Response of Sub-adult North Island Brown Kiwi to Relocation from Captivity to the Wild.

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Anna Rhys Grant

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Abstract

Brown kiwi (*Apteryx mantelli*) juveniles are raised in captivity and released into the wild as sub-adults due to an extremely high mortality rate of young kiwi in mainland habitats where adequate stoat control cannot be achieved. This management technique is known as Operation Nest Egg (ONE). This thesis research investigated aspects of the behaviour of ONE kiwi both before and after release. The aim was to identify factors influencing activity patterns and dispersal in captive-reared sub-adult kiwi released into the wild, and how these influence survivorship and vigour.

Behavioural responses to relocation and release were examined by comparing kiwi's nightly activity levels before release with those after release. Activity was quantified using motion sensitive transmitters. Observations of kiwi and simultaneous collection of data from the kiwi's transmitter showed that the signal pattern from the transmitters could be used to distinguish kiwi's inactive and active periods with a high degree of reliability. Furthermore, continuous walking or running could be distinguished from other activity such as foraging with moderate reliability when the signal from only one kiwi was recorded continuously.

On the first night after relocation and release into the wild kiwi tended to have unusual and low activity patterns relative to other nights after release. This may have been a result of stress associated with the transportation and release. After their first night in the wild kiwi exhibited higher levels of activity than had been recorded before release. It was hypothesised that this increase in activity was a response to a lower rate of energy intake in the wild than in captivity. In support of this hypothesis, activity of captive kiwi increased when prepared food was distributed in many portions around the enclosure relative to when it was provided in one portion. Support is tentative however, because the sample size was small.

Data on the kiwi's daytime locations were collected for up to two years after release. Almost all of the sub-adult kiwi showed dispersal from their release site. Kiwi released in areas lacking resident kiwi tended to disperse further than those released into an area with

several resident kiwi near their release sites. The different dispersal tendencies among areas could be a result of conspecific attraction but firm conclusions were prevented due to some confounding among variables. Kiwi that were later depredated dispersed further than kiwi not preyed on. This relationship may be due to far-dispersing individuals having low site familiarity or a high likelihood of encountering habitat edges and their associated predators.

All kiwi lost weight after release and many did not recover to their pre-release weights for several months after release. There was an almost significant positive correlation between level of pre- to post-release activity increase and weight loss after release. No relationship between level of activity suppression on the first night in the wild and post-release weight loss was detected. However, small sample sizes in the activity studies made it difficult to draw definite conclusions about the impact activity changes had on the kiwi's post-release vigour. No relationship between dispersal distances and weight change after release was detected.

It was suggested that activity change after release might be minimised by releasing kiwi at times when their activity in captivity is naturally higher and by providing a dispersed feeding regime prior to release. It was also recommended that kiwi be released near resident kiwi if possible, provided that aggression from the adults towards newly released kiwi is unlikely.

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For Putiputi – may you be the first of many,

and in loving memory of Tinkerbell (1971-2003).

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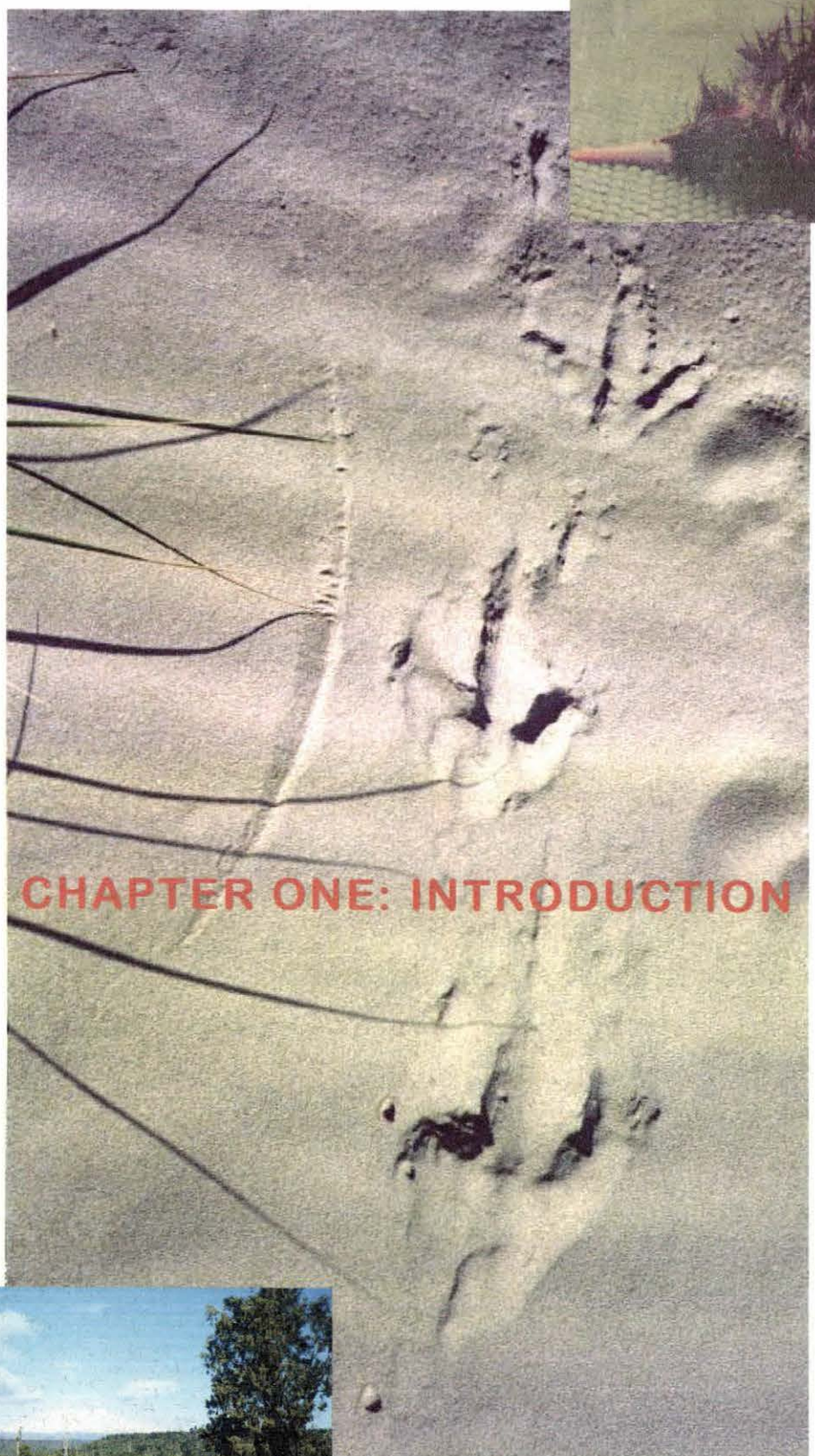
Note on Data Used in this Thesis

Some of the data used in this thesis were collected specifically for the thesis and some data were being collected already as part of the Tongariro Kiwi Protection Project. Data used in Chapters 2 and 3 were collected specifically for this thesis. For Chapter 4, the experimental procedure and collection of activity data were carried out specifically for this thesis but weight and food intake data were collected by Rainbow Springs staff as part of routine management. Location data used in Chapter 5 and weight data used in Chapter 6 were collected over five and a half years from January 1997 till August 2002, by Department of Conservation staff at Whakapapa (and Rainbow Springs staff who collected the final pre-release weights) as part of the Tongariro Kiwi Protection Project. For three of these years (October 1997 till February 1998 and November 1998 till April 2001), I was one of these Department of Conservation staff and during this time I collected a large portion of the data on location and weights of the sub-adult kiwi.



CHAPTER ONE: INTRODUCTION

1. Introduction

1.1 The Kiwi

The kiwi is an endemic New Zealand/Aotearoa bird belonging to the order Struthioniformes. Members of this order are commonly referred to as the ratites and include the cassowaries, emu, ostrich and rheas (Sibley & Ahlquist, 1990). Ratites are flightless and characterised by the lack of a keel – the protrusion on the front of the sternum to which wing muscles are attached on flying birds ("ratite" comes from "ratis", the Latin word for raft or keelless boat) (Jolly, 1990a; Sibley & Ahlquist, 1990; Peat, 1999; Holdaway, 2000). Within the ratites, all kiwi belong in the family Apterygidae and genus *Apteryx* (Sibley & Ahlquist, 1990). Currently, four extant species of *Apteryx* are recognised: brown kiwi (*Apteryx mantelli* Bartlett), tokoeka (*Apteryx australis* Shaw and Nodder), little spotted kiwi (*Apteryx owenii* Gould), and great spotted kiwi (*Apteryx haastii* Potts) (Baker et al., 1995). The current distribution of the four species is shown in Figure 1.1. The brown kiwi is considered to include two taxa: the North Island brown kiwi and the Okarito brown kiwi, with some behavioural characteristics differing between the two. This thesis research deals with North Island brown kiwi, although some aspects may be relevant to other kiwi taxa.

The kiwi species show a size range similar to that of domestic poultry (Reid & Williams, 1975), with the brown kiwi being intermediate in this range. Female kiwi are generally larger than males: in North Island brown kiwi, adult females weigh 2-3.8 kg and adult males 1.7-2.8 kg (Colbourne & Kleinpaste, 1983; Miller, 1995; Martin et al., 1999). The kiwi body is cone shaped with well-developed legs and reduced pectoral muscles. The legs are powerful and constitute about one third of the body weight. Wings are short (40-50 mm) and concealed in the body plumage; feathers are soft, lack interlocking barbs, and do not change in form throughout life; the bill is long (North Island brown female 97-155 mm, male 80-118 mm long) (Robertson & Colbourne, 2001) with nostrils at the tip and whiskers around the base. Plumage of brown kiwi is usually a uniform brown with black striations, but occasional individuals are albino, white or have patches of darker or lighter colour

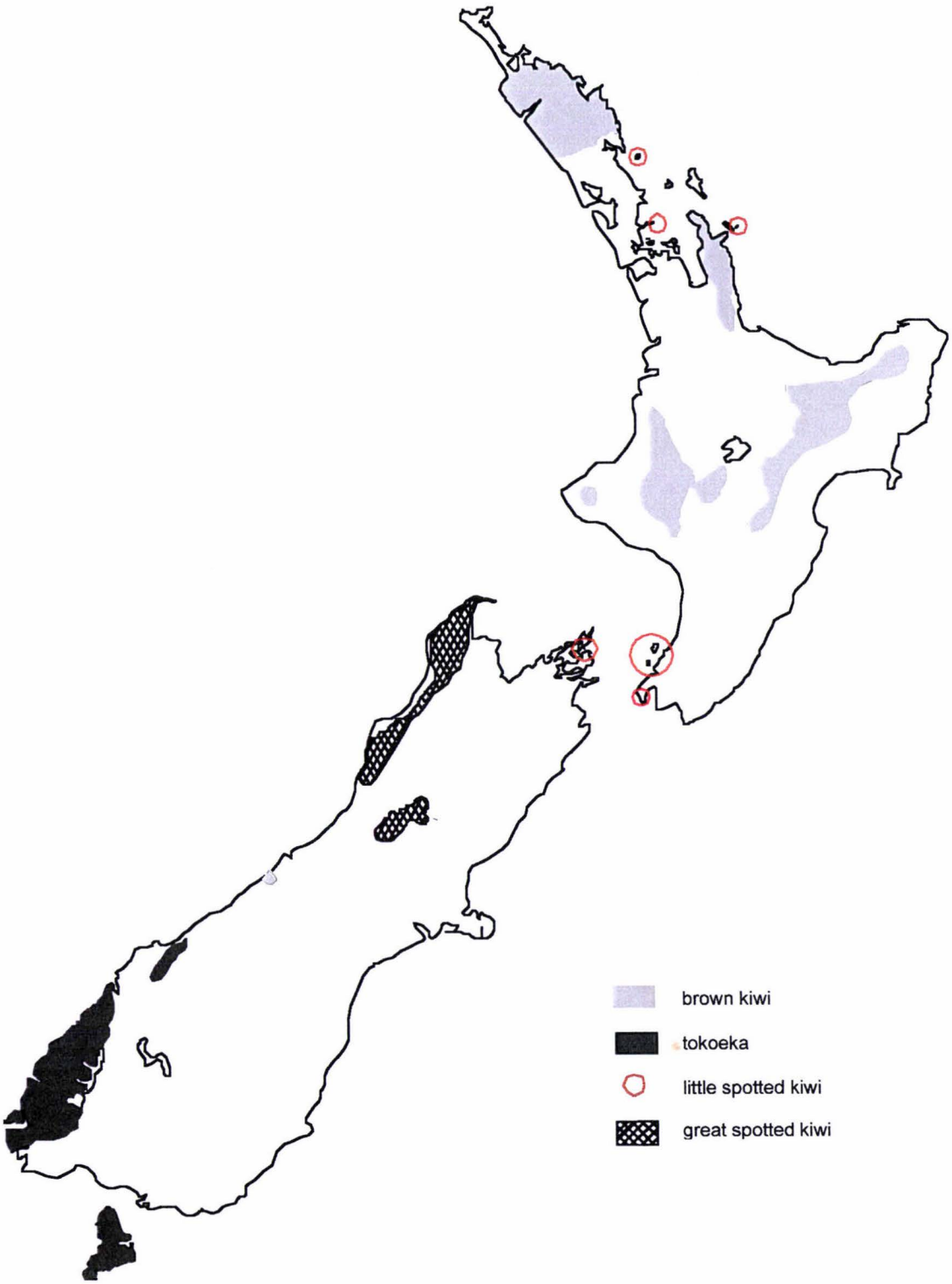


Figure 1.1 Current distribution of the kiwi species (adapted from Peat 1999).

(Reid & Williams, 1975; McLennan, 1990a; Sibley & Ahlquist, 1990; pers. obs.).

Kiwi occupy a range of habitats from coastal to alpine regions, including indigenous and exotic forest, alpine tussock, sand hills, and patches of remnant scrub/bush within farmland (Jolly, 1990b; McLennan, 1990a,b,c,d,e). Kiwi range from primarily nocturnal to completely nocturnal (depending on species and region), and feed on ground-dwelling invertebrates, berries, and occasionally other vegetation matter and aquatic invertebrates (Reid & Williams, 1975; Reid et al., 1982; Jolly, 1990b; McLennan, 1990a,b,e). During the daytime the nocturnal kiwi hide in natural cavities in the ground, hollow logs, specially-dug burrows, or thick vegetation on top of the ground (McLennan et al., 1987; McLennan, 1990b; Miles, 1995; personal observation).

