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**The Behaviour and Development of New Zealand
Falcons (*Falco novaeseelandiae*) Nesting
in Plantation Forest**

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requirements for the degree of
Master of Science
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Abstract

Information on the breeding behaviour and development of wild New Zealand falcons (*Falco novaeseelandiae*) is scarce. It has recently been shown that the species frequently uses plantation forests for breeding purposes and a better understanding of falcons breeding behaviour has implications for forestry harvesting practices as well as strategies to conserve the species.

In this study the breeding behaviour and development of New Zealand falcons were recorded at two nests in Kaingaroa Forest, an extensive plantation forest, using direct hide observations. Both nests were observed during the later part of incubation, the entire nestling and early post-fledging periods. Nest observations were recorded during a four-month period between 5 November 2006 and 2 March 2007.

Incubation was shared between parents and it was observed that the male provided about 30% of the total time on the eggs. The male's investment during the incubation period was primarily incubation of the eggs to allow the female time to hunt. Incubation remained constant after the laying of the last egg in the clutch despite a stoat (*Mustela erminea*) attempting to predate the eggs. During incubation, the male provided only occasional prey for the female. Brooding was also shared by both parents. The male, however, contributed only 10% of the total brooding time, mostly during the first seven days of the nestling period. Brooding activity was high for up to the first six days, before gradually declining until the chicks reached 14 days old at which point it ceased. This decline in brooding coincided with the chicks' development of thermo-regulation. The mean prey delivery rate was 0.82 prey items per hour and the mean feeding rate was slightly higher at 0.90 feeds per hour. Assisted feeding of the chicks was almost always undertaken by the female. The male's primary role during the nestling period was prey delivery. During the early nestling period the female spent the majority of the time brooding chicks. As the nestling period progressed, however, this role shifted primarily to hunting for the young.

By establishing a set of guidelines for forest managers and captive breeders, this study makes a strong direct contribution to the management and conservation of the New Zealand falcon. This study establishes development milestones for breeding events, including the duration of the breeding cycle that will assist forestry managers to minimise their impact upon nesting birds.

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1. Chapter One – Introduction



1.1 Background

The New Zealand falcon or karearea (*Falco novaeseelandiae*) is the only endemic representative bird of prey established in New Zealand. It is currently recognised as a threatened species, largely as a result of predation by introduced predators, habitat destruction and illegal shooting (Fox, 1977a; Hitchmough et al., 2007; Marchant and Higgins, 1993). Although, the New Zealand falcon is classified as a threatened species little is known about its biology (Seaton, 2007). Historically, there has been extensive debate over the species taxonomic description (Fox, 1977a). Presently the species is separated into three distinct forms the bush, eastern, and southern form. The separation of the forms is based on their range, morphology and ecology. The bush form range covers much of the North Island, and extends down the north-west of the South Island. Population estimates during the late 1970's suggest between 3,700 and 4,300 pairs of New Zealand falcon remained (Fox, 1977a). New Zealand falcon have been fully protected since 1970, however the species is probably still in decline (Gaze and Hutzler, 2004).

The New Zealand falcon is generally regarded as a species intolerant of disturbance. However, the New Zealand falcon has recently been identified as breeding extensively in exotic plantation forests, a relatively disturbed habitat type (Addison et al., 2006; Seaton, 2007; Stewart and Hyde, 2004). Prior to this, only one report of breeding was reported within plantation forest habitat (Ryder, 1948; Stewart and Hyde, 2004). The extensive breeding of New Zealand falcons in plantation forests

Traditionally the bush form of the New Zealand falcon nests in extensive tracts of indigenous forest (Fox, 1977a). Nests are frequently in the epiphytes of emergent podocarp trees. Little is known about the breeding behaviour and development of the bush form in the wild as a result of nest sites being often difficult to access and observe. In plantation forests the New Zealand falcon nests on the ground, often in relatively unprotected sites (Seaton, 2007; Stewart and Hyde, 2004). This habit of ground nesting makes them particularly susceptible to nest disturbance and predation.

Many studies have found that the New Zealand falcon is primarily a bird predator (Barea, 1995; Fox, 1977a; Seaton, 2007). The diet of the New Zealand falcon nesting in plantation forests have only recently been reported using pellet and prey remain analyses (Hyde and Stewart, 2002; Seaton, 2007). Direct observations have

proved to be the most accurate method for determining the frequency and biomass of prey items delivered to the nest in other bird of prey species (Collopy, 1983). Therefore, direct observations can indicate the accuracy of Seaton's (Seaton, 2007) findings.

Low productivity has been reported for the bush form in indigenous habitat, yet, in plantation forests it has been found to be as high as the eastern form (Lawrence, 2002; Seaton, 2007) Direct observations may be able to identify disturbances that could contribute to reduced productivity, without the need for long-term research.

1.2 Problem Statement

A number of studies have looked at particular aspects of the breeding biology of the New Zealand falcon (Fox, 1977a; Hyde and Stewart, 2002; Lawrence and Gay, 1991; Seaton, 2007). However, none of these studies have intensively observed the breeding behaviour of wild New Zealand falcons (bush form) in plantation forests during the incubation, nestling and post-fledging periods. A detailed understanding of the species breeding cycle is critical for designing an effective species recovery plan. The bush form of the New Zealand falcon has been reported to be the most at risk of the three forms due to loss of breeding habitat (Fox, 1977a). The New Zealand falcon is currently classified as a threatened species (Hitchmough et al., 2007). Traditionally the bush form of the New Zealand falcon nests in extensive and relatively inaccessible tracts of indigenous forests. Recent reports, however, have found the bush form extensively breeding in plantation forests of the lower North Island (Addison et al., 2006; Seaton, 2007; Stewart and Hyde, 2004). Since this recent discovery, the nesting habits of New Zealand falcon in plantation forests have aided further research into this poorly understood species. Ground nesting within plantation forests provides an excellent opportunity to intensively study the breeding behaviour and development of the bush form in this modified habitat type.

Discrepancies in breeding productivity have been reported between studies on bush falcon (Lawrence, 2002; Seaton, 2007). It is important to understand the factors that influence the productivity of the New Zealand falcon, especially in disturbed habitats such as plantation forests, as this may help to improve their management in other disturbed habitats and identify factors that limit their overall breeding range.

1.3 Aim of the Research

The aim of this research was to conduct an intensive study of the behaviour and development of nesting New Zealand bush falcons in Kaingaroa Forest, an exotic plantation forest, using direct observations from the concealment of a custom-built hide.

1.4 Objectives

The following outlines the four key objectives that were required to achieve the research aim previously mentioned:

- i. Review the relevant literature, and from that, design and construct a hide to enable intensive recordings of the detailed breeding behaviour of the New Zealand falcon
- ii. Design a methodology for observing New Zealand falcons at the nest scrape using a hide for concealment
- iii. Observe and record the breeding behaviour of New Zealand falcon
- iv. Analyse the results of these observations and discuss the findings

1.5 Importance of the Research

This research provides further insight into the details of the breeding behaviour and development of the New Zealand bush falcon. The species is currently threatened and reportedly in decline at least in some parts of its range (Gaze and Hutzler, 2004). The findings from this study may also help to improve the captive breeding and overall management of the species. Captive breeding may become more important in the future management of this species. This study will improve the overall understanding of the New Zealand falcon's breeding biology, and therefore, allow more effective management of the species' long-term future.

1.6 Study Site

1.6.1 Kaingaroa Forest

Kaingaroa Forest is located in the central North Island of New Zealand, extending from the south-east of Rotorua, to just south of the Napier-Taupo highway (Hyde and Stewart, 2002)(Fig. 1.1). Kaingaroa Forest consists primarily of *Pinus radiata* with a few other species of exotic conifer making up the remainder of the production trees (Seaton, 2007). The forest is bordered to the east by an extensive tract of native mixed native podocarp forest (Whirinaki Forest Park), and to the west by intensive dairy farming. Kaingaroa is the largest continuous block of plantation forest in New Zealand; consisting of about 180,000 ha. The forest is divided into about 1,400 different age-class stands of trees, each of which is referred to as a compartment. A complete description of this study site has been previously presented by various authors (Holland and McCutcheon, 2007; Hyde and Stewart, 2002; Seaton, 2007).

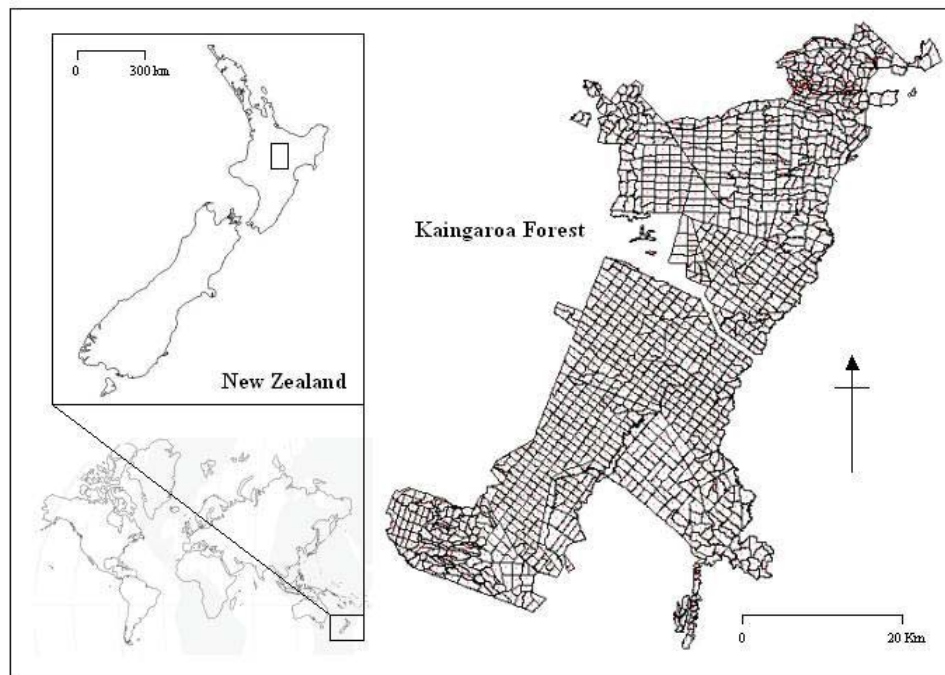


Figure 1.1 Location of Kaingaroa Forest in the North Island of New Zealand. The forest compartment boundaries are also illustrated (adapted from Seaton 2007 p6).

1.6.2 Nest Site Background Information

(i) Nest Site 1 – Compartment 333

The pair of breeding New Zealand falcons in compartment 333 were first identified by a forestry digger driver approximately a week prior to first sighting of the nest for this study. After observing dive-bombing by the resident pair, the digger drivers ceased work until the nest site was located by Wingspan Birds of Prey Trust (Rotorua) staff members. The nest site was located and there were three eggs present. After the nest was located the diggers continued to ridge the slash into rows and make tree planting mounds in the remainder of the compartment. The diggers left a 5 m radius of untouched slash material around the nest site. These disturbances did not result in nest desertion or any failure of the eggs to hatch.

(ii) Nest Site 2 - Compartment 159

The nest was located very shortly after the fourth and final egg in the clutch was laid. The nest scrape in compartment 159 represents a re-nesting attempt, after the previous nest failed from presumed predation during incubation. The nesting attempt observed in this study was about 1 km in a direct line of sight from the pairs' previous nest site.

1.7 Thesis Outline

The following thesis was designed to explain to the reader how the aim was achieved using the General Methods are described in Chapter Three and more extensively in Appendix 1, Manual 1. This thesis is separated into six different sections, as follows:

Chapter One presented a general background to the study, the problem statement, the aim, objectives and importance of the research. The study site and background on the nest sites used in this study were also outlined.

Chapter Two describes the many studies and types of hides used by previous researchers to observe the behaviour of various different birds of prey. It also covers the use of hides for studying the behaviour and development of the New Zealand falcon during the breeding season.

Chapter Three very briefly outlines the methods used during this study in order to achieve the aim. This includes hide observations and coverage, meteorological recordings, disturbances and other biases, and analysis of the data.

Chapter Four describes the main findings of this research.

Chapter Five compares and discusses the findings of this study with those found by other authors.

Chapter Six outlines the main conclusions of this study. Within this chapter the significance of findings from this study are presented and areas requiring further work are addressed.

2. Chapter Two - Literature Review



2.1 Direct Observations of Behaviour using a Hide

Hides, or blinds, have been extensively used to study the behaviour of nesting bird species in the wild using direct observations. Hides are a form of concealment that allows researchers to observe the natural behaviours of the subject birds. They have been successfully used for observing nests of many different bird of prey species worldwide, including: bald eagles (*Haliaeetus leucocephalus*), golden eagles (*Aquila chrysaetos*), turkey vultures (*Cathartes aura*), common buzzards (*Bueo buteo*), red-shouldered hawks (*Buteo lineatus*), marsh harriers (*Circus aeruginosus*), hen harriers (*Circus cyaneus*), black falcons (*Falco subniger*), brown falcons (*Falco berigora*), grey falcons (*Falco hypoleucos*), gyrfalcons (*Falco rusticolus*), New Zealand falcons, and peregrine falcons (*Falco peregrinus*) (Bryan Jr et al., 2005; Collopy, 1983, 1984; Cupper and Cupper, 1981; Dykstra et al., 2003; Ellis, 1979; Fox, 1977a; Hubert et al., 1994; Jenkins, 1978; Redpath et al., 2001). Brown (1976), stated that birds of prey are usually not shy or particularly hard to observe using direct observations, and are therefore good subjects for hide observation.

A range of different types of concealment have been used by studies, and in some cases no concealment was necessary. The style of hide depends very much upon the type of research to be undertaken and the financial resources available. Hides range from large permanent structures to very small and simple portable ones. In some situations it was determined that no concealment was necessary, when observations were made from several hundred metres away. Where photography was used to study the nesting birds' behaviours the hide needed to be considerably closer to the nest site than for observations of the prey delivery (Cupper and Cupper, 1981; Jones, 1998; Moon, 1970). Hides have often been covered with canvas to provide a light-weight means of water-proof protection (Beer, 1965; Cupper and Cupper, 1981; Moon, 1970, 2005).

Many studies, however, using hides do not explicitly state the type of hide used. Often the only information provided about a hide was how far it was placed from the nest and the equipment used to observe the nesting birds (Jenkins, 1978; Wilbur and Jackson, 1983). Ellis (1979), stated that ideally the hide should be placed 15 to 25 m from the nest with a view into the nest to allow comprehensive recordings of some of

the nesting behaviours. In some cases, illustrations of the hide could be used to determine how it was constructed and at least the outer materials that were used.

Various attempts have been made to reduce disturbance caused by direct observations from a hide. One-way glass/mirrors have been installed in some hides over the observation opening to reduce disturbance to the nesting birds (Ellis, 1979). One-way glass poses a number of problems when applied to a portable canvas hide and was therefore deemed infeasible for this study. The principal of one-way glass could, however, be replicated by maintaining a dark interior to the hide and by covering the observation opening with fabric mesh (such as shade cloth used by horticulturalists). Recessing the lenses so they do not protrude from the hide can reduce their visibility to the nesting birds (Ellis, 1979).

Observation equipment generally consisted of a spotting scope with variable levels of zoom such as 15-60x, and binoculars about 10x30. The quality and zoom of some spotting scopes allowed observers to be between 300 and 500 m away from the nest site (Palmer et al., 2003; Wilbur and Jackson, 1983). This was not applicable to the site used in this study as nest compartments were very flat and visibility into the nest scrape was required. The nest sites used in this study also had extensive vegetation slash left behind after clear-felling of the mature trees, further limiting the distance that the hide could be sited from the New Zealand falcon nest. Studies involving cliff nesting birds of prey species often had to observe from distant vantage points (Ellis, 1979; Wilbur and Jackson, 1983). In contrast to this Cupper & Cupper (1981), noted that even the wary species like the marsh harrier can be observed from a hide as close as 4 m from the nest, provided care is taken in the hide design and methods. Feeding behaviour and parental care required that hides were placed between 15 and 40 m from golden eagle nests (Collopy, 1984). Both the requirements of the study as well as the nest site should determine how far away the hide is placed from the nest.

Very few studies reported on the detailed methods used to enter and exit from the hide, before and after conducting observations. In some cases this is may be done during hours of darkness with the notion that birds will not see the observer enter and exit the hide. This method was not practical for daily observations over long periods of time and favored observations at three or more day intervals (Collopy, 1984; Ellis, 1979). Cupper & Cupper (1981), carpeted the floor of the hide to reduce the noise produced by movements of the observer within the hide. Multiple guy rope attachments to the top corners of the hide were used by Moon (2005), to stabilise it in exposed sites.

Resembling the guy ropes used to support old A-frame style tents. Strong gusty winds have been reported as causing camera shake, thus loose attachments of the spotting scope to the hide's outer skin reduced vibration (Ellis, 1979).

Direct observations provide a unique opportunity to see not only what is happening near the nest, but also behaviours of the parents further from the nest. Direct observation is also very useful for verifying the findings from time-lapse photography. Booms & Fuller (2003), did, however, note that observers tire and that observations are almost always a subset of the 24-hour day. When a species can be studied with both time-lapse photography and direct observation, researchers gain an unparalleled level of detail about behaviour (Jenkins, 2000).

2.2 Breeding Behaviour and Development

The breeding behaviour and development of a species is a critical component of their overall life history (Starck and Ricklefs, 1998). Breeding behaviour of some well studied species of birds of prey has been extensively described. These include the bald eagle, turkey vulture, gyrfalcon, and the peregrine falcon (Ellis, 1979; Potapov and Sale, 2005; Ratcliffe, 1980; Wilbur and Jackson, 1983). To study the incubation behaviour of the black-billed gulls (*Larus bulleri*), Beer (1965) used direct observations from a canvas hide.

Unnatural behaviours expressed by captive reared birds have the potential to inhibit successful pairing and breeding (Fox, 1977a). Thus, a description of the behavioural and morphological development of a species in the wild can be used to improve the captive management of a species. This information may be used to ensure that captive breeding follows the same patterns that are observed in the wild. The development of natural behaviours in captive bred birds is especially important if the birds are bred for release back into the wild.

Understanding a species' breeding behaviour is critical for developing of successful conservation management. It is especially important to understand any effects that human induced disturbances have on birds. Elusive and sparsely populated species, such as the New Zealand falcon present a challenging subject to researchers (Fox, 1977a). Species such as falcons are therefore easiest to study during the breeding season when they must return to the nest for a prolonged period of time to attend the eggs and young.

Collopy (1983), stated that although many studies have used analysis of prey remains and pellets to assess the diet of bird of prey species, direct observations remains the most accurate method for determining the frequency and biomass of prey deliveries to the nest. This statement is strongly supported by Southern (1954), who reported that direct observations discovered a prey item fed to young tawny owls (*Strix aluco*), that was completely overlooked by both pellet and prey remain analyses.

The development of a successful management plan relies heavily on a firm understanding of the species' breeding behaviour and development. Human disturbance during the nesting cycle can result in significant changes in behaviour and even lead to nest desertion (Fox, 1977a; Steidl and Anthony, 2000). Effective management during the breeding season can, therefore, produce significant benefits to the long-term future of a species.

2.3 Background to New Zealand Falcon Literature

The New Zealand falcon is one of only two species of diurnal birds of prey currently established, and the only one of which is endemic to New Zealand (Heather and Robertson, 1996; Hyde and Stewart, 2002; Marchant and Higgins, 1993). The New Zealand falcon has successfully adapted to a number of different habitat types, including both forested and open habitats (Fox, 1977a, 1978b). Fox (1977a), reported that historically there has been extensive debate on the taxonomy of the species. Currently it is classified into three distinct forms, the bush, eastern, and southern falcon. The three forms of New Zealand falcon are separated by their range, morphology and habitat use (Fox, 1977a). The bush falcon's range covers much of the North Island south of Auckland, and extends down the west coast of the South Island as far as Greymouth. The eastern falcon is found throughout the relatively dry eastern side of the South Island and only extends to the west coast around the central region. Southern falcons are restricted to Fiordland, Stewart Island and the sub-Antarctic Auckland Islands. Debate over the species separation into three forms, combined with the lack of information on population stability, has led to uncertainty over the species' conservation status (Fox, 1977a; Hitchmough et al., 2007).

Since 1970 the New Zealand falcon has had full legal protection. Although, current population trends remain largely unknown it has been suggested that they may

be in decline in some parts of their range (Gaze and Hutzler, 2004). The Department of Conservation (DoC) currently recognise the bush falcon as Nationally Vulnerable (Category 3), the eastern falcon as in Gradual Decline (Category 5) and the southern falcon as Nationally Endangered (Category 2) (Hitchmough et al., 2007). In 1978, Fox (1978b), estimated that as few as 140-280 southern falcon pairs, 3100-3200 bush falcon pairs, and 450-850 eastern falcon pairs may remain.

Historically, the New Zealand falcon has declined mainly as a result of habitat destruction, illegal persecution and predation by introduced mammals (Fox, 1975; Fox, 1977a). New Zealand falcons remain victims of illegal persecution as a result of their fearless nature and feeding habits. New Zealand falcons have particularly come into conflict with human activities when they hunt racing pigeons, domestic fowl, and game birds (Fox, 1977b).

It may be possible to infer problems in certain critical populations using detailed descriptions of the breeding behaviour. Dykstra *et al.* (2003), stated that the recording of baseline nesting behaviour and prey delivery rates may be able to be used to identify unhealthy populations of a species, when combined with productivity data. Therefore, data from this study may be used to compare New Zealand falcon population 'health' with the management practices of different plantation forests. Lack of population trend data for was identified by Hichmough *et al.* (2007), as a major problem associated with assigning the threat classification to the New Zealand falcon.

The main threats to New Zealand falcon remain illegal persecution, habitat modification, and predation by introduced mammals (Seaton, 2007). Possibly the most serious current threat to the falcon is predation by introduced mammals including the possum (*Trichosurus vulpecula*), mustelids (stoats (*Mustela erminea*) and ferrets (*Mustela furo*), and feral cats (*Felis catus*) (Fox, 1977a; Seaton, 2007). The New Zealand falcon may be able to defend its nest by day, however they are highly susceptible to predation from nocturnal predators. They, like almost all New Zealand endemic birds are maladapted to cope with mammalian predators. Nesting is a critical stage and therefore requires further understanding to accurately identify threats and disturbances during this period.

The Department of Conservation has yet to produce a recovery or captive management plan for the New Zealand falcon. To improve the current management of the New Zealand falcon it is vital that a recovery plan is developed and implemented. The captive breeding programme should closely resemble the breeding cycle found in

wild birds. Therefore information about the specific details of the New Zealand falcons' breeding behaviour is long overdue and very necessary research. The current status of the species is poorly understood. In particular, more work needs to be done establishing the extent of the three forms of the New Zealand falcon. Captive management may have a more active role in their future conservation if declines are found to be widespread. Information on the incubation patterns of wild New Zealand falcons is, however, particularly poorly understood. Deeming (2002), stated that artificial incubation of raptor eggs have probably been using sub-optimal conditions. This is especially important for species such as the New Zealand falcon which is already classified as a threatened species.

The nest of a New Zealand falcon is a slight depression, or scrape formed in the nesting substrate (Fox, 1977a; Stewart and Hyde, 2004). The bush form generally nests in the epiphytes high up in emergent trees within extensive tracts of native forest (Lawrence and Gay, 1991). This nesting habit makes it very difficult to study the breeding behaviour of this form, especially when nests are located considerable distances from vehicle access. Even the estimation of the breeding population of the bush form becomes difficult due to the often remote habitats that they inhabit. Vocalisation surveying has recently been used to locate falcons during the breeding season in plantation forests. This technique has possible application in native forest habitat. This, however, has yet to be determined (McBride, 2008).

