.1 Productivity

During three breeding seasons, 2003-2004 to 2005-2006, we recorded 87 breeding attempts (Table 6.1). Eggs were laid from 20 August to 4 January. Ninety six percent of pairs started breeding between September and December. Outside these months, eggs were only recorded laid twice in August and once in January.

Table 6.1. The number of nest attempts beginning each month.

Month eggs laid	2003/ 2004	2004/2005	2005/2006	Overall number of nest attempts
August	0	0	2	2
September	4	6	6	16
October	6	11	13	30
November	7	6	14	27
December	4	6	1	11
January	0	1	0	1
Total	21	30	36	87

No significant difference in clutch size was recorded between months ($F_{5,82}$=0.86, P=0.52, r^2=0.05). The percentage of eggs surviving to hatch decreased significantly with time ($F_{5,82}$=3.85, P=0.004, r^2=0.20), as did the number successfully fledged per clutch ($F_{5,82}$=2.76, P=0.02, r^2=0.15). Overall, the earlier that eggs were laid in the breeding season, the more likely they were to survive to successfully fledge the nest ($F_{5,82}$=2.64, P=0.03, r^2=0.15) (Fig 2).

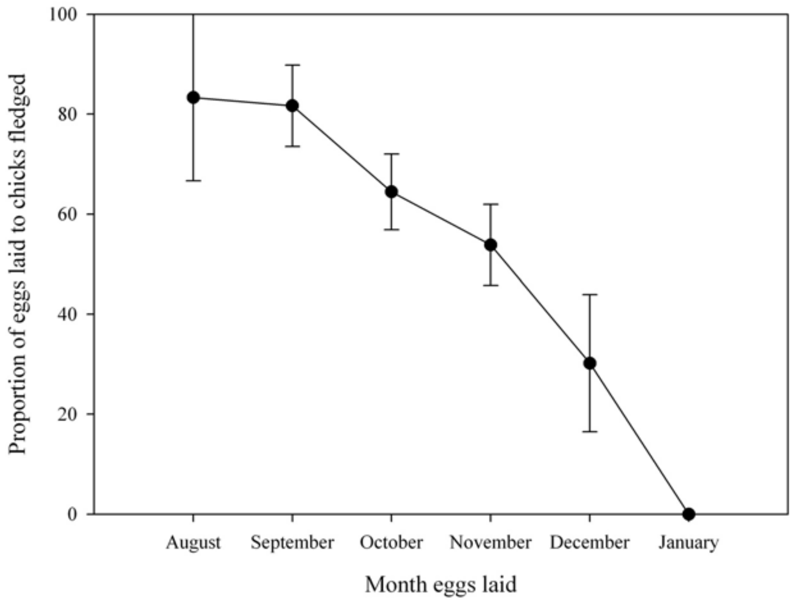

Figure 6.1. Proportion of eggs laid to chicks successfully fledged by the month eggs were laid, illustrating the decline in the success of nests with time of breeding season (*P*=0.03).

Although the mean number fledged was higher in 2003 than in 2004 and 2005 (Table 6.2), no significant difference was recorded between years in any productivity variables. The overall mean number of eggs laid per nest was 2.83, hatched 1.95 and fledged 1.81 (range 1 to 4). Sex ratios were approximately the same in 2003 and 2004, but almost twice as many females fledged than males in 2005 (Table 6.2). Overall, 2 percent of young fledged in October, 13 percent in November, 44 percent in December, 31 percent in January and 11 percent in February.

Table 6.2. Mean productivity values per breeding season 2003 to 2005.

	Breeding season		
Mean productivity values	2003/ 2004	2004/ 2005	2005/ 2006
Number of eggs laid	2.70	2.86	2.94
Number of eggs hatched	2.20	1.69	1.97
Number of chicks successfully fledged	2.15	1.59	1.64
Number of males fledged	1.05	0.86	0.61
Number of females fledged	1.00	0.72	1.06

Fifteen percent of nests failed in 2003, 39 percent in 2004 and 33 percent in 2005. Three pairs recycled, of which only one was successful. The causes of these failures were mostly predation and infertility (Table 6.3). Over the three years, nine percent of nests were infertile and fifteen percent predated. The causes of predation were mostly hard to determine, but included suspected mustelid (*Mustela erminea* or *Mustela putorius*), brush-tailed possum (*Trichosurus vulpecula*), wild pig (*Sus scrofa*) and Australian magpie (*Gymnorhina tibicen*) depredation. Evidence for nest predation was observed at all stages of the breeding cycle before fledging. No predation was recorded post-fledging, but this was most likely due to a lack of observation as it is generally accepted that fledglings are highly vulnerable to predation (Guthrie-Smith 1927, Fox 1977, Lawrence and Gay 1991, Lawrence 2002, Gaze and Hutzler 2004).

Table 6.3. Summary of nest failures, the suspected reason for failure and the total number of nests failed. *Scrape collapsed through a log pile. **Died hatching.

	Breeding season		
Reason for failure	2003-2004	2004-2005	2005-2006
Depredated	0	7	6
Infertile	3	3	2
Forestry	0	1	3
Other	0	1*	1**
Total failed	3	12	12

6.4.2 Forestry management

The number of New Zealand falcon nests located increased over the three breeding seasons. At the same time, the proportion of nest compartments with forestry operations increased from five percent in 2003, to seven percent in 2004, and 25 percent in 2005. Nevertheless, only four nest failures could be directly attributed to forestry operations. Three of these failures were due to land preparation and one due to a harvesting operation.

All chicks survived when land preparation operations remained more than 200 m from the nest scrape until at least the time that the chicks were able to thermo-regulate themselves (after 14 days old). After chicks were 14 days old, land preparation operations continued up to 5 m from the nest (leaving a 5 m radius of undisturbed ground around each nest) without negative effects.

In contrast, when land preparation operations were within 100 m of a nest scrape and nests were in the incubation or pre-laying phase, three clutches failed to hatch and only one nest attempt successfully fledged young. These nests were located whilst land preparation operations were being carried out close to the nest and the adults would have spent a large proportion of time in nest defence and not incubating. This illustrates that, although some pairs can be successful after disturbance from land preparation operations in these early stages, failure of the nest attempt is far more likely than when disturbance occurs later in the breeding attempt. To our knowledge, no nests were destroyed due to land preparation operations crushing the nests. This was probably largely due to the willingness of forestry managers to promote falcon awareness, and to the vigilance of machine operators. Also, the high intensity monitoring taking place during this study allowed most nests to be marked before an operation began. In other commercial forests, disturbance and damage from mechanical operations may therefore be higher, especially considering the commonly held, but false belief, that New Zealand falcon in plantations forests nest in trees, not on the ground.

It is hard to assess the overall effects of harvesting because only two nests were affected by harvesting during this study and only one of these failed. Nevertheless, the distance and timing of the disturbance seems broadly consistent with those for land preparation. One nest was successful, while the harvesting operation crushed the other nest early in the breeding attempt. The failed nest was not located, but is presumed from the falcons' defensive behaviour, recorded by forestry staff, to have been in the mature tree line being felled. The successful nest was in the adjacent clear-fell compartment to that being felled.