Monogamy appears to be the dominant breeding system in most kiwi taxa and populations with pairs defending a territory (Jolly, 1990b; McLennan, 1990a,b; Taborsky & Taborsky, 1999). Females lay eggs that are about 18-25% of their own weight and one or two are laid per nest (Reid & Williams, 1975). Male North Island brown kiwi do virtually all of the incubation, which lasts 75-92 days (Potter, 1989; McLennan, 1990a). Chicks hatch fully feathered with their belly distended with yolk that will nourish them for their first week of life. Chicks are not fed by their parents, but are brooded by the male during the day and some of the night. Within a week the chick ventures outside to feed, but comes back to the nest to rest (Jolly, 1990b; McLennan, 1990a). When they are about three weeks old North Island brown kiwi chicks leave the nest permanently (McLennan, 1990a). Sexual maturity is probably normally reached somewhere between 18 months and four years (Reid & Williams, 1975), but at what age most kiwi in the wild are able to form a territory and find a partner is unknown.

For the purpose of this study, four life stages in North Island brown kiwi are recognised. These stages follow those of Robertson & Colbourne (2001), apart from the distinction between juveniles and sub-adults, which here is defined according to weight rather than age. The stages are: Chicks: young still in the nest or going back to the nest each day; Juveniles: young kiwi no longer going back to the nest during the

day, that have not attained 800 g in weight (this weight can be reached at between 13 and 33 weeks of age in wild kiwi (unpublished data, Whakapapa Department of Conservation; Gibbs, 2000)); Sub-adults: kiwi that have attained 800 g but not 4.5 years of age; and Adults: kiwi that have attained 4.5 years of age. This thesis deals mainly with sub-adult North Island brown kiwi.

1.2 History of Kiwi Decline

Fossil evidence indicates that kiwi were once widely distributed throughout the three main islands (and probably some offshore islands (Butler & McLennan, 1991; Lowe et al., 1996)) although some range displacement would have occurred during the Pleistocene glaciation cycles (Baker et al., 1995). By the time of first human settlement in Aotearoa by Polynesians, about 1000-800 years ago (Flannery, 1994; McCulloch, 1995), kiwi are estimated to have numbered around 12 000 000[1] (Peat, 1990; Peat, 1999; Robertson, 1999). The decline of kiwi is linked to the arrival of humans.

The early Polynesians hunted kiwi for their feathers and for food (Andrews, 1990; Jolly, 1990a; Peat, 1999), and in the later years of Polynesian settlement, fires were lit to encourage growth of edible plants. Many of these fires spread over huge areas and resulted in large-scale destruction of forest, particularly in the east of the South Island (Flannery, 1994; McCulloch, 1995). Reductions in kiwi numbers over the centuries since Polynesian settlement have been inferred from the growing rarity of kiwi feather cloaks and increasing infrequency of kiwi bones in middens (Andrews, 1990). Overhunting by humans and loss of the kiwi's forest habitat probably accounted for these reductions. Estimates of kiwi abundance at the time of first European contact in the 1700s have not been made. However, given that more than 40 years passed between first European contact and the first published record of knowledge of kiwi

[1] Estimated from current home range sizes extrapolated to area covered in potential habitat at this time (Peat, 1990).

by Europeans in 1811, it seems unlikely that kiwi were densely populated and conspicuous throughout the country at this time (Falla, 1979; Andrews, 1990; Peat, 1999).

Anecdotal reports of conspicuous kiwi decline since the start of European settlement were occurring by the mid 1800s (Peat, 1999). Reports from collectors (who hunted kiwi to sell to overseas collectors, museums and producers of fashion items), illustrated a progressive pattern of decline, as certain species became harder to find or disappeared from some areas (Andrews, 1990). Ironically, the activity of collectors was probably contributing substantially to the decline, along with predation by dogs, cats, and humans, and accelerating habitat destruction as forest was cleared for settlement (Andrews, 1990; Peat, 1999).

Plans to introduce mustelids to New Zealand in the mid to late 1800s, in an attempt to control the earlier introduced rabbits, were met with many warnings and protests from natural historians, who predicted that the impact of mustelids on flightless birds would be severe (King, 1984; Hill & Hill, 1987; Andrews, 1990). Professional collectors responded to the imminent introduction by accelerating their efforts to collect rare specimens before they disappeared (Andrews, 1990). In spite of the warnings, mustelid (ferret (*Mustela furo*), stoat (*Mustela erminea*) and weasel (*Mustela nivalus*)) releases began in 1882, and continued for about 15 years (Marshall, 1963; King, 1984). Pioneering conservationists then attempted to establish populations of vulnerable bird species (including kiwi) on predator free islands (e.g. Hill & Hill, 1987). Many of these attempts were successful, and the descendents of these translocated individuals now constitute important populations for conservation and research (Butler & McLennan, 1991).

Some idea of the rate of kiwi decline during the 1800s can be gained from the accounts of naturalists and explorers. Buller (1888) refers to reports of 100 or more kiwi being caught in a single night. But by 1892, Charlie Douglas wrote this about the birdlife in the areas he explored, "Years ago the Karangaroa [Karangarua] and other rivers...were celebrate for their ground birds, the kiwi made night hedious with its piercing shriek...The digger with his dogs, cats, rats, ferrets and guns have nearly

exterminated the birds... The cry of the kiwi is never heard... But the flats of the Copeland [Copland]...was [is] full of birds all tame and inquisitive as of old." (Douglas, 2000). A.P. Harper visited the Copland Valley only three years later than Douglas and wrote, "It is hard to believe that birds could disappear so quickly...never,...have I seen such a dearth of birds – of kiwis we neither saw nor heard a trace, ..." (King, 1984). In 1896, the Animals Protection Act gave kiwi formal protection from humans (Andrews, 1990; Peat, 1999), possibly in the belief that this would bring an end to the kiwi's problems. However, as little was known about kiwi demographics and behaviour in the wild (Reid & Williams, 1975), the impact that mustelids and other predators might have, was also unknown.

Recent estimates of past kiwi abundance put numbers in 1923 at around 5 000 000 for all kiwi and around 2 500 000 for North Island brown kiwi (Robertson, 1999). At the time however, there were no attempts to precisely index kiwi abundance. Population trends of most kiwi taxa remained unknown until the last two decades of the 1900s but up until this time kiwi (with the exception of the little spotted kiwi) were not considered to be in danger of extinction on the New Zealand mainland, as they were still widely distributed in many mainland forests, sometimes at apparently high densities (Reid & Williams, 1975; Falla, 1979; McLennan, 1988). This apparent tenacity of the kiwi was in stark contrast to most other endemic flightless terrestrial birds, which had disappeared from all but the most inaccessible parts of the mainland by the middle of the 1900s (Robertson, 1985; Clout & Craig, 1995) or were extinct (Holdaway, 1989; Worthy & Holdaway, 2002). A large kiwi that once lived on the eastern side of the South Island appears to have gone extinct before the arrival of Europeans (Worthy & Holdaway, 2002), but no extant kiwi species were considered to be in danger of extinction in the mid 1970s (Reid & Williams, 1975). By 1981 the little spotted kiwi (by now confined to offshore islands) was the only kiwi species considered endangered (Williams & Givin, 1981).

Gathering of baseline data on kiwi abundance began in the 1970s (Reid, 1983), and by the mid 1980s repeat surveys were showing that some mainland populations were clearly in decline (McLennan & Potter, 1992). Reports now started coming from the public of no longer hearing calls or seeing kiwi sign in areas where they had been

apparent a few years earlier (e.g. McLennan & Potter, 1992). Impacts of various human activities, particularly on North Island brown kiwi, also became more apparent during the 1980s, with reports of kiwi being killed by dogs, vehicles, gin traps and cyanide poison (McLennan, 1988; Taborsky, 1988; Miller & Pierce, 1995). By 1998, total kiwi numbers were estimated to be about 79 000, and North Island brown kiwi around 30 000 (Robertson, 1999).

1.3 Kiwi Recovery Programme

The Kiwi Recovery Programme was implemented following the publication of the first Kiwi Recovery Plan in 1991 (Robertson, 1996). All kiwi taxa were included in this plan, which covered the period from 1991 to 1995. It placed a high priority on safeguarding the little spotted kiwi as this species was the only taxa then considered endangered. However, the plan also acknowledged that the conservation status of many kiwi taxa was unknown and that anecdotal evidence pointed to declines in many parts of the country. The plan emphasised the need to determine threats to kiwi populations; in particular, to research the survival of and threats to juveniles after leaving the nest, and to use the results of this research to devise management plans aimed at promoting recovery of kiwi populations (Butler & McLennan, 1991).

Radiotracking studies of North Island brown kiwi during the 1980s gave reason to suspect that chick and juvenile survival was poor (e.g. McLennan, 1988), although difficulties in attaching and maintaining transmitters on chicks meant that the cause of their low survival was unable to be established with certainty (Powlesland, 1988). Surveys of the demographic structure of great spotted and brown kiwi populations on the mainland (McLennan & Potter, 1993) showed that independent juveniles made up a significantly smaller proportion of the population (3%) than in a similar survey of little spotted kiwi on Kapiti Island (41%) that was free of cats, mustelids, possums, feral dogs and pigs (Colbourne, 1992). These studies implied that lack of recruitment of juveniles to adulthood was a significant factor in the decline of kiwi on the mainland and added weight to the idea of McLennan & Potter (1992) that introduced mammalian predators had been largely responsible for this decline. It was now clear

that the next step in the process of determining the specific agents of kiwi decline needed to focus on the chick and juvenile stages of the kiwi life cycle.

The breakthrough in identifying the key agent of kiwi decline came in the mid 1990s. Pooled data on young kiwi (chick and juvenile) mortality, adult mortality, egg production and hatching success, from seven different brown kiwi mainland study sites around the country were used to construct a population model (McLennan et al., 1996; Basse et al., 1997; Basse et al., 1999). This model confirmed that kiwi populations were declining and showed that this decline would only cease if the survival rate of young kiwi to adulthood increased. Population decline would stop if survival rate of hatched young to adulthood increased from an estimated 6%, to 19%. It also showed that stoat predation was the main factor preventing survival of young kiwi. Predators had been responsible for 56% of the known deaths of young kiwi, and 60-79% of these predations had been carried out by stoats. It was estimated that this 19% survival rate would be achieved if predator control (targeting stoats) could reduce the predation rate to 33% (McLennan et al., 1996). Further population modelling divided young kiwi into chicks (up to three weeks of age) and juveniles (over three weeks old), and found that even if predation of chicks was reduced to zero, the predation rate on the juveniles was so high that populations would still be in decline (Basse et al., 1997). Therefore, simply targeting predators around nests was not an option to promote kiwi recovery, as juveniles had been known to travel distances of 1-2 km after leaving the nest (e.g. Miller, 1996), while still at a stage very vulnerable to predation.

The second Kiwi Recovery Plan (1996-2006) had the same long-term goal as the first: "*To maintain and, where possible, enhance the current abundance, distribution and genetic diversity of kiwi,*" and stated that there was now a "much clearer understanding of the genetic diversity of kiwi, what their threats are, and what the management and research priorities are to be able to achieve this long-term goal." Accordingly, the emphasis had moved from research aimed at identifying major threats towards management aimed at removing the short-term risk of extinction of the most endangered taxa and recovering other representative populations, while concurrently researching how best to counter the threats. The kiwi species now

considered to be at most risk of extinction was brown kiwi (the little spotted kiwi now having several stable or growing populations on predator free islands), with the Okarito taxa being considered particularly at risk (Robertson, 1996). Brown kiwi and the Haast tokoeka (*Apteryx australis* subspp.) were classified as category A threatened taxa (receiving highest priority for conservation action), while the remaining kiwi taxa were classified as category B (Molloy & Davis, 1994).

Research on how best to counter the threats to kiwi included determining what level of stoat control was needed to reduce the predation rate on young kiwi to 33% and thus allow 19% of young to reach adulthood. Mustelid trapping in combination with monitoring survival of young kiwi was undertaken. It was found (assuming that predation on young kiwi by predators other than stoats was negligible) that stoat numbers had to be reduced to between 1 and 2 per km^2 for up to nine months of the year, for 19% of young kiwi to survive (McLennan, 1998; Basse et al., 1999). The target of 1-2 stoats per km^2 represents a required reduction in stoat numbers of at least 70% in most forests (McLennan, 1998). Basse et al. (1999) considered that using current techniques, this level of predator control is too difficult to apply efficiently in areas of mainland forest larger than 1000 hectares. While more efficient methods of stoat control are being researched and developed (e.g. Norbury, 2000) alternative methods are needed for maintenance of key kiwi populations in large tracts of mainland forest.

1.4 Operation Nest Egg

Adults in mainland populations of brown kiwi have a low annual mortality rate of about 8% (based on survival records of radiotransmittered kiwi of unknown age but believed to be sexually mature), compared with an estimated mortality rate of kiwi in their first year of life of 94% (McLennan et al., 1996). As more than half of young kiwi deaths are due to predation, it is obvious that the young are much more susceptible to predation than adults. Adult kiwi tend to be aggressive and large enough to not be vulnerable to the smaller (and generally most common) forest predators – stoats (McLennan, 1988; Butler & McLennan, 1991; Reid et al., 1994). Direct evidence of this was seen on footage from a video camera set up at the nest of

an Okarito brown kiwi. A stoat was filmed entering the nest burrow and repeatedly attempting to attack the adult female, who succeeded in defending herself (Reid et al., 1994). The fact that major predation impacts are restricted to the young stage of the kiwi life cycle has meant that their rate of decline has been slower than that of most endemic flightless birds, and explains how kiwi have persisted on the mainland until now (Basse et al., 1999) when the majority of flightless birds have been extirpated from the mainland.