2.4 Ground Nesting Bush Falcons in Plantation Forests

Recently the bush form of the New Zealand has been recorded extensively breeding in plantation forests throughout the lower North Island (Addison et al., 2006; Seaton, 2007; Stewart and Hyde, 2004). Prior to 1994, only a single report could be obtained of New Zealand falcon breeding in plantation forests (Ryder, 1948; Stewart and Hyde, 2004). Their ability to breed in plantation forestry poses a significant opportunity for the species to be successfully managed outside of conservation land (Seaton, 2007). Gaze & Hutzler (2004) suggested that land-use conversion into pine plantations may be detrimental to the New Zealand falcon. Subsequently, however, research on plantation nesting falcons suggests that this habitat type may support crucial

populations (Seaton, 2007). Especially if intensification of farmland continues throughout its breeding range, successful management of plantation nesting falcons may become increasingly important for their long-term survival.

The bush form inhabiting indigenous forests has been reported to have lower productivity than the eastern form (Lawrence, 2002). In contrast, however, Seaton (2007), stated that where the bush form nests in exotic plantation forests, very similar productivity to the eastern form were found. He proposed the main reasons for their improved productivity in plantation forests were a combination of effective forest management and an abundant food supply. Although, the precise reasons for improved productivity in plantation forests require further research. Lawrence (2002) proposed that the New Zealand falcon could provide a useful bio-indicator of the 'health' of an ecosystem as they are a top natural predator.

New Zealand plantation forests provide an opportunity to conserve key populations of New Zealand falcons (Seaton, 2007). It is important that forest managers understand the causes of nesting failure and success within plantation forestry. Disturbance events that result in complete nesting failures should be considered extreme impact. Detailed observations of the breeding behaviour in disturbed habitat types may identify more subtle effects of disturbance events. Disturbances during the breeding cycle can potentially cause detrimental changes to the behaviour of nesting falcons. Steidl & Anthony (2000), found that disturbance from recreational camping 100 m from the nest of bald eagles caused significant negative effects on their nesting behaviour. Extensive study of the behavioural and morphological changes in wild New Zealand falcon may provide managers with the information they require to improve falcon nesting success; especially when different management practices can be precisely compared.

New Zealand falcons breeding within the interior of pine plantation forests always nest on the ground (Seaton, 2007). However, those nesting on the border of pine plantations nested up off the ground usually within epiphytes of native emergent podocarp trees. Seaton (2007) suggests that ground nesting, at least in plantation forests, is due to the lack of available above ground nest sites. The New Zealand falcon's habit of ground nesting within plantation forests makes them susceptible to predation (Hyde and Stewart, 2002).

2.5 Hide Observations of Nesting Bush Falcons

Bird of prey species are generally not shy (Brown, 1976). This makes them good subjects for direct nest observations. The New Zealand falcon is one of the most aggressive bird of prey species during nest defence (Fox, 1977a). The New Zealand falcon is a relatively small bird of prey, and therefore as suggested by Newton (1979), should be more tolerant of disturbances.

Ground nesting in plantation forests provides an excellent opportunity to study the breeding behaviour of bush falcon using direct observations from a hide. Direct observations from hides have been successfully used to study wild New Zealand falcons at the nest (Fox, 1977a; Jones, 1998; Moon, 1970, 2005). Provided that care is taken in the setup of the hide and disturbance during sensitive stages in the breeding cycle is avoided, nest desertion should not occur. In the event that the nesting pair seems unduly disturbed by the presence of the observation hide, it should be immediately removed (Fox, 1977a; Moon, 1970, 2005). Hubert *et al.* (1994), show that hides can be effective tools in describing the feeding behaviour of nestling common buzzard.

Improvement in the knowledge on the behavioural and morphological development of the bush form of the New Zealand falcon may help to improve age estimation of the eggs and the young taken at a distance (Penteriani *et al.*, 2005).

Direct observations aided by the ground nesting habit of plantation nesting New Zealand bush falcons should improve the overall understanding of this threatened species. Comparisons between different management practices by plantation forests may be possible using a combination of breeding behaviour, morphological development and productivity of New Zealand falcon. Management practices that provide the best conditions for nesting falcons can then be implemented by forest managers. Furthermore, the relative condition of New Zealand falcon populations within different plantation forests may indicate the overall health of that ecosystem (Lawrence, 2002). This study also provides an opportunity to further our understanding of adaptation of New Zealand falcons to forestry practices

3. Chapter Three - Methods



3.1 General Methods

In this study, the breeding behaviour and development of two pairs of New Zealand bush falcons, in Kaingaroa Forest (exotic plantation forest), was observed. Direct observations were made from a custom built hide, for part of the incubation, the entire nestling and early post-fledging period. Intermittent unconcealed observations were made during the egg laying period and later stages of the post-fledging period. The nest scrapes were located using the techniques extensively described by Stewart & Hyde (2004). Both nest scrapes were situated on the ground with minimal cover provided by the nest tree fern (*Dicksonia* sp.). They were in unplanted forest compartments with only slash remains from recent clear-fell harvesting of the mature trees. Nest observations were made between the 5th of November 2006, and the 2nd of March 2007. To avoid confusion, a glossary of terminology used in this thesis is located in Appendix 4.

3.2 Hide Observations

Once the nest scrape was located, the hide was constructed to the south of the nests location. This was used to reduce the likelihood of sun strike affecting nest observations. The two nests were observed using a 25x 60 spotting scope and 10 x 50 binoculars from a hide situated between *ca.* 20 and 50 m from the nest site. Some observations were made unaided when optic equipment was not necessary. Observations were undertaken continuously for *ca.* 6 hours per observation day. Observation periods were only made during daylight and occurred at two main sections of the day. “Morning” observations generally started within an hour of sunrise and continued until near midday. “Afternoon” observations generally started in the mid-afternoon and continued until after sunset, once the light became too dim to see activity at the nest with the spotting scope (Dykstra et al., 2003). Occasional observations were made from mid-morning until mid-afternoon as an overlap of the two main observation periods. Due to the long duration of the study the start time of the observation days was adjusted slightly for the seasonal changes in sunrise times. The hide was sited in a location that provided both a good view into the nest scrape and also visibility of regular food transfer sites. Refer to Figure 3.1 of the hide setup in C333. The observer

approached the hide whilst attempting not to illicit a defensive response from the nesting falcons.



Figure 3.1 The custom-built hide setup in compartment 333. Ridging of the clear-felled slash can be seen in the foreground, running diagonally towards the nest scrape.

3.2.1 Recordings made during Observations

During the incubation period, the following observations were recorded:

- a. Incubation bouts and provider
- b. Egg turning
- c. Prey deliveries

During the nestling and early post-fledgling period recorded observations were:

- a. Brooding bouts and provider
- b. Prey deliveries, provider, type of delivery, prey passed, and to whom
- c. Feeding bouts, provider, prey fed, number of food portions, and to which young

Prey items delivered and fed to the young were classified to the finest taxonomic level possible from observations. The prey items were also assigned a size class and recordings were made as to the level of preparation, such as plucked, decapitated and wingless. Throughout the field observations in any other notable behaviour of either

parents, or young in and around the nest area were recorded. All possible disturbance events were also recorded. Important stages in the breeding cycle of the falcons were recorded. Behavioural developmental stages in the young; including first feeding, first self-feeding and first flights were also recorded. Refer to Manual 1 in Appendix 1 for a full detailed description of the methods and hide design used in this study.

3.2.2 Identification of Individuals

The adults were identified primarily using their differences in size. The New Zealand falcon is reverse sexually dimorphic, the female weighing about a third more than the male (Marchant and Higgins, 1993). The female at compartment 333 and both parents at compartment 159 had been colour banded previously. Where visible these band combinations could be used to identify the adults. Other features used to determine the sex of the adults included facial markings (especially the malar stripes and occipital ridge colouring), shape of the head, vocalisation differences, and occasionally behavioural differences (Collopy, 1984; Jenkins, 2000). Identification of the chicks in and around the nest was based on size, pattern of down loss, and once banded from their coloured leg band combinations.

3.3 Hide Observation Coverage

Continuous observation from the hide lasted about six hours per day (SD= 1.13, range= 15 minutes - 7 hours and 27 minutes). The hide was setup at two different nest sites, both within unplanted forest compartments. Each nest site was a different pair of New Zealand falcons observed during the 2006-2007 breeding season.

3.3.1 Nest Site 1

Observations from the hide at compartment No. 333 covered the last 6 days of the incubation period, the entire nestling period, and 15 days of the post-fledging period. Hide observations at compartment 333 totaled 278 hours. Further unconcealed observations of the fledglings were made intermittently and cover the period of just over nine weeks (until Day 93) of the post-fledging period.

3.3.2 Nest Site 2

Hide observations at compartment No. 159 covered the last 18 days (*ca.* half) of the incubation period, the entire nestling period, and 3 days of the post-fledging period (calculated from the fledging date of the female young). Once the young reached 39 days old no further observations were made of the fledglings. A total 342 hours were observed from the hide at compartment 159.

3.3.3 Morphological Development of Young and Prey Remains

The nest was visited regularly after the chicks had hatched to obtain photos of the chicks' morphological development. Time in the nest area was kept to a minimum to reduce nest disturbance. Generally the nest was visited soon after the observations ceased in the hide. Whenever the nest was visited, prey remains were recorded and any pellets found were collected.

3.4 Meteorological Data

A remote weather station was installed in the nest compartment, at the start of the entrance track to the hide. Meteorological data was recorded before and after each hide observation period and included the following:

- a. Min., Max. and current temperatures
- b. Rainfall
- c. Cloud cover (none, light cloud, patchy cloud, overcast)
- d. Wind speed (none, light, moderate, strong)
- e. Fog (presence or absence)

Considerable changes in the weather conditions during the hide observations were also recorded on the field data sheets. Figure 3.2, illustrates the remote weather station used in this study.



Figure 3.2 Remote weather station. The rain gauge can be seen on the left side of the upright, and the min./max. thermometer was housed inside the wooden covering on the right side of the upright.

3.5 Disturbance to the Nest and Other Bias:

Neither New Zealand falcons, nor, their eggs were handled as part of this research study. The banding of the chicks at both nest compartments was done by experienced members of the Raptor Association of New Zealand (RANZ). The banding of these chicks was part of a separate long-term study that is being managed by the association.

3.5.1 Methods Employed to Reduce Disturbance

A number of methods were used in order to reduce the disturbance to the nesting falcons:

- a. The floor of hide was carpeted to reduce noise inside the hide
- b. Lenses of the optical equipment did not project outside of the hide
- c. The hide was entered as discretely as possible
- d. Shade netting (often used in horticulture) was used as a screen to cover the observation flap opening on the hide
- e. Maintained a dark interior to the hide (acts in a s one-way glass works)
- f. Avoided making observations from close to the shade netting covering of the observation flap. As this may minimise the visible movements within the hide

- g. Path taken to enter the hide was not directly towards the nest. This may reduce the apparent threat to the nesting falcons from the approaching observer
- h. Hide was placed as far away from the nest, whilst still being able to conduct the necessary observations.
- i. Observations were only made from the hide after at least a week had elapsed since the laying of the last egg. Thus, minimising disturbance to the nesting birds during this sensitive period (Fox, 1977a)

3.5.2 Observations Suggesting Natural Behaviour Observed

Observations from the hide suggest that neither the adults, nor, the young falcons were overly perturbed by the presence of the hides near the nest. Several situations during hide observations in this study suggested that the New Zealand falcon behaviour was that of natural behaviour. The following is a list of some of the points that led to this conclusion:

- a. No observations of the nestlings suggested that they were disturbed by hide or the observer within
- b. Prey species were observed feeding within 2 m of the hide
- c. One prey item was caught by both parents using cooperative hunting against the base of the hide
- d. One of the young fledglings tried unsuccessfully to land on the roof of the hide
- e. An early roost of the nestlings in compartment 333 was between nest scrape and the hide
- f. After the observer entered the hide the adult falcons quickly re-settled onto the nest and relaxed
- g. In some cases the adult falcons did not leave the nest during observer entry of the hide
- h. Occasionally adults resumed dozing soon after the observer had entered the hide
- i. Adult falcons very rarely swooped the observer during entry of the hide

3.5.3 Addressing Bias

(i) Only one of the three young falcons was a female, therefore, our data best represent behaviour of male falcon nestlings.

- (ii) At compartment 333 the female disappeared between the time the chicks were 13 and 16 days old, therefore data at this site from day 17 onwards must take this fact into account.
- (iii) A single observer conducted all of the observations at both nest sites, thus reducing observer bias between sites (Vekasy et al., 1996).
- (iv) To reduce observer fatigue continuous observations lasted no longer than 7.5 hours.

3.6 Analysis of Data

All of the field data was categorised and the relevant information input into Microsoft Office Excel 2003 (version 11). Any subsequent analyses and presentations of the data for this thesis were also made using the previously mentioned software.

3.7 Equipment Failures

Fogged lenses were probably the most difficult failure of the equipment used in this study. Fogging of the spotting scope usually only reduced the visibility slightly. In some cases the binoculars or unaided observations had to be employed for short periods until the lens cleared. The spotting scope used in this study was very tolerant of rain on the lens. It had a lens hood which prevented most of the rain from reaching the lens. During extremely windy weather events the hide shook quite considerably, making observations through the scope difficult due to lens shake. This was improved by making the observation cover (shade cloth) extra loosely attached to the spotting scope.

4. Chapter Four – Results



4.1 Introduction

In the following chapter the results from direct observations are explained in detail. This chapter will cover the incubation and egg turning, prey delivery, and lastly the feeding of the young.

Where C333 and C159 are used in the following text, these refer to nest compartment numbers 333 and 159 respectively. Red and Yellow refer to chicks hatched during this study at C333, and are therefore not to be confused with other New Zealand falcons given the same names in prior research (Fox, 1977a). The female at C333 disappeared from Day 16, she was presumed dead. The nest at C159 was known to be a re-nesting attempt after their previous clutch of eggs were presumed to have been predated. The previous nest scrape was located in a neighboring compartment about 1 km in a direct line of sight of the nest scrape observed in this study. Additional observations of interest are included in Appendix 5.

4.2 Incubation and Egg Turning

4.2.1 Incubation

Incubation in this study was defined as the observed time that either parent spent sitting on the eggs during the incubation period. Direct observations, however, were unable to determine when the incubating parent was actually heating the eggs. The incubation period was initiated on the day the last egg was laid and continued until the last chick hatched (Nice, 1954).

Daily incubation remained consistently high over the observed incubation period at both nest compartments [range = 90.3 - 99.2%]. The highest daily incubation recording, 99% of observed time, was made on the day prior to hatching at C159. Weather on this day consisted of very strong and gusty winds. The eggs were only left unattended very briefly between incubation bouts throughout the incubation period (Fig. 4.1) The mean period between incubation bouts, inter-incubation bout length, was a mere one minute. Incubation remained very high over the whole incubation period with the exception of two events.

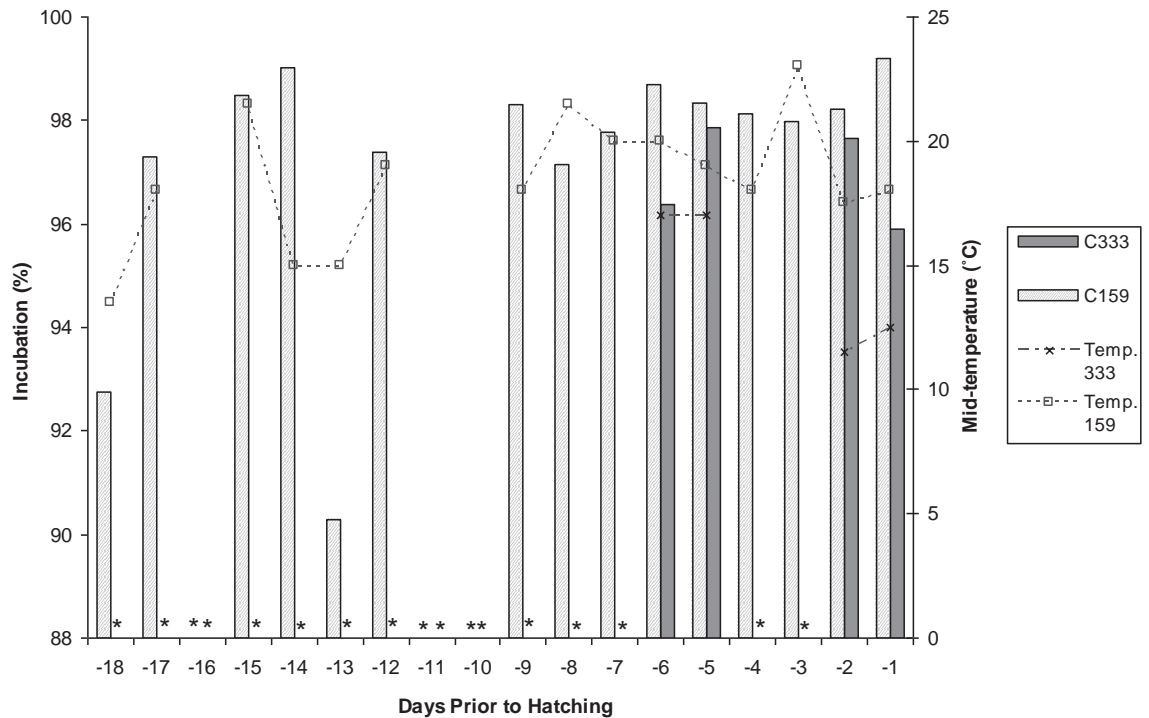


Figure 4.1 The observed daily incubation. Observations lasted on average six hours per day. Hatching date was defined as the day on which the first eggs hatched (hatch dates = 12.11.06 at C333 & 22.01.07 at C159). -1 on the x-axis represents one day prior to hatching. Mid-temperature represents the mid-point between the maximum and minimum temperature recorded during the observation period. * = missing data. Data represents daytime observations from *ca.* 06:15 h to 17:15 h in C333 and *ca.* 05:50 h to 21:00 h in C159. Incubation period at C159 = 25 days.

Daily incubation remained above 95%, with the exception of two days when disturbances occurred at C159. The first event occurred 18 days prior to hatch when the hide was entered for the first time. The second such event was observed 13 days prior to hatch when a stoat attempted to predate the eggs (Fig. 4.1). The eggs were repeatedly defended from the stoat with loud kekking calls and swooping flight attacks (dive-bombing). Both of these events caused noticeable reductions in the daily incubation by the New Zealand falcons.

Male and female New Zealand falcons share responsibility of the diurnal incubation. The partitioning of diurnal incubation, however, is not equally shared between the sexes. Overall the female's provided two thirds of the total diurnal incubation (Table 4.1). Female's also spent longer per incubating bout and undertook more incubation bouts than the males. Uncharacteristically however, the male at C159 contributed slightly more incubation than the female on three observation days (see Appendix 2, Fig. A.2). Data from C333, however, only represents 4 days of the total incubation period of *ca.* 30 days (based on mean New Zealand falcon incubation period

of 32 days by Fox (1977a)). In contrast, C159 data represents just over half of 25 day incubation period.

Table 4.1 Summary statistics for observed incubation periods. Times greater than 10 minutes were rounded to nearest whole number. Percentages and shortest bout values were rounded to one decimal place.

		C333		C159	
		Time (mins.)	%	Time (mins.)	%
Mean incubating bout	♂	23		36	
	♀	35		42	
Total time incubating	♂	477	32.4	2086	36.0
	♀	993	67.6	3702	64.0
Longest incubation bout	♂	82		106	
	♀	98		184	
Shortest incubation bout	♂	1.0		0.4	
	♀	0.6		0.2	
		Count	%	Count	%
No. of incubation bouts	♂	21	41.2	58	39.7
	♀	30	58.8	88	60.3

4.2.2 Egg Turning

Egg turning was recorded as occurring whenever the attending falcon turned the eggs with their beak (Nelson 1970), rotated within nest scrape with up and down wing movements, or made up and down wing movements without rotation. Up and down movements of the wings were thought to represent the involvement of the feet in egg turning. It should be noted that rotations within the nest scrape were not always accompanied by up and down wing movements. Hide observations, however, could not confirm with certainty the use of the falcon's feet in turning of the eggs.

The mean egg turning rate for both nest compartments prior to hatch was 4 turns per hour, but between days this varied between 0.2 and 8.4 turns h^{-1} (Fig. 4.2). Daily egg turning rates showed a bimodal distribution over the observed incubation period. Observed egg turning rate peaks occurred at Day 17 and the day of hatch (Day 0). The egg turning rate recorded on the day of hatch was one and half times as frequent as the mean turning rate prior to hatch. Although a single egg remained for up to a week after the first eggs hatched, virtually no further egg turns after Day 1 were observed. The rate of egg turning by the males (*ca.* 4 turns h^{-1}) was lower than the females (*ca.* 6 turns h^{-1}). C333 generally had higher egg turning rates than C159, based on the six comparable days between the nest compartments.

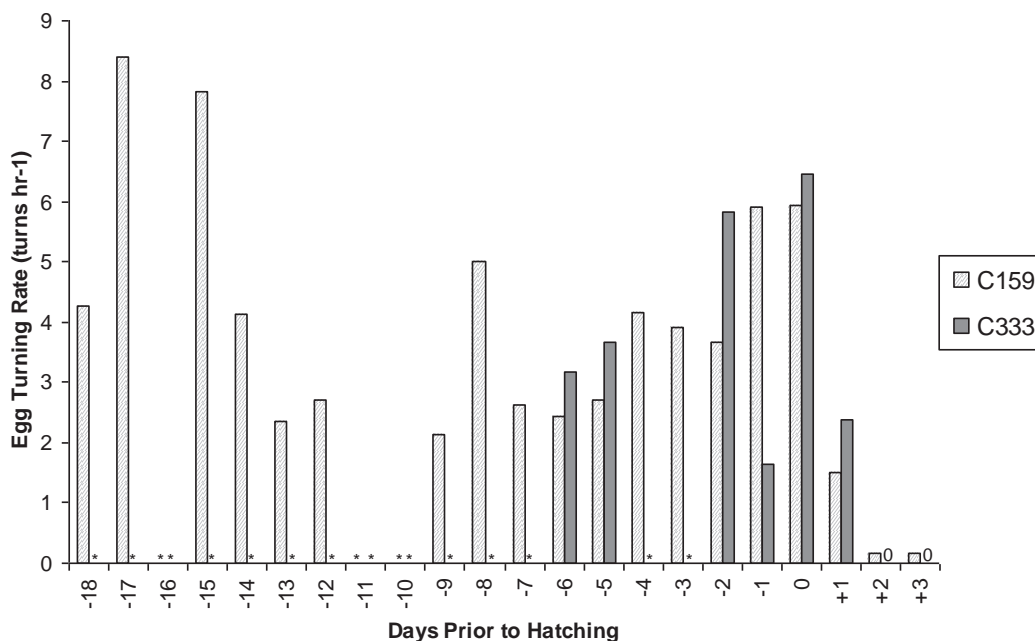


Figure 4.2 Daily observed egg turning rate. Observations lasted on average six hours per day. * = missing data. Clutch size = 3 at C333 & 4 at C159. Hatch date at C333 was 12.11.06 & at 22.01.07 at C159. Data represents daytime observations from *ca.* 06:15 h to 17:15 h in C333 and *ca.* 05:50 h to 21:00 h in C159. No further egg turning was observed after Day 3.