Plantation pest control was carried out over most of Kaingaroa Forest during or before the study period. The most common pest control method employed was poisoning of plantation pests using 1080 (sodium monofluoroacetate) poison bait. This was the only control method used in the compartments where falcon nests were located. 1080 was either locally applied to a compartment from the ground, or was aerially applied over larger areas using a helicopter. Poison was applied in either cereal or carrot bait form. Some nest compartments had both aerial and ground control applied in both bait types in the same month. The time since pest control was applied in nest compartments ranged from one month to over three years. No significant effect of time since 1080 application, bait type or application method was recorded on any falcon productivity variables.

Various herbicides were used for desiccant spraying including Escort, Silmax, Glyphosate, Orion glyphosate, Mustang and Organosilcone. Release sprays applied included Terbuthylazine, Release, Gardoprim, Velpar, Silmax, Tordon, Optimax, Galant and Versatil. The time since desiccant sprays were applied within a nest compartment varied from six to 65 months, and the time since release sprays were applied, one to 35 months. Desiccant sprays were applied aerially and compartment wide before tree planting. Release spraying involved localised spot spraying of young pine trees. No falcon productivity variables were significantly affected by the type or time since herbicide was applied. The age of the compartment in which a nest was located and the number of rotations a compartment had been through was also not significantly related to any productivity variables.

6.5 Discussion

6.5.1 Productivity

Productivity values for New Zealand bush falcon breeding in pine plantations (1.81 chicks successfully fledged per nest with 29 percent of nests being unsuccessful) were very similar to those previously recorded for the eastern form of the falcon in the open hill country of the South Island (mean number fledged 1.88, with 28 percent of nests being unsuccessful) (Fox 1977). Eastern falcons were recorded as laying eggs between 1 October and the 27 November (Fox 1977). The bush falcons we studied in Kaingaroa Forest had a much longer breeding season, with egg laying ranging from 20 August to 4 January. As with other raptor species elsewhere (Newton and Marquiss 1984, Nicoll 2004), we attribute these differences to variations in day length, temperature and rainfall between areas.

Fledging success in bird species varies with time and can be affected by several factors including weather (Newton and Marquiss 1984, Nicoll 2004), prey abundance (Janes 1985), habitat (Little et al. 1995), disturbance (Sergio and Bogliani 2000), age (Mearns and Newton 1988, Newton and Rothery 2002) and competition (Hakkarainen and Korpimaki 1996). We found that the earlier in the breeding season New Zealand falcons lay their eggs, the more likely they are to survive to fledge successfully. This may be related to prey abundance. For example, several raptor species apparently time chick rearing or fledging to coincide with the greatest abundance of fledgling prey (Newton 1986, Sodhi and Oliphant 1993), and this may also apply to New Zealand falcon (Fox 1977). Small bird abundance in Kaingaroa Forest increases from January to February (Chapter 2). This is particularly true for Chaffinches (*Fringilla coelebs*), the species most commonly preyed upon by falcons in Kaingaroa Forest (Chapter 3). Most falcon chicks fledge the nest in December and January. We suggest therefore, that New Zealand falcon pairs are timing the fledging-to-independence period of their young to coincide with the greatest abundance of prey and the pre-fledgling period with high nestling prey availability. These are the periods of greatest food demand (Kenward et al. 1999), and fledglings provide an easy prey source on which to feed chicks and enable fledglings to develop their hunting skills on relatively naïve fledgling prey. Laying eggs relatively early also allows the adults time to moult before winter, increasing their chances of survival through times of poor weather (Nilsson and Svensson 1996).

6.5.2 The effects of forestry management

Land preparation and harvesting operations were the only forestry practices to negatively impact the breeding success of New Zealand falcons. Our results illustrate that the stage at which a nest was disturbed combined with the distance of the operation from the nest, determine whether breeding success was negatively affected. We found that New Zealand falcons are more resilient to disturbance than many other species of raptor (Newton 1979, Toyne 1997, Sergio and Bogliani 2000), with no signs of egg or chick abandonment due to disturbance. Despite this resilience, we suggest that nest failure is largely due to disruptions during the incubation and brooding of the breeding cycle. Pairs that were disturbed before chicks reached 14 days of age had a greater chance of failure than those disturbed later. This may be due in part to the inability of chicks to thermo regulate before they reach 14 days old (Fox 1977, Stewart-Badger 1995). Disruption of adult hunting may also reduce provision rates to the chicks.

Other studies have suggested that the breeding success of New Zealand falcons may be limited by predation by introduced mammals (Fox 1977, Lawrence and Gay 1991, Barea 1995, Gaze and Hutzler 2004). Consistent with this, we showed that predation was the greatest cause of nest failure during this study. Control of these predators should have a positive effect on the productivity of falcons. 1080 poison baits are widely used for predator control in New Zealand (Alterio 2000) and have been found to be effective in reducing the densities of a variety of introduced mammalian predators (Gillies and Pierce 1999). We, however, recorded no direct adverse effect on falcon productivity from application of 1080 pest control, whatever the bait type or application method. We suggest that the lack of any observed effect of 1080 is due to the widespread and regular application of 1080 bait over Kaingaroa Forest. This did not allow us to test its effectiveness using proper control areas. Nevertheless, it is unlikely falcons would consume a lethal dose as they rarely feed on carrion (Fox 1977). Rather, they feed primarily upon small birds (Chapter 3) that feed very little on bait when it is sieved properly before application (Powlesland et al. 1999). Furthermore, 1080 poison is unlikely to bioaccumulate in the food chain (Eason 2002). Consequently, we recommend the continued use of 1080, because of its likely benefits in reducing predation pressures, and also because of the resulting general increase in prey abundance (Powlesland et al. 1999), which may offset any potential risks from the use of 1080. Reducing predator numbers further, by introducing programs that target potential predators as well as plantation pests, would be likely to benefit falcons even more. Other poisons, however, should be used with caution; particularly those with the potential to move up the food chain or accumulate in the environment. Further study should concentrate on pre- and post-operation monitoring of New Zealand falcon survival.

Most of the herbicides applied in Kaingaroa Forest have a low toxicity to bird species (Tomlin 1994) and as such are unlikely to directly harm falcons. Nonetheless, desiccant spraying has the potential to reduce the breeding success of falcons by removing vegetation cover over large areas and reducing the numbers of birds on which falcons prey (Slagsvold 1977, Santillio et al. 1989). In the end, we could detect no negative effect of herbicide on falcon productivity and therefore it seems that the herbicide sprays used in Kaingaroa Forest have no marked negative effect on breeding success.

6.5.3 Management guidelines

Based on the results of our study, we outline management frameworks to minimise that negative impacts on New Zealand falcon productivity resulting from land preparation (Fig. 6.2) and harvesting operations (Fig. 6.3) and at the same time create little disruption to forestry operations. In summary, falcons require a 200 m set back during land preparation until chicks are 14 days old. This set back can be reduced to 15 m after the chicks are 14 days old. During harvesting operations, a 200 m set back should be maintained early in the breeding cycle. Operations can continue with no negative effect after chicks reach 40 days old. These procedures are discussed in more detail in the appendix. If pre-operation monitoring can be established, mechanical operations can be planned so as to avoid compartments containing nest sites or can be timed so as not to reach the nest area until the appropriate time, avoiding the need for these procedures.