While it is not known at what stage of development kiwi can be considered an adult in terms of mortality likelihood, preliminary research showed that kiwi over 800 g in weight had a much lower predation rate than those under 800 g (McLennan, 1988). Kiwi attain this size in the wild at ages ranging from 13 weeks (unpublished data, Whakapapa Department of Conservation) to 33 weeks (Gibbs, 2000). As kiwi had been kept in captivity for many years, putting young kiwi in a predator free environment until they reach a more "predator-resistant size" was seen as a possible method for maintaining kiwi populations in large tracts of mainland forest. As early as 1991 it was suggested that the young of particularly endangered kiwi taxa could be incubated and raised in captivity, then released back to the wild at between six and 12 months of age (Butler & McLennan, 1991).

An initial trial of captive-rearing and release involved releasing ten captive-reared kiwi (most of whom were under one year old) that were over 1000 g in weight onto Motukawanui Island (predator free and previously kiwi free) in July 1995 (Miller, 1995; Miller, 1996; Robertson, 1996; Colbourne, 1998). By February 1996 the two eldest birds had already attempted to breed and seven of the ten were definitely still alive (Miller, 1996), showing that captive-reared kiwi could cope with a wild situation in the absence of predators and resident territory-holding kiwi. Captive-reared kiwi were first released back into mainland forests containing resident kiwi in 1996. Three kiwi were released onto the Northland mainland and four Okarito brown kiwi were released into Okarito Forest. The following year more captive-reared kiwi were released at Northland, Okarito, Lake Waikaremoana and Tongariro Forest. Results of these releases were initially mixed, with several deaths by various predators at the Northland sites and deaths due to adult kiwi aggression at Okarito, but up until at least

January 1998 no captive-reared released bird over 1000 g had been preyed on by a stoat or cat (Colbourne, 1998). This showed that although the process needed refinement, the new management technique (by now known as Operation Nest Egg (ONE)) had potential to substantially increase the number of kiwi reaching adulthood.

1.5 Captive Rearing and Relocation as Conservation Management Tools

Relocation is defined as "Any intentional movement by humans of an animal or a population of animals from one location to another" (Fischer & Lindenmayer, 2000). Three types of relocation are further defined below.

(1) Supplementation: "Addition of individuals to an existing population of conspecifics" (IUCN, 1998; Fischer & Lindenmayer, 2000).
(2) Re-introduction: the "attempt to establish a species in an area which was once part of its historical range, but from which it has been extirpated or become extinct" (IUCN, 1998).
(3) Translocation: the "deliberate and mediated movement of wild individuals or populations from one part of their range to another" (Fischer & Lindenmayer, 2000).

Note that in many previous publications the term "translocation" has been given the definition that "relocation" has been given here.

Operation Nest Egg involves relocation, initially of kiwi eggs or chicks from the wild into captivity, and subsequently of kiwi sub-adults from captivity into the wild. This relocation into the wild is sometimes in the form of supplementation and sometimes in the form of re-introduction. This thesis studies ONE where it is used to supplement kiwi populations, however some findings are also relevant to the use of ONE as a re-introduction technique.

Captive-rearing and release of young animals sourced from the wild (sometimes termed "headstarting" (Heppell et al., 1996), to supplement a population, is an

appropriate management tool if the species is particularly vulnerable in the wild during the immature life-stage. Captive-rearing for population supplementation or reintroduction has been used with some success in other species including takahe (*Notornis mantelli*) (Maxwell & Jamieson, 1997), coho salmon (*Oncorhynchus kisutch*) (Berejikian et al., 1997), bald eagles (*Haliaeetus leucocephalus*) (Meyers & Miller, 1992), and piping plovers (*Charadrius melodus*). Some captive-rearing for release programmes used puppet feeding or brooding to reduce imprinting of the young on human caretakers, and provided foraging opportunities similar to what would be encountered in the wild (Powell et al., 1997; Maxwell, 1997). Factors considered when choosing release sites for the young included the distribution of conspecifics and potential predators (e.g. Powell et al., 1997). In some cases, young were held in captivity at the release site prior to release and provided with supplementary food after release (e.g. Meyers & Miller, 1992).

Behavioural problems associated with captive-rearing may be assumed to be least likely to occur in species that have little or no parental care (Snyder et al., 1996). Kiwi are a highly precocial bird (O'Conner, 1984), and in North Island brown kiwi, parental care appears to be restricted to brooding during the daytime for about the chick's first three weeks of life (McLennan, 1988 & 1990a; McLennan et al., 1996). Therefore, it seems to be assumed that young kiwi do not imprint on their caregiver, and simulated adult kiwi are not used in chick rearing. ONE kiwi are generally raised in outside enclosures with a natural soil base and added leaf litter, which provides some opportunity for the kiwi to forage for invertebrates in the soil. However, because of the limited space in the enclosures this supply of invertebrates gets depleted and it is necessary to provide kiwi with a supplemental artificial diet. This artificial diet is generally provided in one easily accessed portion, therefore although the kiwi have the opportunity to do some foraging in captivity, they can probably acquire their energy needs without foraging. ONE kiwi are released immediately upon relocation to the wild habitat and are not provided with supplementary food after release.

1.6 Objectives of this Study

Operation Nest Egg has now become standard management practice at many kiwi sites around the country. As well as being used to supplement existing kiwi populations, it is now used as a technique to reintroduce kiwi to areas where they had gone extinct, as part of ecosystem restoration or mainland island management programmes. Associated with the development and extension of ONE comes the need to make this management technique as effective as possible. A stated objective of the 1996-2006 Kiwi Recovery Programme is to monitor the fate of captive-reared sub-adults released to the wild "to determine the most cost-effective age" and the "best time of year for release" (Robertson, 1996). This plan suggests that particular times of year may be more suitable than others, possibly depending on local food availability, predator abundance, or territoriality of resident kiwi. Determining the best age to release kiwi is important because individuals must be old or large enough at release to have substantially decreased their vulnerability to predation, but above a certain age kiwi may be more likely to face aggression from prior resident kiwi (McLennan, 1998). Choice of appropriate sites to release kiwi is also likely to be important.

This thesis investigates aspects of the behaviour of captive-reared kiwi both before and soon after their release into the wild, providing an insight into how readily kiwi adapt to their new environment. Suggestions are made on ways to ease the transition between captivity and the wild.

The thesis also quantifies kiwi's movements in the longer-term after release. McLennan (1998) highlighted the need to determine the factors that influence dispersal distances and settlement patterns of young kiwi. Dispersal distances and settlement patterns are investigated here along with their relationship to sex, age, season, and area of release.

Aim of this Thesis

The primary aim was to identify factors influencing activity patterns and dispersal in captive-reared sub-adult kiwi released into the wild, and how these influence survivorship and vigour. Contributing aims were:

1. To develop a method of quantifying activity in both captive and wild kiwi.

2. To explore changes in kiwi activity levels after relocation and release.
3. To determine whether the ease with which food is collected accounts for observed changes in activity.
4. To quantify dispersal patterns and identify factors that influence dispersal.
5. To investigate the relationship between dispersal pattern and the likelihood of being killed by a predator.
6. To assess factors that may influence weight changes in kiwi following release.

Thesis Layout

- Chapter two addresses aim 1 by developing a method for quantifying activity in kiwi.
- Chapter three focuses on aim 2 by comparing pre-release activity with post-release activity in sub-adult kiwi.
- Chapter four addresses aim 3 by assessing activity of captive sub-adult kiwi when different food provisioning regimes are applied.
- Chapter five deals with aims 4 & 5 by quantifying dispersal of sub-adult kiwi from their release site, and exploring relationships of dispersal with the timing and location of the release, and with the age, sex and subsequent survival of the kiwi.
- Chapter 6 addresses aim 6 by analysing relationships between activity changes, dispersal distances and post-release weight changes. The findings of the thesis are also summarised, further research is suggested, and management recommendations are made.

1.7 Study Sites and Subjects

Study Sites

The kiwi releases that were monitored for this thesis took place in two forests within an area of the North Island of New Zealand known as the Tongariro region (Figure 1.2).

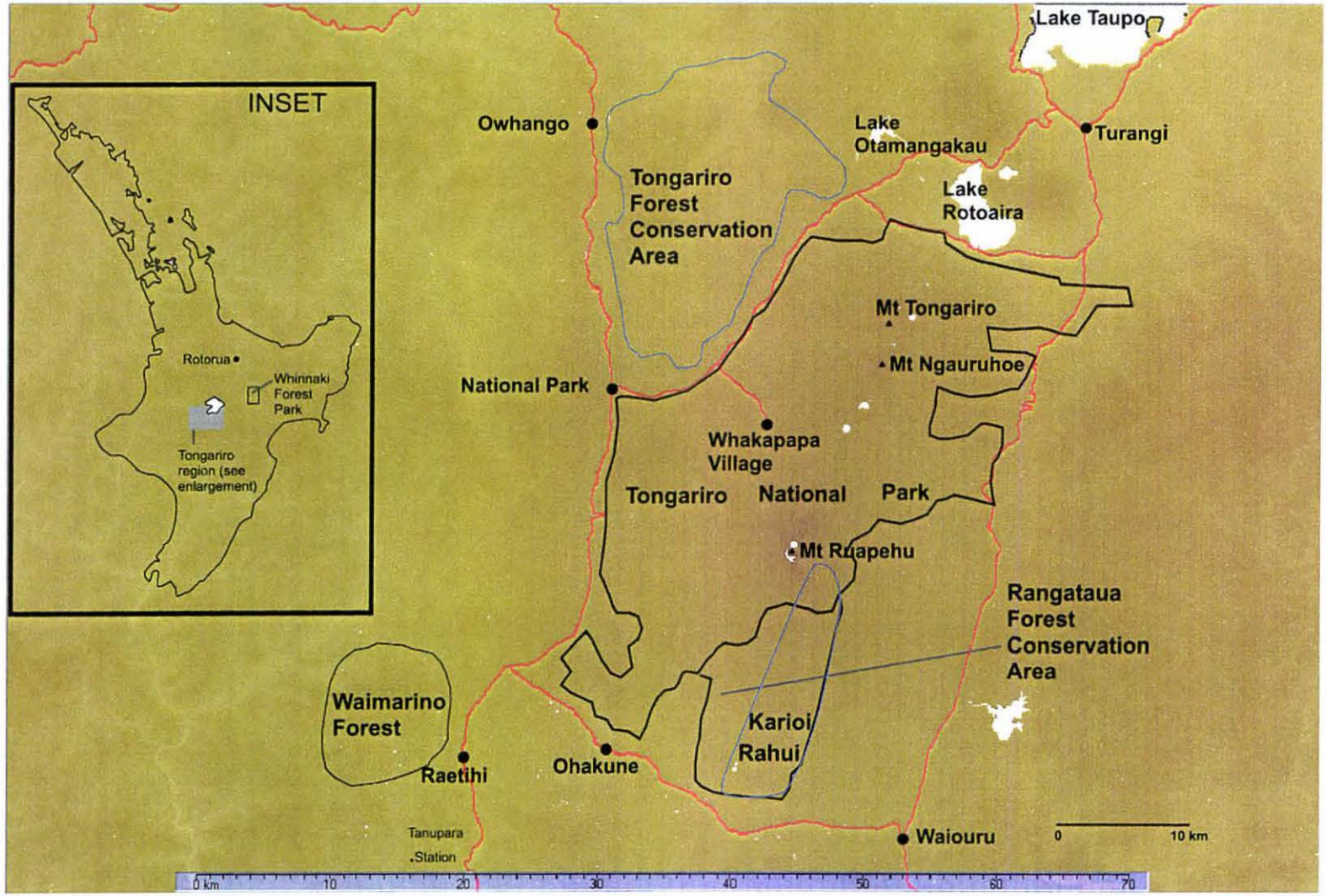


Figure 1.2 Location of study sites. Inset shows the Tongariro region, Rotorua, and Whirinaki Forest Park within the North Island of New Zealand. Main map is an enlargement of the Tongariro Region showing the two main study sites: Tongariro Forest Conservation Area and Karioi Rahui; and the two areas/sites where eggs were sourced for the release of kiwi into Karioi Rahui: Waimarino Forest and Tanupara Station.

Tongariro Forest Conservation Area

Tongariro Forest Conservation Area (TFCA) is a reserve of about 15 000 hectares to the north-west of Tongariro National Park (Figure 1.2 and 1.3). Landforms include rolling hill country, plateaux, steep mudstone-sandstone country, and lahar plains dissected by gorges (McSweeney & Smith, 1984). Geologically TFCA consists of sedimentary rocks buried beneath varying thicknesses of volcanic rocks, ash, and lahar deposits (McSweeney & Smith, 1984; NZ Forest Service, 1986). Altitude in TFCA ranges from about 300 m in the northwest to 1076 m on Taurewa Hill. Soils are yellow-brown pumice and loam and related steepland soils derived from various volcanic ash showers, with boundaries between differently derived ash resulting in widespread poor drainage (McSweeney & Smith, 1984).

Historically, the area containing TFCA was mostly forested with a few patches of tussock, bog and scrubland. The forest types were very diverse, due to the diversity of landforms and surfaces, as well as the area's proximity to both the podocarp/tawa (*Beilschmedia tawa*) forests of west Taupo and the beech (*Nothofagus* spp.) to mixed podocarp forests of the Tongariro volcanoes (McSweeney & Smith, 1984). The forest was logged and burnt from 1903 through till 1972 (Miles, 1995). While few areas remain unmodified by logging, in several areas the impact was light because low impact extraction methods were used to remove the scattered merchantable trees, and some very large trees that exceeded the capacity of the logging equipment were left standing (McSweeney & Smith, 1984).