4.3 Brooding of the Nestlings

Observed brooding events were defined as the time spent by either parent sitting or otherwise covering at least half of the full brood of chicks (Dykstra et al., 2003). The nestling period in this study began on the day of hatch of the first chick and continued until the first flight was observed by one of the chicks. Day zero refers to the day of hatching of the first chicks in both nest compartments. Note, in C333 one chick hatched a day later than the other two, but died before day 10.

The amount of daily brooding showed a general downward trend from hatch date through until the chicks were 13 days old (Fig. 4.3). After Day 13, any further brooding was termed stress brooding, occurring only when environmental conditions were particularly adverse. Observed brooding was highest on the day of hatch when brooding of the chicks was almost continuous. Daily brooding remained consistently above 80% until the chicks were five and two days old at C333 and 159 respectively. After Day 6 at C333 and Day 3 at C159, the amount of brooding showed a general downward trend until Days 13 and 12 respectively. The time between incubation bouts, inter-brooding bouts, were generally short from hatch date until Day 5 (Fig. 4.4). From Day 6 the parents left the chicks for longer periods each day. The parents only began to leave the

chicks unattended for more than four hours during the day once they had reached 10 days old.

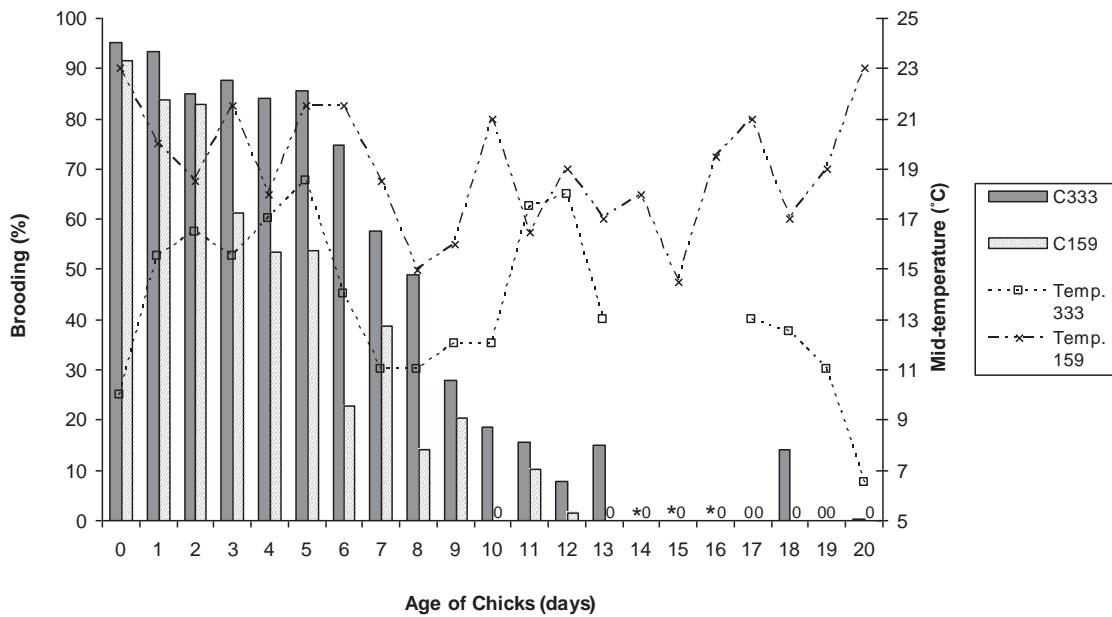


Figure 4.3 Percent of observed time brooding the chicks per day. Observations lasted on average six hours per day. Age 0 = hatch date (12.11.06 in C333 and 22.01.07 in C159). * = missing data. 0 = no brooding observed. Mid-temperature represents the mid-point between the min. and max. temperature recorded during observation. Data represents daytime observations from *ca.* 05:20 h to 20:50 h for C333 and *ca.* 06:00 h to 20:30 h for C159. From Day 16 female parent in C333 absent (presumed dead).

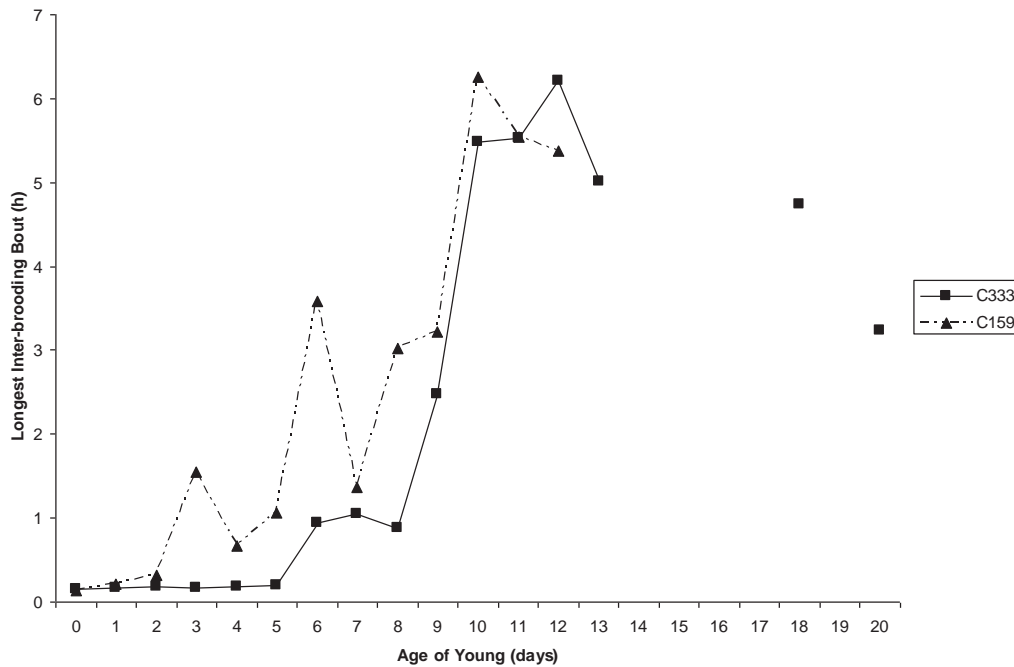


Figure 4.4 Longest inter-brooding bout (h) per day. Observations lasted on average six hours per day. Age 0 = hatch date (12.11.06 in C333 and 22.01.07 in C159). Days 14-16 at C333 were missing data. From Day 17 at C333 no brooding was observed, with exceptions of Day 18 and 20. From Day 13 in C 159 no brooding was observed in C 159. Data represents daytime observations from *ca.* 05:20 h to 20:50 h for C333 and *ca.* 06:01 h to 20:31 h for C159. From Day 16 female parent in C333 absent (presumed dead).

Ambient temperature is likely to affect the intensity of brooding with more brooding occurring on colder days (Fig. 4.3). Variations in temperature were most significant during the period of transition to complete thermo-regulation by the chicks. Mid-temperature represents the average of the minimum and maximum temperatures recorded during that days' hide observation period. The mid temperature between hatch and when the chicks reached 10 days old was on average 6°C colder in C333 than 159. By the time the chicks reached 14 days old the majority of the diurnal brooding had ceased.

Time of day appeared to affect the amount of brooding done by the falcons. Once the chicks were six days old they were left unattended for just under an hour (Fig. 4.4). The longest unattended period was towards the end of the morning observations as the temperature was warming up. From about Day 8 brooding parents focus their reduced brooding progressively earlier in the morning. All observed brooding of the chicks greater than 10 days old occurred before 8 am.

The females did most of the brooding of the chicks, especially on hatch date (Figs. 4.5(a) & (a)). The longest observed brooding bout, three and half hours, was by the C333 female when the chicks were a day old (

Table 4.2). Almost all of the brooding by the male falcons occurred before the chicks reached seven days old (Figs. 4.5(a) & (b)). The males' involvement in the chick brooding varied considerably between nest compartments. At C333 the male's brooding bouts generally lasted half as long as the female's. Compared with slightly longer than the female's at C333 (

Table 4.2). The male's contribution to brooding at C333 was insignificant, about 20% of that provided by the male at C159. The male at C159 provided considerable brooding from the day of hatching and Day 5, after which he undertook no further brooding (Fig. 4.5(b)). The female at C333 disappeared from about Day 17, presumed dead (Fig. 4.5(a)). On the following day, Day 18, the male spent much more time brooding than earlier in the nestling period. On this day he spent much of the observed time in and around the nest area. This was in contrast to the male's behaviour at C159; from Day 6 he returned to the nest area only to deliver prey.

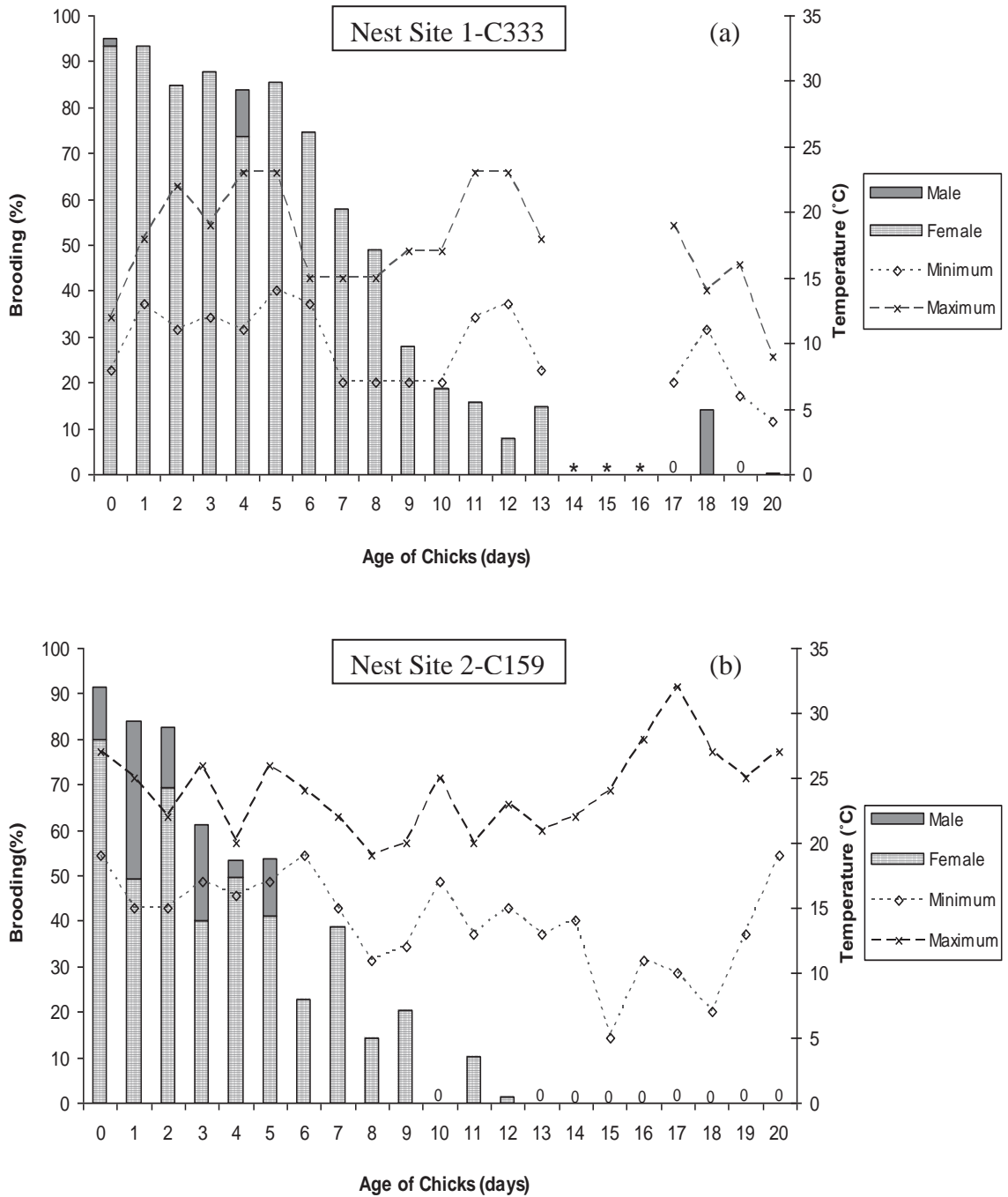


Figure 4.5 Percent of observed time brooding per day at (a) C333, (b) C159. Observations lasted on average six hours per day. Age 0 = hatch date (12.11.06). * = missing data. 0 = no brooding observed. Minimum and maximum represent temperatures recorded during the observation period.. Data represents daytime observations from *ca.* 05:20 h to 20:50 h at C333 and *ca.* 06:01 h to 20:31 h at C159. On Day 2 at C333, male provided a short amount of brooding. At C333 from Day 16 the female parent was absent (presumed dead). The last brooding event observed was a very brief bout on Day 20 in C333. The last brooding event was recorded on Day 12 at C159.

Table 4.2 Brooding summary statistics. Times greater than 10 minutes were rounded to nearest whole number. Percentages and shortest bout values were rounded to one decimal place.

		C333		C159	
		Time (mins.)	%	Time (mins.)	%
Mean brooding bout	♂	11		23	
	♀	26		19	
Total time brooding	♂	97	3.2	365	18.0
	♀	2907	96.8	1661	82.0
Longest brooding bout	♂	37		77	
	♀	211		87	
Shortest brooding bout	♂	0.3		1.9	
	♀	0.2		0.1	
		Count	%	Count	%
No. of brooding bouts	♂	9	7.4	16	15.5
	♀	112	92.6	87	84.5

Adverse weather conditions were recorded on both Days 18 and 20 in C333. The weather in C333 on Day 18 consisted of cold temperatures with periods of heavy rain. Day 18 had the highest rainfall recorded during an observation day, 8.5 mm during 6 hours. Unfavorable weather conditions were also recorded at C333 when the chicks were 20 days old. It was windy, overcast, and the lowest temperatures to date were recorded, 4°C minimum and 9°C maximum. Apart from these two observation days, weather conditions during the brooding stage (hatch to Day 20) of the nestling period were relatively mild for both nest compartments. During the brooding stage mean minimum and maximum temperatures recorded at C333 were 10 & 18°C and 14 & 24°C at C159.

Single chick mortalities were recorded at both nests, early in the nestling period. The youngest chick at C333 died between the afternoon of Day 9 and first light of Day 10, when the chick was 8 or 9 days old. By Day 8 the youngest chick was noticeably less developed than the older chicks, however, it was still being fed (see Appendix 2, Fig. A.3). The chick mortality at C333 coincided with the observation of the two older chicks leaving the nest scrape for the first time. On Day 10 the female was observed briefly leaving the older chicks to brooder the younger one in the nest scrape. The younger chick remained motionless and was presumed dead prior to the hide observation on that day. The chick mortality at C159 occurred between the ages of 5 and 7 days old. The chick was presumed to have died at 6 days of age, although, the precise age could not be determined.

Minor human induced disturbances were recorded on Days 4 and 5 in C333, however, brooding appeared largely unaffected. Both disturbance events were caused by forest contractors being present in the nest compartment. The disturbance on Day 4 forced the observer to leave the hide briefly. The disturbance on Day 5 was very brief. On both of these days the amount of time spent brooding remained above 80%. Further descriptions of these disturbance events can be found in Appendix 5, under the heading “Tree Planting Mound Surveyors”.

4.4 Prey Delivery

Prey delivery in this study refers to the passing of captured prey items by the adult falcon near to, or at, the nest area. When possible, repeated deliveries of the same prey item were removed from the analyses. Therefore any prey deliveries were assumed to be deliveries of fresh items (first time brought to the nest area) (Palmer et al., 2004; Vekasy et al., 1996). Prey deliveries during the incubation period were also excluded from the following analysis due to very low occurrences. Only 11 prey items were delivered over 120 hours of observation during incubation [mean = 1 prey item per 6 hours 19 minutes at C333 & 1 prey item per 13 hours 29 minutes at C159]. The analyses of prey delivery rate represent a combination of the nestling period and the early part of the post-fledging period observed from the hide.

The rate of prey deliveries increased from the day of hatch to about Day 16, after which it leveled off and remained relatively high for the remainder of the nestling and early post-fledging periods. The peak in prey delivery appeared to occur several days earlier in C159 than C333 (Fig. 4.6). Although there was substantial daily variation on the whole prey delivery rates were quite similar between nest compartments [C333 = 1 prey item per hour 12 minutes; mean delivery rate C159 = 1 prey item per hour 15 minutes]. An abnormally high prey delivery rate was recorded at C159 on Day 20, when over two prey items per hour were delivered to the nest area. When the chicks at C333 were 20 days old, the recorded prey delivery rate was considerably higher than that of any other observation day from either nest compartment. The following day in the same compartment, Day 21, no prey items were delivered.

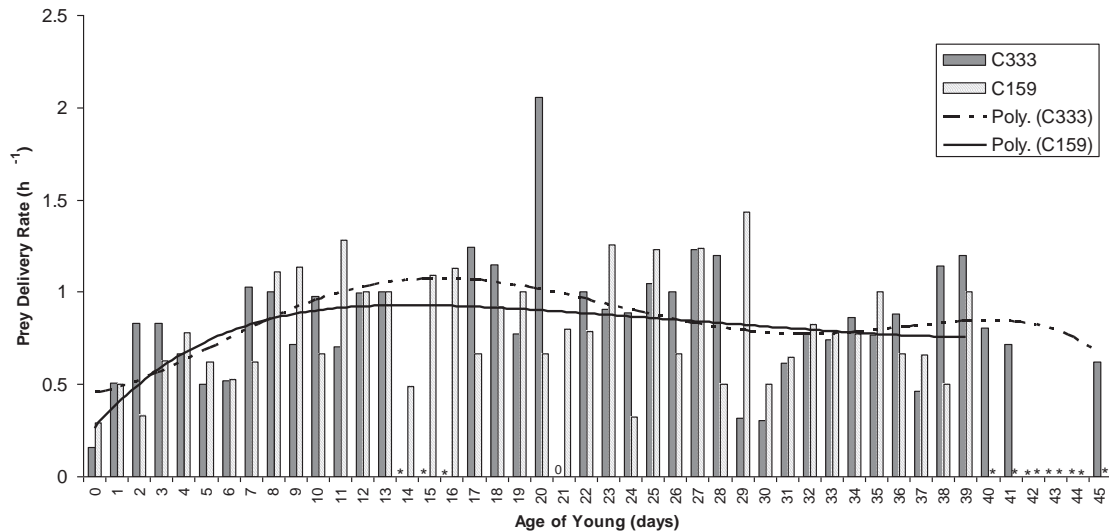


Figure 4.6 Observed hourly delivery rate of prey items to the nest area throughout the nestling and early post-fledgling period. * = missing data. 0 = observation days in which no prey deliveries was observed. Observations were only made during daylight and covers at C333 and *ca.* 06:00 h to 20:31 h at C159. Excludes any prey deliveries made prior to hatch date. The female parent was absent from Day 17 (presumed dead) at C333. That the prey delivery rate for day 34 at C333 is the mean of the morning and afternoon observations. Both male chicks at C333 fledged at 31 days of age. The male chick at C159 fledged at 31 days and the female at 36 days of age.

Very low prey delivery rates were recorded on the day prior to fledging of the male chicks (Fig. 4.6). There were very low prey delivery rates recorded when the C333 young were 29 and 30 days old. Similarly low delivery rates were recorded in C159 when the young were 28 and 30 days old. The delivery rate on Day 35, one day prior to fledging of the female chick at C159 did not show the same trend.

Birds (Aves) made up the majority of the delivered prey items at both nest compartments, with the tiny remaining proportion being made up by both mammals (Mammalia) and insects (Insecta). During observations at the nest in C159, no prey items delivered to the nest were identified as belonging to the class Insecta. The proportions of prey deliveries from different prey classes were quite similar between the two compartments. Compartment 159 had a slightly higher proportion of prey deliveries that could not be identified to prey class using observations [unknown prey class at C333 = 22.3%; C159 = 31.0%].

During the early nestling period, all prey items delivered by the male were passed to the female parent, before they were fed to the young. Half way through the nestling period the type of transfer of prey deliveries made by the male changed. The male began to pass prey items directly to the chicks, instead of first passing them to the female before they were fed to the young. The first prey delivery by the male parent

directly to the chicks was observed at Day 17 in C333 and Day 12 in C159 (refer to Fig. 6.1, Chapter six).

Male's provided the majority of the prey deliveries during the nestling and early post-fledging periods. The females at both nests were recorded delivering prey items that they had caught from Day 12. Female-caught prey items were recorded when no prey pass was heard or seen near the nest and prey did not resemble cached items. The solo male in C333 provided his chicks with a higher prey delivery rate than both parents combined at C159. Over the first 14 days of the nestling period at C333, while the female was still present, prey delivery rate averaged 1 item every hour 20 minutes. After the female disappeared from C333, the prey delivery rate by the solo male was higher than that provided by both parents in C159 during the same period [1 prey item per hour and 5 minutes; 1 item per hour and 13 minutes respectively]. The C333 female contributed a mere 7% of the prey deliveries, compared to 20% that was provided by C159 female over the same time period.

The allocation of whole prey items was unequally shared between young within each brood. From Day 22 nearly all prey deliveries were whole prey items passed directly to the young. At which point the chicks were confidently self-feeding and often monopolised whole prey items passed to them. Allocation of prey deliveries between the two young in each nest was quite variable between observation days (Table 4.3). Yellow, one of the two male young at C333, received substantially (10%) more of the observed overall whole prey item deliveries than Red. At C333, between Day 22 and 30 both young received similar daily allocation of whole prey items. However, from days 31 onwards, Yellow generally received more than his sibling Red. Pale, the female from the C159 brood, received only slightly more (6%) of the overall whole prey items than her male sibling Dark.

Table 4.3 Observed allocation of whole prey items between the young from 22 days of age. n = number of whole prey items passed per observation day. Σ = cumulative prey items passed. Day 45 at C333 was omitted as no recipients of whole prey item deliveries could be identified. Data represents daytime observations from *ca.* 05:08 h to 21:00 h at C333 and *ca.* 06:00 h to 20:31 h at C159. All male young fledged on Day 31, the female at C159 fledged on Day 36.

Age of Young (days)	C333					C159					
	Red (♂)	Σ Red	Yellow (♂)	Σ Yellow	n	Age of Young (days)	Dark (♂)	Σ Dark	Pale (♀)	Σ Pale	n
22	3	3	1	1	5	22	1	1	1	1	2
23	1	4	1	2	6	23	2	3	6	7	8
24	2	6	2	4	7	24	2	5	0	7	2
25	4	10	4	8	8	25	2	7	5	12	7
26	4	14	4	12	8	26	2	9	2	14	4
27	4	18	4	16	8	27	1	10	5	19	6
28	3	21	4	20	8	28	1	11	1	20	2
29	1	22	0	20	2	29	3	14	2	22	9
30	1	23	1	21	2	30	1	15	2	24	4
31	0	23	3	24	4	31	3	18	1	25	4
32	0	23	5	29	5	32	3	21	2	27	5
33	0	23	3	32	5	33	2	23	2	29	4
34	3	26	4	36	9	34	1	24	0	29	5
35	3	29	2	38	5	35	1	25	5	34	6
36	2	31	1	39	6	36	3	28	0	34	4
37	0	31	0	39	3	37	1	29	1	35	4
38	4	35	3	42	8	38	2	31	1	36	3
39	3	38	4	46	8	39	3	34	3	39	6
40	0	38	3	49	6						
41	2	40	3	52	5						

4.5 Feeding of the Young

In the following section assisted feeding and self-feeding will be used to describe the type of feeding events with respect to level of parental input. Assisted feeding refers to events where at least one parent is present during the feeding event, tearing up prey into food portions which were then passed individually to at least one of the young (Dykstra et al., 2003). Self-feeding on the other hand, refers to feeding events when the young either tear up prey independently of their parents, or swallow the prey item whole. Feeding rate of the young included all feeding events of the young New Zealand falcon, regardless of whether the prey item was a fresh prey delivery, previously cached prey or remains from a previous feed.