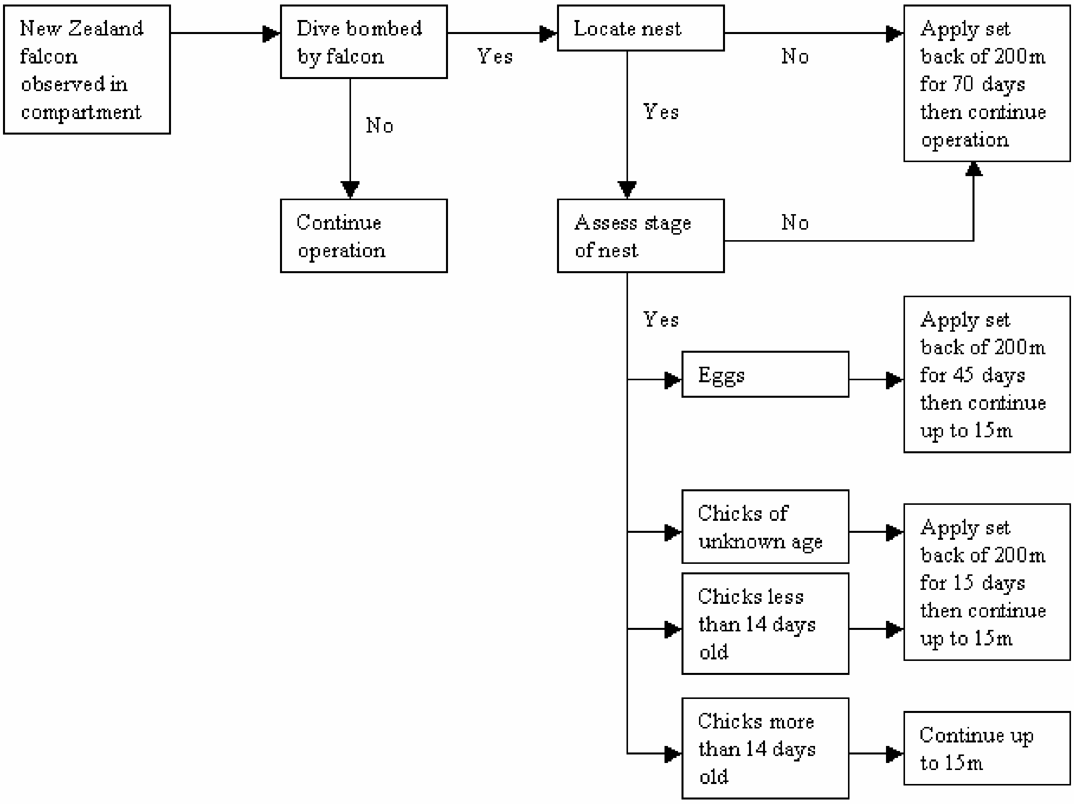

Figure 6.2. Flow diagram illustrating a stepwise management process for **land preparation** operations to follow to ensure there are no negative impacts of these operations on New Zealand falcon productivity. (See Appendix for detailed notes).

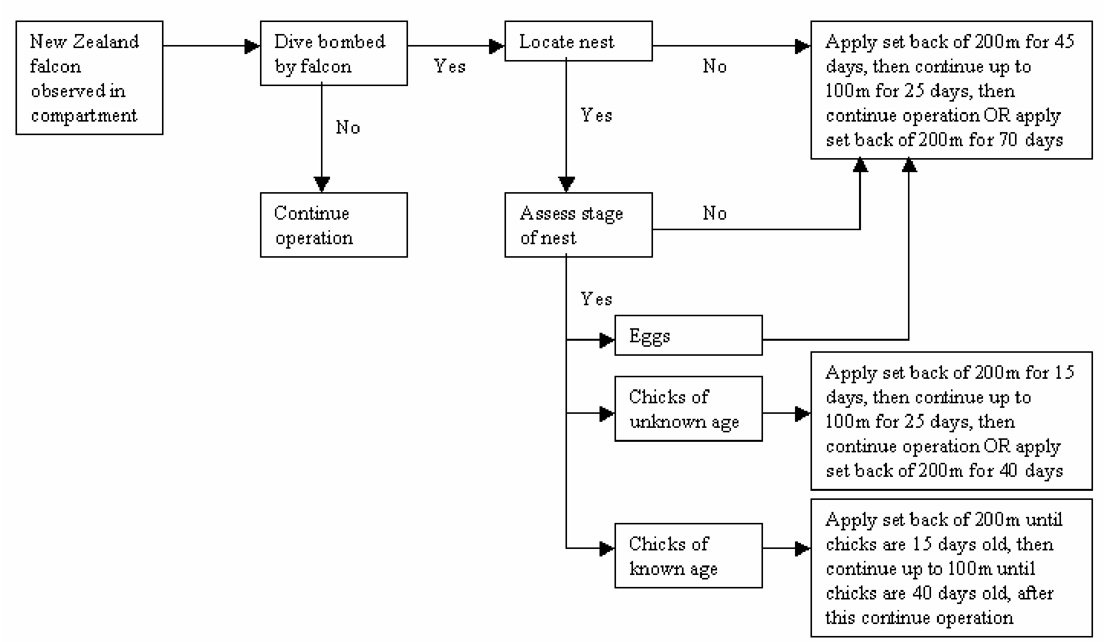

Figure 6.3. Flow diagram illustrating a stepwise management process for **harvesting operations** to follow to ensure there are no negative impacts of these operations on New Zealand falcon productivity. (See Appendix for detailed notes).

6.6 Conclusions

We conclude that the productivity of New Zealand falcons in pine forests is similar to those inhabiting other habitats in New Zealand. Predation has the greatest impact on New Zealand falcon breeding success. As a result we suggest that 1080 pest control should continue. Of the forestry management practices investigated, negative impacts were restricted to mechanical operations. We outline a management framework that if followed, will minimise these impacts and minimise disruption to forestry operations.

6.7 Acknowledgments

This research was made possible by funding from Kaingaroa Timberlands, Timberlands Limited, Carter Holt Harvey, Hancock Forest Management Ltd., New Zealand Forest Managers and the Tertiary Education Commission in the form of an Enterprise Scholarship. We thank volunteers Mathew Clement, Shane McPherson and David Brill for their hard work in the field. We are also grateful for the contributions of the Department of Conservation New Zealand and Massey University, and advice and guidance from Wingspan Birds of Prey Trust and the Raptor Association of New Zealand.

6.8 Appendix

Additional notes to Figures 3 and 4

Characteristic New Zealand falcon alarm calls are given when the nest is approached up to 400m away, and are the first sign that can alert machine operators to a nest site (Addison et al. 2006). On approaching a falcon nest, the adult pair will begin to dive bomb the person or machine approaching. This becomes more vigorous the closer the nest is approached and the more advanced the breeding attempt is, until falcons repeatedly strike the intruder. There is variation in behaviour between pairs, and a few pairs will make very little noise and dive bomb very little, but the intensity of aggressive calling and dive-bombing behaviour generally increases with the stage of the breeding cycle.

6.8.1 Land preparation

Our results indicated that if land preparation operations moved within 200 m of a nest scrape before chicks were 14 days old, breeding attempts had a greater chance of failure. Therefore, once nest sites are located, operations should be planned so as not to move within 200 m of the nest until chicks are at least 14 days old.