Vegetation composition is still diverse with associations gradually merging rather than changing abruptly from one vegetation type to another (NZ Forest Service, 1986). Vegetation associations include: almost continuous canopy tawa (*Beilschmiedia tawa*) forest, sometimes with emergent rewarewa (*Knightia excelsa*); unlogged tawa with scattered rimu (*Dacrydium cupressinum*) and northern rata (*Metrocideros robusta*); logged forest consisting of hardwoods, shrubs, and scattered podocarps, with toetoe (*Cortaderia toetoe*) along old tracks and skid sites; intact forest with various associations of podocarp species, kaikawaka (*Libocedrus bidwillii*) kamahi (*Weinmannia racemosa*), and other hardwoods; remnants of matai (*Prumnopitys taxifolia*) dominant dense podocarp forest; remnant stands of

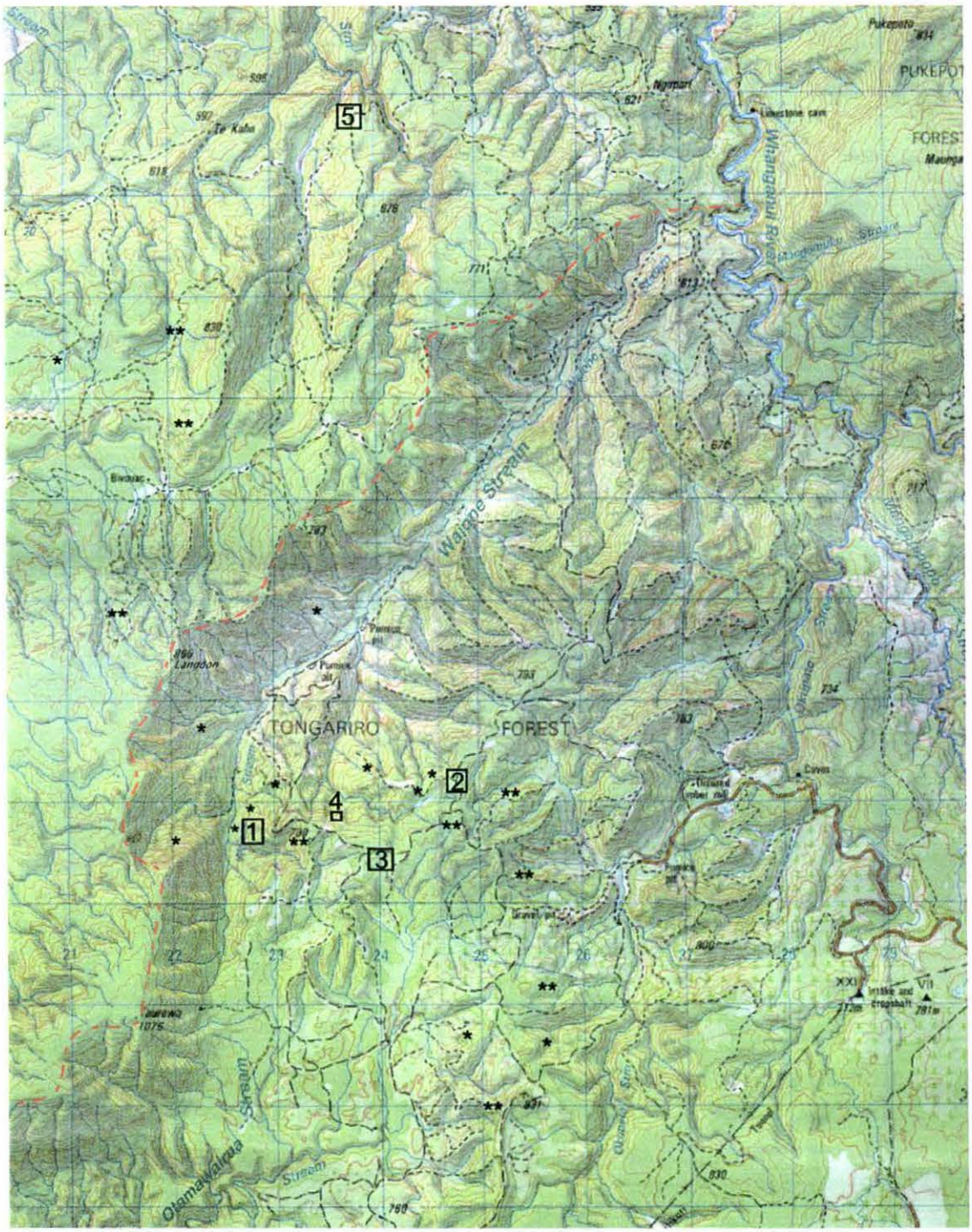


Figure 1.3 Map of Tongariro Forest Conservation Area (TFCA). All land on this map south-west of the Whanganui River is part of TFCA. The red broken line shows an approximate division between East and West TFCA. Boxes with numbers inside or beside show locations of ONE kiwi release sites. Table 1.1 shows which kiwi were released at which of these sites. * indicates location of resident kiwi during the period of release of ONE kiwi.

kaikawaka dominant forest, bog pine (*Halocarpus bidwillii*)/mountain toatoa (*Phyllocladus asplenifolius* var. *alpinus*) scrub; bog and tussock communities; manuka (*Leptospermum scoparium*) dominant scrub; and toetoe shrublands (McSweeny and Smith, 1984; NZ Forest Service, 1986).

The Taurewa-Langdon ridgeline forms an approximate boundary between the areas termed East and West Tongariro Forest (Figure 1.3). A 1991 survey showed that there was a remnant population of kiwi in Tongariro Forest with a seemingly higher density in the east than the west (unpublished data, Tongariro Conservancy, Department of Conservation). Kiwi monitoring continued through the 1990s in the eastern side of the forest with some individuals being caught and equipped with radiotransmitters in the early 1990s (Miles, 1995). In 1995 there were estimated to be up to 50 pairs of North Island brown kiwi in TFCA, "assumed to function as a more or less single interacting population over an area of 15 000 hectares" (Keys & Speedy, 1995). However intensive monitoring combined with anecdotal evidence (e.g. Miles, 1998) was strongly pointing to the conclusion that although most kiwi attempted to breed regularly, virtually no recruitment of young into the breeding population was occurring. This was despite the initiation of stoat control in one of the sites of highest kiwi density. In 1996 the first eggs from a kiwi nest in Tongariro Forest were sent to an incubation facility and in January 1997 the first captive-reared Tongariro Forest kiwi was released back into East Tongariro Forest. Since then and up until the 2001-2002 breeding season, almost all detected nests have had their eggs removed for artificial incubation and captive-rearing as part of ONE.

Until 2000 all management of kiwi in TFCA had taken place on the eastern side. In 2000 it was decided to begin releasing kiwi into West TFCA in the hope that this would allow kiwi recruitment to occur over a larger part of the forest. Therefore the 2000 cohort of ONE releasees were all released in the catchment of the Mako Stream in West TFCA. This area was not known to have any resident kiwi at the time (pers. obs., pers. comm. Ross Martin). Approximate release sites for all TFCA kiwi are shown on Figure 1.3 with the numbers corresponding to the numbers shown for individuals in Table 1.1.

TFCA Release Sites (Figure 1.3 shows the location of each site)

1. 600-700 m altitude. Moderately steep. Hardwood forest with scattered emergent podocarps. Tree ferns common. Moderately open understorey with patches of ground ferns.
2. 720-780 m altitude. Gentle contours. Hardwood forest with regenerating podocarps. Shrub hardwoods in sub-canopy. Ground cover varies from mainly open to thick patches of ground fern and toetoe.
3. 740-760 m altitude. Gentle to moderate contours. Mosaic of manuka and hardwood forest. Variable sub-canopy and understorey with some patches of ground ferns and toetoe. Boggy areas.
4. 700-720 m altitude. Moderate contours. Hardwood forest with occasional emergent podocarps. Mainly open understorey with scattered low-lying shrub hardwoods.
5. 500-570 m altitude. Gentle to moderate contours. Tawa/rewarewa canopy, other hardwoods in sub-canopy as well as tree ferns and pole podocarps. Mainly open understorey though occasional ground fern patches.

Karioi Rahui

The Karioi Rahui is the name used for an area of land on the southern slopes of Mt Ruapehu where an ecosystem restoration project has been initiated. The Karioi Rahui covers part of Tongariro National Park and part of the adjoining Rangataua Forest Conservation Area (Figure 1.2 and 1.4). It is bounded in the west by the Omarae Stream and in the east by the exotic plantations of Karioi Forest. Most of the Karioi Rahui is on the irregularly undulating andesitic Rangataua lava flow (Scientific Advisory Committee, 1980). Altitude in the Karioi Rahui ranges from 680 m to about 1500 m.

Beech forest dominates the canopy over the whole altitude range in the Karioi Rahui and in the rest of Rangataua Forest. Podocarps are interspersed below 850 m and although some were selectively logged up until 1960, this was mainly restricted to areas east of the lava flow so most of the forest canopy of the lava flow is unaltered (Scientific Advisory Committee, 1980).

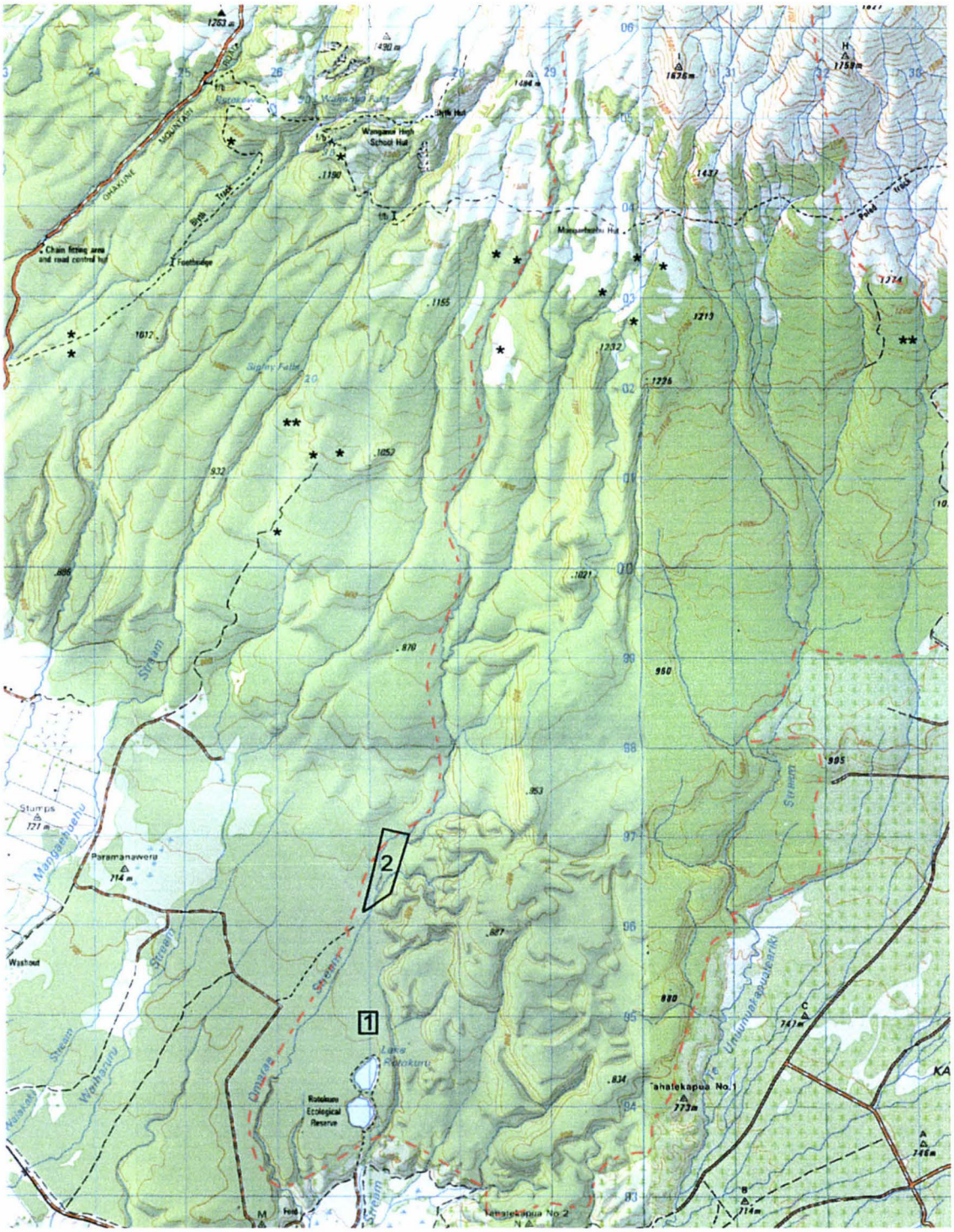


Figure 1.4 Map of Karioi Rahui. The red broken line shows the approximate boundary of the Karioi Rahui. Numbers 1 and 2 show locations of ONE kiwi release sites. Table 1.1 shows which kiwi were released at which sites. * resident kiwi prior to release of ONE kiwi (from Oates, 2001 & Specht, 2002).

Up to 850 m the forest is dominated by red beech (*Nothofagus fusca*), silver beech (*Nothofagus menziesii*) and rimu with a minor component of miro (*Prumnopitys ferruginea*) and Hall's totara (*Podocarpus hallii*) (pers. comm. Nick Singers). The red and silver beech are generally of large stature (Atkinson, 1981). Above 850 m the podocarps become uncommon and the forest is red and silver beech, with silver beech increasing in dominance as altitude increases and pure silver beech prevailing at about 950 m (pers. comm. Nick Singers). At 1000-1100 m mountain beech replaces silver beech (pers. comm. Nick Singers). Occasional emergent kaikawaka and mountain toatoa, bog pine and silver pine (*Halocarpus biformis*) become associated with mountain beech, and patches of tussock-grassland become interspersed with the forest above about 1200 m. Mountain beech persists in small patches of stunted trees up to an altitude of around 1500 m. The tussock-grassland patches become replaced by rocky alpine herbfields between 1400 and 1500m (pers. obs.). Sub-canopy and ground cover consists mainly of dense crown fern (*Blechnum discolor*) and *Dicksonia lanata*, water fern (*Histiopteris incisa*), small-leaved coprosmas and the mingimingi species *Leucopogon fasciculatus* and *Cyathodes junipera* (pers. comm. Nick Singers).

The Karioi Rahui restoration project began in the 1990s with pest control initiated in 1998 through a network of bait station lines. One of the aims of the project was to restore a kiwi population to the area. Although kiwi have been recently heard near the Round the Mountain track, as well as in a few spots in Rangataua Forest Conservation Area and the National Park to the west of the Karioi Rahui (Figure 1.4; Oates, 2001; Specht, 2002), no kiwi had recently been heard in the lower part of the Karioi Rahui (pers. comm. John Luff). Eggs were sourced from nearby remnant kiwi populations, the eggs incubated and chicks raised at Rainbow Springs, Rotorua, and the sub-adults released into the lower part of the Karioi Rahui. The majority of eggs came from kiwi in Waimarino Forest, a production pine forest about 25 km west of the Karioi Rahui, and two eggs came from a patch of bush on a farm about 5 km south of Waimarino Forest (Tanupara Station) (Figure 1.2). The first of these kiwi releases took place in May 2000.