The feeding rate showed a general bell-shaped curve during the nestling and early post-fledging periods. Feeding rates showed a general increase from the day of hatch, through until Day 25. After the peak, feeding rates declined until fledging and then continued to decline into the early post-fledgling period. The overall mean feeding rate was slightly higher at C333 than at C159, 1 feed per hour and 1 feed per hour and 17 minutes respectively (Fig. 4.7). However, the self-feeding by the young on prey remains occurred twice as frequently at C333 than C159. The feeding rate was unusually high, over 2 feeding events per hour, at C333 on days 17 and 32 (Fig. 4.8(a)).

On cold observation days, the feeding rate of the young tended to be above average (Figs. 4.8(a) & (b)).

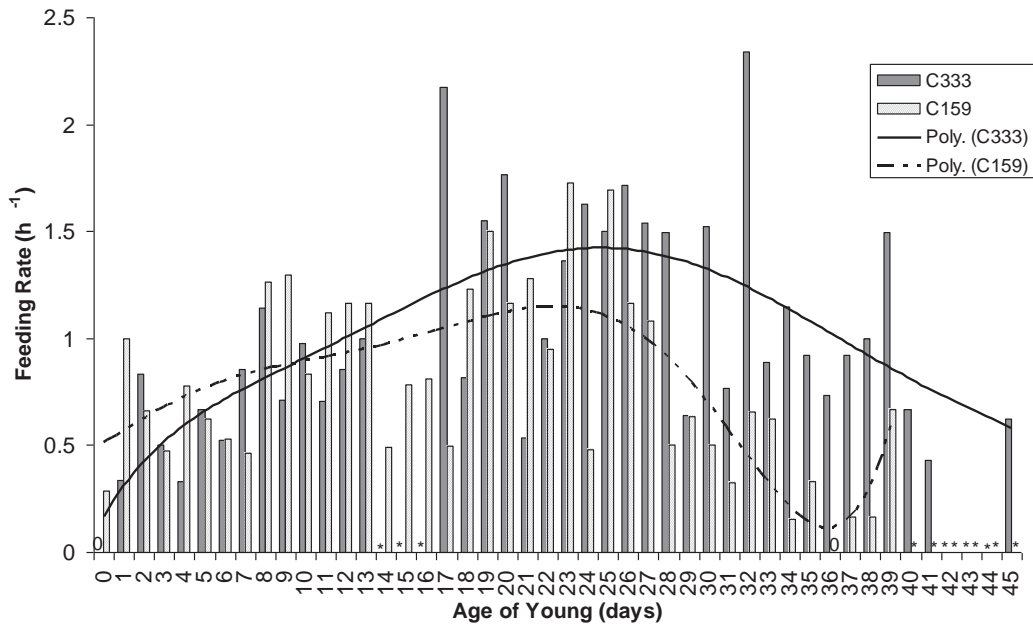


Figure 4.7 Observed hourly feeding rate of the young throughout the nestling and early post-fledgling period. Trend lines are 6th order polynomials ($R^2=0.45$ C333 & $R^2=0.52$ C159). * = missing data. 0 = no feeding of the young was observed. Observations were only made during daylight and cover from *ca.* 05:08 h to 21:00 h at C333 and *ca.* 06:00 h to 20:31 h at C159. From Day 16 female parent at C333 was absent (presumed dead). The first self-feeding by the chicks was observed at 17 days in C333 and 18 days old at C159. Both male chicks at C333 fledged at 31 days of age. The male chick at C159 fledged at 31 days and the female at 36 days of age.

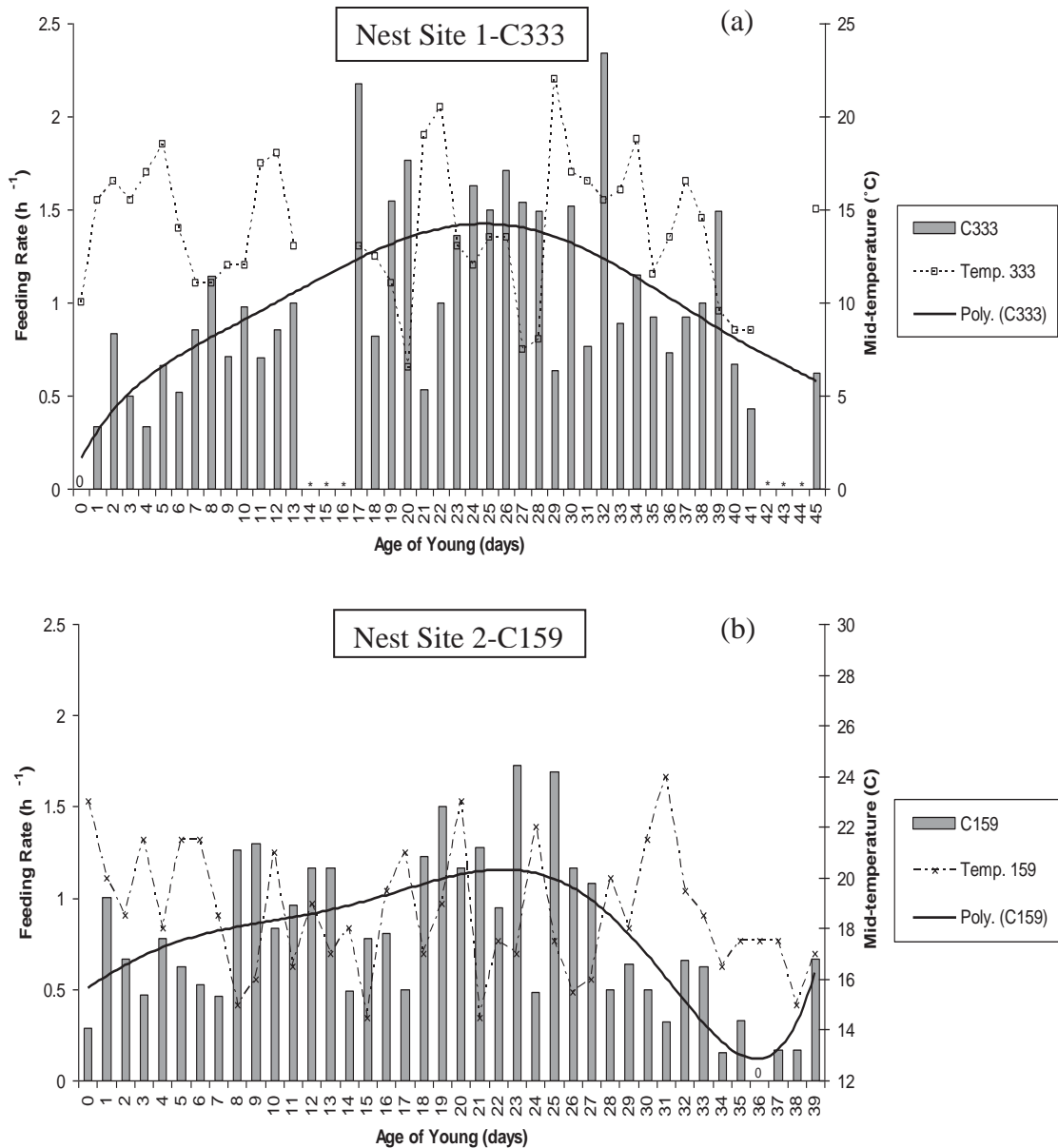


Figure 4.8 Observed hourly feeding rate of the young, throughout the nestling and early post-fledgling period at (a) C333 and (b) C159. Trend lines are 6th order polynomials ($R^2=0.52(a)$ & $0.45(b)$). * = missing data. 0 = no feeding of the young was observed. Observations were only made during daylight and cover from *ca.* 05:08 h to 2100 h at C333 and *ca.* 06:00 h to 20:31 h at C159. From Day 16 female parent at C333 was absent (presumed dead). Day 34 at C333 represents an average of the morning and afternoon observation. The first self-feeding by the chicks was observed at 17 days old at C333 and 18 at C159. The male chicks fledged on Day 31 and the female at C159 on Day 36.

Temperature had a significantly negative effect on the feeding rate of the young at both nest compartments [$F=11.44$, $P=0.001$].

The female parent at C333 provided all of the assisted feedings of the chicks prior to her disappearance somewhere between the ages of 13 and 16 days old. After the female's disappearance the male assisted with most feeding events at 17 and 18 days of age, after which no further assisted feeding events were observed. The first true self-

feeding event was observed when the chicks were 17 days old at C333 and 15 days old at C159. The female parent at C159 however, continued to assist with the feeding of the chicks to a lessening extent until they reached 28 days old. Prior to the first observation of self-feeding in the chicks, the male at C159 was only once observed attempting to assist the chicks feeding. The male's assistance to the chicks consisted merely of passing the whole prey item to the 11 day old chick twice, resulting in an unsuccessful feed. No observations were made of the C159 male tearing up prey into smaller and manageable food portions for the chicks. On one observation day four song thrushes were brought to the nest in relatively quick succession. Occasionally very small nestlings of prey species were brought to the nest.

Sub-adults made up nearly 40% of the prey fed to the young, where age of the prey could be determined. Just over half of the prey fed to the young at C333 were identified to a particular age class, two fifths of which were sub-adults. Although only about 17% of prey fed to the young in C159 could be identified to an age class, nearly one third of them were also sub-adults (see Appendix 2, Fig. A.10).

The mean number of food portions fed per feeding event showed a slightly upward trend with increasing age of the chicks in both nest compartments (see Appendix 2, Figs. A.8 & A.9). After the peak in C159 by about day 14, the mean number of food portions per feed leveled off (see Appendix 2, Figs. A.6 & A.7). Neither the sex, nor the location of the chick in the nest scrape, appeared to significantly affect the mean number of food portions it received per feeding event at C159.

The diet of young New Zealand falcon chicks consisted primarily of small introduced passerine species. A single tui was recorded as prey remains at C159, yet this species was not observed being fed to the young. One bellbird was observed being passed to a fledgling at C333 during observations outside of the hide. This is another species that was fed to the young, however it was not identified during hide observations. Chaffinches (*Fringilla coelebs*) made up the majority of prey items fed to the young at both nest compartments (Figs. 4.9 & 4.11). Greenfinches (*Carduelis chloris*) and blackbirds (*Turdus merula*) were occasionally fed to the young at both nest compartments. North Island (NI) robins (*Petroica australis longipes*) were a minor component young's diet and were only observed in C159. Yellowhammers (*Emberiza citrinella*) were also a minor prey species, only observed at C 333 (Fig. 4.9). Only one species of mammal and insect were fed to the young, a weasel (*Mustela nivalis*) and huhu beetle (*Prionoplus reticularis*). The frequency of yellowhammer and blackbirds

were considerably lower in this study compared to analysis of pellet and prey remains by Seaton (2007) (Figs. 4.3 & 4.4). They also show a much wider range of prey species, relative to this study.

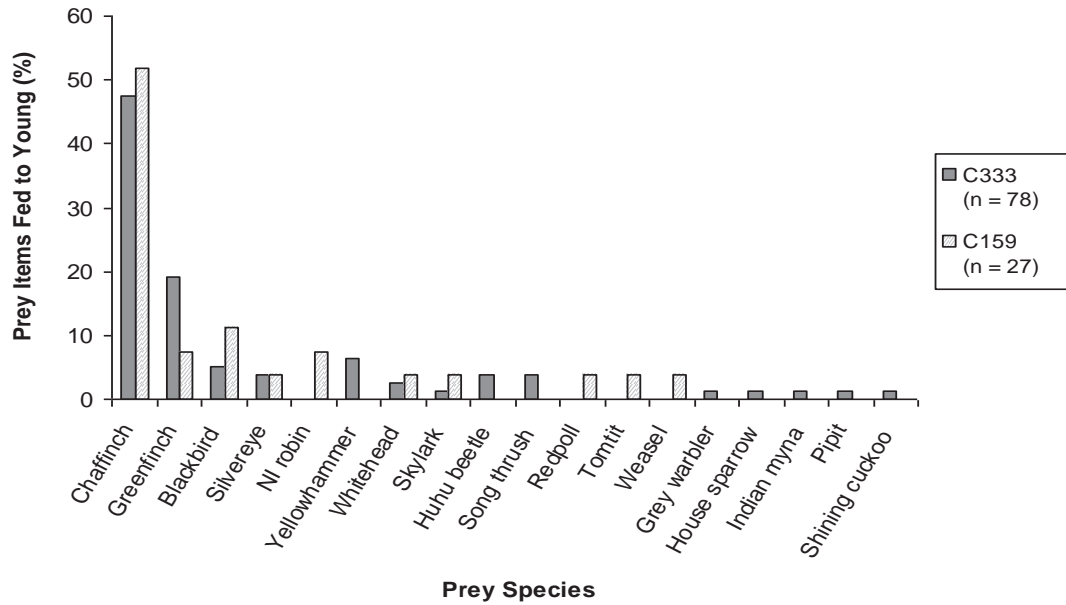


Figure 4.9 Observed percent of known prey species fed to young. Unknown prey items accounted for 59% of the total prey items at C333 and 83% at C159. From Day 16 female parent at C333 was absent (presumed dead).

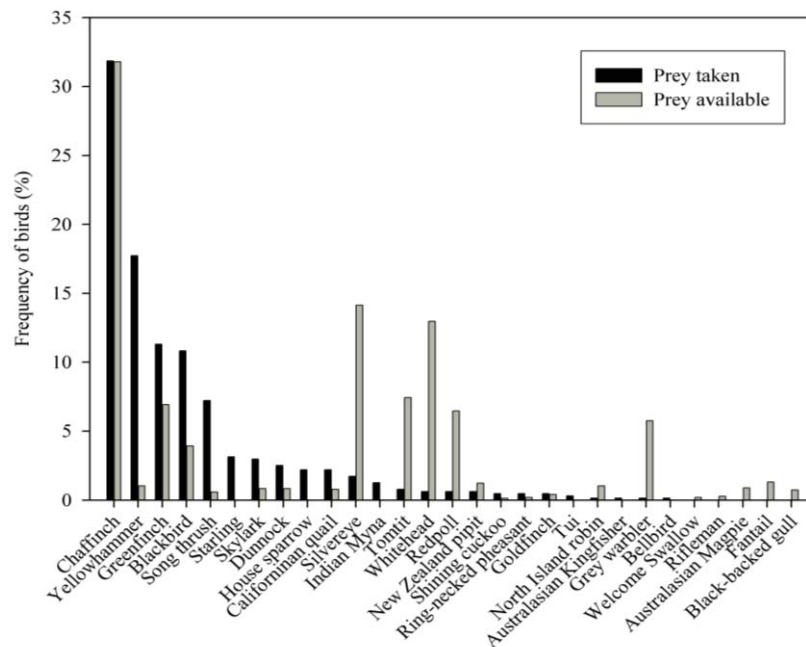


Figure 4.10 Frequency of bird species taken by nesting New Zealand falcon compared to prey availability. (reproduced from Seaton 2007, p36)

At both nest compartments, chaffinches made up the bulk of the biomass of prey fed to the young (Fig. 4.11). Although, blackbirds were not frequently fed to the young,

they made up a significant component of the overall biomass of the prey fed to the young. In C159, blackbirds provided a near equal proportion of the total prey biomass of chaffinches. As a result of their above average biomass, NI robin, song thrush (*Turdus philomelos*) and weasels make up considerably more of the food than relative frequency suggests.

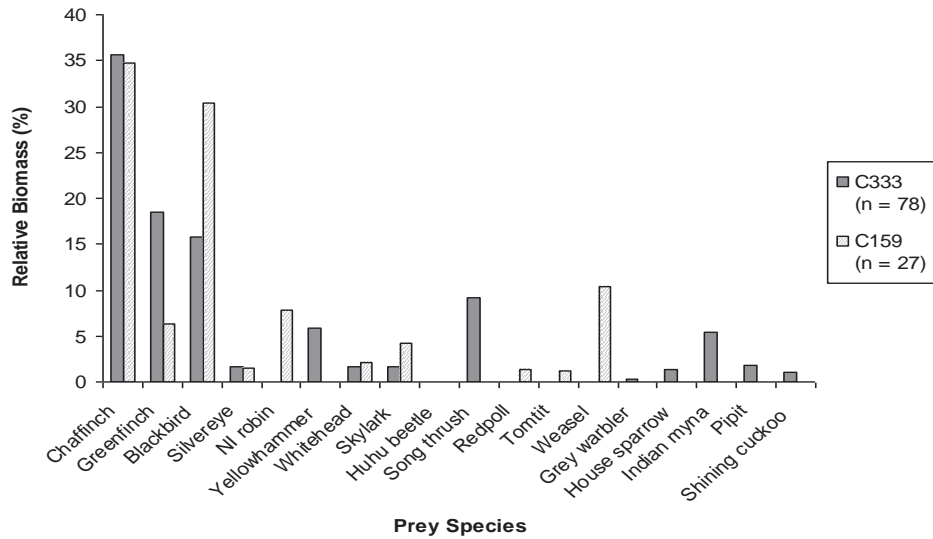


Figure 4.11 Relative biomass of prey species fed to the young. Unknown prey items accounted for 59% of the total prey items at C333 and 83% at C159. From Day 16 female parent at C333 was absent (presumed dead).

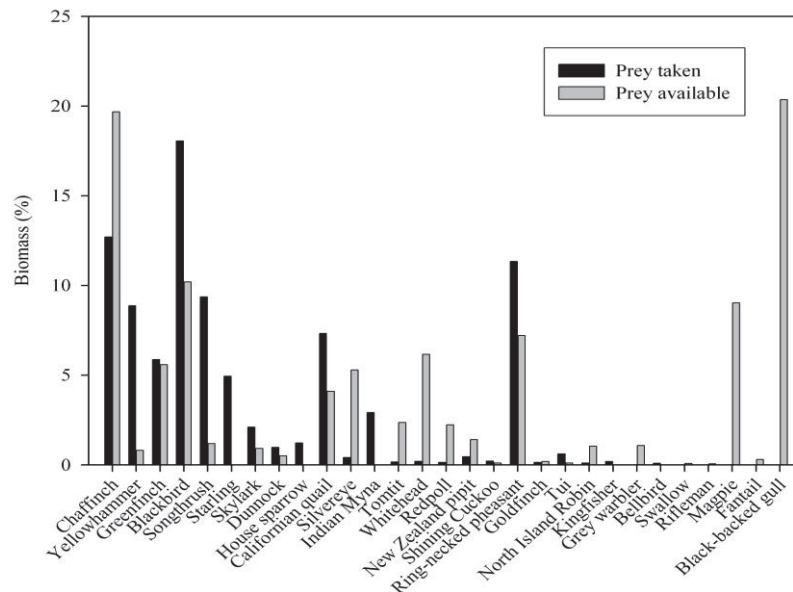


Figure 4.12 Biomass of prey species taken by nesting New Zealand falcon compared with the biomass of prey available. (reproduced from Seaton 2007, p37)

5. Chapter Five - Discussion



5.1 Introduction

This chapter is organized into four main sections: incubation, brooding, prey delivery, and feeding of the young. As in the rest of this thesis, the three forms of the New Zealand falcon are identified as the bush, eastern and southern form.

5.2 Incubation

5.2.1 Introduction

Generally, the incubation period is defined as being initiated after the laying of the last egg in a clutch and continuing until the hatching of the last chick (Nice, 1954). In this study incubation was recorded as when ever either parent was sitting on the eggs. Results from this study are consistent with the report that captive peregrine falcons do not initiate full incubation until after completion of the clutch (Cade, 1960).

5.2.2 The Incubation Period

Fox (1977a) reported that the incubation period for New Zealand falcons is between 29 and 35 days. In this study, the incubation period could only be calculated at one nest, a mere 25 days, considerably shorter than reported by Fox. Unfortunately, the incubation period calculated for C159 did not completely satisfy the definition described by Nice (1954), as one egg failed to hatch. It is unknown whether this egg was the last to be laid, or whether it would have hatched in synchrony with the other three eggs on Day 0. The incubation period found in this study was also shorter than that found in gyrfalcon. A considerable range in incubation periods have also been reported between authors for this species (Potapov and Sale, 2005).

One possible reason for the very short incubation period may be the combination of nearly constant incubation by the parents and warm ambient temperatures recorded during the incubation period for C159 (Ratcliffe, 1980). Ratcliffe (1980), reports that some of the variation in incubation periods of peregrine falcons was related to ambient temperature. Although, one egg in the clutch failed to hatch, results from C159 suggest that the incubation period in New Zealand falcon can be as short as 25 days.

5.2.3 Constancy of Incubation

Near continuous incubation was undertaken by the parents once the last egg of the clutch was laid, although there were variations due to ambient temperature. This result is consistent with other studies for both the New Zealand falcon and other falcon species overseas (Fox, 1977a; Fox, 1995; Murray, 1998). Zebra & Morton (1983) reported that even over a considerable range in temperature, incubation remained constant for white-crowned sparrows (*Zonotrichia leucophrys*). However, Cain (1985) observed similar variation, when compared to this study, in incubation due to change in temperature of bald eagles.

New Zealand falcon eggs in this study were generally left unattended for periods of about one minute. This is consistent with times reported by other authors, for both captive and wild New Zealand falcon (Fox, 1977a; Murray, 1998). The direct observations in this study failed to distinguish when the parents were actually heating the eggs, and when they were simply covering the eggs. Therefore, the recorded incubation in this study represents the proportion of observed time that either parent spent sitting on the eggs.

In this study, two different events were identified as the cause of the most obvious reductions in incubation. One such event was the first entry into the hide for observation. As a result of this disturbance, the female remained off the nest for nearly 15 minutes. The apparent impact of the event was accentuated because observation on his day was only *ca.* 3.5 hours. As a result, the female spent less than 7% of the observation period off the nest scrape. The second event that interrupted incubation was observed when a stoat attempted to predate the falcon's eggs. In this instance, the male and female were independently able to defend the clutch of eggs from the stoat. King (1990) reported that stoats can be active at any time of day or night. As this event occurred during the day, it is not possible to conclude what would have happened if the stoat had approached the nest at night. Stoats present a considerable risk to the nesting falcons. Fox (1977a), suggests that they predated the nests of New Zealand falcons, and this was later confirmed by other authors (Gaze and Hutzler, 2004; Seaton, 2007). Stoats were also reported by Ratcliffe (1980) to occasionally depredate the merlin (*Falco columbarius*), a small species of falcon. The New Zealand falcon has been observed attacking stoats and in some cases even preying on them (Fox, 1977a; King, 1990; Seaton, 2007). However, the agile and aggressive stoat is a formidable predator

capable of tackling prey much larger than itself (King, 1990). Fox (1977a) went as far as saying that for the New Zealand falcon, mustelids (primarily stoats and ferrets) present the most likely predators. The habit of New Zealand falcons nesting on the ground in pine forests makes them highly susceptible to nest predators (Hyde and Stewart, 2002). Although, the stoat presented a considerable risk to the New Zealand falcon's eggs incubation by the parents remained relatively high. Overall, the incubation by the New Zealand falcon remained relatively constant, even when significant nest disturbances occurred.