Once chicks were 14 days old or more, land preparation operations were able to move up to within 5 m of a nest with no immediate negative effect on chick survival. However, between 30 and 40 days old, chicks are also vulnerable. At this age they begin to roam away from the nest scrape on the ground and can be up to 10 m from the nest before they are able to fly. Chicks at this stage have the tendency to freeze or hide under log piles when threatened (pers. obs.), making them difficult to observe and prone to being driven over. We therefore recommend that a 15 m undisturbed radius around each nest scrape be enforced until chicks are 40 days old and have advanced their flying skills sufficiently to avoid machinery.

If compartments cannot be surveyed for falcon breeding activity before land preparation operations begin, we suggest that operators upon spotting or hearing defensive falcon behaviour withdraw at least 200 m. If bulldozer operations in particular are not pulled back immediately after dive-bombing occurs, the chances of the nest being driven over are high. Excavator operators will probably observe falcon defensive behaviour earlier than bulldozer operators, but if machine operators are not familiar with the falcons, or with the signs of their breeding, there is still a high risk of destroying nests. One of the most important factors in the whole process therefore, is that operators are well informed of how to identify New Zealand falcons and their breeding behaviour.

6.8.2 Harvesting operations

Our results also indicate that harvesting operations have the potential for the destruction and disturbance of New Zealand falcon nest sites. As with land preparation operations, if breeding behaviour is observed, harvesting operations should be moved back at least 200 m from the area until chicks are at least 14 days old. After this time, operations can continue up to within 100 m of the nest until chicks are fully fledged (40 days old) (Fox 1977). After which, operations can continue felling over the nest site. If the nest site cannot be located or the nest stage identified, then operations should stay out of the area, keeping more than 200 m away from the area in which they are dive-bombed for 45 days and 100 m away for a further 25 days.

CHAPTER 7.

NATAL DISPERSAL OF NEW ZEALAND FALCON IN PLANTATION FORESTS

Female New Zealand falcon just prior to fledging. D. Brill 2006.

Chapter reference:
Seaton, R., J. D. Holland, E. Minot, and B. P. Springett. 2007. Natal dispersal of New Zealand falcon in plantation forests. Accepted for publication by Notornis.

7.1 Abstract

Natal dispersal of the New Zealand falcon (*Falco novaeseelandiae*) was documented using relocations of radio-tagged and colour banded falcons in Kaingaroa pine plantation. The age at which fledglings commenced natal dispersal was highly variable. The earliest fledglings dispersed 42 days after fledging, whilst others did not disperse out of their natal territories, remaining there to breed. After 91 days, 87% of fledglings had begun dispersal out of their natal territory. The mean time for the onset of dispersal was 76 days. Males tended to disperse earlier than females, but no significant difference was recorded. Both radio telemetry and colour band recoveries indicated that a large proportion of fledglings dispersed out of the study area. Mean natal dispersal distance within Kaingaroa Forest was 9.6 km. No significant difference was observed in natal dispersal distances between the sexes, although males generally roamed further afield than females. During this study, several females were recorded successfully breeding during their first year, a year earlier than usual. Males did not attempt to breed until they were two years old. We conclude that the high emigration rates and favourable breeding conditions in pine plantations make these habitats highly likely to act as source populations for neighbouring areas where populations of the New Zealand falcon may be in decline.

7.2 Introduction

Natal dispersal is the movement of juveniles between their natal territory and their subsequent breeding territory (Greenwood 1980). For many non-migratory species natal dispersal is the furthest they will travel during their lifespan (Newton and Marquiss 1983, Wiens et al. 2006). Commonly, it is also a period during which high mortality occurs (Newton 1979). The causes for the onset of natal dispersal are varied and involve a complex variety of environmental and social factors (Clobert et al. 2001). Distances travelled during natal dispersal can vary widely between individuals, populations and landscapes (Wiens et al. 2006). Factors influencing the distance and timing of natal dispersal include parental aggression (Nilsson 1990, Lawrence and Gay 1991), prey density (Nilsson 1989, Kenward et al. 1993a), food provision (Davies 1978), brood size (Kenward et al. 1993b), weather (Wiens et al. 2006), population density (Newton and Marquiss 1983) and physical and behavioural development (Kenward et al. 1993a).

The New Zealand falcon (*Falco novaeseelandiae*) is classified as threatened by the New Zealand Department of Conservation (Hitchmough et al. 2007). Describing dispersal is important if we are to understand the dispersion of a species in the landscape and can influence how a species is managed to ensure its conservation. Yet, few studies have concentrated on dispersal of the New Zealand falcon (Fitzgerald 1965, Lawrence and Gay 1991, Barea 1995). Traditionally, New Zealand falcons breed in a range of habitat types, varying from rough pasture and tussock lands to beech and podocarp forests (Fox 1977). Recently, they have also been discovered breeding in exotic pine plantations (Stewart and Hyde 2004, Addison et al. 2006).

This study develops a clearer understanding of the distribution of the New Zealand falcon by documenting their natal dispersal in a pine plantation using radio-tagged and colour banded falcons.

7.3 Method

We documented the natal dispersal of New Zealand falcon fledglings by both tracking radio-tagged chicks from their nest sites and relocating colour banded fledglings in their eventual breeding territories.

Nest surveys were undertaken during three consecutive breeding seasons, September to March 2003 to 2006. Potential falcon nesting habitat was identified from previous records of nesting falcon from Wingspan Birds of Prey Trust, the Raptor Association of New Zealand, the New Zealand Department of Conservation and several forestry companies. From these records, compartments containing pine trees aged less than four years old were identified as the most suitable for nesting. Compartments were surveyed on foot to solicit defensive behaviour, and listen and watch for other characteristic breeding behaviour. Forestry workers were also encouraged to report sightings of falcons. All of the fledglings from nests located during the first two breeding seasons were colour banded in order to identify individuals in subsequent breeding seasons. Fledglings were either banded on the nest or trapped after 50 days (before this time fledglings were not interested in the traps) with a balchatri or dho gaza trap (Bloom 1987). In addition to the chicks we banded, Wingspan Birds of Prey Trust and the Raptor Association of New Zealand had banded 20 falcon chicks in Kaingaroa Forest since 1997.

Backpack harnesses or tail mounts (Kenward 2001) were used to attach 22 radio transmitters to 22 falcon fledglings so they could be tracked to their breeding grounds. During the first 91 days from fledgling, individuals were located on a weekly basis. Thereafter their position was plotted once a month until the following breeding season. During the early stages of dispersal fledgling, falcons were located by driving to suitable vantage points and recording observations and/or triangulations using a hand held yagi aerial and TR4 Telonics receiver. Subsequently, a car mounted omni directional aerial was used in conjunction with a hand held yagi to enable more efficient searching. At the start of the 2005 breeding season, fledglings that could not be located on the ground were followed up with an aerial search by flying 1 km transects over Kaingaroa Forest using a scanning receiver and two yagi aerials mounted to a Micro-light aircraft.

Natal dispersal was considered initiated once a fledgling had moved more than 1.7 km from their nest site. This placed them outside of the 9 km^2 mean adult male falcon home range recorded in Kaingaroa Forest (Chapter 4), effectively making them independent of their parents (Newton and Marquiss 1983). The difference in the initiation of natal dispersal between male and female falcons was assessed using a paired *t*-test.