Karioi Rahui Release Sites (Figure 1.4 shows the location of each site)

1. 720-740 m altitude. Flat. Large red beech dominant in canopy with occasional silver beech and rimu. Ground cover mostly very dense crown fern and *Dicksonia lanata.*

2. 720-760 m altitude. Almost flat. Red beech dominant in canopy. Silver and red beech in sub-canopy. Ground cover varies from dense crown fern and *Dicksonia lanata* to less dense sapling red and silver beech and small-leaved coprosmas.

Kiwi Studied

Thirty-one kiwi were studied in this thesis. All were ONE kiwi raised at Rainbow Springs Wildlife Park, Rotorua (Figure 1.2 inset). Ten of these kiwi were studied at Rainbow Springs prior to release and 28 were studied after release into TFCA or Karioi Rahui. The two kiwi not studied after release were ONE kiwi from Whirinaki Forest (Figure 1.2 inset) that were being raised at Rainbow Springs at the same time as the Tongariro kiwi. Details of all kiwi studied are listed in Table 1.1.

In the first 2-3 years of ONE in Tongariro Forest, the aim was to release kiwi when they reached about 1300 g. By 2000, when kiwi were being released into West TFCA and Karioi Rahui for the first time, it had been decided to lower the release weight to 1000 g. Consequently, kiwi released into West TFCA and Karioi Rahui were almost all younger than those that had been released into East TFCA (Table 1.2). In addition, because almost all kiwi hatched in the spring or summer, the younger released West TFCA and Karioi Rahui kiwi were nearly all released in the autumn or winter, in contrast to East TFCA kiwi that were released in all seasons (Table 1.1).

Release Procedure

Pre-release quarantine conditions were set-up on the kiwi's enclosure four weeks before the planned date of release. During quarantine kiwi had three-four faecal and two cloacal samples taken and had weight and condition checks at regular intervals. Samples were analysed for the presence of specific nematodes, bacteria and protozoa. If positive samples were taken from any kiwi, they were usually given appropriate treatment for the particular pathogen, and the quarantine for that individual and any enclosure mate continued for a further four weeks. Therefore in some cases, release

Table 1.1 Individual kiwi used in this thesis. From: where the kiwi came from as an egg (or chick if specified), date of hatch, date of release into the wild, release area and site (site numbers correspond to no.s shown on Fig.s 1.3 & 1.4), thesis chapters that data from this kiwi contributes to, dates between which these data were collected, the kiwi's status in October 2002. E TFCA: East Tongariro Forest, W TFCA: West Tongariro Forest, KR: Karioi Rahui. [1]These kiwi are believed to be males based on bill measurements up until the time of their deaths (remains were insufficient for sexing by autopsy). [2]Data from these kiwi are included in Figure 5.1 but not in the chapter 5 statistical analysis because they could not be sex-assigned with confidence at the time the data were analysed. [3]Data from these kiwi were used in the analysis of factors influencing pre-release activity, but not pre- and post-release combined.

Name	From	Hatched	Sex	Released When	Release Area (and site)	Chapters	Dates	Current status
Te Aukaha	E TFCA	2.1.96	M	20.1.97	E TFCA (1)	5	1.97-11.98	Paired with Koha. Became dad Sept 2002
Antz	E TFCA (chick)	~ 11.12.96	F	26.9.97	E TFCA (1)	5	9.97-6.98	Transmitter failure June 1998
Speedy	E TFCA	22.12.96	M	26.9.97	E TFCA (1)	5	9.97-7.99	Transmitter failure Aug 1999
Titch	E TFCA	13.1.97	F	14.1.98	E TFCA (1)	5	1.98-7.99	Transmitter failure Jul 1999
Wahanui	E TFCA	28.9.97	F	28.8.98	E TFCA (2)	5	8.98-6.00	Alive. Not known to have mate
Awhi	E TFCA	14.10.97	F	24.3.99	E TFCA (2)	2,3,5	1.99-6.00	Dead. hypothermia/disease Jun 2000
Anaru	E TFCA	22.10.97	?	28.8.98	E TFCA (2)	5[2]	8.98-3.99	Transmitter fell off Mar 1999
Koha	E TFCA	25.12.97	F	21.12.98	E TFCA (2)	5	12.98-10.00	Paired with Te Aukaha. Became mum Sept 2002
Kahuma	E TFCA	8.1.98	F	21.10.98	E TFCA (2)	5	10.98-8.00	Alive. Not known to have mate
Waitangi	E TFCA	6.2.98	M[1]	31.3.99	E TFCA (3)	2,3,5	1.99-10.99	Depredated. Probably by pig Oct 1999
Hot Chick	E TFCA	12.2.98	M[1]	21.4.99	E TFCA (3)	2,3,5	2.99-1.00	Depredated. Probably by ferret Jan 2000
Gonzo	E TFCA (chick)	~ 12.5.98	M	24.3.99	E TFCA (2)	2,3,5	1.99-11.99	Transmitter failure Nov 1999
Moenui	E TFCA	3.2.99	M	19.8.99	E TFCA (4)	2,3,5	7.99-12.99	Dead. Traumatic internal injury Dec 1999
Iwa	E TFCA	2.10.99	M	4.5.00	W TFCA (5)	2,3[3],4,5	3.00-8.01	Depredated. Probably by stoat Aug 2001
Mawhitiwhiti	Waimarino	20.10.99	F	2.5.00	KR (1)	5	5.00-2.02	Paired with Tiakariti
Koru	E TFCA	21.10.99	F	4.5.00	W TFCA (5)	5	5.00-3.02	Alive. Not known to have mate
Plop	E TFCA	24.10.99	F	8.6.00	W TFCA (5)	5	6.00-4.02	Alive. Not known to have mate
Pango	Waimarino	24.10.99	?	2.5.00	KR (1)	5[2]	5.00-7.00	Transmitter failure July 2000
Jake	E TFCA	26.10.99	?	4.5.00	W TFCA (5)	2,3,4,5[2]	3.00-5.00	Dead. Scavenged and/or predated
Te Ngahere	Whirinaki (chick)	~ 12.11.99	M	29.4.00	Whirinaki	2,3[3],4	3.00-4.00	Alive. Became dad 2002

Table 1.1 (cont.)

Name	From	Hatched	Sex	Released When	Release Area (and site)	Chapters	Dates	Current status
Taz	Whirinaki	14.11.99	?	29.4.00	Whirinaki	2,3[3],4	3.00-4.00	killed by dog ~May 2000
Putanui	Waimarino	17.11.99	F	2.5.00	KR (1)	5	5.00-2.02	Alive. Not known whether mated
Te Hamua	E TFCA	29.1.00	M	20.6.00	W TFCA (5)	5	6.00-4.02	Alive. Not known whether mated
Ataahua	E TFCA	1.2.00	F	20.6.00	W TFCA (5)	5	6.00-4.02	Alive. Not known whether mated
Komutu	E TFCA	7.2.00	M	6.7.00	W TFCA (5)	5	7.00-8.01	Dead. Apparent drowning Aug 2001
Tuatea	Waimarino	11.2.00	M	6.7.00	KR (1)	3,5	7.00-1.01	Depredated. Probably by ferret Jan 2001
Taniko	E TFCA	27.2.00	F	5.9.00	W TFCA (5)	5	9.00-6.02	Alive. Not known whether mated
Tangiora	Waimarino	2.10.00	?	30.3.01	KR (2)	5[2]	3.01-5.02	Alive
Tiakiriti	Tanupara Station	21.10.00	M	30.3.01	KR (2)	5	3.01-5.02	Paired with Mawhitiwhiti
Tua	Tanupara Station	28.10.00	?	30.3.01	KR (2)	5[2]	3.01-8.01	Dead. Unknown cause Jun-Aug 2001
Zinger	Waimarino	2.1.01	M	26.4.01	KR (2)	5	4.01-2.02	Alive

Table 1.2 Mean ages (in days) of kiwi released into East and West TFCA and Karioi Rahui.

East TFCA	West TFCA	Karioi Rahui
346	182	163

dates were postponed and total quarantine time was longer than four weeks. Most kiwi also had their transmitter fitted to them at least two weeks before the planned release date.

Release sites were chosen before the release day. General release sites were chosen using prior knowledge of the area. Releases took place during the hours of daylight, so release burrows at these sites were picked out and if necessary augmented by digging, lining the floors with dry foliage and covering up holes. A route to the site was also marked. Up to three kiwi were released at a time but separate release burrows 100 m or more apart were chosen for each individual.

Kiwi were usually transported to their release sites by the staff who had been responsible for their care in captivity. On the day of the release, kiwi were removed from their burrows in their enclosure, usually weighed and sometimes had bill measurements taken, and placed in a cardboard pet-carrying box. These boxes were placed in a car, covered with a piece of clothing to provide shade, and the kiwi were driven to the road-end nearest to the release site. This journey in the car usually took about two hours.

Getting to release sites in Tongariro Forest involved a quad or 4-wheel drive trip of about 30 minutes, followed by a walk of not more than ten minutes except in the case of the first four released kiwi where there was a walk of about 30 minutes. Kiwi were transported on a quad or 4-wheel drive by a passenger holding the kiwi carry box. Getting to Karioi Rahui release sites involved a walk of about 30-40 minutes from the road-end. A number of invited people usually attended releases, although the numbers present varied from one release to another with as few as five or as many as about 50. Depending on factors such as the distance to the release site, the number of people present and whether any official ceremony took place, it took between about one and three hours to get the kiwi from the road end and into its burrow.

Once at the release sites, kiwi were removed from their box, given a brief check that nothing major was wrong, if necessary their transmitter strap was replaced, people

were given a chance to see the kiwi and sometimes photographs were taken and a karakia recited, then the kiwi was put in its burrow. Most people would then leave quietly and generally one of the Rainbow Springs staff would stay a few minutes to ensure the kiwi stayed in the burrow.

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CHAPTER TWO: QUANTIFYING ACTIVITY IN KIWI

2. Quantifying Activity in kiwi

2.1 Introduction

Time-activity budgets can be used in ecological research to improve understanding of an animal's biology. For example, the proportion of each day that an animal spends foraging and resting can provide information about its energy needs and habitat requirements. As activity budgets can be determined both in captivity and the wild, they are a useful method of investigating behavioural changes after a translocation from captivity to the wild or vice versa. This chapter investigates a method for quantifying activity of brown kiwi both in captivity and in the wild.

North Island brown kiwi are nocturnal, cryptic, and often inhabit scrub or areas with dense undergrowth, making continuous visual observation difficult. Systematic visual monitoring of kiwi has mostly been conducted from near entrances to nests to determine departure and return times of incubating birds, the age at which chicks leave for the first time, and what predation threats kiwi face while on the nest (McLennan, 1988; Potter, 1989; Reid et al., 1992, 1993, Reid et al., 1996; Ward-Smith, 1998). One study that has involved visual monitoring of juvenile kiwi that have permanently left the nest was that of (Chan, 1999). Chan (1999) monitored kiwi fitted with transmitters equipped with infra-red light emitting diodes. The diodes emitted a flash (visible through night-vision equipment) each time the transmitter pulsed. Chan's (1999) study sampled night-time habitat selection of juvenile kiwi. A limitation with the method was that getting close enough to sight the kiwi involved "inevitable disturbance", and only kiwi inhabiting relatively open areas of bush were chosen for the study so that disturbance would be minimised (Chan, 1999).

Investigation of kiwi activity budgets over continuous periods of up to 15 hours, in the wild and in captivity, requires a method that minimises observer-induced bias. This precluded sustained visual monitoring. A viable alternative is to monitor activity from a distance using radio-telemetry. Various radio-telemetry methods have been used to measure activity of free-ranging animals that are difficult to observe. For example, activity has been quantified by placing a receiver close to an animal's daily

resting site (such as a nest, cave, den or roost), determining the hours that an animal occupies this site, and classifying all other hours as times of activity (Clark et al., 1993). This method is applicable to animals that return to the same place everyday. However, as it relies on the assumption that the animal does not rest anywhere else, it may be most appropriate for individuals that have an strong incentive to return to the site, such as those incubating eggs.

Triangulation of a signal source has been used to measure activity by identifying shifts in an individual's location (Mech et al., 1966). This method is labour intensive, requiring at least two observers to take simultaneous bearings at regular intervals, and may give biased results (Garshelis & Pelton, 1980; Garshelis et al., 1982).

Fluctuations in the tone or strength of a transmitter signal received by a stationary antenna has also been used as a gauge of activity (Lindzey & Meslow, 1977; Colbourne & Powlesland, 1988; McLennan, 1988; Grigg et al., 1992; Taborsky & Taborsky, 1992; Custer et al., 1996; Boyer et al., 1997; Caley, 1997; Green et al., 1998; Brigham et al., 1999; Refinetti, 1999). However, the reliability of this method is not often tested rigorously, and when it has been, inconsistent results have been produced. For example, Refinetti (1999) claimed that fluctuations indicated locomotory activity but that signal strength was not sensitive to stationary activity such as grooming, tremor or respiration. Data on which these claims were based were not shown. Lindzey & Meslow (1977) reported that the method of noting fluctuating signals indicated general activity patterns (such as diurnal or nocturnal), but did not allow sensitive analysis of activity schedules. Simultaneous observation and signal monitoring records made during their study showed that fluctuations often occurred with only slight movements by a resting animal. Singer et al. (1981) found that signal fluctuations were not correlated with mean movements per hour (determined by distances between hourly radio fixes) or with peaks in feeding, and concluded that signal fluctuation was a poor index to activity in their study. Custer et al. (1996) verified through direct observation of feeding lesser scaup (*Aythya affinis*) that the radio-signal weakened or disappeared when the duck was underwater, and that the pattern of weak and strong signals characteristic of feeding was distinguishable from other activities. This showed that signal fluctuations were a reliable indicator of

feeding activity in their particular situation. The reliability of a fluctuating signal as an indicator of activity therefore seems dependent on the situation and the species being studied. Nevertheless, even if it can be verified that a fluctuating signal correlates with activity, most applications of this method rely on subjective evaluations about signal strength (Knowlton et al., 1968; Brigham et al., 1999).