5.2.4 Shared Incubation

The New Zealand falcon exhibits a shared pattern of incubation, with both the male and female contributing directly to the incubation of the eggs. The partitioning of diurnal incubation was unequally shared between the sexes. The female provided considerably more of the incubation, with males providing only one third of diurnal incubation. Furthermore, females also contributed more incubation bouts than males. Enderson *et al.* (1972), found consistent levels of male involvement in the diurnal incubation of peregrine falcons. The males' incubation from this study was within the range (30-50%) found by Nelson (1970) for male peregrine falcons. Poole & Bromley (1988b), however, reported much lower contributions by male gyrfalcons of between 5 and 25% of total incubation. These values for the male gyrfalcon, however, include nocturnal incubation and therefore may underrepresent the male's contribution to diurnal incubation. Cade (1960), reported all captive male peregrines shared the diurnal incubation, although, the proportion varied significantly between individuals. Cade's (1960) findings were consistent with the variation in male incubation investment found between pairs observed in this study.

Egg laying is a very energetically expensive process, draining the female of body reserves (Fox, 1977a; Meijer *et al.*, 1989). In this study the male's investment in incubation freed-up hunting time for the female by providing relief from incubation duties. In the gyrfalcon it was reported that the male provides the female with the majority of her food requirements (Potapov & Sale 2005). Male New Zealand falcons provided little supplementary prey items to the female during the incubation period. Incubation relief by the male has also been reported in the gyrfalcon (Jenkins, 1978; Platt, 1989).

The amount of incubation contributed by the male at C159 was quite variable between days. Similar variation has also been reported in studies of peregrines and captive New Zealand falcons (Murray, 1998; Ratcliffe, 1980). During the final week of incubation for three observation days, the male from C159 provided slightly over half (*ca.* 56 %) of the total observed incubation. Murray (1998) made no recordings of greater than 44% of diurnal incubation by a captive male New Zealand falcon. The male peregrine falcon has been recorded as undertaking half of daytime incubation (Nelson, 1970). This was recorded during mid-incubation, and further to that it was noticed that the males' contribution declined towards the end of the incubation period. No such decline in the male's contribution to incubation was observed in this study.

The female New Zealand falcon probably provides nocturnal incubation of the eggs. In peregrines this has been reported also to be the case (Herbert and Herbert, 1965; Nelson, 1970). Nocturnal incubation by the female New Zealand falcon was suggested by Murray (1998), who found that the female was almost always the last one seen on the eggs before dark. Crowe (*pers. comm.* 2008) using of time-lapse video recordings confirmed that the female New Zealand falcon undertook all nocturnal incubation. Data from this study support the findings of Crowe, as in almost all cases the female was sitting on the eggs at first light. The daily investment of the male in the act of incubation will therefore be closer to half that which was found in this study; when nocturnal incubation is taken into account.

Incubation on the day prior to hatching was one of the highest recorded. The process of hatching usually takes 72 hours (Fox, 1995). Just prior to hatching, the chick inside the egg needs relatively high humidity, and this can only be controlled by the incubating parent (Nelson, 1970). The incubation at both nest compartments was consistently high. This is supported by Fox (1977a), who stated that incubation becomes constant proper incubation by the female is initiated. Once an incubation pattern has established it remains relatively constant throughout the incubation period (Zerba and Morton, 1983).

Findings from this study support the suggestion by Fox (1977a), that the incubation of wild New Zealand falcons closely resemble that found in other species within the genus *Falco*.

5.3 Egg Turning

5.3.1 Introduction

Egg turning rates have largely been left out of studies of the breeding behaviour of birds of prey. This may be partly due to the difficulty in identifying egg turning events. In most bird species, egg turning is an essential behaviour that allows the embryo to develop properly (Fox, 1995). Turning of the egg during the first 55% of the incubation period ensures that the delicate network of blood vessels from the chorioallantoic membrane surrounds the entire inside of the shell (Fox, 1995). Deeming (2002) provides some support for the inclusion of egg turning by the feet, however, they reported uncertainty as to the exact role that the feet play. The involvement of falcons' feet in the turning of their eggs is supported by the observations of rotations in the nest area without up and down wing movements. However, it was not possible to determine if up and down wing movements resemble even the movement of the feet.

5.3.2 Egg Turning Rate

The behaviour of egg turning was highly variable between days and this compares to high variability reported by Deeming (2002) between studies of the same species. The turning rate on the day of hatch was quite high at both C159 and C333. This may have been due to the difficulty in differentiating comfort behaviours from those of egg turning. During the day of hatch, the chick is moving around in the egg and vocalising to the attending parent (Fox, 1995). These movements of the underlying chicks may affect the behaviour of the parent sitting on them. After the hatch date of the first chicks, egg turning rates dropped dramatically. Single egg turns were recorded at C159 two and three days after hatching of the first chicks and, therefore, probably misidentified. It is likely that no further egg turning is needed at this stage in the incubation for the remaining egg/s to hatch successfully (Fox, 1995).

Egg turning rates during artificial incubation in New Zealand falcon were reported to be highly variable between studies (Fox, 1977a), even though turning rates have been found to be very similar between even distantly related bird species (Fox, 1995). This variability in the egg turning rates used in artificial incubation may result in reduced hatchability and an increase in the rate of atypical hatching. Deeming (2002) supported this, stating the conditions used for artificial incubation of raptor eggs are

probably sub-optimal. In this study the egg turning rate for New Zealand falcons was on average four turns per hour. This is consistent with findings by Fox (1995) using mercury tilt switches inside a dummy egg. He found egg turns occurred four times per hour in bantams (*Gallus gallus domesticus*), and both captive and wild common buzzards. Egg turning rates, however, reported for wild peregrine falcons (Enderson et al., 1972; Herbert and Herbert, 1965) were under half that found both in this, and Fox's (1995) study. Burnham (1983) stated that turning rates used for artificial incubation of peregrine falcons eggs was only one turn every two hours. The mean egg turning rate of four turns per hour was a stark contrast to the same number of turns per day used in artificial incubation of New Zealand falcon eggs (Fox, 1977a). Suggesting egg turning rates used in artificial incubation of falcons' eggs may be far below that provided by wild birds.

Egg turning rates have been found to change throughout the incubation period (Pulliainen, 1978). During the observed incubation period in this study, egg turning rate changed considerably. The type of egg turning changes just after half-way through the incubation period (Fox, 1995). The eggs no longer require actual turning, and now only need to be moved in order for them to return to their equilibrium point. This change in egg turning technique was not identified as observed behavioural changes; however, reduced turning rates may indicate this changeover. Pulliainen (1978), also reported changes in the egg turning rates over the incubation period.

The male New Zealand falcon was recorded undertaking fewer egg turns relative to the amount of incubation that he provided. This suggests that the female falcon is responsible for most of the turning of the eggs. The mean egg turning rate prior to hatch date for both compartments combined was four turns per hour. This is a stark contrast to the same number of egg turns per day in artificial incubation of New Zealand falcon eggs (Fox, 1977a).

5.4 Brooding

5.4.1 Introduction

Brooding was recorded when one of the adults covered at least half of the brood of nestlings. As with many other birds of prey, the New Zealand falcon is semi-altricial; the chicks hatch with a thin covering of white natal down and their eyes only partially

open (Burnham, 1983; Deeming, 2002; Newton, 1979; Starck and Ricklefs, 1998). The young require parental brooding until they develop the ability to control their own body temperature, thermo-regulate. Note that where ages of the chicks are referred to for C333 prior to 10 days old, the youngest chick which subsequently died, was a day younger than the other chicks.

5.4.2 Development of Thermo-regulation

Brooding of the nestlings starts as soon as the chicks hatch out of their eggs, and continues until they are able to thermo-regulate. Stress brooding is then undertaken intermittently when weather conditions are particularly poor.

As suggested by Fox (1995), brooding of the chicks immediately after hatch was nearly continuous. After the day of hatch, brooding remained very high for the first few days before progressively dropping off. Brooding remained near continuous until the chicks reached between three and six days old. In contrast to this, continuous brooding was reported by Fox (1977a) to continue in the eastern form until the chicks reached about 10 days old. The decline in the amount of brooding done by the parents occurred over about a 10-day period. Gradual decline in brooding has also been reported in New Zealand falcon, peregrine falcon, and gyrfalcon (Crowe, 2008; Fox, 1977a; Potapov and Sale, 2005; Ratcliffe, 1980). These results suggest that the New Zealand falcon chicks gradually gained the ability to regulate their own body temperature during this period of declining brooding.

This gradual increase in thermo-regulation is probably associated with the relative development of the chicks. The amount of time spent brooding by the parents in C159 showed a considerable drop when the chicks were only three days old. The chicks at this age are still only sparsely covered by white natal down and appear very similar to that of recently hatched chicks. Fox (1977a) reported that captive New Zealand falcon chicks three days old were comfortable at a temperature 1 °C lower than on hatch date. Day old captive chicks of the bush form have been reported to survive a single period of up to three hours without brooding (Debbie Stewart pers. comm. 2008). This however, appeared to represent the upper extreme of tolerance for a chick at this age. The secondary down at this age has not begun to grow through, suggesting that the chicks are now generating a bit more of their own heat in the form of metabolic heat. Another

possibility is that by three days old the chicks are capable of tolerating a greater temperature gradient.

In contrast to C159, the drop off in brooding in C333 was not seen until the chicks had reached 6 days of age. In another study on New Zealand falcon, brooding still remained constant even at 7 days old (Fox, 1977a). Jenkins (2000) also reported significant differences between the point of decline in brooding between different populations of peregrine falcons. The thicker grey down grows through the natal down between about the age of nine and eleven days, and is noted as the point at which partial thermo-regulation by the chicks is achieved (Fox, 1995; Potapov and Sale, 2005; Stewart, 2007). Data from this study suggest that partial thermo-regulation may be achieved as early as 6 days old, at which time the chicks were only brooded for about 60% of the day (C159 only). This is consistent with partial thermo-regulation by captive New Zealand falcon young (Stewart-Badger, 1997).

5.4.3 Factors Affecting Brooding

The recorded ambient temperature at C159 was considerably warmer than C333 during the first 20 days of the nestling period. The warmer temperatures may have allowed the parents to leave the chicks longer between brooding bouts. Consistent with this, the time between brooding bouts at C159 averaged three times as long at C333. Ambient temperature has also been reported by Ratcliffe (1980) to influence the brooding of young by peregrine falcons. The C159 female in this study, left the chicks for 1.5 hours when they were only three days old, even during moderate rain showers. From observations, it was not possible to determine if the chicks were left longer in C159 due to the chicks ability to withstand the temperature gradient for longer, or that the parents were forced to leave their chicks for longer. The lower amount of brooding seen in C159 when the chicks were six days old, may have been as a result of the observation from the hide being made in the afternoon. This result may be explained by temperature, as during this afternoon observation temperatures were several degrees above average.

Once the chicks reached 10 days old, morning brooding was restricted to before 8 am. These data suggest that the New Zealand falcon chicks had considerable control of their body temperature from 10 days old. At 10 days old the grey down would have been starting to grow through the natal down, aiding in the chicks ability to maintain

their body temperature. Fox (1977a), stated that from 11 days old the chicks were partially thermo-regulating and that stress brooding occurred for only short periods throughout the day. This was also noted as the period of peak growth rate in the young of both eastern and bush forms (Fox, 1977a; Stewart-Badger, 1997). Also by Day 10 the chicks were able to leave the nest scrape and seek shade from the sun. From about the age of 14 days old, the chicks were only brooded occasionally when weather conditions were particularly unpleasant. In C159, the last observed brooding events occurred when the chicks were 13 days old. The chicks were probably completely thermo-regulating by this age.

5.4.4 Role of the Sexes

The female undertook the majority of the brooding of the chicks at both nest compartments. Jenkins (1978) reported this to also be the case in gyrfalcon. The female parent was always present on the eggs when they hatched. The female is probably able to anticipate the hatching of the chicks, as they make cheeping noises within the egg over 24 hours prior to hatching (Fox, 1995). The male's contribution to brooding at C333 was negligible (3%). This was very different from the C159 male, who provided nearly 20% of the total brooding. The male parents at both nests provided some brooding of the young until they reached five days old in C333 and six days old in C159. At this point male brooding virtually ceased. The exception was the male in C333 who undertook some stress brooding after the female died. This is similar to the findings by Brunton (1988) for killdeer, where the removal of one parent caused the remaining parent to spend considerably longer attending to the nest. The proportion of the brooding that was undertaken by the male was also found to drop off as the chicks grew older in bald eagles (Cain, 1985). The drop off in male brooding, however, was a gradual process with some male brooding occurring near the time that brooding ceased completely.

The reduced effort by the male in C333 may have forced the female to invest more effort into the brooding of the young. Increased energy expenditure by other species of falcon have resulted in higher mortality rates (Daan et al., 1996), providing further support that the C333 female died during the nestling period.

Two definite stress brooding periods were recorded at C333, when the chicks were 18 and 20 days old. From 18 days old the chicks have nearly, if not fully, reached

their adult weight (Fox, 1977a; Stewart-Badger, 1997). The chicks at this age also had a complete covering of secondary down. This developmental stage is consistent with other New Zealand falcon studies (Fox, 1977a; Stewart-Badger, 1997). The female at C333 had disappeared and was presumed dead. From Day 17, the male in C333 provided all of the necessary care of the young. Although, it was possible that the female deserted the young, this was considered to be incredibly unlikely. This was based on no further sightings of the female, the male's behaviour her disappearance, and also due to the females relative investment in the young at this age. When the chicks were 18 days old in C333 the male undertook a reasonable amount of brooding. This coincided with cold temperatures and most importantly, the highest rainfall recording during observation for any observation day. The coldest recorded mid-temperature during brooding observations was recorded when the chicks were 20 days old. Mid-temperature represents the average between the maximum and minimum temperature recorded during the hide observation period each day. It is likely that cold ambient temperature resulted in the final stress brooding event observed at C333. These two observation days with stress brooding may represent rather unusual behaviours, or have been accentuated by the loss of the female parent. This is supported by Jenkins (1978) stat that the female remained close to the nest to provide stress brooding when necessary in gyrfalcons.

5.4.5 Nestling Mortalities

A single nestling mortality was recorded at each of the nest compartments. The first occurred at C333 when the youngest chick (8 days old) of the three, died in the nest scrape. The dead chick was found abandoned by its' day older siblings in the nest scrape. The younger chick was still observed feeding on the morning of day 9, when it would have been 8 days old. Hide observations were unable to establish whether the youngest chick died prior to, or after it was abandoned by its older siblings. From our observations it was not possible to determine the definite cause of death, but there are several likely scenarios. Day 10 was the first time that that either of the older chicks had been observed outside of the nest scrape, suggesting the younger chick may have died of exposure due to lack of brooding during the night. This theory is supported by the observation of the female spending most of the brooding time on the larger chicks, only returning to brood very briefly the motionless chick in the nest scrape. The slight

asynchrony in hatching of the chicks may have led to reduced competitive advantage of the younger chick (Newton, 1979). Therefore, even the slight hatching asynchrony may be responsible for the eventual death of the youngest chick. Court (1988) found that about 10% of nestling mortalities in the peregrine falcon can be attributed to asynchronous hatching of the chicks. It has been suggested that asynchronous hatching is an adaptation in birds of prey that allow brood size reductions to occur in times of poor food supply (Lack, 1947). This theory is known as the brood reduction theory and has been supported by some studies on raptors (Fox, 1995; Newton, 1979).

The second chick mortality occurred at C159 when one of the three chicks died between five and seven days old of unknown causes. Hide observations, however, were not able to determine the exact day in which the chick died. In C159, all three chicks hatched on the same day, synchronously. At this age it was often hard to identify whether two or three chicks were feeding, as generally only two of the chick's heads were raised at a time.

5.5 Prey Delivery

5.5.1 Introduction

In this study prey delivery refers to the passing of captured prey items by the adult falcon near to, or at, the nest area. When possible, repeated deliveries of the same prey item were removed from the analyses. Prey deliveries, prior to the development of self-feeding in the chicks, were generally from the male to the female parent. After self-feeding in the chicks was first observed, most prey items were delivered directly to the chicks. The prey delivery rate may provide some indication as to the hunting success of the parents during the observation period. As stated by Collopy (1983), direct observations may provide the most accurate method of determining the prey delivery rate to the nest.

5.5.2 Prey Delivery Rate

Prey delivery at both compartments showed a general upward trend till about Day 17 and Day 11 in C333 and C159 respectively. This coincided with the major growth stage of the chicks reported in several studies (Fox, 1977a; Fox, 1995; Stewart-

Badger, 1997). Prey delivery rates were highly variable between observations days. This is perhaps unexpected considering that feeding rates need to remain relatively high in order for the chicks to continue to grow and develop. Jenkins(1978) referred to the feeding rate as being unpredictable, he stated in gyrfalcon this was due to the irregularity in prey availability and hunting success. Prey delivery rates were also found to be highly variable between observation days at peregrine falcon nests (Olsen et al., 1998). Observations in this study were only made during about half of the day, therefore, prey delivery rates may have shown less variation over the whole day.

New Zealand falcon were often recorded caching prey items during the day (Fox, 1977a). Caching provides short term storage of prey, mainly for feeding the young during periods of difficult hunting within the same day. Occasionally they may feed on a prey item from a cache of the previous day, but, this is not very commonly observed (Fox, 1977a). Caching of prey may serve to even out feeding rates of the young throughout variations in both prey availability and hunting success during the day (Fox, 1977a; Holthuijzen et al., 1990). Poole & Boag (1988a), however, suggested that caching was a means by which prey remains were prevented from building up in the nest area. Fox (1977a), proposed that the caching behaviour of New Zealand falcon was particularly common as a result of evolving in the absence of mammalian predators.

The male at both nests caught the majority of the prey items fed to the young at both nests. From Day 12 the females began to hunt for the young, yet, female caught prey deliveries only made up a small proportion of the prey fed to the young even during the early post-fledgling period. Fox (1995), supported this finding, stating that only once the chicks secondary down grows through (12-14 days old) can the female leave the chicks to hunt. Over the final few days of diurnal brooding, the female was able to spend some time hunting prey. Observations from this study suggest the female generally remained relatively close to the nest during the early nestling period between brooding bouts. During this time the female was probably guarding the young, with only a small proportion of her time hunting prey relatively close to the nest. In peregrines the female also spent considerable time during the nestling period guarding the young (Ratcliffe, 1980). When the female was not visible from the hide frequent begging calls suggested that she generally remained close to the nest. This was also supported by virtually all prey deliveries by the male, first being passed to the female before being fed to the young. Once the chicks were able to self-feed, the female began to hunt further from the nest and spent less time guarding the young.

The prey delivery rate in C159 peaked sooner than C333. The prey availability may have been lower during the nestling period of C159 than C333, due to later time in the breeding season that nesting occurred. The absence of the female in C333 from 16 days old, may have meant that the male invested more time to hunting than he had when the female was still present. After prey deliveries peaked in both nest compartments the prey delivery rate plateaued off, declining slightly as the nestling period progressed. Prey delivery rates were just over one item per hour. When the chicks were 20 days old in C333, the highest recorded prey delivery was observed. This may represent a very successful morning of hunting that was accentuated by the short observation period on that day of about 3.5 h.

Considerably reduced prey delivery rates were observed at both nest compartments on the day prior to the fledging of the male chicks at both nest compartments. This is strongly supported by Brown (1955), who suggested the parents may actively reduce the prey deliveries in an attempt to assist the fledging of the young. Although, reduced prey deliveries prior to fledging at C159 caused a reduction in feeding rate, the feeding rate at C333 remained moderately high. This was due to the very high proportion of feeding by the young at C333 on prey remains.

5.5.3 Roles of the Sexes

The first successful prey deliveries by the male directly to the chicks occurred on the same day that the chicks were first observed self-feeding. The male's access to the nest has been suggested to be controlled by the female. In this way the female is able to control the males' investment in the young (Carlier and Gallo, 1995). The change also coincides with the end of most of the brooding by the female. In this way the female can control the amount of prey which she receives during the days in which her time available for hunting is reduced, as a result of brooding and guarding the young.

The male provided most of the prey items passed during prey deliveries. The male provides food for the female at least during the early stages of the nestling period, until she begins to hunt for herself. This is consistent with Herbert & Herbert's (1965), findings that the peregrine falcon male provides most of the prey during the nestling period. Olsen *et al.* (1998) found that male peregrines provide over 90% of the prey deliveries from hatch until the chicks reach adult weight. On some occasions it was not possible to determine if a prey pass had occurred prior to the female's arrival at the nest

scrape with prey. Male kekking calls almost always preceded his arrival near the nest area. As the male approached the female would make begging calls prior to food being passed to her. These distinctive calls were used in some cases to indicate a prey pass that occurred out of sight of the hide observer.

The C333 male's overall investment in the nestlings appeared to increase after the female's disappearance. After the female was recorded as absent from C333, presumed dead, the male provided more prey deliveries than both parents at C159. This may partly be explained by an increased effort by the male in providing food for the young. This theory is supported by a study on kestrels (*Falco tinnunculus*) that found males made more strikes at prey when energy requirements at the nest were increased (Meijer et al., 1989). At the same time that the C333 male was providing more prey deliveries he was also providing more time brooding the young. Nest defense behaviour by the male was also noted to increase after the loss of the female parent. All of these observations support the statement that the male increased his investment in the young after the female's disappearance.

5.5.4 Allocation between Young

Once the chicks reached 22 days old, they were able to actively tear apart and consume whole prey items (WPI), without assistance from their parents. Prior to 22 days old, there appeared to be relatively equal partitioning of prey portions fed during assisted feeding events. Personal observations suggest that the recipient of WPIS was at least somewhat selective in the New Zealand falcon parents. The allocation of WPIS appeared to be unequally shared between the offspring in the brood. Although, a considerable proportion of the WPI prey deliveries were received by an unknown recipient, it is assumed that the observed trends represent actual differences in the prey allocation between young.

Data from this study suggest that self-feeding is an important behavioural development in the New Zealand falcon chicks. This is both consistent and contrary to the findings of different authors for peregrine falcons (Anderson et al., 1972; Herbert and Herbert, 1965). Self-feeding may be unimportant in times of high prey abundance and more important during prey shortages. Yellow, one of the two male siblings at C333, received considerably more of the WPI prey deliveries. Prior to fledging both siblings received very similar allocation of the WPI passed by the male parent. From

Day 31, when both siblings were able to fly short distances, Yellow had an apparent competitive advantage over Red. On three consecutive observation days, he received all WPI where the recipient was known. During this time his male sibling, Red, was very vocal and made many attempts to obtain the prey.

Pale (♀) received a slightly higher proportion of the WPI prey deliveries, than her male sibling Dark. This is consistent with Boulet *et al.* (2001) who found that the female siblings receive more of the overall prey deliveries. However due to the low differences in total WPI received it was not possible to determine if an actual difference in allocation occurred at C159 nest. Care should be taken in interpreting these results, however, as the proportion of WPI passed to an unknown recipient outweigh any proposed allocation bias by the parent/s. Anderson *et al.* (1993), found that in the American kestrel (*Falco sparverius*) the larger female nestlings were capable of significant competitive advantage over the male, for both small and medium sized prey items. There appeared to be some competitive advantage of the female New Zealand nestling at C159. This was especially noticeable during the assisted feeding events on Day 25, when the female nestling received considerably more of the food portions from the adult female than the male sibling. The larger female American kestrel nestling requires *ca.* 7 % higher food resources than the male to reach adult weight (Anderson *et al.*, 1993). This value is very similar to the 6 % greater number of WPI's allocated to the female nestling, than the male, found in this study.