Each year the colour bands of individual birds were noted in order to determine their age and the distance moved from their natal site. Natal sites and breeding territories were plotted in the GIS system, ArcMap 9.0, and the distance between them was measured in a straight line. The differences in natal dispersal distance and age of first breeding between males and females were assessed using Kolmogorov-Smirnov two sample tests. Pairs that did not attempt to breed were included in the analyses of natal dispersal distance if they were observed together within the same compartment all season.

7.4 Results

Eleven male and eleven female New Zealand falcon fledglings were fitted with radio transmitters and tracked for 91 days. Eighty-four breeding pairs were located in Kaingaroa Forest during the 2003 to 2005 breeding seasons. From these nests and those previously located by Wingspan Birds of Prey Trust and the Raptor Association of New Zealand, 112 fledglings were colour banded.

Falcon fledglings dispersed out of their natal home range an average of 76 days after fledging. The mean onset of natal dispersal differed between males (74 days) (Fig. 7.1) and females (77 days) (Fig. 7.2), but this was not significant (t=-0.96, d.f.8, P=0.18). However, the first males began natal dispersal 42 days after fledging (Fig. 7.1) and the first females 56 days after fledging (Fig. 7.2).

After 91 days 91% of males and 82% of females had dispersed out of the natal home range. Four females and nine males could not be located in Kaingaroa Forest after 91 days.

One female did not disperse out of the natal home range and remained to breed there the following breeding season. One male died 91 days after fledging (cause unknown), without dispersing.

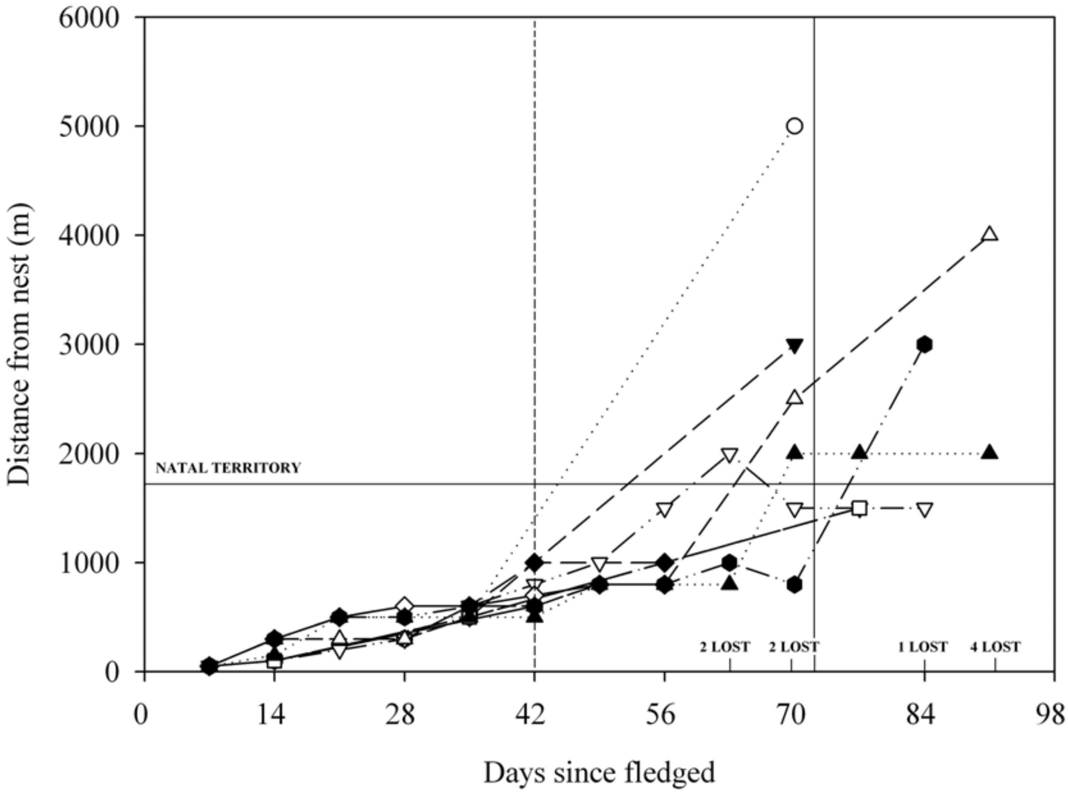

Figure 7.1. Weekly dispersal distances of **male** New Zealand falcons for the 91 day period after fledging (n=11). Dotted vertical line: initiation of dispersal out of the natal home range. Solid vertical line: mean timing of dispersal out of the natal home range. ‘Lost’ indicates that an individual could not be located after that time.

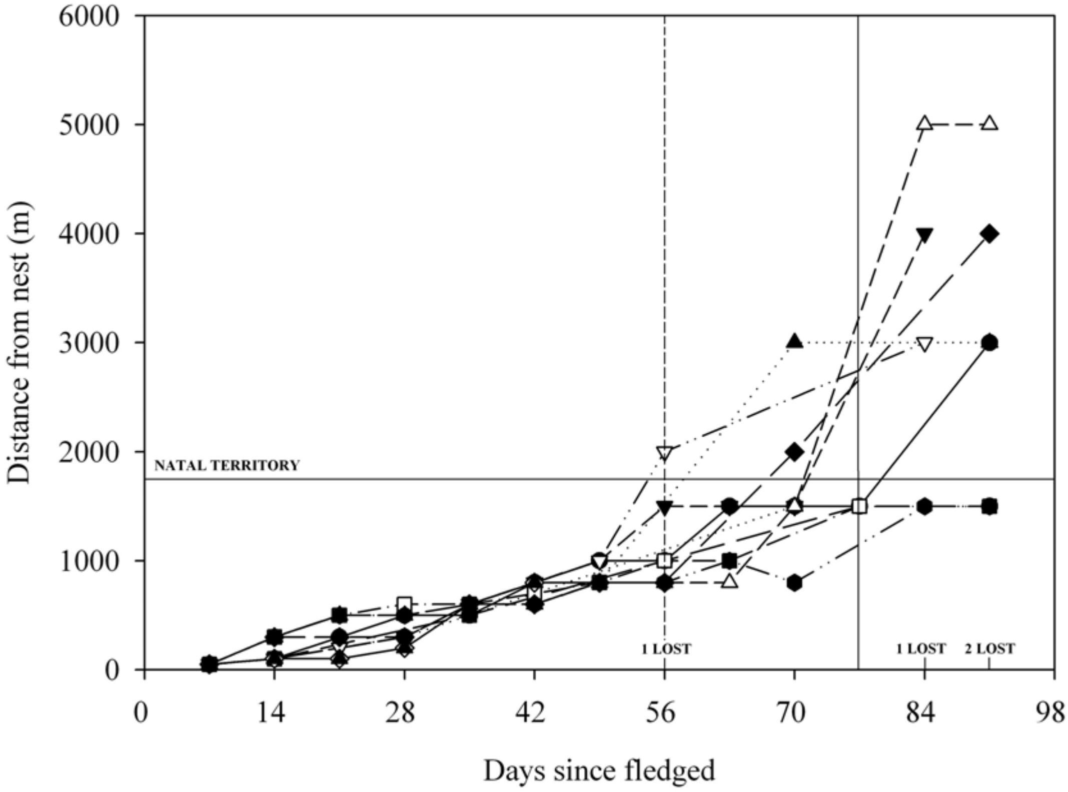

Figure 7.2. Weekly dispersal distances of **female** New Zealand falcons for the 91 day period after fledging (n=11). Dotted vertical line: initiation of dispersal out of the natal home range. Solid vertical line: mean timing of dispersal out of the natal home range. 'Lost' indicates that an individual could not be located after that time.