Nams (1989) found that it was possible to differentiate between three different behaviours in striped skunks (*Mephitis mephitis*), due to a decrease in pulse spacing of up to 10% (for example, a transmitter initially pulsing at once per 1.5 seconds, could change to pulsing as often as once per 1.35 seconds) with different positions of the animal's body relative to the transmitter. However, such small changes in pulse rate would be imperceptible by ear, and in Nam's (1989) study a specially designed interface board was used to measure pulse intervals from tape-recordings of the radio-signals.

Motion-sensors have been incorporated into radiotransmitters to monitor animal activity. Transmitters with motion sensors allow the subjectivity involved in collecting activity data to be removed, due to a change in signal from one specified pulse rate to another when motion or a change in posture is detected. A number of studies have demonstrated with simultaneous visual observations that the occurrence of particular behaviours or levels of activity can be identified from the motion sensing data, with various levels of confidence (Knowlton et al., 1968; Jackson et al., 1972; Swanson et al., 1976; Garshelis & Pelton, 1980; Garshelis et al., 1982; Gillingham & Bunnell, 1985; Kunkel et al., 1991; Lariviere et al., 1994; Exo et al., 1996; Whittingham, 1996; Berger, 1997; Whittingham et al., 2000; Hassall et al., 2001).

The present study investigates kiwi activity in captivity as well as in the wild. Therefore, data collection methods need to be similar in captive and wild studies to allow a comparison between behaviour in the two settings. The first two methods outlined above are not applicable as both require the animal to travel a greater distance for movement to be detected than is available in the captive setting. Moreover, the first method is inappropriate for wild sub-adult kiwi, because one cannot assume they will return to the same site each day. The third method appears to

lack reliability and is subjective. The fourth and fifth methods both use changes in pulse interval to indicate activity, and this eliminates much of the subjectivity associated with other methods. Data from motion-sensing transmitters have the additional advantage of being precise and easy to interpret, as signals will always pulse at one of the pre-specified rates and the differences between rates can be set to be distinguishable by ear.

This chapter involved collection of data from motion-sensitive transmitters worn by kiwi, and conducting simultaneous visual observations of the kiwi. Specifically the following questions are addressed: (a) does the signal pattern from a motion-sensitive transmitter make it possible to differentiate between an active and inactive kiwi with a high level of reliability? If so (b) does the signal pattern from a motion-sensitive transmitter make it possible to differentiate among defined active behaviours in kiwi with a high level of reliability? And (c) are the different methods used in this study to record the transmitter data consistent in their ability to allow behaviours to be differentiated? A system for identifying kiwi behaviour based on activity transmitter data is developed, with the ultimate aim of providing a method to quantify total time spent per night in different behaviours.

2.2 Methods

Nine brown kiwi between the ages of 4 and 17 months were used in this study. All were raised at Rainbow Springs Wildlife Park, Rotorua, and were subsequently released into Tongariro or Whirinaki Forests (from where they had been collected as eggs or chicks) as part of the Department of Conservation's Operation Nest Egg.

Data collection for this study took place in four phases, three in captivity and one in the wild. Phase 1 took place between 19 January and 21 March 1999 at Rainbow Springs in Rotorua and involved monitoring four kiwi (named *Awhi*, *Gonzo*, *Waitangi*, and *Hot Chick*). Phase 2 took place between 26 July and 18 August 1999 at Rainbow Springs and involved monitoring one kiwi (named *Moenui*). Phase 3 took place between 20 August and 3 September 1999 and involved monitoring *Moenui* in Tongariro Forest after his release. Phase 4 involved monitoring four kiwi (named *Iwa*,

Jake, *Taz*, and *Te Ngahere*) at Rainbow Springs between 24 March and 13 April 2000.

All individuals had a Sirtrack™ 20 g (2% of the minimum body weight of the kiwi used in this study) kiwi transmitter attached to either leg around the tibio-tarsus, using the standard attachment procedure (Miles & McLennan, 1998; Robertson & Colbourne, 2001). The transmitters contained mercury switch motion detectors, consisting of a mercury ball inside a vertically orientated tube. Activity detected in the transmitter put the signal pulse rate to the "active" mode and after 10 seconds of no activity being detected the pulse rate changed to the "inactive" mode. Transmitters used during phase 1 emitted 20 pulses per minute in the inactive mode and 50 pulses per minute in the active mode. Transmitters used during phases 2, 3, and 4 emitted 30 pulses per minute in the inactive mode and 60 pulses per minute in the active mode.

Phase 1

The four kiwi were kept within an enclosure complex totalling 646.75 m^2 in area (Figure 2.1). The complex comprised eight enclosures, separated by corrugated iron and wooden fences. These enclosures were partly on the side of a hill, with enclosures 1-4 at the top, and enclosures 8 and 9 being on predominantly level ground. The enclosures had a soil base and vegetation consisting of some large trees and smaller shrubs and ferns. This vegetation was dense and overgrown in places. Burrows had been made in each enclosure using cavities covered over with logs, earth, branches, punga fronds and other plant material. Each enclosure had a water tray and a wooden box where the kiwi's food dish was placed every evening. Kiwi could go into this box to feed ad libitum throughout the night.

Awhi was in enclosure 3 and *Gonzo* in enclosure 4 for the duration of the monitoring. *Waitangi* was in enclosure 7 and *Hot Chick* in enclosure 9 during January and February. During March, *Waitangi* was in enclosure 2 and *Hot Chick* was in enclosure 1.

Signals from the kiwi transmitters were received by an ATS DCCII scanning receiver and data logger, through a three-element Yagi antenna that was tied to a tree in

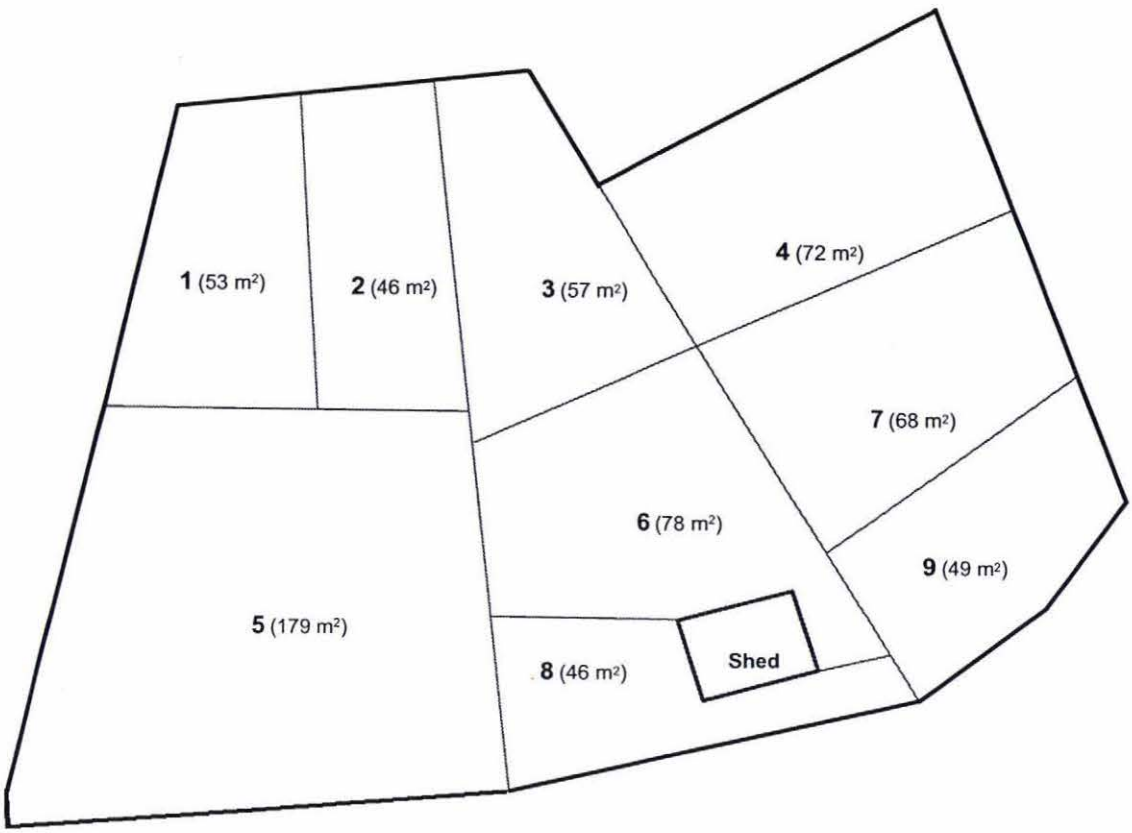

Figure 2.1 Plan of the enclosure area where kiwi were kept during monitoring (phase 1).

Fences separating enclosures

Perimeter fence

enclosure 6 at a height of about 2 m. The data logger-receiver system was set to continuously record data from the four kiwi transmitters. For pre-specified time periods of 20 or 15 seconds, the following information was stored: year, Julian day (1-365), time (hh:mm), transmitter frequency, and pulse count (number of pulses received during the period) (Table 2.1). At the end of each of these time periods, the system would switch to the frequency of the next transmitter and the process was repeated. The data resulting from this collection method were therefore discrete (interval) data. The data logger-receiver was set to record data on about half of the nights during this two month period. Data were normally collected from the late afternoon or evening until about two hours after sunrise. Data collected using this automated set-up are from here on referred to as "automated data."

Table 2.1 Example of automated data (collected in 15-second periods) after downloading, importing into excel, and deleting unnecessary columns. This shows (for example) that during a 15 second sample of the minute 22:41 on Julian day 93 (2 April) 2000, the data logger recorded 8 pulses from transmitter frequency 155 (*Jake*).

year	Julian day	time	frequency	pulse count
0	93	22:41	155	8
0	93	22:41	374	8
0	93	22:42	447	9
0	93	22:42	836	15
0	93	22:42	155	9
0	93	22:42	374	7
0	93	22:43	447	9
0	93	22:43	836	15
0	93	22:43	155	8
0	93	22:43	374	9

At the same time as automated data were being collected, an independent method of recording activity transmitter data was used. This involved listening to the transmitter signal through a Telonics TR4 receiver (attached to a 3-element Yagi directional antenna) and manually recording the activity data. Interval sampling, where each of the four transmitter channels was listened to for a set period (5 minutes or 1 minute) before manually switching the TR4 to receiving the next channel, and focal sampling of a randomly picked individual for up to three hours, were both used. At the beginning of each transmitter sampling period, the time and whether the transmitter was in active or inactive mode was recorded, and at each subsequent change in the signal mode, the time (hh:mm:ss) was recorded in writing (Appendix 1). Although individuals were usually sampled within pre-determined time-intervals, the data collected within each of these intervals were of a continuous nature (exact times of signal mode change were recorded), in contrast to the discrete automated data. Data recorded by this method of listening and recording times of signal mode change, are from here on referred to as "manual data."

Some "observation data" were collected by indirect observation during daylight, when it was known the kiwi were in their burrows (see phase 2 of methods for full explanation), but observation data were not collected at night because it was not possible to see the kiwi at night-time unless the observer was inside their enclosure.

Phase 2

Moenui was kept within another enclosure complex totalling 478 m^2 in area (Figure 2.2) enclosed by a corrugated iron fence. The whole complex comprised eight enclosures and an access pathway, separated by wooden fences. These enclosures were on the side of a hill with enclosures 1-3 at the top, and enclosures 4-8 sloping downwards from the access pathway. The enclosures had a soil base topped with leaf litter. Vegetation consisted of recently planted young native shrubs, trees and ferns and a few more mature trees. About three to four burrows in each enclosure had been made using cavities covered over with logs, earth, branches, tree fern fronds and other plant material. Each enclosure had a water tray and a wooden box where the kiwi's food dish was placed each evening. Kiwi could go into this box to feed ad libitum throughout the night.

Moenui had enclosures 1, 2 and 3 to himself (ramp-doors in the fences separating enclosures allowed movement from one to another) comprising a total area of 141 m^2. Observations were made from the access pathway. A wooden fence about 1 m high separated this pathway from each enclosure. The vegetation was open enough to allow night-time observation from the pathway (using night-scope or moonlight) when the kiwi was in some parts of his enclosures. There were periods during most nights of observation when the kiwi was obscured from view behind vegetation, so observations were made opportunistically.

Observational recording of the kiwi's activity was done both at night and during the day. During the day recording was done by indirect observation (because the kiwi could not be seen) whenever it was known that the kiwi was in its burrow ("in burrow" became one of the defined behaviours – Table 2.2). The particular burrow the kiwi was in each day was determined prior to starting night-time observations. The observer focused on the entrance to the burrow so that the time the kiwi left the burrow after dark could be recorded. Direct observation would then begin. After two nights of preliminary observations, behaviours were grouped into discrete, defined categories (Table 2.2). Each time the observed behaviour changed from one of these categories to another, the time (hh:mm:ss) and the new behaviour were recorded

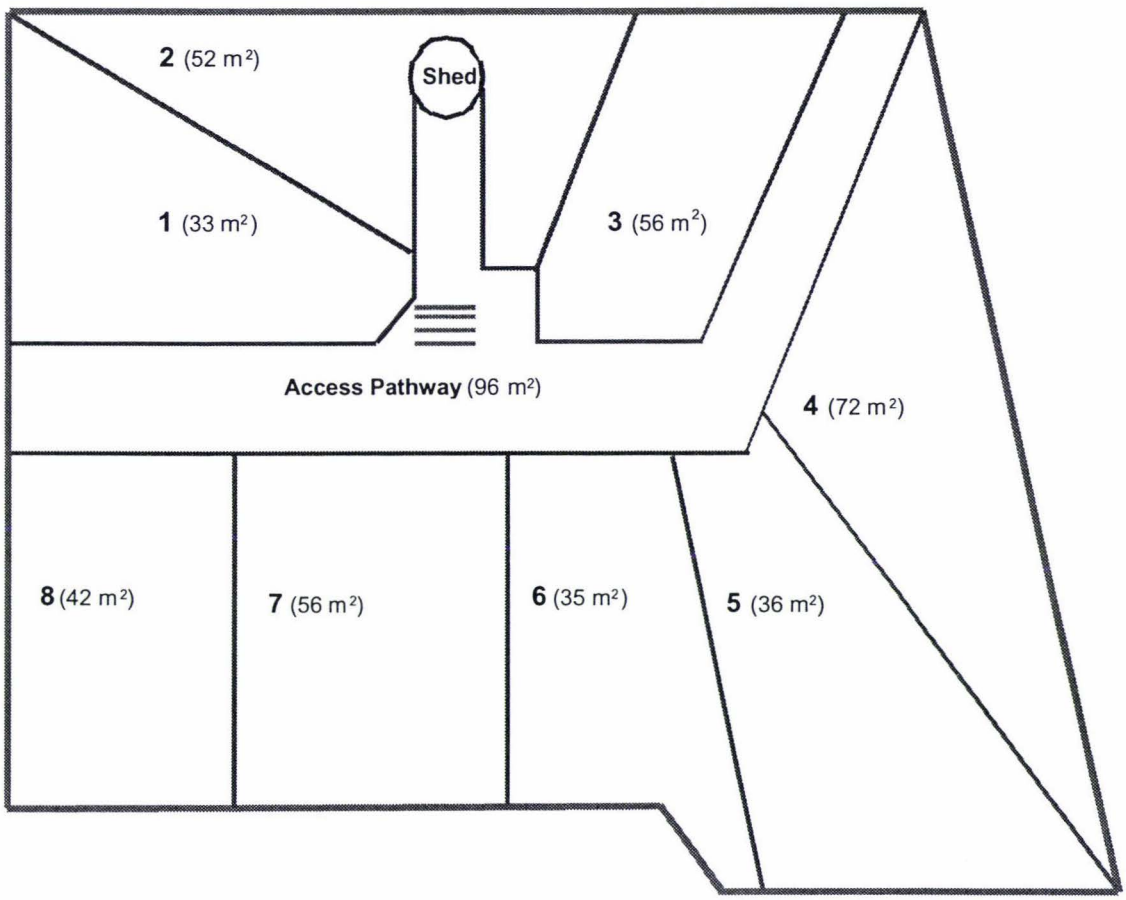

Figure 2.2 Plan of the enclosure area where kiwi were kept during observation (phases 2 and 4).