The female nestlings are likely to develop more strength than the male siblings late in the nestling period, yet, the male's may completely make up for this by increased agility and flight abilities (Anderson *et al.*, 1993; Beebe, 1960; Newton, 1979; Newton and Marquiss, 1979). The size of prey brought back to the nest has been found to affect the level of competitive advantage that different sexed chicks would have over one another (Anderson *et al.*, 1993). When very small items were delivered, the larger female's gain an advantage over the male young as they were able to swallow larger portions whole (Anderson *et al.*, 1993). Observations during this study suggest this could also have been occurring between New Zealand young. An example of this was when one chick was unable to swallow a large food portion during assisted feeding. The assisting parent proceeded to retrieve the large food portion and pass it to another chick capable of swallowing it. Although, the size of the sexes are considerably different, food requirements of the nestlings to reach adult weight may be less than proportional to their body mass (McDonald *et al.*, 2005). Boulet *et al.* (2001), suggested that this may be due

to more efficient conversion of food into biomass by the female young. In the New Zealand falcon the larger females continue to build up body mass for several days after the male young have already reached their adult weight (Fox, 1977a). This delay in development of the adult feather growth in female young, may largely explain why they are capable of outgrowing their male siblings.

5.6 Feeding of the Young

5.6.1 Introduction

Feeding of the young is an incredibly important component of the breeding behavior of New Zealand falcon. During nestling period, the feeding behaviours of the parents change from assisted feeding to prey passes to the young. Prey remains are prey items either retrieved from a previous cache site, or any item left in the nest area from a previous prey delivery.

5.6.2 Feeding Rate

The feeding rate showed a general bell-shaped distribution with respect to the age of the young. This is similar to the pattern of feeding rate described by Poole & Boag (1988a), in the Gyrfalcon. The difference, however, found in this study is that the feeding rate did not show the plateau at peak feeding rate. Initially the chicks are fed by the female either on the day of hatching or the following day. This is within the range of first feeds of falcon chicks found by other authors (Enderson et al., 1972; Fox, 1977a; Jenkins, 1978; Nelson, 1970; Olsen, 1995). Some even reported that the first feeding of the chicks can occur within 4 hours of hatching (Enderson et al., 1972). Observed feeding rates in both nest compartments showed a general increase in the feeding rates from the first feeds to 26 days old in C333 and 23 days old in cmpt159. After the peak in both nest compartments, feeding rates showed a general downward trend until observations ceased in the early post-fledging period. This trend probably relates to the changes in food requirements of the chicks. Therefore, also corresponding to changes in the growth rate of New Zealand falcon chicks (Fox, 1977a; Stewart-Badger, 1997; Stewart, 2007). During the first few days, only a small amount of food is required by the young as they are metabolising their yolk sac (Fox, 1995). Once the chicks reach adult

weight at about 18-22 days old, most of the chicks' growth is now focused on feather growth (Fox, 1977a; Stewart-Badger, 1997). Peak feeding rates were reached just after the time at which most weight gain in the chicks was reported to have ceased. At 25 days old the young were very active and adept at self-feeding. Development of self-feeding marked the point at which prey remains were first fed on by the chicks. At C333 no assisted feedings were on prey remains, and only a very small number at C159 were on prey remains, prior to self-feeding by the young. The feeding rate in this study was consistent to that found in another study of New Zealand falcon chicks at three-quarters grown (Fitzgerald, 1965). Two very high feeding rates were recorded in C333, when the chicks were 17 and 32 days old. The high feeding rate coincided with the first observations of self-feeding in C333. The chicks were regularly seen feeding on prey remains once they were able to self-feed. Self-feeding may at least partially explain the high feeding rate on this day.

The proximate cause for changes in the feeding rate is likely to be the change in food requirements of the young. Temperature was shown to have a significantly negative effect on the feeding rate of the young New Zealand falcon. This may have been partly due to increased food requirements of the young during colder temperatures for body heat regulation. Another possibility is that temperature affects the hunting success and therefore also the feeding rate of the young. Temperature may also affect the behaviour of the young.

5.6.3 Parental Involvement

The female provided all of the assisted feeding of the young. Several other authors found the same result in peregrine falcon (Enderson et al., 1972; Jenkins, 2000; Jenkins, 1978). The exception to this was observed in C333 when the female disappeared and was presumed dead. The male provided only a few assisted feeding events in the absence of the female, during the first two days that young were able to self-feed. Time constraints on the solo male may have restricted his ability to provide the young with self-feeds. Jenkins (1978), stated that after brooding has ceased the male makes only very brief visits to the nest to pass prey to the young. Prior to the development of self-feeding in the young, the male was very rarely allowed access to the young during prey deliveries.

The first self-feeding event was observed in C159 when the chicks were 15 days old, two days earlier than C333. This is in contrast to reports by Crowe (2008), who made no observations of self-feeding by the young at another New Zealand falcon nest during the first 22 days of the nestling period. With the peregrine falcon direct prey passes to the chicks only occurred once the young were 20 days old (Carlier and Gallo, 1995). The adult female at C159 provided assisted feeding for a further 13 days after the chicks were able to self-feed. With peregrine falcons, there is considerable overlap between the assisted feeding and self-feeding of the young (Ratcliffe, 1980). In this way the female New Zealand falcon may more effectively be able to control the amount of food that is fed to each of the chicks by assisting their feeding, rather than allowing them to self-feed. Based on observations, it would appear that competitive advantage of one sibling was more likely to develop with self-feeding events rather than with parent assisted feedings.

Competition between the young for food was considerably aggressive. The competition for food occurred at two levels, prior to receipt, and post receipt of food. Certain observations suggest that the intensity of begging calls may affect both the number of feeds or prey passes that the young receives. Vocal competition may also be occurring prior to the decision by the parent of which chick to pass the prey (Ratcliffe, 1980). On several occasions after whole prey items were passed by the parent directly to the chicks, their sibling stole or fought for the item received. Most assisted feeding events involved the partitioning of single prey item between the siblings in the brood. Therefore assisted feeding behaviour by the parent probably enables prey to be more equally shared between the chicks. This is supported by the observations that neither the sex of the chick, nor its location within the nest scrape appeared to affect the number of food portions per feed that it received.

The females' urge to feed the young may override her fear of the increasingly aggressive chicks (Carlier and Gallo, 1995). Prior to the death of the female in C333 (Days 0-16), she provided all of the observed assisted feeding events. The male provided assisted feedings of the chicks on the first day of observation after the females' death, when the chicks were 17 days old. The male was observed assisting with the chick feeding on only two observation days, after which all further feeds were self-feeds by the chicks. Results from this study suggest that although the female at C159 assisted with the feeding of the young for many days after they were able to self-feed, this may have been unnecessary. As the chicks grew in size they became increasingly

intimidating to the parents. On one occasion during feeding, one of the chicks grabbed the lower mandible of the female parent with its beak. The female parent pulled backwards, escaping the chick's powerful grasp. This observation supports Jenkins (1978) theory that food delivery visits to the nest shorten as the chicks grow older due to their increased aggressiveness towards the parents.

The male parent at C333 was reported successfully rearing two male young from 17 days old, through until nine weeks post-fledging. Based on the dates of juvenile dispersal of New Zealand falcon found by Seaton (2007), the fledglings could have dispersed from their natal compartment.

5.6.4 Diet of the Young

New Zealand falcons have been reported by a number of authors to be predominantly bird predators (Barea, 1995; Barea et al., 1999; Fitzgerald, 1965; Fox, 1977a; Guthrie-Smith, 1927; Lawrence and Gay, 1991; Seaton, 2007). The majority of the prey deliveries at both nest compartments were birds, with the small remainder consisting of insects and mammals. Some studies have identified the presence of large mammal species in the diet of New Zealand falcons, such as rabbit (*Oryctolagus cuniculus*) and European hare and (*Lepus europaeus*) (Fox, 1977a; Seaton, 2007). This study however, found only one small mammal, a weasel, in the prey items fed to young. No prey deliveries to the C159 nest area were identified as insects. This suggests that insects may be unfavorable prey, and only occasionally used to supplement prey for the chicks when other hunting is poor. Prey deliveries were harder to identify at the nest in C159 as the hide site was further from the nest throughout the nestling and early fledging period. This was the most likely reason for the higher proportion of prey deliveries that were not able to be identified to a particular prey class. The ability of this study to identify prey items to species level were considerably limited. Prey delivered by both parents was often plucked, dewinged, and decapitated. This has also been reported in various other studies of falcon prey deliveries (Barea et al., 1999; Potapov and Sale, 2005). Preparation of the prey before being delivered to the nest, made some items difficult, if not impossible, to identify from direct observations alone.

The parents passed live prey items on two observed occasions in this study. The behaviour of feeding live prey items has previously been reported for the New Zealand falcon (Fox, 1977a). The first live prey item was a huhu beetle passed at C333 when the

young were 14 days old. The second prey item was a partially live silvereye which was passed directly to one of the young on Day 39 at C333.

A large proportion of the prey items fed to the chicks were identified as sub-adult prey items. Nest robbing has been previously reported in several other studies of New Zealand falcon (Fox, 1977a; Sopp, 1958) and also on several occasions during this study. Some observations of sub-adult birds were harder than others to distinguish. Nestling prey fed to the young in this study varied from tiny naked chicks, through to large blackbird nestlings with primaries partially unfurled from their sheaths suggesting they were close to fledging. From Figure A.10, Appendix 2, a New Zealand falcon chick can be seen clutching a large blackbird nestling in its talons. The primary pin feathers are partially unfurled from their sheaths.

Direct observations of other birds of prey species have identified previously unreported prey items and have been found to be the most accurate method of determining the frequency and biomass of prey delivered to the nest (Collopy, 1983; Southern, 1954). In this study, however, all prey items were previously reported in diet analyses from pellet and prey remains methods used by Seaton (2007). Similarly, chaffinches made up the majority of the prey items fed to the young New Zealand falcon nesting in plantation forests. Chaffinch predation by the eastern form of the New Zealand falcon comprised much less of the diet, compared with this study (Fox, 1977a). As suggested by Seaton (2007), this may be explained by the super-abundance of chaffinches present in plantation forests, compared with other habitat types. Both, the frequency, and biomass of prey species reported in this study closely followed trends identified in previous work using pellet and prey remain analyses (Seaton, 2007). Therefore, when both pellet and prey remains are used to study the diet of New Zealand falcon, they probably present an accurate representation.

Often it was hard to determine the prey species fed to young using direct observations, due to the prey being plucked, and frequently decapitated. The North Island robin made up only a very small component of the diet based on pellet analysis (Seaton, 2007), however at C159, they contributed over 7% of the prey items fed to the young.

Larger prey items were generally easier to identify than smaller ones. This may mean that the proportion of some small bird species may have been underestimated. Booms & Fuller (2003), noted the same difficulty in identifying small prey items when they used time-lapse photography. Some species of bird were easier to identify than

others based on observations alone. Conspicuous features such as the white wingbar on the covert feathers of the chaffinch wing aid in its identification (Heather and Robertson, 1996). Observations in this study also failed to identify at least two species of bird from the diet of the young at the two nest sites. These prey items may have been delivered outside of the observed periods or may have been misidentified. Diet analysis using direct observation is probably most effective for cross-checking previous work using pellet and prey remains, or used in conjunction with other analysis methods.

6. Chapter Six - Conclusions



6.1 Overview

In this research the details of the breeding behaviour and development of New Zealand bush falcons in plantation forests were addressed. This represents a very important stage in the species life history. Findings from this study generally support the findings of incubation observations made on captive New Zealand falcons and wild eastern form birds (Fox, 1977a; Murray, 1998). This provides support to the notion that captive birds express relatively natural behaviours during the breeding cycle.

The patterns of behavioural development were very similar to those found in overseas studies on other species of falcon. The exact timing of different developmental stages, however, was not as consistent. Even within the same species, the expression of behaviours such as self-feeding do not appear to be strictly controlled by the age of the young. Figure 6.1, shows a summary of major milestones during the breeding cycle of the New Zealand falcon. Table 6.1, summarises the major areas of New Zealand falcon breeding behaviour that require further research. In particular this table indicates the significance of findings from this study.

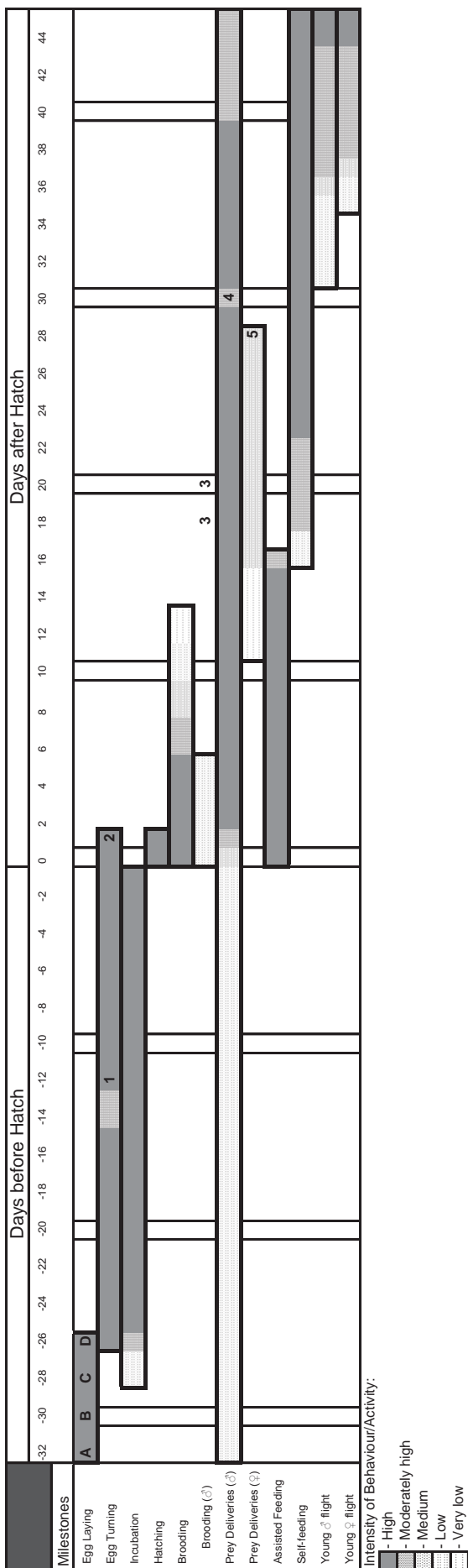


Figure 6.1 Typical milestones of the New Zealand falcon breeding cycle, based on data from this study and Fox (1977 & 1995). Hatch date for C333 was 12.11.06 & 22.01.07 at C159.

6.2 Direct Observations from Hide

Direct observations from a hide proved to be a very effective tool for observing the breeding behaviour and development of the New Zealand bush falcon nesting in plantation forests. Although at times, weather conditions were severe in Kaingaroa Forest; the custom-built hide used in this study proved capable of withstanding these conditions. Observer fatigue was largely overcome by maintaining approximately half-day observation periods and a wide field of view from the hide. The majority of the problems encountered with regards to the weather affecting the visibility of the nest, could be remedied by the use of nitrogen-filled optics (fog-proof). Optical equipment failure resulted in only brief periods of compromised observations.

Thermo-regulation in New Zealand falcon chicks appears to be gained gradually over several days in the early nestling period (Table 6.1). Chicks hatch totally dependent on their parent's body heat for survival. Over the following 12 days they gradually develop the ability to maintain their own body against increasingly severe temperature gradients. The results from this study suggest that the ability of the chick to regulate their own temperature occurs slightly earlier than Fox (1977a) found for wild pairs of the eastern form. However, without experimentally exposing chicks to certain environmental conditions it was difficult to determine a precise age at which chicks were capable of complete thermo-regulation. Complete thermo-regulation may best be defined as the point when the young require no further covering by their parents, even during extreme weather conditions. The morphological development of New Zealand falcon followed very similar trends to that previously reported for both captive and wild New Zealand falcons (Fox, 1977a; Stewart-Badger, 1997).

Table 6.1 Summary of the previous understanding of New Zealand falcon breeding behaviour, major areas for improvement, and the significance of results found in this study.

Behaviour	Prior understanding and anecdotal recordings	Understanding gained by this intensive study	Significance and recommendations
Incubation Behaviour			
(i) Period of incubation	29 to 35 days long Few studies have calculated it	As short as 25 days	Requires further investigation of influential factors More intensive incubation period calculations
(ii) Constancy	Constant throughout	Confirmed and supported by constancy during disturbance	Disturbances during incubation should be minimised
(iii) Parental involvement	Shared incubation by parents	Confirmed, plus shows much variability between days	Further understanding of male investment in incubation
(iv) Male role	Captive birds showed occasionally about 40% of diurnal incubation	Male can contribute over half diurnal incubation in a day	Male role in diurnal incubation is important
(v) Egg turning rate	Artificial egg turning rate based on overseas bird of prey species Poorly understood in New Zealand falcon	Found to be consistent with overseas turning rates	Improved understanding of egg turning rate
(vi) Egg turning technique	Lack of detailed observations	Suggest feet play role in egg turning	Recommend the use of dummy egg fitted with mercury tilt switches to determine role of feet
Brooding			
(i) Thermo-regulation	Considerably abrupt change in brooding from 9 days old as secondary down grows Artificially reared young thermo-regulating at 10 days old	Gradual transition from as early as 3 days old Only very brief brooding from 10 days	Gradually gain the ability to thermo-regulate Young may partially thermo-regulate prior to the growth of secondary down Wild young may develop as quickly as artificially reared ones
(ii) Factors affecting brooding	Development of the young primarily, with some weather effect	Development of the young, and both weather and time effects	Brooding is not as strictly controlled as previously suggested
Prey Delivery			
(i) Prey delivery rate	Poorly understood Anecdotal reports	Increased up to a peak delivery rate then levels off and remained relatively high	Captive rearing of young New Zealand falcon should follow this feeding pattern
(ii) Parental role	Male provides most of the prey deliveries	Consistent Female's can have a minor role Male is capable of providing all necessary prey deliveries to young	Female's primary role in later nestling period is supplementing male prey deliveries and feeding young
(iii) Allocation between young	Largely unknown	Possible competitive advantage develops between the young	Even when highly availability of prey competitive advantages can develop in a brood of young Requires further investigation as to the extent and possible reasons
Feeding of the Young			
(i) Feeding rate	Anecdotal reports at different times in the nestling or post-fledging periods	Increases to a peak then declines at a similar rate	Feeding of captive young should follow this general trend
(ii) Parental assistance	Female provides all feeding of young	Consistent, however, male is capable of assisting with feeding	Female controls the male's access to the young
(iii) Diet fed to young	Exotic passerine species made up most of prey fed to young in plantation forests	Consistent findings	Diet analyses using pellet and prey remains are accurate methods

Research in plantation forests have found an abundant food supply for New Zealand falcons in plantation forests. Results from this study, however, suggest that hunting success can be considerably variable between days. As a result of this variable food supply, nestling mortalities are likely to occur. The New Zealand falcons' habit of caching may help to smooth out some of this variation in hunting success, yet, prey remains from the previous day were rarely fed on. The results from this study, suggest that a dominant nestling developed within both of the broods of New Zealand bush falcon. This competitive dominance appeared to be reduced by the sub-dominant nestling's tendency to feed on prey remains.

Direct observations were shown to have limited use in analyzing the diet of New Zealand falcon young. Prey items were often difficult to identify and this was further complicated by prey items often being plucked and decapitated before being delivered to the nest. Although, observations failed to identify a considerable proportion of prey items brought to the nest, both the frequency and biomass of prey closely resembled those from pellet and prey remain analyses (Seaton, 2007).

Comparing the results found in this study with future research in different habitats will aid the development of better management practices in plantation forestry. A useful index of the 'health' of a population can be generated when productivity, detailed behaviour and morphological development are combined (Dykstra et al., 2003). This would be incredibly useful for forest managers to directly compare the current management practices employed in their forests to the relative 'health' of the New Zealand falcon population. New Zealand falcon populations can also be assigned a risk criterion in which targeted management can be focussed.

Direct observation using the custom-built hide described in this study significantly contributed the overall understanding of breeding behaviour and development of New Zealand's only endemic bird of prey, the New Zealand falcon. However, this study identified a number of key aspects of New Zealand falcon breeding behaviour that require further research before the species can be effectively managed throughout its range.

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Appendices



Appendix 1 - Manual 1

Manual 1

Andrew C.W. Thomas

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8. Equipment List

(includes extended field trip, forest security, hide components and tools, Infrared video gear, remote weather station)

8.1 General:

- Petrol jerry cans (40 litres total)
- Liquid detergent, plus hand wash/sanitizer
- Alcohol wipes, plus lens cleaners
- Duct tape
- Electrical tape
- Plastic bags, including zip-lock bags and rubbish bags (a hundred odd zip-lock bags for collection of pellets and prey remains)
- Permanent markers
- Forest map
- Compass
- GPS handheld unit
- Voice recorder
- Small macro digital camera
- Batteries
- Writable CD's for backing up photos
- Bird field guide (to identify prey species, is desirable to have good prior knowledge)

- Tape measure (25 m)
- Ruler (30 cm with millimetres on one side)
- Cell phone
- Cell phone charger
- Jack
- Flat block of wood for jack platform
- Jack stands (x2)
- Tow rope
- Spade (strong)
- Pruning saw
- Carpet strip (for putting under tyre if added traction needed)
- Spare tyre (with correct pressure)
- Two buckets for washing up
- Tramping boots (sturdy)
- Tent set
- Tarpaulin
- 30 m of rope (for tying up the tarp)
- 20 litre water bottle
- Gas stove cooker
- Lighter
- Pots and a frying pan
- General battery charger
- Power source for battery charging or 12 Volt inverter

8.2 Safety:

- First aid kit and survival kit
- Field first aid book
- Medicines (pain killers, anti-inflammatory drugs, asthma, allergies)
- High visibility vest
- EPIRB (Emergency Position Indicating Radio Beacon, because there is only poor cell phone coverage throughout the forest)
- Fire extinguisher
- Fire blanket

8.3 Hide Components (length x width x height):

- Plywood x 2 - marine grade and three ply (1.55 m x 1.20 m x 7 mm and other sheet 1.20 m x 1.15 m x 7 mm)
- Plywood squares x 4 - marine grade and three ply (each 120 x 120 x 7 mm)
- Wooden corner uprights - treated x 4 (188 x 5.1 x 2.5 cm)
- Wood inner framing of top - treated x 4 (1.20 m x 25 mm x 51 mm)
- Wooden pallet (105 cm x 91 cm)
- Wood stain - water-proofing
- Carpet for flooring to reduce noise (1.20 x 1 m) (rubber underside to prevent slipping)
- Canvas - brown(1.8 m wide x 5 m long, 6 oz)
- Shade cloth material - black (hessian like fabric, made from plastic) (60 cm x 40 cm, or larger than the observation flap)
- Rubber strips x 4 (each 9 cm long x 4 cm wide)
- Rubber squares x 4 (each 4 cm x 4 cm)

- Velcro (3 cm wide x 5.4 m long)
- Ribbon tape (for hide opening ties)
- Rope (20 m)
- Pegs x 8 - long and plastic
- Folding chair (with extra foam padding for seat and arm rests)
- Rubber mallet - large
- Screwdriver - standard (slotted)
- Staple gun
- Staples
- Spotting scope (minimum 25x zoom & 50 mm lens)
- Tripod x2 (sturdy)
- Binoculars (10x 50)
- Digital SLR camera
- 70-300 mm telephoto lens
- Mini DVD video camera
- Mini DVD's
- Jar (for toiletries)
- Clipboard
- Water-proof notebooks
- Several large regular notebooks for hide observations
- Stopwatch
- Mechanical pencil and spare leads
- Eraser

8.4 Hide Construction Tools:

- Sewing machine
- Pins
- Needle and thread (for hand sewing)
- An Iron (for making creases in canvas)
- Chalk (marking canvas and outline of hide)
- Wood saw
- Power drill
- Hammer
- Nails - galvanized and flat head (four [4 mm x 100 mm], four [?? x 60 mm], plenty of Clout nails [2.5 mm x 30 mm])
- Rasp
- Sandpaper
- Scissors

8.5 Infrared Video Gear

- Refer to Crowe, J.P. (2008).