Of those fledglings tracked for the initial 91 day period, 11 were fitted with transmitters with a 12 month life span. We attempted to radio track these six males and five females through to the following breeding season. We successfully tracked three fledgling females through this period but no fledgling males. We were only able to track these three females because they remained relatively close to their natal sites, dispersing less than 4 km (Table 7.1). We were not able to follow the natal dispersal of any other fledglings through this period due to the large distances over which they dispersed and the low intensity tracking technique employed. We therefore changed our searching technique and attempted to locate lost individuals by an aerial search the following breeding season. One female was located breeding 11.3 km away from her natal site. All other radio-tagged fledglings could not be located and were assumed to have left Kaingaroa Forest.

Of the 112 colour banded fledglings, 13 females and five males, were relocated in Kaingaroa Forest in subsequent breeding seasons. Of those relocated, the mean natal dispersal distance was 9.6 km, 8.7 km for females and 10.5 km for males (Table 7.1). Within Kaingaroa Forest distances dispersed by male falcons ranged from 4.9 km to 16.7 km, and 1.6 km to 34.8 km for females. Natal dispersal distances did not differ significantly between the sexes (Kolmogorov-Smirnov two-sample test K=0.63, n.s.). For several individuals the natal dispersal distance could not be ascertained because we could not be certain that they did not breed in a year prior to first locating them attempting to breed. However, if the movement of pairs between nest attempts can be assumed to be minimal, which is the case in many other raptor species (Newton and Marquiss 1983, Wiens et al. 2006), then the distance to any nesting attempt (irrespective of age) may be regarded as similar to the natal dispersal distance. Including these individuals changes the mean dispersal distances for the two sexes to 12.4 km for females and 10.6 km for males.

Several females were recorded breeding successfully in their first year, whereas no males were recorded breeding successfully until their second year (Table 7.1). The mean age of the first breeding attempt of females was 1.6 years, while males on average did not breed until 2.5 years (Table 7.1). This difference was not significant (K>1.17, *P*=0.20).

Table 7.1. Natal dispersal distances of New Zealand falcons (colour banded and radio tagged individuals combined), the age they were first located in a pair, and the age that they first attempted to breed.

Sex	Season fledged	Season relocated	Age of first breeding attempt (years)	Natal dispersal distance [1] (km)	Age first located	Natal dispersal distance[2] (km)
Female	1997/1998	2003/2004	Unknown	Unknown	6	27.91
	2000/2001		Unknown	Unknown	3	10.00
	2001/2002		Unknown	Unknown	2	9.57
	2002/2003		Unknown	Unknown	1	34.82
	2001/2002	2004/2005	3	5.85	2	5.85
	2002/2003		1	23.24	1	23.24
	2002/2003		2	3.80	1	3.80
	2002/2003		2	4.90	1	4.90
	2001/2002	2005/2006	2	1.59	2	1.59
	2002/2003		1	11.36	1	11.36
	2002/2003		1	9.20	1	9.20
	2002/2003		1	9.55	1	9.55
	2002/2003		Unknown	Unknown	1	9.84
		Mean	1.6	8.69		12.43
Male	2001/2002	2004/2005	Unknown	14.05	2	14.05
	1999/2000	2005/2006	Unknown	Unknown	4	4.89
	2000/2001		3	9.75	3	9.75
	2001/2002		2	7.56	2	7.56
	2001/2002		Unknown	Unknown	2	16.65
		Mean	2.5	10.45		10.58

[1] Natal dispersal distances of individual falcons first breeding attempts
[2] Natal dispersal distances of individual falcons to the nest they were first located breeding, irrespective of whether they had possibly bred in another location in previous years

7.5 Discussion

The age at which New Zealand falcon fledglings dispersed was highly variable among individuals. Nevertheless, previous studies of dispersal in New Zealand falcon suggest that dispersal may be initiated later in indigenous forest (Lawrence and Gay 1991, Barea 1995). This may be the result of lower bird densities. Compared with indigenous forests, pine plantations have higher densities of the birds on which falcons feed (Clout and Gaze 1984). Thus, falcons fledging in pine plantations may develop hunting skills more rapidly (Newton and Marquiss 1983), resulting in earlier independence and dispersal.

Male goshawks disperse earlier than females as a result of their smaller size, allowing earlier physical and behavioural development (Kenward et al. 1993b). This may be expected to occur in other raptor species with strong sexual dimorphism, although for New Zealand falcons we recorded no significant difference in the onset of dispersal between the sexes. Nevertheless, the mean onset of dispersal was slightly earlier for males; the earliest individuals to disperse were male; a greater proportion of males had dispersed 91 days after fledging; and more males could not be located in the study area after 91 days. Therefore, although there is variation among individuals, there is a strong suggestion that males generally disperse earlier than females.

Radio telemetry and colour band recovery data indicate high emigration out of the study site. As a result, the dispersal distances of New Zealand falcons could not be fully described. The high emigration rates, however, indicate that the high densities of breeding falcons located in pine forests (Chapter 5) could potentially supplement falcon populations in surrounding areas where they are in decline (Gaze and Hutzler 2004).

Many raptor species, including European sparrowhawks (*Accipiter nisus*), northern goshawk (*Accipiter gentilis*) and peregrine falcon (*Falco peregrinus*) show sex related differences in natal dispersal distances (Newton and Marquiss 1983, Restani and Mattox 2000, Bechard et al. 2006). Yet of those New Zealand falcons remaining within the study site, we found no significant difference between the sexes in dispersal distance. However, many more females were relocated breeding within the study site than males and more radio-tagged males dispersed out of Kaingaroa Forest. Although the data are not strong enough to support male biased dispersal it does seem that males are more likely than females to roam further afield during the transitionary period between natal and breeding territories.

Several female falcons were recorded breeding successfully in their first year, a year earlier than in other habitats (Seaton and Hyde 2007). Earlier than usual breeding in other species of raptor is related to particularly favourable breeding conditions (Newton 1979). The early breeding in Kaingaroa Forest indicates that conditions in the pine forests were more favourable than in the more traditional forest and open hill country habitats of New Zealand falcon.

We conclude that the large proportion of individuals dispersing out of Kaingaroa Forest and the favourable breeding conditions afforded in this habitat indicates that, where New Zealand falcons occur in pine plantations, they are highly likely to act as source populations for neighbouring areas where falcons are in decline. We suggest that more long-term banding studies be carried out and that more intensive radio tracking or remote tracking methods be employed to more accurately describe natal dispersal and recruitment.

7.6 Acknowledgements

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CHAPTER 8.

CONCLUSIONS

Two New Zealand falcon chicks in the nest scrape, approximately 16 days old. D. Stewart 2003.

"A few years more, and the clarion cry of this fierce little hunter
will be a thing of the past!"

