Breeding success of New Zealand falcons (*Falco novaeseelandiae*) in a pine plantation

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Abstract: Productivity data on the New Zealand falcon (*Falco novaeseelandiae*) were collected from 87 nest sites in Kaingaroa pine plantation during three breeding seasons, 2003 to 2006. On average, 1.81 chicks were successfully fledged per nest, with young reared successfully at 71% of nests. Breeding occurred between August and March, with most eggs laid before December and most chicks fledged by February. Fifteen percent of nests were depredated, 9% contained eggs that failed to develop and 4% failed owing 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. The population of falcons in Kaingaroa Forest increased during a period of pest control using 1080 bait so we see no reason to discontinue its use. Although impacts from forestry operations were low and restricted to land preparation and harvesting operations, there is potential for adverse impacts to increase. Mechanical forestry operations can continue without negative impacts by avoiding a buffer zone of 100–200 m around an active falcon nest.

Keywords: 1080 pest control; biodiversity; fledging; exotic forestry management; Kaingaroa Forest

Introduction

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 indigenous habitat (Stewart & Hyde 2004). Some commercial forestry management practices, including mechanical operations and the application of various chemicals, have the potential to negatively impact falcon productivity (Avery & Leslie 1990) and hence long-term population viability. Mechanical operations such as land preparation (windrowing and mounding) and harvesting pose a physical threat to falcon nests, and may disturb incubation and brooding behaviour. Herbicides and poisons used for mammal pest control may reduce breeding success, either through direct toxicity or by more indirect effects such as altered prey abundance (Spurr 1979; Avery & Leslie 1990; Eisler 1995; Blus & Henny 1997).

The contribution of pine plantations to New Zealand's native biodiversity is increasingly well documented, with a wide diversity of indigenous flora and fauna existing in plantation forests (Jackson 1971; Clout & 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 & Bogliani 2000). Despite this, the forestry industry is still generally perceived as being environmentally destructive (Maclaren 1996). Hence the forestry industry stands to gain by implementing environmentally sustainable forestry management practices and by highlighting the positive effects of forestry on biodiversity.

Since the human colonisation of New Zealand, indigenous forest cover has been reduced from 82% to 24% (14 million hectares) (Ewers et al. 2006). 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 an opportunity to assess the breeding success of the bush form of the species (Fox 1977). 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 bush form of the New Zealand falcon within a plantation forest, to investigate the impact of forestry practices on falcon productivity, and to suggest how negative impacts may be avoided.

Study area

This research was conducted in Kaingaroa Forest, a pine plantation on the central plateau of the North Island of New Zealand. Kaingaroa Forest comprises 180 000 hectares of radiata pine (*Pinus radiata*) plantation that is harvested in discrete compartments, creating a mosaic of different-aged pine stands. Compartments were on average 70 ha and ranged from 1 to 300 ha. Approximate forest bounds are 38–39° S and 176–177° E. The forest is at altitudes of 200–900 m a.s.l. on white pumice soils originating c. 1800 years ago from the eruption of the Taupo Caldera.

Methods

Productivity

Previous falcon nest sites in pine forests (recorded by Wingspan Birds of Prey Trust (Stewart & Hyde 2002, 2004), the Raptor Association of New Zealand, the Department of Conservation and several forestry companies) were all located in pine stands aged less than 4 years old and on the ground.

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.

For each breeding season, nest sites were located by first identifying all pine stands less than 4 years old. These stands were then systematically surveyed on foot at intervals of 2–4 weeks in order to listen and watch for characteristic falcon breeding behaviour. Breeding falcons invariably revealed their presence to any approach within 100 m of the nest, and typically at far greater distances (>500 m). By using this two-step process, we aimed to survey and describe the majority of the breeding falcon population in Kaingaroa Forest. To ensure that falcons were not also breeding in older compartments, those older than 4 years were searched opportunistically throughout the study period. Further, forestry workers, who work in all-aged stands throughout the study area, also provided sightings of falcons throughout the study. Addison et al. (2006) did record a pair of falcons nesting in a mature stand. This does not seem common, however, and was not recorded in Kaingaroa Forest.

Nest site visits were timed so that laying, hatching 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 recorded. 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 were investigated using one-way ANOVAS.

Forestry management

Forestry management data were collated from forestry databases covering the period back to the establishment of the forest, over 60 years ago (Kaingaroa Timberlands). 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 the study area (Kaingaroa Forest), the windrows of pine slash are 5 m apart, and trees are planted in mounds between the windrows. These operations can be carried out at the same time using a mechanical excavator. The distances of mechanical operations from the nests at different stages of the breeding cycle were recorded 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.

Results

Productivity

During three breeding seasons, 2003/04 to 2005/06, we recorded 87 breeding attempts (Table 1). Eggs were laid from 20 August to 4 January and 96% of pairs started breeding between September and December. Outside these months, eggs were only recorded as being laid twice – once in August and once in January. Clutch size did not differ 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. 1).