- Battery x 2 (with leads)
- Battery charger
- Infrared camera
- Plastic rain cover for camera (modified small drink bottle)
- Infrared LED lamp
- Video Cassette Recorder (VCR) in waterproof case
- VCR tapes (new and high quality 3 hr tapes)
- Monitor screen

- Cables x 3 (short piece between camera and LED lamp, short piece between monitor and VCR, and long -50 m- cable to VCR)

8.6 Remote Weather Station:

- Outdoors thermometer
- Rain gauge (150 mL maximum volume)
- Screws x 2
- Wooden stake
- Plywood casing (protects from direct sunlight and rain)
- Wire

It is always so hard to plan for the unexpected. Invaluable knowledge was shared from other researchers and photographers. Including assistance from Dr. Nick Fox, and Geoff Moon.

9. Hide

9.1 Designing the Hide

It is critical to develop a meticulous hide design. Firstly decide on the specific requirements of the hide structure required to undertake your observations. Does the hide need to be portable, if so, you need to take this into consideration while choosing construction materials. Where is the hide going to be positioned and on what substrate? What is the weather like at the proposed study site (wind force, rainfall, temperature)? Is it going to be weather proof? What types of hide have been used in the past for observing your study species? Take into account the size of the equipment that will

eventually be used inside the hide. A good way of doing this is by setting up the internal components of the hide on a flat area of concrete. Mark out the minimum size requirements for the base of the hide using chalk and measure the height of the observation window. A decision now needs to be made as to the height of the hide. Does the observer need to be able to stand upright in the hide? It is a wise idea to ensure that all of the measurements of the hide design are in the same units.

The hide design requirements of this study:

- Specialized for the ground nesting habit of New Zealand falcons in pine plantations
- Able to be used for four months of continuous field work
- Comfortable enough to allow a single researcher to conduct ca. 6 hours of continuous observation per day
- Strong enough to withstand vey strong winds
- Water-proof
- Visibility into the nest scrape and also the surrounding nest compartment

9.2 Hide materials list and specifications

1. Top: Three ply, marine grade plywood top 1.55 m long x 1.20 m wide and 7 mm thick with an inner framing. Inner framing is treated 51 x 25 mm (2" x 1") timber each of the four lengths were 1.20 m long and were attached on their narrow side to the top. The inside dimensions of top's inner framing was 1.15 m long x 1.20 m wide.
2. Base: Three ply, marine grade plywood base is 1.20 m long x 1.15 m wide and 7 mm thick. It has slots measuring 51 x 25 mm to allow the corner uprights to fit inside the top. The corner slots were covered with rubber strips. The plywood

base is attached to a robust wooden pallet to provide stability. The dimensions of the pallet were 1.05 m long x 9.10 m wide, and 13 cm high

3. Carpet (reduces noise): 1000 x 1200mm with a rubber underside to prevent slip
4. Canvas: 180 mm high x 5000 mm long, 6 oz canvas. Dark brown
5. Wooden Corner uprights (x 4): treated 51 x 25 mm (2”x 1”) and 1880 mm long. Each with a 100 mm galvanized nail imbedded 50 mm into top (drill hole before inserting pointed end of top nail). These lengths of timber need to be completely knot-free, as knots significantly weaken timber strength. Upright base is 120 x 120 mm board nailed onto end of upright.
6. Velcro: 5.4 m long and 3 cm wide

9.3 Hide construction

Top (refer Fig. 1):

1. Cut the plywood top to 1.55 x 1.20 m
2. Cut the wood for the inner framing into four 1.20 m lengths. They should be free of any knots in the timber.
3. Slightly round the corners off the long sides using the rasp and then sand all of the sides of the wood with the sandpaper
4. Nail the inner framing together to make a an oblong 1.20 m x 1.15 m x 51 mm
5. Nail the inner framing to the top. There should be an overlap outside the inner framing of 10 cm at the front and the back of the top
6. Mark out holes on the inside of the inner framing, 12.5 mm from the front/back and 25.5 mm from the side (precise measurements are important). Drill 4 mm diameter holes in each of the corners of the inner framing
7. Paint the plywood top with water-proofing wood stain (green or brown) four times, allowing it to dry fully between each coat

8. Staple a 20 cm strip of ribbon tape to the inside of the inner framing. The ribbon tape should be attached to the rear of top, 30 cm from the rear left-hand corner

Base (refer Fig. 2):

9. Cut the plywood base to 1.2 x 1.15 m
10. In the corners cut out slots 2.5 cm (from 1.2 m side) x 5.1 cm (from 1.15 m side)
11. Remove any slats off the wooden pallet whilst still maintaining its structural integrity (reduces base weight)
12. Nail the plywood base onto the pallet. Pallet should be 12 cm from the front and back, and 7.5 cm from either side of the plywood base
13. Nail small struts from the edge of the pallet to the underneath of the plywood base, where extra supports are needed
14. Staple the carpet onto the plywood base, with the rubber side downwards
15. Staple the four rubber strips (9 cm x 4 cm) to each of the corners of the base

Corner uprights (refer Fig. 2):

16. Cut each of the four wooden uprights to 1.88 m long
17. Slightly round the corners off the long sides using the rasp and then sand all of the sides of the wood with the sandpaper
18. In the centre of one end of each upright drill a 50 mm deep hole to snugly accommodate a 100 mm flat head nail
19. Hammer into 100 mm flat head nail into the hole that has just been drilled
20. Cut the plywood squares to 12 cm by 12 cm
21. Drill a hole in the centre of the other end of upright, to tightly fit a 60 mm nail

22. Mark each of the upright bases in the centre, 6 cm from each side
23. Hammer a 60 mm nail through each of the upright bases in the centre
24. Line up the nail in the base with the hole in bottom of the upright and hammer the base to the upright
25. Drill holes through the centre of the four rubber squares, just large enough for them to fit tightly over the head of the 100 mm flat head nails

Canvas (refer to Figures 7-9):

26. Using chalk mark out the positions of the sleeve, Velcro strips, ribbon tape and the observation window.
27. The sleeve measuring 23 cm from the end of the canvas (180 cm side), rule another line at 20 cm
28. Fold the sleeve end over at 13 cm from the end and iron a crease in the canvas
29. Sew the sleeve at the 20 cm chalk line. Then a second line 1 cm from the cut edge of the canvas.
30. Ensure that the sleeve is at the left hand end of the canvas. Then mark on the canvas the inside, outside, top and bottom using the chalk.
31. The hide framing needs to be constructed with the canvas sleeve on the rear left corner upright.
32. One person needs to pull the canvas tightly around the corner uprights. Another person remains inside the hide and marks where the Velcro will go around the corner uprights (careful with these measurements!)
33. The person who was on the inside of the hide now exits. The person still holding the canvas on the outside once again stretches it tightly around the hide frame.

- Overlap the sleeve on the rear left-hand corner by 5 cm, make a mark on the canvas at this point (careful with this measurement!)
34. Relax the canvas and then re-stretch it around the hide corner uprights. Check that all of these chalk markings on the canvas are accurate
 35. One person holds the top of the hide in place, while another removes the canvas from the rear left-hand corner upright. Insert the corner upright back into position after the canvas sleeve has been removed
 36. Pin out the Velcro strips at the markings that have just been made
 37. Ensure the Velcro alongside the canvas sleeve is the loops side and is facing outwards
 38. Sew on the Velcro strips, once sure they are correctly in place
 39. Sew on the ribbon strips as indicated in Fig. ??
 40. Setup the base of the hide and erect the folding chair on top of it
 41. With a tape measure, sit on the folding chair and measure where the observation flap needs to go. The size of the observation flap will depend on the type of research that is being conducted. Take into consideration how wide field of view is required. The observation flap size should be kept to a minimum, as this is where the falcon may be able to see movement inside the hide
 42. Mark the outline of the observation flap onto the inside of the canvas
 43. One person holds the top up and in position, while another puts the canvas onto the rear left-hand corner upright
 44. The stretch the canvas around the corner uprights
 45. Check that all of the Velco strips are in the correct places and that they hold the canvas onto the frame tightly
 46. Check that the observation flap is in exactly the right place

47. One person holds the top of the hide in place, while another removes the canvas from the rear left-hand corner upright. Insert the corner upright back into position after the canvas sleeve has been removed
48. Cut the observation flap into the canvas
49. Attach a piece of black shade cloth larger than the observation flap. The shade cloth should only be attached along its top edge
50. One person holds the top up and in position, while another puts the canvas onto the rear left-hand corner upright
51. Check the entire hide setup to ensure that it will be sufficient to undertake the desired observational research
52. Make any necessary changes to the hide

Four lengths of ribbon at the sleeve end of the canvas just after the Velcro loops and also on the outside. At the door end (end of the canvas furthest away from the sleeve) of the canvas four lengths ribbon tape (top, upper-middle, lower-middle and bottom of canvas) are on the outside and four on the inside.

9.4 Nest Site Selection

Firstly a nest site must be selected that is suitable for good observations to be possible from a hide. The nest needs to have good visibility into the scrape from a reasonable distance away from the nest site. The hide needs to be positioned on relatively flat ground, unless the ground can be easily leveled. The nest site should ideally be well lit and the hide is best placed approximately to the South of the nest to avoid sun glare during the observations. Observe the nest from ~300 m to see where both parents regularly perch when near the nest site. It is best if these are not too close to the

proposed hide site. Observe where the female usually enters the nest, this is likely to be where she feeds the chicks from later in the nesting cycle. If she will often feed with her back to the hide, then the precise details of feeding will be difficult to record, if not impossible. An open and exposed nest is better than one that is well concealed. After site selection has been made, the forest manager should be contacted to ensure that the hide can be erected in the desired compartment for the length of the nesting cycle. Not until the site has been confirmed by the forest manager should the hide be constructed at the nest site.

9.5 Hide Site Selection

Watch the nest from a considerable distance. Determine which way the adults enter and leave the nest. Determine where there are openings around the nest that may provide visibility down into the nest scrape. Locate the main perch of the male, especially the sites where he passes prey to the female. The hide site needs to be South of the nest site so that the sun doesn't cause glare on the observers scope lens. Ensure that the height of the vantage point (where the hide will be sited) will provide a view down into the nest scrape. The hide site should be as far away from the nest as possible, whilst still being able to make the required observations. This distance from the nest scrape will vary according to the nature of the research being conducted and the observation equipment that the observer has available to them. The hide site should ideally have a clear path to it from an access road. The hide site may need to be located away from main access roads, if security is an issue.

9.6 Initial Hide Site Development

An area the size of the base of the hide needs to be cleared and leveled. If it can be compacted down then this will improve the stability of the hide later. Measure to the height of the scope and check that the contents of the nest scrape are visible.

9.7 Erecting the Hide

The hide must be constructed very systematically. It is advisable to put up the hide before hand to get a feel for how it fits together, and to practice putting it together.

1. Carry out the base of the hide with the roof lying on top of it.
2. Place the base in position first, ensuring that it is stable and facing directly towards the nest scrape.
3. Logs may be pushed under the corners of the base as this will improve its stability.
4. Insert one of the uprights into the canvas sleeve, and then wrap the other uprights in the canvas.
5. Take the uprights to the hide site.
6. One person stands on the base and holds the roof up, ensuring the front is facing the nest. The other person inserts the nails on top of the uprights through holes in the corners of the top (ensure the upright in the canvas sleeve is positioned at the back left corner of the hide, and that the Velcro alongside the sleeve is on the outside of the hide).
7. While the roof is being held up, four guy ropes are attached to the uprights and pegged securely into the ground using long pegs. The guy ropes should radiate outwards from the hide at about 45° from each of the corners. The outer structure is now secured in position.

8. One person rolls the canvas around the outside of the four corner uprights, while the other person attaches the inner Velcro straps of the canvas around each of the corner uprights. The canvas should be attached as tightly as possible as this will reduce the flapping during observations.
9. The top Velcro strip (hooks) at the end of the canvas can be attached to the top Velcro strip on the outside of the canvas sleeve (loops), and tie the top and second ribbon ties. This allows entry through the bottom two thirds of the canvas door.
10. From the inside of the hide, pull the canvas up inside the inner framing of the top and then staple it to the inner framing using the staple gun. Tie the ribbon tape at the top of the canvas door to the ribbon tape on the inner framing of the top.
11. After erecting the hide frame, the observer should back off at least 400 m and observe the nest to ensure the falcons accept the hide and return to nest duties. If the falcon will not return to nest duties and appear distressed to the presence of the hide, then the hide must be removed from the compartment immediately.

9.8 Inserting the Internal Components of the Hide

The padded collapsible chair is inserted into the hide first, then setup. The tripods, toilet jar, and extra warm clothing can be put inside the hide at this point.

9.9 Securing the Hide

A second guy rope can be added to each of the four corners of the hide. After pegging them down these outer guy ropes should also be tied to large logs. So that even if the pegs pull out of the ground the hide can be held upright by the logs. The guy ropes should all be very tight to prevent most of the movement of the hide, even in very strong winds.

9.10 Entering the Hide

Prior to approaching the hide, weather variables should be recorded at the remote weather station. Entering the hide should be made as discretely as possible. If a feeding event is occurring, wait until this has been completed before entering the hide to reduce disturbance. Try to avoid eye contact with attending falcon, as this may cause added stress to the nesting birds.

Once inside, set up both tripods after being seated in the hide. Then attach the scope and immediately check the nest area through the scope. The video camera can then be mounted on the other tripod.

9.11 Recommendations for Changes

- The hide became very hot in the middle of the day. A paler shade of brown canvas would have been better. However, the hide needs to blend in with the surrounding colours for security from theft and vandalism.
- More openings in the sides of the hide would have improved visibility, but were too time consuming for my project. More openings would have also allowed the hide to be cooler. The downside is that more wind and light may get into the hide. If enough light enters the hide then this can create a silhouette of the observer inside. Then if the observer makes any movements the falcons can see these movements via the silhouette.
- Use a zipper to close and ribbon tape to tie open the observation flap. I used Velco for both of these and although it was very strong, it caused more noise than was desired.

10. Remote Weather Station

(refer to Fig. 6)

- Main stake: treated 25 x 25 mm (1" x 1") garden stake, 1075 mm with a pointed base
- Rainfall gauge: 150 mm maximum volume
- Maximum/minimum thermometer (degrees Celsius): mercury with needles to record min. and max.
- Thermometer wooden casing (protects from direct sunlight): 100 mm wide x 100 mm deep, top is 140 mm long

Siting of the weather station:

The weather station should be out in the forest compartment at least ~25 m from mature edge trees. It should be on the way to the hide but not too close that the hide affects the recordings.

11. Addressing Bias

A single observer was used for all of the observations made at both nest sites. To reduce observer fatigue observation bouts generally lasted six hours, and no longer than. The adult falcons, except for the male from compartment 333, had been banded previously by another study. New Zealand falcon are reverse sexually dimorphic, with the males only two-thirds the size of the females. This allowed the incubating and brooding bird to be identified to sex. Slight variation in the facial features and patterning also aided in the sexing of the adults on the nest scrape. The chicks were banded at 13 days old at compartment 333 and 32 days old at compartment 159. They were banded by experienced members of the Raptor Association of New Zealand (RANZ) for a long-term study on the falcon in Kaingaroa Forest. Prior to banding the chicks were

identified by slight differences in their morphological development, especially their patterns of down loss.

12. Field Data Sheet Layout

12.1 Recordings made during Hide Observations

During the incubation period, the following observations were recorded:

- A. Incubation bouts and provider
- B. Egg turning
- C. Prey deliveries

During the nestling and early post-fledgling period recorded observations were:

- A. Brooding bouts and provider
- B. Prey deliveries, provider, type of delivery, prey passed, and to whom
- C. Feeding bouts, provider, prey fed, number of food parcels, and to which young

Throughout the field observations in this study any other notable behaviours of either parents, or young in and around the nest area were recorded. All possible disturbance events were also recorded. Prey items were classified to the finest taxonomic level possible from observations. A detailed description of each prey item was also recorded wherever possible. Important stages in the breeding cycle of the falcons were recorded. Behavioural developmental stages in the young; including first feeding, first self-feeding and first flights were also recorded.

Fig. 1.



- (a) Top underside, showing inner framing
- (b) Top's upper with green waterproofing wood stain
- (c) Holes in the corner inside inner framing of top, for nails of corner uprights
- (d) Top of a corner upright, showing nail extending 5 cm

Fig. 2.



- (a) Top inner framing (left) and corner uprights (right)
- (b) Base pallet, note reinforcing struts in place
- (c) Plywood base attached to pallet
- (d) Carpeted plywood base

Fig. 3.



(a)



(b)

-
- (a) Hide framing, without canvas attached
 - (b) Hide fully complete with canvas attached

Fig. 4.



- (a) Front view of hide, showing observation flap partially open
- (b) Back left-hand corner of hide, showing the ribbon tape ties used to close the hide door
- (c) Internal equipment setup of hide

Fig. 5.



(a)



(b)

(a) View of the hide at the closest observation site in compartment 333

(b) View of the hide from the nest scrape (approx. 10x magnification). Maybe what the hide looks like to the attending falcon

Fig. 6.



(a)

(a) Remote weather station

Appendix 2 – Additional Figures

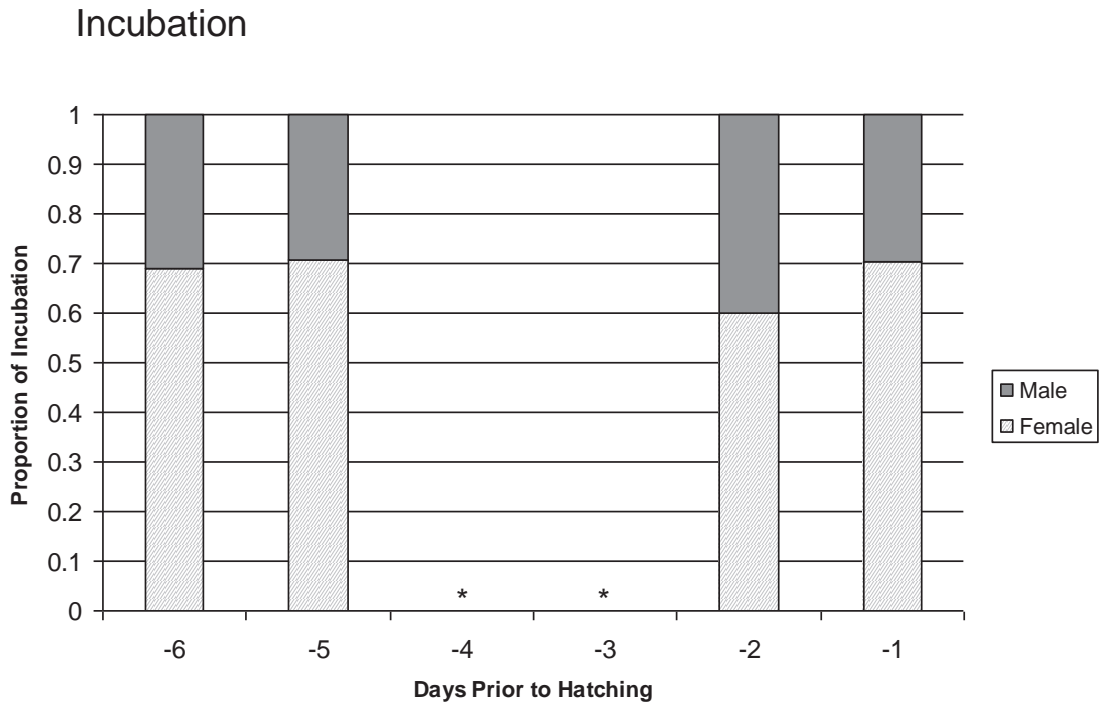


Figure A.1 The proportion of incubation provided by each sex, per observation day at C333. Incubation was defined as the time spent sitting in the nest scrape on the eggs. Hatching date was defined as the day in which the first eggs hatched (hatch date = 12.11.06). * = missing data. Observations were only made during daylight and cover from ca. 06:15 to ca. 17:15.

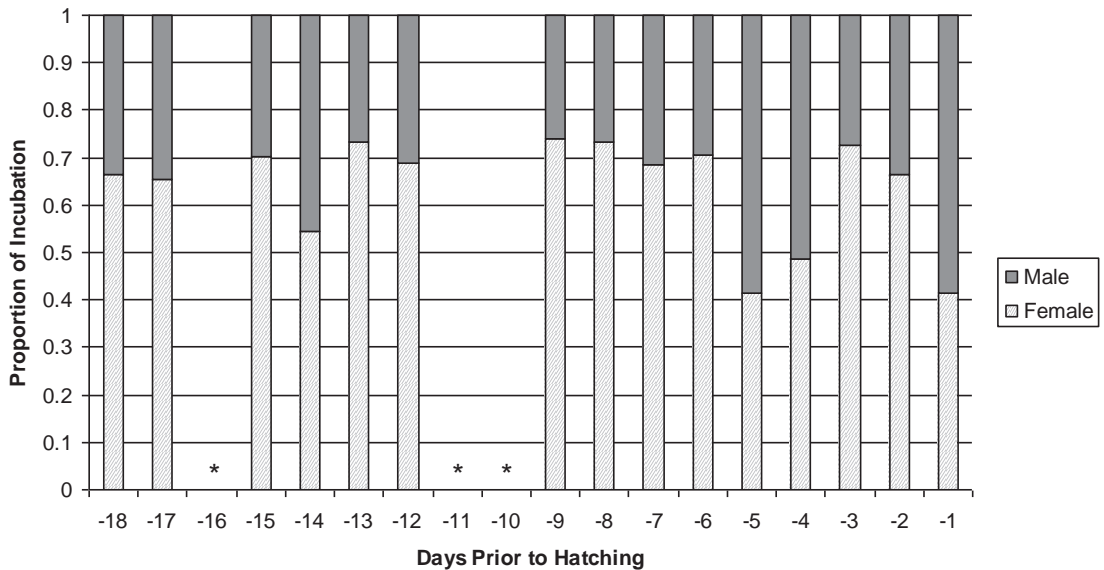


Figure A.2 The proportion of incubation provided by each sex, per observation day at C333. Incubation was defined as the time spent sitting in the nest scrape on the eggs. Hatching date was defined as the day in which the first eggs hatched (hatch date = 22.01.07). * = missing data. Data represents daytime observations from ca. 05:50 h to 21:00 h in C159.

Brooding



Figure A.3 The brood of three chicks in the scrape at C333 on Day 8 (20.11.06). The youngest nestling (7 days old) is noticeably underdeveloped and can be seen in the bottom right of the nest scrape.