W.L. Buller, 1888

8.1 Overview

This thesis explores how commercial enterprise can contribute to the sustained conservation of a threatened species. Commercial interests and the conservation of biodiversity are often seen as opposing interests. Using the case of the New Zealand falcon I have illustrated that if suitable land management practices can be identified, exotic plantation forestry and indigenous biodiversity conservation need not be mutually exclusive land-use options.

Before this research the extent to which plantation forests could provide suitable habitat for New Zealand falcon was unknown and detailed ecological descriptions of the bush form of the species were lacking. It was generally accepted that, although New Zealand falcon had been recorded within this habitat, plantation forests would not support significant numbers of falcon. This research proves otherwise, establishing that if the management of commercial pine plantations is suitable, this habitat can support relatively high densities of New Zealand falcon and have a significant role to play in their conservation.

For purposes of discussion the following section is split in to three parts illustrating the significance of the research. 1. The ecological requirements of the New Zealand falcon in plantation forestry. 2. Recommendations for forestry management sympathetic to New Zealand falcon. 3. The implications for the conservation of New Zealand falcon and for forestry.

Finally, suggestions for further work are made based on this research.

8.2 Ecological requirements

Prey density is a limiting factor in determining the densities of many raptor species (Newton 1979). The diet of New Zealand falcons in Kaingaroa Forest comprised mostly bird species (Chapter 3). Therefore, the relatively high numbers of prey birds recorded in pine forests in comparison to other habitats (Clout and Gaze 1984) partly explains the very high densities of New Zealand falcons recorded in Kaingaroa Forest. High densities of prey are driven by a diversity of pine stand ages and the abundant edge habitat that a mosaic of stand ages creates (Chapter 2). Like in other plantation forests around the world (Avery and Leslie 1990), this encouraged a high diversity of bird species. Prey bird abundances may have been further encouraged by pest control carried out by the forestry company (Powlesland et al. 1999). Stand edges not only provide the New Zealand falcon with high prey abundances, but also with ideal conditions for hunting (Chapter 4). As a result, prey availability is particularly high. The extent to which plantation forests can provide ideal conditions for New Zealand falcons, is emphasised by the records of females breeding at less than a year old, a year earlier than previous records (Chapter 7).

Where food is not equally available across a landscape, birds should nest close to areas of relatively high food abundance (Pyke et al. 1977, Newton 1979). In Kaingaroa Forest, prey density increases with pine stand age and is particularly high along mature pine stand edges (Chapter 2).

Other raptor species, including black sparrowhawk, *Accipiter melanoleucus* (Malan and Robinson 2001), and merlin, *Falco columbarius* (Little et al. 1995), also nest along plantation edges in order to take advantage of suitable hunting conditions in nearby open habitats while nesting off the ground, away from predators. It seems New Zealand falcon pairs, being adapted to several niches, preferentially nest close to the edges of mature pine stands in order to take advantage of the particularly high prey densities, but also to enable them to take advantage of the hunting opportunities offered by young and mature pine stands (Chapter 5). Other raptor species inhabiting plantation forests, are restricted in number by the availability of nest sites provided by plantation trees (Newton 1996, Sergio and Bogliani 2000, Malan and Robinson 2001). In contrast, New Zealand falcons are restricted by the availability of open ground for nesting. Understorey vegetation cover generally increases with pine stand age (Allen et al. 1995). This restricted most nest sites to pine stands less than four years old or within the very edges of older stands (Chapter 5). New Zealand falcon nest sites are mostly located within young stands, but adjacent to mature pine stands, simultaneously providing suitable nest sites and an abundant food source.

New Zealand's avifauna evolved largely without mammalian predators (Tennyson and Martinson 2006). Consequently, many species are ecologically naïve and prone to unsustainable levels of predation from introduced mammals (Diamond and Veitch 1981, Holdaway 1989). Although New Zealand falcons are predators of some of these introduced mammals (Chapter 3) they and their nests are also prone to predation by them (Chapter 6). Because falcons in pine plantations always nest on the ground (Chapter 5), their eggs and chicks are particularly prone to predation (Chapter 6). There are no records of depredations of adults during the breeding season, but it seems likely that adults on the nest, particularly at night, are prone to predation. In other species of falcon further depredation of juveniles before they are recruited into the breeding population is common (Newton 1979, Sherrod 1983). Considering the large numbers of potential predators, this also seems highly likely in New Zealand falcon, further suggesting that introduced predators are limiting New Zealand falcon populations in pine plantations.

Natal dispersal in New Zealand falcons regularly occurred out of the study site (Chapter 7), suggesting that the population in Kaingaroa Forest is not isolated. While the neighbouring dairy farmland is mostly not suitable for breeding (Fox 1977), New Zealand falcons have been recorded breeding in the pine plantations to the south and in the podocarp forest to the east of Kaingaroa (pers obs). On several occasions falcon pairs were located nesting in the epiphytes high off the ground in the podocarp forest immediately bordering young pine stands. In fact, it seems that prior to pine forest being planted, the adjacent podocarp forest was the only local breeding area for New Zealand falcons as the Kaingaroa Plateau was mostly covered in low scrub (Nicholls 1990, Boyd 1992). Thus, it seems highly likely that this is where the population of falcons breeding in Kaingaroa Forest came from. It would follow that there is free movement between pine and podocarp habitats. Falcon species however, are commonly conservative nesters, choosing to nest in similar nest sites to those from which they fledged (Newton 1979). Therefore, how much exchange there is between pine and podocarp nesting habitats remains debateable. Nevertheless, the high frequency at which fledglings dispersed out of the study site suggests that where suitable breeding habitat exists, New Zealand falcon will readily colonise these areas. Thus, where pine forests are suitably managed, it seems they are highly likely to hold populations of New Zealand falcon. Like with many other species of raptor inhabiting plantation forests, including hobby, *Falco subbuteo*, European sparrowhawk, *Accipiter nisus*, tawny owl, *Strix aluco*, northern goshawk, *Accipiter gentilis*, hen harrier, *Circus cyaneus*, Montagu's harrier, *Circus pygargus*, and long-eared owl, *Asio otus* (Avery and Leslie 1990, Newton 1996, Sergio and Bogliani 2000, Petty and Thomas 2003), suitability depends on the creation of a mosaic of different aged stands across a plantation to ensure a constant provision of suitable habitat for nesting and hunting.

8.2 Management recommendations

This research illustrates how economic concerns and ecological requirements can be integrated by employing an interagency approach to conservation. A variety of organisations, including conservation agencies, forestry companies and research institutions, have been key in this research and their continued co-operation will be important in the ongoing management of New Zealand falcon in this habitat. In this thesis I have been able to demonstrate how, when working together, these organisations can provide workable solutions with positive outcomes for biodiversity and commercial ventures.

The presence of New Zealand falcon potentially has benefits for the forestry industry beyond that of meeting environmental best practice certification requirements. Birds of prey around the world are iconic species, and New Zealand is no different. The New Zealand falcon appears on the 20-dollar note, and other birds of prey are used on all manner of corporate logos. Indeed, one of the main sponsors of this research, Kaingaroa Timberlands Ltd., adopted the falcon as its company logo during the course of this study. Despite holding far higher indigenous biodiversity values than many other commercial land-uses in New Zealand (Maunder et al. 2005) the forestry industry is still largely seen as one that is environmentally destructive. If the forestry industry as a whole adopted the New Zealand falcon as an emblem of the industry, this could be used to illustrate the environmental benefits of forestry in New Zealand and help change the public perception of forestry to one that is environmentally beneficial.