Although the mean number of falcons fledged was higher in 2003 than in 2004 and 2005 (Table 2), no significant difference was recorded among 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 1–4). Equal numbers of males and females fledged in 2003 and 2004, but female fledglings outnumbered males by nearly 2:1 in 2005 (Table 2). Overall, 2% of young fledged in October, 13% in November, 44% in December, 31% in January and 11% in February.

Fifteen percent of nests failed in 2003, 39% in 2004 and 33% in 2005. Three pairs re-cycled, of which only

Table 1. Number of nest attempts by New Zealand falcons in Kaingaroa Forest during 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

Table 2. Mean productivity values (*n*) per New Zealand falcon nest in Kaingaroa Forest for each breeding season 2003 to 2005.

	Breeding season 2003/04	2004/05	2005/06
Nests assessed (*n*)	20	28	36
Eggs laid	2.70	2.86	2.94
Eggs hatched	2.20	1.69	1.97
Chicks successfully fledged	2.15	1.59	1.64
Males fledged	1.05	0.86	0.61
Females fledged	1.00	0.72	1.06

Table 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.

Reason for failure	Breeding season 2003/04	2004/05	2005/06
Predation	0	7	6
Infertile	3	3	2
Forestry	0	1	3
Other	0	1*	1**
Total failed	3	12	12

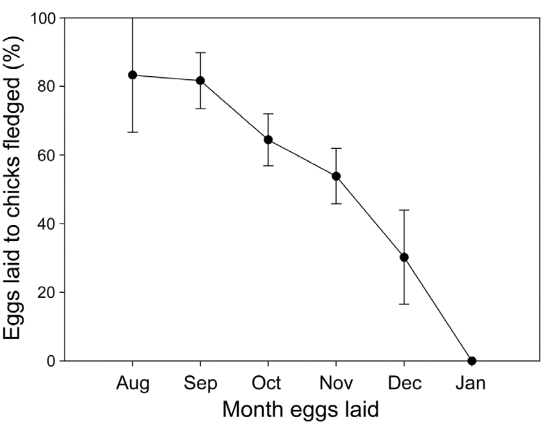

Figure 1. Percentage of eggs laid to chicks successfully fledged by the month eggs were laid, illustrating the decline in the success of nests with time of breeding season ($P = 0.03$). The data are mean ± standard error.

one was successful. Over the three years, the causes of these failures were mostly predation (15%) and hatching failure (9%) (Table 3). The causes of predation were mostly hard to determine, but we suspected mustelids (*Mustela erminea* or *M. furo*), brushtail possums (*Trichosurus vulpecula*), wild pigs (*Sus scrofa*) and Australian magpies (*Gymnorhina tibicen*). 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 & Gay 1991; Lawrence 2002; Gaze & Hutzler 2004).

Forestry management

We found an increasing number of New Zealand falcons over the three breeding seasons. At the same time, the proportion of nest compartments with forestry operations increased from 5% in 2003, to 7% in 2004, and 25% in 2005. Nevertheless, only four nest failures could be directly attributed to forestry operations (Table 3). Three of these failures were due to land preparation and one due to a harvesting operation.

For 12 potentially threatened nest sites, all chicks survived when land preparation operations remained more than 200 m from the nest scrape until the chicks were able to thermoregulate (after 14 days old). After chicks were 14 days old, land preparation operations continued as close as 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 found while land preparation operations were being carried out within 100 m of the nest and the adults would have spent a large proportion of time in nest defence and not incubating. Thus, although some pairs can be successful after disturbance from land preparation operations in these early stages, nest failure is far more likely than when disturbance occurs later in the breeding attempt. To our knowledge, no nests were destroyed because of land preparation operations crushing the nests.

It is hard to assess the overall effects of tree felling because only two nests were affected by harvesting during this study. 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 found, 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 clearfell 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 predator control method employed was poisoning of plantation possums and rats using 1080 (sodium monofluoroacetate) poison bait. This was the only control method used in the compartments where falcons were nesting. Poison was applied in either cereal or carrot bait form. Both application methods and both bait types were used in some nest compartments and were either locally applied to a compartment from the ground or aerially applied over larger areas, using a helicopter. The time since predator control was applied in nest compartments ranged from 1 month to >3 years. The number of chicks successfully fledged was not related to the time since 1080 application ($F_{1,2} = 3.8$, $P = 0.19$), bait type ($F_{3,78} = 0.44$, $P = 0.72$), or application method ($F_{3,78} = 0.25$, $P = 0.86$). The 1080 control was applied throughout the 3 years of the study and during that time the breeding falcon population increased from 20 to 36 pairs. While the increase in falcon numbers may be purely coincidental to the use of 1080, there was no evidence of a negative impact.