▬▬	Perimeter fence
▬▬	Wooden fence (about one metre high) separating one enclosure from another and each enclosure from the access pathway
≡	Steps up to top enclosures and shed

(focal animal sampling (Altmann, 1974)) using a voice-activated dictaphone. Length of night-time observation periods was determined by how long the kiwi remained visible and by the length of time before which observer fatigue set in. Data collected in this way are from here on referred to as "observation data."

Table 2.2. Ethogram of behaviours observed in captive kiwi.

number code	behaviour	description
0	In burrow	Not visible but is known to be in a burrow or wooden box/shelter. (This behaviour was usually only discernible with certainty during daylight hours or at the beginning of darkness prior to the bird being seen exiting the burrow).
1	Foraging	Probing or sniffing ground, poking bill among leaves, sticks or logs, or lifting head back to ingest food while standing, sometimes taking an occasional step forward, and sometimes moving forward at a walk (without probing) for up to 20 seconds at a time.
2	Travelling	Moving forward constantly at a walk or run for a period of more than 20 seconds.
3	In feedbox	Inside box in which food dish was placed. (Note: sometimes kiwi would use the feedbox as a daytime shelter. In these cases, if the bird was seen going into the feedbox in the half hour before dawn and was still there at dawn, the bird was classified as in burrow while in the feedbox (rather than in feedbox) because the bird was using the box as a daytime shelter).
4	Grooming	Scatching body or head with foot or preening body feathers with bill.
5	Standing	Standing on both feet — not visibly doing anything else.
6	Not visible	Not seen or heard (during hours of darkness).
7	Other	Visible or audible outside of burrow doing anything not fitting any of above descriptions.

Automated data were collected simultaneously with observation data. The data logger-receiver system used in phase 1 was set up in the shed adjacent to the kiwi enclosures with the antenna tied to a tree in enclosure 2 at a height of about 2 m. The data logger-receiver system was set to log data from *Moenui*'s transmitter, storing the number of pulses received during every 60 second period. Once set up with a fully charged battery, the data logger could record activity continuously for about 70-90 hours, and was often left on during the day as well as at night-time, so the transmitter signal pattern during the inactive daytime hours was obtained.

Manual data were sometimes collected simultaneously with automated data, using focal sampling for variable durations. If observation data were also being collected,

the manual data were recorded onto the dictaphone along with the observations (by recording the receiver sound into the dictaphone, or by saying the time and "active" or "inactive").

Phase 3

Simultaneous manual and observation data recording was undertaken by two independent observers on evenings when the kiwi was known to be in a burrow in an open area of forest where night-time viewing would be possible. One observer was at a tent site within receiving range of the kiwi's transmitter, recording manual data as described above. The other observer sat on a stump 5-10 metres in front of the burrow, from about 10 minutes before it became dark in the evening. With a night vision scope, the kiwi was viewed as it left its burrow and until it moved beyond the observer's viewing range. Observation ceased after this, as following the kiwi would have risked disturbance by noise or torchlight. Observed behaviours were recorded according to the categories defined in Table 2.1.

Manual data were also collected during the inactive day-time hours.

Automated data collection could not be used to monitor kiwi in the wild because it relied on the input from the receiver to the data logger being in a particular signal strength range, which it seldom was in the wild due to kiwi ranging over larger areas.

Phase 4

Kiwi were kept in the same enclosure complex as in phase 2 (Figure 2.2). *Taz* and *Te Ngahere* were together in enclosure 3, while *Jake* and *Iwa* were in enclosure 8. Observation data were collected in the same way as in phase 2 apart from differences due to there being four kiwi, rather than one, to observe. At onset of darkness, observation would be focussed on the entrance to any burrow that one of these kiwi was known to be in. When the kiwi appeared from this burrow, it would be observed until it went out of sight. The other three kiwi would then be looked for until one was seen, and the process would be repeated. Kiwi in the same enclosure were distinguished by the presence of a band on *Jake*'s leg and distinctive spotty plumage of *Taz*. Observation data were only recorded when it was known which kiwi was in

view, and the identity of the individual was recorded. Natural lighting was relied upon for observation, and this greatly decreased the amount of night-time observation possible compared with phase 2.

Automated data were collected simultaneously with observation data as in phase 1. The data-logger system was set up in the shed with the antenna taped to the roof and pointed towards enclosure 8. The system was set to store the number of pulses received in 15 second time periods, scanning each transmitter in sequence.

Downloading, Processing and Analysis of Data

Automated data were downloaded from the data logger onto a personal computer, and imported into excel files (Table 2.1). The data were then combined from the various collection methods and sorted by individual and chronological sequence (Table 2.3 & 2.4 first 5 columns).

Table 2.3 Example of automated data from phase 4 (collected in 15-second periods) after sorting by individual, conversion of pulse count to seconds active/60 and entering the observed behaviour corresponding to each minute.

year	Julian day	time	frequency	pulse count	sec.s active/15	sec.s active/60 (auto.)	observed behaviour
0	91	5:58	374	15	15	60	In Feedbox
0	91	5:59	374	15	15	60	In Feedbox
0	91	6:00	374	16	15	60	Travelling
0	91	6:01	374	16	15	60	Travelling
0	91	6:02	374	16	15	60	Travelling
0	91	6:03	374	15	15	60	Travelling
0	91	6:04	374	15	15	60	Travelling
0	91	6:06	374	16	15	60	Travelling
0	91	6:07	374	14	12	48	Travelling
0	91	6:08	374	15	15	60	Travelling
0	91	6:09	374	14	12	48	Travelling
0	91	6:11	374	16	15	60	Travelling
0	91	6:12	374	14	12	48	In Burrow
0	91	6:13	374	9	0	0	In Burrow
0	91	6:14	374	8	0	0	In Burrow
0	91	6:15	374	9	0	0	In Burrow

Table 2.4 Example of automated data (collected in 60-second periods) after conversion of pulse count to seconds active/60, entering seconds active/60 from the corresponding manual data, and entering the observed behaviour.

year	Julian day	time	frequency	pulse count	sec.s active/60 (auto.)	sec.s active/60 (manual)	observed behaviour
99	223	20:03	287	50	36	14	foraging
99	223	20:04	287	57	53	49	foraging
99	223	20:05	287	41	14	15	foraging
99	223	20:06	287	45	24	37	foraging
99	223	20:07	287	51	38	30	foraging
99	223	20:08	287	45	24	23	foraging
99	223	20:09	287	60	60	56	grooming
99	223	20:10	287	54	46	60	grooming
99	223	20:11	287	50	36	52	foraging
99	223	20:12	287	40	12	22	foraging

Automated and manual data were processed to make them directly comparable. This was done by converting automated data pulse counts to a number of seconds active out of 60. The number of manual data active seconds within an automated data sampling period were summed and their frequencies graphed. The frequencies of each pulse count from the simultaneous automated data were also graphed. Analysis of the data in the two graphs enabled the range of pulse counts equating to fully active and fully inactive periods to be identified (details are presented in the Results section (pp 47-50)). Pulse counts in between these two designations were then assigned by even distribution amongst the remaining seconds. Since manual data were not collected during phase 4, seconds active per pulse count were assigned to data from this phase based on those assigned to phase 1 automated data collected in 15-second periods, with adjustments proportional to the difference in the pulse rates between the phase 1 and phase 4 transmitters (Table 2.3 column 6). Resulting seconds active from 15- and 20-second data were multiplied by four and three respectively to get a number of seconds active out of 60 (Table 2.3 column 7).

For each minute that observation data existed for an individual, the predominant behaviour observed was entered onto the same file (Table 2.3 & 2.4 last columns). For each minute that manual data existed for an individual, the number of active seconds recorded in that minute by manual data collection was also entered onto the automated data file (Table 2.4 column 7).

Minimum lengths of each bout of transmitter activity and transmitter inactivity at the same time as the occurrence of any single observed behaviour, were quantified from simultaneous manual and observation data. These values were entered into additional files along with the observed behaviour.

Questions a and b (see p. 35) were addressed firstly by performing analyses of variance on seconds active out of 60 during different observed behaviours (separate tests were performed on data for which different automated data collection periods had been used) to see whether there was clear separation between different behaviours according to the number of seconds recorded as active. Behaviours were then grouped into classes based on these results and analyses of variance performed with these classes as factors. The pattern of transmitter signal changes in different behaviours was further investigated by performing analyses of variance on minimum lengths of active and inactive transmitter bouts (quantified from manual data), with the same behaviour classes as factors. These results, combined with the general observations noting how the transmitter signal changed as the kiwi moved in different behaviours, were used in devising a system to classify behaviour according to the temporal pattern of seconds active out of 60. This system was checked against every minute for which observation data and automated and/or manual data existed, and the proportion of minutes classified correctly was calculated.

Question c (see p. 35) was addressed both by comparing the ability of manual and automated data to correctly classify behaviour, and by calculating regression values and correlation coefficients between manual and automated data quantification of total seconds of transmitter activity during a time period.

2.3 Results

In phase 1, a total of 83 hours 55 minutes (5035 minutes) of simultaneous manual and automated data, and 1 hour 40 minutes (100 minutes) of simultaneous manual and indirect observation data, were collected. During phase 2, 15 hours 39 minutes (939 minutes) of simultaneous manual and automated data; 33 hours 39 minutes (2019

minutes) of simultaneous observation and automated data; and 7 hours 43 minutes (463 minutes) of simultaneous observation, manual, and automated data were collected. During phase 3, 26 minutes of simultaneous direct observation and manual data; and 3 hours 24 minutes (204 minutes) of simultaneous manual and indirect observation data were collected. During phase 4, 35 hours 29 minutes (2129 minutes) of simultaneous observation and automated data were collected.

Total observations made during phase 2 and 4, were 3440 minutes of "In burrow", 283 minutes of "Foraging", 269 minutes of 'Travelling', 2 minutes of 'Grooming', 6 minutes of 'Standing', 24 minutes of 'In feedbox', and 17 minutes of 'Other'. All seven behaviours were observed during phase 2, but only four ('In burrow', 'Foraging', 'In feedbox', and 'Travelling') were observed during phase 4. 'In burrow' was the most common observed behaviour recorded, as this was the kiwi's daytime behaviour and behaviour was much easier to identify during the day than at night. Ability to view kiwi at night-time was sporadic. Although kiwi were often seen emerging from their burrow the first time they left after night-fall, and could usually be kept in view for some time, it was never possible to keep them in view from the beginning of one active period until they became inactive again. Therefore inactive behaviour at night-time was never directly observed, and although it was inferred on some occasions when the kiwi could not be seen and the transmitter signal was continuously inactive, such periods were not classified as inactive observations as this would lead to interdependence between the two methods and not allow a true test of the reliability of the transmitter data. On some occasions, however, the kiwi could not be seen for periods of up to 13 minutes while the transmitter signal was still mainly active.

General Observations of Kiwi Movement and Changes in Signal Mode

For most of the time that kiwi were observed outside of their burrow, their behaviour was classified as either 'Foraging' or 'Travelling'.

While observing kiwi and simultaneously listening to the transmitter signal, it was noted that the signal was mostly active during 'Foraging', but that short bouts of an inactive signal were fairly common. Foraging behaviour was characterised by

frequent probing of the bill into the substrate for variable periods, followed by walking for a variable distance, often with the kiwi occasionally half stopping and sniffing audibly. On many occasions the signal went inactive when the kiwi stopped to probe its bill into the ground and then back to active when the kiwi took its next step with the leg carrying the transmitter. On a few occasions the inactive signal was not produced by the transmitter during probing, apparently because the probe did not last 10 seconds, or because the probe was particularly vigorous resulting in occasional movement by the whole body. In general however, the inactive signal was triggered regularly during sustained 'Foraging'. In contrast, when the kiwi was observed to be primarily 'Travelling', the transmitter signal was seldom heard to go inactive.

On two evenings it was possible to see kiwi inside their burrow before they emerged. On one, movement by the bird was noted for 15 minutes before emerging and the bird was seen actively probing the ground inside the burrow. On the other, indiscernible shuffling-type movement by the bird inside the burrow was noted for five minutes, after which the bird was not seen until it emerged from the burrow six minutes later. Also, one kiwi was able to be observed inside its burrow after re-entering at dawn. Movement by this kiwi inside the burrow was noted for 18 minutes, including it occasionally protruding half of its body out of the entrance before turning and going back inside.