Several plantation forests are known to contain breeding populations of New Zealand falcon (Stewart and Hyde 2004, Addison et al. 2006), but others do not (pers obs). Differences in plantation management are central in determining the presence or absence of breeding falcons. High densities of prey are a critical factor in determining the densities of falcon that exist in any plantation. Thus the implementation of management practices that promote New Zealand falcon populations will also benefit general ecosystem health and biodiversity.

Plantation managers can promote New Zealand falcons on their estates by:

1. Creating a mosaic of pine stand ages, with abundant edge habitat to promote high prey density and availability.
2. Providing a regular supply of clear fell stands for nesting throughout a plantation each year, bordered on at least one side by an older, mature pine stand.
3. Leaving pine slash after tree felling operations, to encourage prey and provide sheltered nest sites for falcons.
4. Carrying out control of introduced mammalian predators in order to increase breeding success and prey abundance.
5. Employing procedures that enable ground based operations to avoid negative impacts to nesting falcons.

Other than the requirement of a minimum setback around falcon nest sites, this illustrates that the management of pine plantation forests for New Zealand falcon will impose very little on current forestry practices. This differs from the management often required for many other species in plantation forests overseas, which can require relatively large undisturbed areas and a high proportion of indigenous mature forest within the plantation e.g. grey goshawk, *Accipiter novaehollandiae*, and brown goshawk, *Accipiter fasciatus* (Burton and Olsen 2000a).

Clear fell forestry is controversial because of its aesthetic and environmental impacts (Maclaren 1996). However, this research illustrates that it is specifically this form of forestry that produces the necessary ecological requirements for high densities of breeding falcons. Although the optimal clear fell size could not be identified, it is clear there is a limit and plantation design that creates a high proportion of stand edge will encourage maximum New Zealand falcon densities.

8.3 Conservation

Initiatives for land-use change from plantation forestry to dairy farming are currently encouraging the large-scale clearance of plantation forests in New Zealand (Maunder et al. 2005). Considering the relatively limited opportunities that intensive agricultural landscapes afford for indigenous biodiversity (Maunder et al. 2005), this conversion has significant implications for the conservation of biodiversity in rural New Zealand. The New Zealand falcon exemplifies this. Unlike many other species of falcon (Newton 1979, Village 1990, Ratcliffe 1993), New Zealand falcons have not adapted to breed in urban or intensively managed agricultural landscapes. The only modified landscapes to which New Zealand falcons have adapted are plantation forestry and low intensity hill country grazing. A large amount of New Zealand's contemporary landscape is therefore unable to sustain falcon populations. Therefore plantation forests can play a significant role in falcon conservation. Not only can plantation forests increase the area of potential habitat, but they can also act as source populations for surrounding areas where falcons are in decline.

Although there are 1.8 million hectares of plantation forest in New Zealand (Statistics New Zealand 2004), not all of this forest is managed in a manner suitable to sustain falcon populations. For example, farm forestry and other relatively small forestry blocks are clear felled all at once so only provide suitable conditions for nesting briefly and are unlikely to sustain falcon populations. Therefore the degree to which New Zealand falcons are using this habitat needs to be further clarified. A revision of the conservation status of the New Zealand falcon based on its use of plantation forests would therefore be premature at this stage.

Nevertheless, where plantations are managed to produce a mosaic of stand ages it seems likely that similarly high falcon densities to those recorded in Kaingaroa Forest will occur in pine plantations across New Zealand. Considering this, the implications to the conservation status of the species are significant. If suitable forestry management practices can be implemented in all of New Zealand's commercial plantation forests, this represents a unique opportunity for industry to actively manage the recovery of a threatened species.

Considering the relatively small proportion of land in conservation estate globally, one of the biggest challenges facing conservation biology today is how to encourage biodiversity on land where conservation is not the primary concern (Knight 1999, Norton 2000). Increasingly, the forestry industry is recognising the need to improve their environmental image and are taking advantage of the economic benefits accruing when they support and enhance biodiversity in their plantations (Norton 1998). If suitable management practices can be identified for the mutual benefit of industry and biodiversity, the opportunities for conservation on private land, where biodiversity may have previously been neglected, are significant. This study demonstrates that production landscapes in New Zealand should not be ruled out as important habitats for the conservation of threatened species and the enhancement of indigenous biodiversity.

8.4 Suggested further work

There remains a short fall in the amount of research being carried out on private land and recommendations for the suitable management of biodiversity in these areas. Plantation forests in New Zealand and internationally, if managed suitably, have the potential to harbour a wide variety of biodiversity. In order for plantations to reach their full potential more research into the management of this system for biodiversity is required. Here, I have been mostly concerned with New Zealand falcon and below I suggest what I consider are the most important research areas for falcons in pine plantations in the future.

The extent of the use of plantation forests by New Zealand falcon

This thesis examined the ecological requirements of New Zealand falcon in plantation forests and how plantations could be managed to support falcons. The assessment of the extent of plantation forest currently available to, and used by New Zealand falcons, was beyond the scope of this work. However, this is key to fully understanding the significance of plantation forests to New Zealand falcons. Before we can fully assess the conservation potential of plantation forests, we need to know if all three forms of the New Zealand falcon are equally adapted to plantation environments. We also need to determine the factors restricting them nationally (e.g. why are there no falcons in Northland or Coromandel when apparently suitable habitat, including pine plantations, exist there?). Remote sensing has proven useful in assessing the suitability of habitat for New Zealand falcons in the past (Leiendecker 2002) and maybe a useful tool here. Nationally, plantation forests could be identified and classified by, for example, size and management technique. Questionnaires could establish presence/absence and population densities could be more accurately assessed using ground surveys. Remote sensing could then be used to identify the amount of potential habitat available to falcons compared to that actually used. This would enable broader conclusions about the New Zealand falcon's use of plantation forests to be made and provide a framework for ongoing management in this habitat.

Interaction of New Zealand falcon with other habitats

The amount of exchange between Kaingaroa Forest and surrounding areas by New Zealand falcon could not be assessed due to limitations of the radio tracking methodology, and the number of colour banded individuals. Understanding how populations interact with surrounding habitats is an interesting theoretical and practical question. Raptor species are often conservative nesters. Therefore movement between habitat types could be restricted. Alternatively, New Zealand falcons may move freely between habitat types. If this is the case, do falcons only nest on the ground because of a lack of suitable tree nest sites available in pine plantations? Would they use nest boxes if they were provided? If New Zealand falcons do use nest boxes, they may have the potential for reducing predation and have practical implications for the management and study of the species.

Pest control and New Zealand falcons

This study indicated that the 1080 pest control carried out by the forestry company was beneficial to New Zealand falcon populations, by decreasing predation on nests and increasing prey densities. However, adult and juvenile survival was not assessed and the relative threat of each predator species could not be fully addressed. The effect of pest control requires further study, including pre- and post-pest control monitoring of survival. Other types of control are employed in other plantation forests (e.g. Brodifacoum) and the effect of these other chemicals, especially of bioaccumulative forms of control, requires critical assessment. Video surveillance of nest sites and decoy wax eggs are non-invasive options that could be used to establish the relative threats posed by each predator species.

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