Various herbicides were used for desiccant spraying, including Escort®, Silmax, glyphosate, Orion glyphosate 360, 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 6 to 65 months, and the time since release sprays were applied, from 1 to 35 months. Desiccant sprays were applied aerially or by ground crews before tree planting. Release spraying involved localised spot spraying of weeds surrounding young pine trees. Herbicide use had no significant effect on falcon breeding success ($F_{7,74} = 1.37$, $P = 0.23$). The number of chicks successfully fledged was not significantly affected by the age of the compartment in which a nest was located ($F_{4,7} = 1.25$, $P = 0.30$) or the number of rotations a compartment had been through ($F_{1,2} = 0.17$, $P = 0.72$).

Discussion

Productivity

Productivity values in Kaingaroa (1.81 chicks successfully fledged per nest with 29% 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% 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 & Marquiss 1984; Nicoll 2004), we attribute these differences to variations in day length, temperature and rainfall between areas.

Raptor fledging success varies with time and can be affected by weather (Newton & Marquiss 1984; Nicoll 2004), prey abundance (Janes 1985), habitat (Little et al. 1995), disturbance (Sergio & Bogliani 2000), age (Mearns & Newton 1988; Newton & Rothery 2002) and competition (Hakkarainen & Korpimäki 1996). We found that the earlier in the breeding season New Zealand falcons lay their eggs, the more likely the chicks 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 & Oliphant 1993), and this may also apply to New Zealand falcons (Fox 1977). Small-bird abundance in Kaingaroa Forest increases from January to February (Seaton 2007). This is particularly true for chaffinches (*Fringilla coelebs*), the species most commonly preyed upon by falcons in Kaingaroa Forest (Seaton et al. 2008). Most falcon chicks fledge in December and January. We suggest, therefore, that New Zealand falcon pairs are timing the pre-fledgling period with high nestling prey availability and the post-fledgling period with maximum fledged prey. 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. Birds that laid their eggs early were able to moult before winter, thus increasing their chances of overwinter survival (Nilsson & Svensson 1996). 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 & Gay 1991; Lawrence 2002; Gaze & Hutzler 2004).

Effects of forestry management

Our 3-year study covered only a fraction of a typical 30-year rotation of radiata pine at Kaingaroa Forest. However, the forest was divided into a mosaic of compartments at all stages from initial land preparation through to final harvest. Thus, we could observe the effects of forestry management at all phases of the operation. Typically, nesting was limited to stands with trees less than 4 years of age, and hunting tended to occur along the ecotone between young and mature stands. Land preparation and harvesting operations were the only forestry practices to reduce the breeding success of New Zealand falcons. The stage at which a nest was disturbed, combined with the distance of the operation from the nest, determined whether breeding success was reduced. We found that New Zealand falcons are more resilient to disturbance than many other species of raptor (Newton 1979; Toyne 1997; Sergio & 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 thermoregulate 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 predation by introduced mammals limited the breeding success of New Zealand falcons (Fox 1977; Lawrence & Gay 1991; Barea 1995; Gaze & 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. Poison baits are widely used for selected predator control in New Zealand (Innes & Barker 1999) and have been found to be effective as a secondary poison by the predators consuming poisoned prey (Gillies & Pierce 1999). Toxic 1080 baits are typically used for the control of rats and brushtail possums in New Zealand forests (Innes & Barker 1999), and are used extensively in Kaingaroa Forest. 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 (Seaton et al. 2008) 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.

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). However, we could detect no negative effect of herbicide use on falcon productivity.

Management recommendations

Based on the results of our study, we outline management frameworks to minimise the negative impacts on New Zealand falcon productivity resulting from land preparation and harvesting operations (Appendix 1) which, at the same time, create little disruption to forestry operations. In summary, falcons require a 200-m set back during land preparation or harvesting until chicks are 14 days old. This set back can be reduced to 15 m after the chicks are 14 days old. Full operations can continue once the young falcons can fly (Appendix 1). If nests can be monitored beforehand, 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.

Conclusions

We conclude that the productivity of New Zealand falcons in pine forests is similar to those inhabiting other habitats in New Zealand. Predation had 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 with minimal disruption to forestry operations.

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Appendix 1. Recommended instructions for forestry workers

When you get within 300–400 m of a falcon's nest, especially if you are on foot, they will start to fly and call 'kek–kek–kek'. The closer you get to the nest, the more aggressive and vocal the parent birds become and they will dive-bomb you. If the female is incubating and the male is away hunting, she may not come off the eggs until you are a few metres away.

Before land preparation starts (between September and February) walk through compartments less than 4 years old and look for falcons.

If forestry workers find falcons in a compartment we recommend they inform the Environmental Officer and observe the following steps:

Activity	Immediate response	Operational response
Falcons dive-bomb	Fall back 200-m radius	Continue operation after 75 days
Eggs are found	Fall back 200-m radius	Continue operation after 45 days
Small fluffy white chicks	Fall back 200-m radius	Continue operation after 20 days
Large grey chicks	Fall back 200-m radius	Continue operation after 20 days
Feathered chicks that cannot fly	Fall back 100-m radius	Continue operation after 15 days
Young falcons that can fly	No problem	Continue operation