Prey Delivery

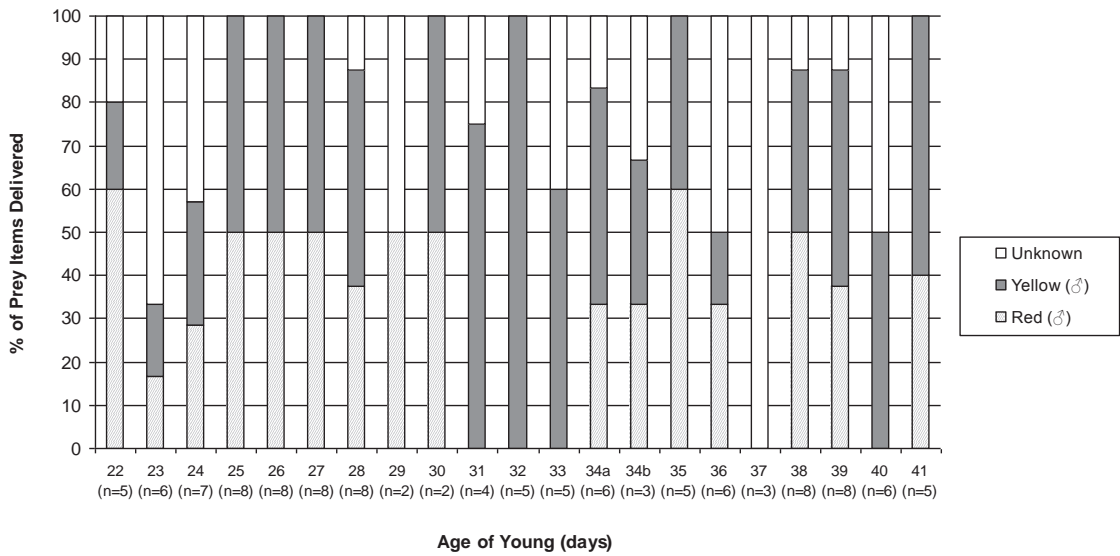


Figure A.4 Observed allocation of whole prey items between young at C333. “34a” represents a morning observation when the young were 34 days old whereas “34b” represents an afternoon observation on the same day. n = number of prey items passed per observation day. Observations were only made during daylight and cover from ca. 06:00 h to 20:31 h. The female parent was absent from Day 17 (presumed dead) at C333, therefore all whole prey items passed by the male parent. Both male chicks fledged at 31 days old.

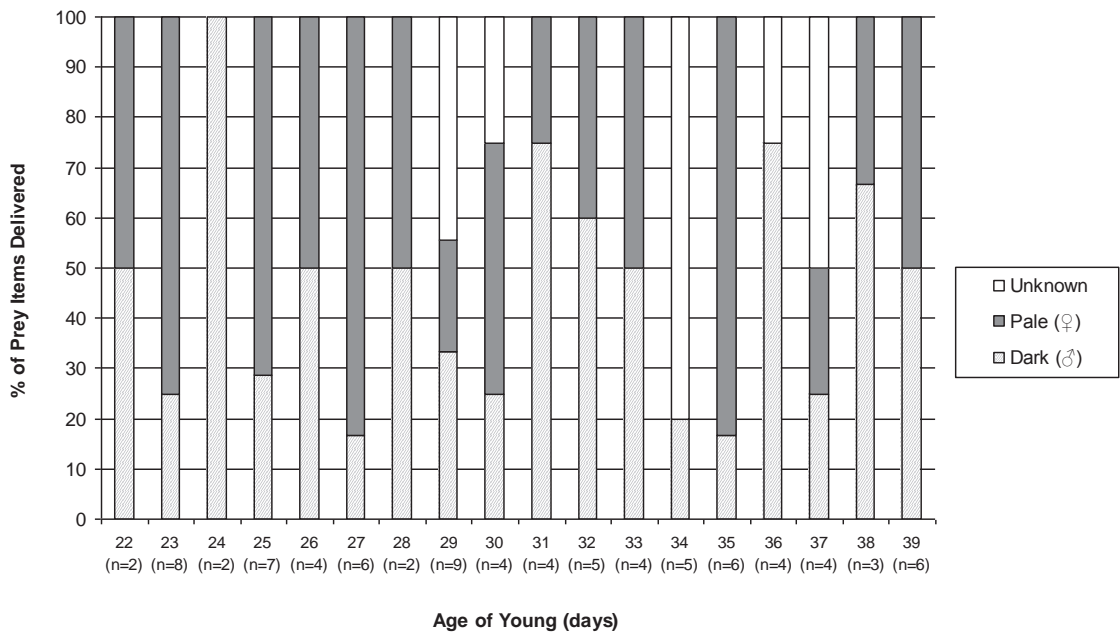


Figure A.5 Observed allocation of whole prey items between young at C159. n = number of prey items passed per observation day. Observations were only made during daylight and cover from ca. 06:00 h to 20:31 h. The male chick fledged at 31 days and the female at 36 days old.

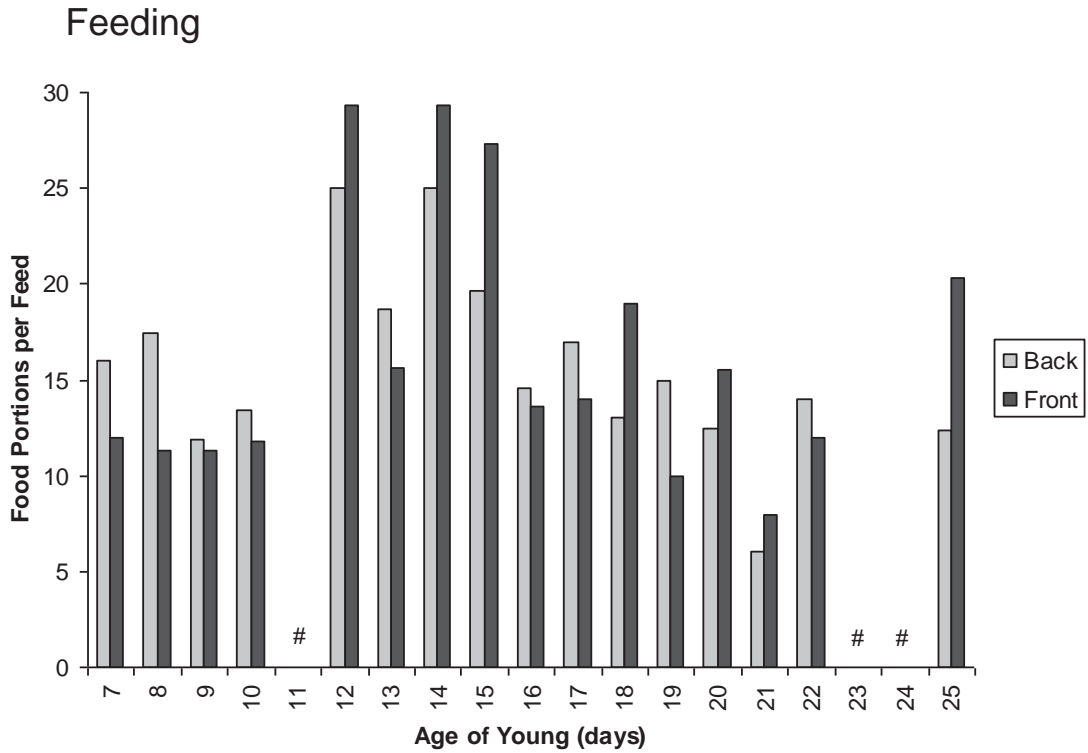


Figure A.6 Mean observed number of food portions adult feeds per feeding event at C159, comparing the location of the offspring during feeding. # = feeds contained unknown number of food portions. Observations were only made during daylight and cover from ca. 06:00 h to 20:31 h.

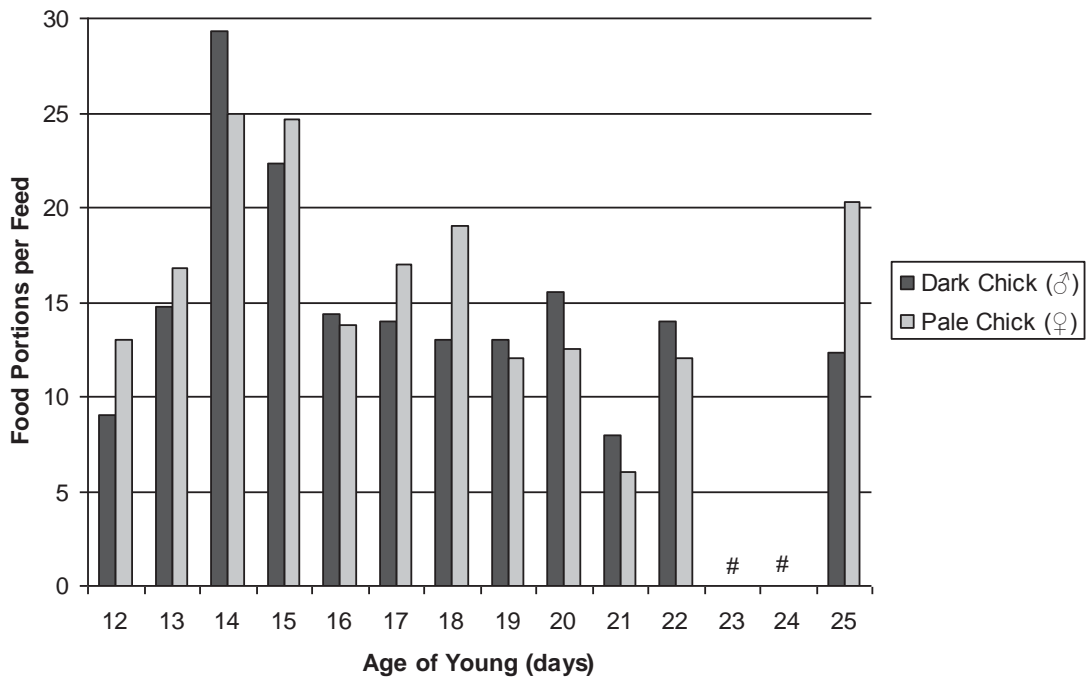


Figure A.7 Observed mean number of food portions adult feeds per feeding event at C159, comparing the sex of the offspring. # = feeds contained unknown number of food portions. Observations were only made during daylight and cover from ca. 06:00 h to 20:31 h.

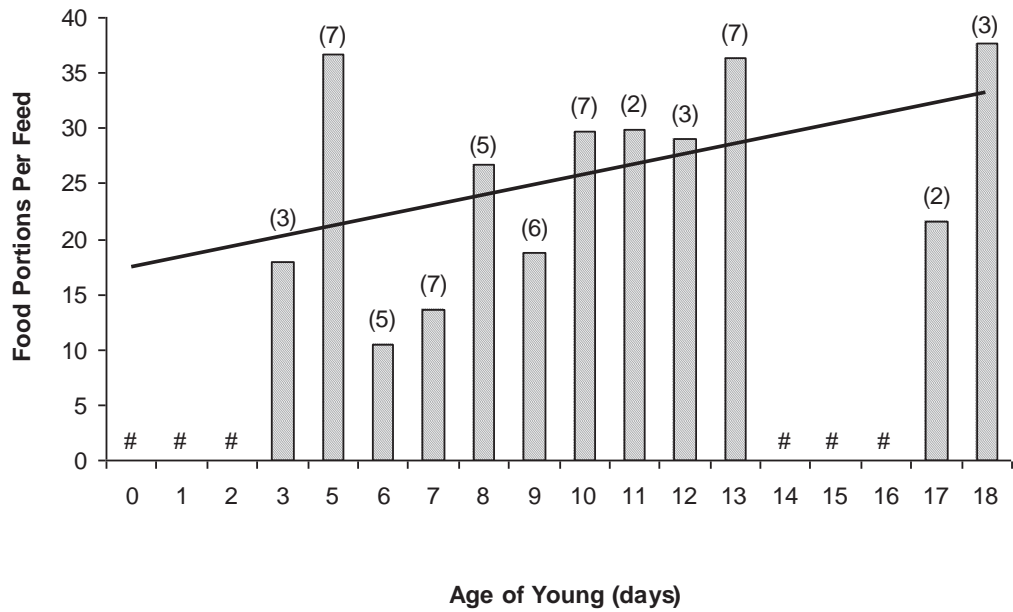


Figure A.8 Observed mean number of food portions adult feeds per feeding event at C333. # = feeds contained unknown number of food portions. Values above the bars inside brackets are the number of feeding events recorded during observation on that day. Observations were only made during daylight and cover from ca. 05:08 h to 21:00 h.

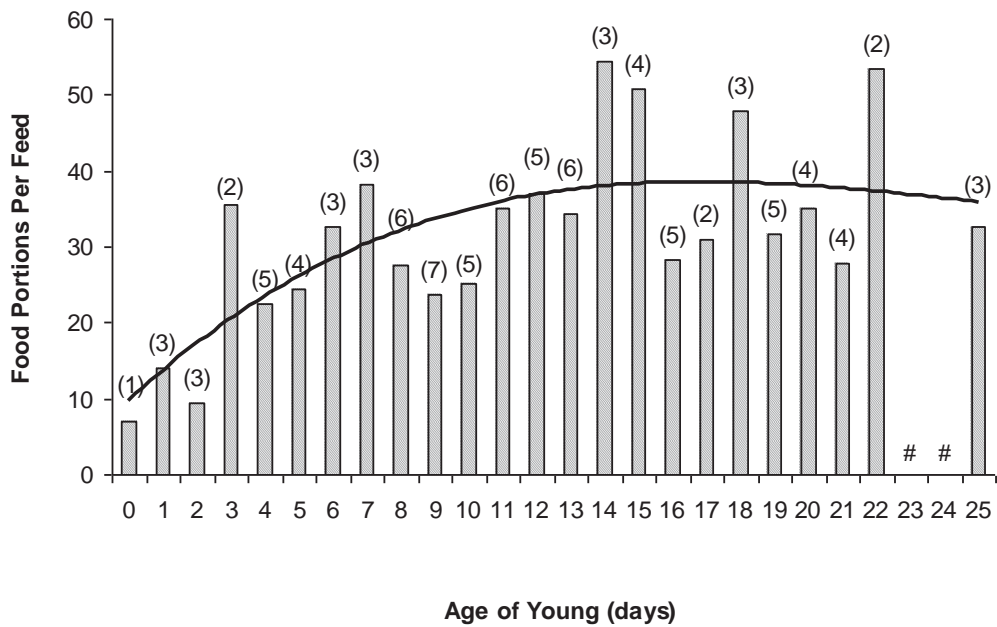


Figure A.9 Observed mean number of food portions adult feeds per feeding event at C159. # = feeds contained unknown number of food portions. Values above the bars inside brackets are the number of feeding events recorded during observation on that day. Observations were only made during daylight and cover from ca. 06:00 h to 20:31 h.



Figure A.10 A New Zealand falcon chick clutching a large blackbird nestling that it was feeding on. The primary pin feathers can be seen partially unfurled from their sheaths.

Appendix 3 - Suggested Further Research

- i) Kaingaroa Forest would be a great site to study the post-fledging behaviour of the bush form of the New Zealand falcon. I have done some work on the early post-fledgling behaviour, but only during the time when the parents are still providing food for the fledglings. There is considerable scope for doing this for other pairs and making a big project out of it. It is a very important stage in the falcon life cycle due to the high mortality rate during this period. Determining what are the causes for mortalities in juvenile New Zealand falcon will be directly applicable to the conservation management of the species.

- ii) Other work could include a detailed study on the calls made by adults and chicks near the nests, and comparing these with behaviours observed. Interaction calls between the male and female (such as begging calls, chups and whining). This should follow on from the preliminary work done by Fox (1977a).

- iii) Research into competition with and between the species would be interesting work. At a small scale the research could look at competition between nestlings within a brood of young. Some preliminary work looking at this was covered in this thesis. What competition exists between the native birds of prey species; New Zealand falcon, Australasian harriers (*Circus approximans*), and morepork (*Ninox novaeseelandiae*). All three of these species breed within Kaingaroa, however, sample sizes for morepork may be low. Do they compete for the same food resources, such as huhu beetles or passerine nestlings, during the breeding season?

- iv) A more detailed study is needed of the incubation of the New Zealand falcon. The turning of falcon eggs are very poorly understood. This research should probably involve captive birds due to the sensitivity of the birds during this stage in the breeding cycle. If possible a dummy egg should be used to determine the egg turning rate. This dummy egg needs to have electronic tilt switches within it. Temperature fluctuations of the eggs would also be interesting to measure. This may also be achieved using a dummy egg with an electronic heat sensor inside it. This work will be very useful for optimizing the artificial incubation of New Zealand falcon eggs.

Appendix 4 - Glossary of Terms

Brooding - The behaviour of covering the young to regulate their body temperature and protect them from environmental conditions, such as rain and wind

Stress brooding - Any brooding event that occurs after the young are able to thermo-regulate. Stress brooding is usually reserved for adverse weather conditions such as heavy rain or very hot temperatures

Feeding (by the young) - The consumption of prey brought to the nest by the parent falcon

Assisted feeding - At least one parent is present during the feeding event, tearing up the prey into food portions which are then passed to individual young

Self-feeding - When the young either tear up prey independent of their parents, or swallow the prey item whole

Incubation - In this study it was defined as the proportion of observed time spent by either parent directly covering the eggs

Inter- incubation/brooding bout - The period of time between either brooding or incubation bouts

Mantle - To cover food with outstretched wings and body

Prey delivery - Refers to the passing of captured prey items by the adult falcon near to, or at, the nest area

Prey remains - A prey item that was retrieved from a previous cache site or appeared exactly the same as an item previously cached during the observation period.

Alternatively, any prey item that was left in the nest area, often partially consumed, from a previous prey delivery

Satiate - To be satisfactorily full

Scrape - Shallow depression in the substrate used by some falcon species as a nest

Slash - The waste vegetative material left behind after clear-felling in a forest compartment has occurred. Slash consists mainly of branches from plantation trees as well as any understorey vegetation

Thermo-regulation - The ability to maintain ones own body temperature

Appendix 5 – Observations of Interest

Responses to Human Induced Disturbances

(a) Helicopters

A small helicopter flew directly over the nest in compartment 159 on 30.01.07 at 08:53:32 when the chicks were 8 days old. She looked up at it occasionally, but appeared largely unconcerned by it. The helicopter was similar in size to the one in the image below. The adult female was at the time perched close to the nest.



(Retrieved from: <http://www.helicoptermuseum.co.uk/aircraft/r22.jpg>)

A large spraying helicopter did two very low sweeps almost directly above the nest scrape at compartment 159 on 12.02.07, Day 21, at 10:52:57. The adult female at the time was perched near to the nest on a tree stump. She remained silent throughout the event and did not appear to be particularly stressed. Very little apparent response. This event was recorded using the SONY mini DVD handycam. Helicopter was similar to the one illustrated below.



(Retrieved from: http://www.premieraviation.ie/images/site/photo_gallery/hd_bk117_image.jpg)

(b) Small Single Prop Aircraft – Low Altitude

The female at C333 was observed keeking and chasing a very low flying small aeroplane. The plane was in a direct flight path over the nest scrape. The female soon

gave up chase and returned to the neighboring mature trees where she was originally perched. The aeroplane was similar to the one pictured below.



(Retrieved from: <http://www.dkimages.com/discover/previews/968/90073601.JPG>)

(c) Jumbo Jet Aircraft (ca. 747) - High Altitude

Both Red and Yellow at compartment. 333 on 15.12.06, Day 33, looked up briefly as a large high altitude jumbo jet aircraft flew over the nest cmpt.

On 22.12.06, Day 40, at 9:22:23 a high altitude jumbo jet flew over compartment 333. Red looked up into the sky five times, presumably in response to aircraft noise. Even though jumbo jets regularly fly over this compartment.

(d) Tree Planting Mound Surveyors

When the chicks were 4 days old tree planting mound surveyors entered compartment 333. They were counting mounds formed previously by large diggers. The observer left the hide during the observation period to notify the surveyors of the presence of the nesting New Zealand falcons.

The following day, mound surveys approached the hide to pass on information of a sighting of defensive New Zealand falcon in another forest compartment. This visit was very brief and appeared to illicit minimal response from the brooding falcon.

(e) Hunting Activities (vehicles and gunshots from a large rifle)

On 22.02.07, Day 31, at 14:10:30 in compartment 159 both Pale and Dark responded to loud gun shots heard in the distance. Pale responded by becoming alert and looking out in the direction of noise. Dark just turned and looked in direction of noise.

Both nest sites were located adjacent to large main roads. The frequent traffic passing the nest sites of the New Zealand falcon appeared to have little effect on their behaviour.

Juveniles Feeding on Insects:

During the early post-fledgling period huhu beetles may be important components of the fledgling diet in exotic pine forests. This may be especially the case as fledglings start to hunt for themselves during the dependency period (de Roland et al. 2005; Seaton 2007). Insect hunting has been previously reported in New Zealand falcon by several authors previously (Fox 1977; Lawrence & Gay 1991; Seaton 2007). Insects potentially provide an easily available and abundant food resource. This theory was supported by observations made during the post-fledgling period. One of the fledglings from C333 was observed catching several huhu beetles at 85 days old. Remains at this site suggest that the same log had supplied beetles for several previous feeds.

Range of food pass types observed in this study

Perched transfer, direct aerial transfer, aerial dead drops. (no aerial live drops were observed).

Mobbing of recently fledged juveniles by prey species:

A flock of four chaffinches swooped the fledglings at 11:07:03 on the 22.12.06 (Day 40) in compartment 333.

As the fledglings from compartment 333 were flying around on 29.12.06 (Day 47) at 6:34:59, they were mobbed by finches that were out in the compartment.

Inter-specific Interactions

(a) Stoat (*Mustela erminea*)

A stoat was seen on the 22.12.06 (Day 40) in cmpt 333 at 06:47:30, running around on the top of sideways stump where the fledglings were sitting that morning.

Adult male from cmpt 333 was bombing a stoat on the 23.12.06 (Day 31) at 11:01:24.

The stoat was possibly seen again on the same day at 13:23:35, based on the adult male's behaviour.

A stoat tried to catch Yellow, one of the fledglings, while I was observing him from an unconcealed location in cmpt 333 on 10.01.07 (Day 59).

A stoat tried to get the eggs in cmpt 159 on 09.01.07, 13 days prior to hatch.

(b) Feral pigs

A sow with 3 young ($\frac{2}{3}$ grown) bolted past my hide at 18:28:20 on the 28/01/07 in cmpt 159. No kekking from Ad. female falcon (she just turned to face her nest). Pigs came within ~5m of my hide (West to East direction). Either they saw me move in the hide, heard me (as I was downwind of them). All four were totally black coloured.

(c) Australian Magpies (*Gymnorhina tibicen*)

On 06.02.07 (Day 15) at 7:54:13 magpie in the South-East matures were heard calling, soon after the female was heard kekking. Most likely they are being hassled or moved on by the female.

(d) Black Shag (*Phalacrocorax carbo*)

On 28.01.07 (Day 6) during observations at cmpt 159, both parents were seen aggressively dive-bombing a black shag *ca.* 75 m away from the hide. The black shag was getting progressively lower to the ground with every strike. During the attacks both falcon were kekking loudly. During the attacks, the black shag appeared increasingly distressed and was making loud calls. The black shag calls reminded me of the noise cats make during fights. The black shag was successfully evicted from the nest compartment. Aggressive responses by both adults and juvenile New Zealand falcons towards black shags have been previously reported (Fox 1977, Fox 1978, Lawrence & Gay 1991).