Conversion of Automated Data to a Format Comparable with Manual Data

Twenty seconds activity was recorded in 52.79%, and zero seconds activity in 26.71% of the 1756 manual data 20-second blocks sampled (Figure 2.3a.i). The simultaneous automated data recorded pulse counts of 14 or more in 52.10%, and of nine or fewer in 28.02% of the 20-second periods (Figure 2.3a.ii). An automated data count of 14 or more was therefore assigned as 20 seconds activity and counts of nine or fewer as no activity according to automated data, in the phase 1 20-second sampling periods. Automated data counts of between 9 and 14 pulses were then assigned by even distribution among 1 to 19 seconds active/20 (Table 2.5a).

Fifteen seconds activity was recorded in 49.04%, and zero seconds activity in 24.16% of the 985 manual data 15-second blocks sampled (Figure 2.3b.i). The simultaneous

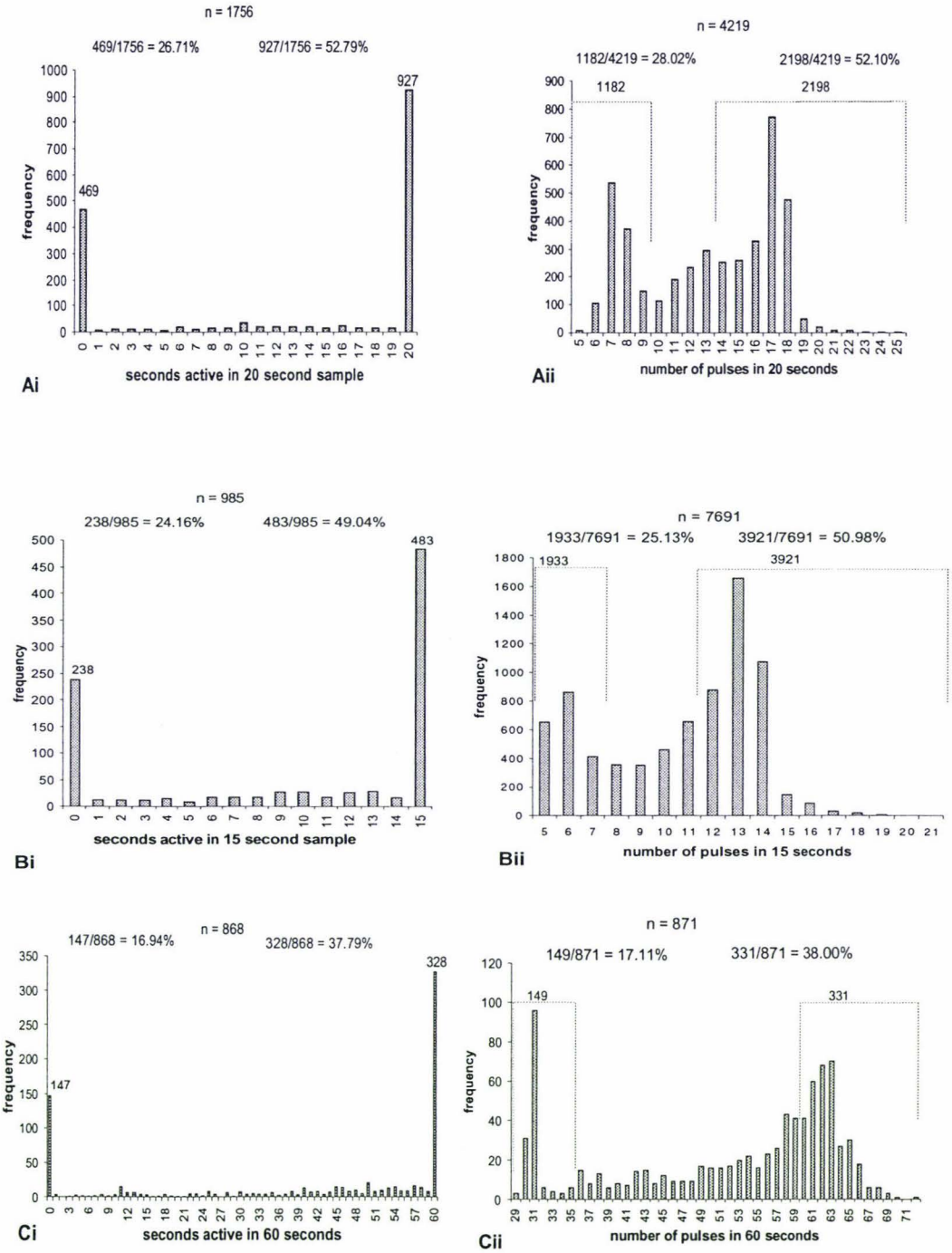

Figure 2.3 Frequency graphs relating seconds active to number of pulses (= pulse count) recorded by data logger. (a.i) Frequency of seconds active/20 from a sample of phase 1 manual data (when simultaneous automated data were collected in 20-second periods). (a.ii) Frequency of number of pulses recorded by data logger in 20-second periods during phase 1 (while manual data were also being collected). (b.i) Frequency of seconds active/15 from a sample of phase 1 manual data (when simultaneous automated data were collected in 15-second periods). (b.ii) Frequency of number of pulses recorded by data logger in 15-second periods during phase 1 (while manual data were also being collected). (ci) Frequency of seconds active/60 from phase 2 manual data. (cii) Frequency of number of pulses recorded by data logger in 60-second periods during phase 2 (while manual data were also being collected).

Table 2.5 Conversion of pulse counts per data logger scan to seconds active per time period. (a) 20- and 15-second periods, (b) 60-second periods.

A

phase 1 transmitters				phase 2-4 transmitters	
pulses in 20 seconds	seconds active/20	pulses in 15 seconds	seconds active/15	pulses in 15 seconds	seconds active/15
≤ 9	0	≤7	0	≤10	0
10	4	8	3	11	3
11	8	9	6	12	6
12	12	10	9	13	9
13	16	11	12	14	12
≥14	20	≥12	15	≥15	15

B

phase 2-4 transmitters	
pulses in 60 seconds	seconds active/60
≤35	0
36	2.4
37	4.8
38	7.2
39	9.6
40	12
41	14.4
42	16.8
43	19.2
44	21.6
45	24
46	26.4
47	28.8
48	31.2
49	33.6
50	36
51	38.4
52	40.8
53	43.2
54	45.6
55	48
56	50.4
57	52.8
58	55.2
59	57.6
≥60	60

automated data recorded 12 or more pulses in 50.98%, and seven or fewer pulses in 25.13% of the 15-second periods (Figure 2.3b.ii). An automated data count of 12 or more was therefore assigned as 15 seconds activity and counts of seven or fewer as no activity, in the phase 1 15-second sampling periods. Automated data counts between 7 and 12 were then assigned by even distribution among 1 to 14 seconds active/15 (Table 2.5a).

Transmitters used during phase 4 pulsed at 1.5 times the rate of phase 1 transmitters while in inactive mode and at 1.2 times their rate while in active mode. The maximum pulse count assigned as no activity according to automated data phase 1 15-second sampling periods (7), was therefore multiplied by 1.5 to find the equivalent maximum pulse count in phase 4 15-second sampling periods (7*1.5 = 10.5, maximum whole number = 10); and the minimum pulse count assigned as 15 seconds activity according to automated data phase 1 15-second sampling periods (12), was multiplied by 1.2 to find the equivalent minimum pulse count in phase 4 15-second sampling periods (12*1.2 = 14.4, minimum whole number = 15). Automated data counts between 10 and 15 were then assigned by even distribution among 1 to 14 seconds active/15 (Table 2.5a right-hand side).

Sixty seconds activity was recorded in 37.79%, and zero seconds activity in 16.94% of the 868 manual data 60 second blocks sampled (Figure 2.3c.i). The simultaneous automated data recorded pulse[1] counts of 60 or more in 38.00%, and of 35 or fewer in 17.11% of the 60-second periods (Figure 2.3c.ii). An automated data count of 60 or more was therefore assigned as 60 seconds activity and counts of 35 or fewer as no activity, in the phase 2 60-second sampling periods. Data counts between 35 and 60 were then assigned by even distribution among 1 to 59 seconds active/60 (Table 2.5b).

[1] With transmitters that transmit 60 pulses per minute when in active mode, 60 or 61 (61 if the beginning of the recording period coincided exactly with a pulse) should always have been recorded by the data logger when activity was continuous over one minute, if the data logger was always operating as it was supposed to. However, the data logger would occasionally (usually 2-3 times a minute) increment by two rather than one with a single pulse emitted by the receiver (verified through visual observation of the data logger operating) particularly when the signal was in active mode. The impression from watching and listening to the data logger was that these idiosyncracies would have little effect on the potential to interpret the data correctly, as they were fairly consistent and data in the high 50s or 60s were only observed to be recorded when the signal was heard to be continuously or close to continuously active.

Relationship of Activity Transmitter Signal Pattern with Observed Behaviour

The number of seconds active out of 60 (derived from automated data collected in 60 second periods) varied with observed activity (one way ANOVA, $f = 735.44$, $p < 0.001$; Appendix 2); with "In burrow" being different from 'Foraging', 'Travelling', 'In feedbox', 'Grooming', and 'Other'; 'Standing' being different from 'Foraging', 'Travelling', 'In feedbox', and 'Other'; and 'Travelling' being different from 'Foraging' and 'Other' (Tukey's pairwise comparisons) (Table 2.6). Based on these results, each defined behaviour was placed in one of three classes, on which further analysis was performed. Class 0 consisted of 'In burrow' and 'Standing' (inactive); class 1 consisted of 'Foraging', 'Grooming', 'In feedbox' and 'Other'; while class 2 consisted of 'Travelling' (Table 2.6, 2.7). Number of seconds active out of 60 varied according to behaviour class (one way ANOVA, $f = 2908.04$, $p < 0.001$; Appendix 3), with all three being different from each other (Tukey's pairwise comparisons).

Table 2.6 Mean number of seconds active out of 60 (derived from automated data collected in 60 second periods) during specific observed behaviours. Numbers on the far left of the table show which behaviours were placed in each of the three classes used in the next set of analyses.

	observed behaviour	n	mean	S.E.
0	In burrow	1380	4.7	0.3
	Standing	6	17.3	7.9
1	Foraging	271	44.0	0.9
	Grooming	2	53.0	7.0
	In feedbox	10	56.2	1.7
	Other	17	48.2	4.2
2	Travelling	237	59.0	0.2

Table 2.7 Mean number of seconds active out of 60 (derived from automated data collected in 60 second periods) during observation of three behaviour classes. 0 includes 'In burrow' and 'Standing'; 1 includes 'Foraging', 'Grooming', 'In feedbox', and 'Other'; 2 is 'Travelling'.

observed behaviour class	n	mean	S.E.
0	1386	4.7	0.3
1	300	44.7	0.9
2	237	59.0	0.2

The number of seconds active out of 60 (derived from automated data collected in 15 second periods (phase 4)) varied with observed activity (one way ANOVA, f = 162.86, $p < 0.001$; Appendix 4); with 'In burrow' being different from 'Foraging', 'Travelling' and 'In feedbox'; and 'Travelling' being different from 'In feedbox' (Tukey's pairwise comparisons) (Table 2.8). Observed behaviours were then grouped into the same classes as above and further analysis performed on these classes (Table 2.9). Seconds active varied according to behaviour class (one way ANOVA, f = 244.37, $p < 0.001$; Appendix 5) with all three classes being different from each other (Tukey's pairwise comparisons).

Table 2.8 Mean number of seconds active out of 60 (derived from automated data collected in 15 second periods) during specific observed behaviours. Numbers on the far left of the table show which behaviours were placed in each of the three classes used in the next set of analyses.

	observed behaviour	n	mean	S.E.
0	In burrow	2060	5.5	0.4
1	Foraging	12	45.0	7.8
	In feedbox	14	43.7	6.0
2	Travelling	32	58.1	1.2

Table 2.9 Mean number of seconds active out of 60 (derived from automated data collected in 15 second periods) during observation of three behaviour classes. 0 is 'In burrow'; 1 is 'Foraging' and 'In feedbox'; 2 is 'Travelling'.

observed behaviour class	n	mean	S.E.
0	2060	5.5	0.4
1	26	44.3	4.7
2	32	58.1	1.2

Results of these analyses suggested that it was possible to classify behaviour into one of these three classes based on the activity transmitter data. Behaviours were kept in these three classes for the next set of analyses, which involved looking at the

transmitter signal pattern in more detail by comparing lengths of time that the transmitter stayed in each signal mode, within and among behaviour classes.

Natural logs of lengths of active signal bouts varied according to observed behaviour class (one way ANOVA, $f = 62.97$, $p < 0.001$), with class 2 (mean = 663.7 seconds, SE = 259.6; Appendix 6) having the longest transmitter active bouts (Tukey's pairwise comparisons) and class 0 the shortest (mean = 22.0 seconds, SE = 2.7). Natural log of lengths of inactive signal bouts varied according to behaviour class (one way ANOVA, $f = 120.56$, $p < 0.001$; Appendix 7), with class 0 (mean = 347.3 seconds, SE = 62.8) having significantly longer transmitter inactive bouts (Tukey's pairwise comparisons) than class 1 or 2 (combined mean = 11.5, SE = 0.8) (Table 2.10).

Table 2.10 Mean minimum lengths of single bouts of transmitter (a) activity and (b) inactivity, while kiwi were observed to be in different behaviours. 0 = 'In burrow' or 'Standing', 1 = 'Foraging', 'In feedbox', 'Grooming' or 'Other', 2 = 'Travelling'. N = number of times that the signal went to this mode, during this observed behaviour, when the minimum length of time it stayed in this mode was able to be quantified. Mean: mean minimum length, of continuous occurrence of this signal, during this observed behaviour. Observation time: total time this behaviour was observed, during simultaneous collection of manual data. % tx active/inactive: total time the transmitter was in this mode (during this observed behaviour), as a percentage of the total time this behaviour was observed.

A

observed behaviour	n	mean (sec)	S.E. (sec)	range (sec)	95%C.I. (sec)	observation time (min.)	% tx active
0	75	22.0	2.7	10-181	16.6-27.4	491	5.6
1	165	42.2	3.5	10-310	35.4-49.1	149	77.9
2	16	663.7	259.6	22-3735	110-1217	191	98.3

B

observed behaviour	n	mean (sec)	S.E. (sec)	range (sec)	95%C.I. (sec)	observation time (min.)	% tx inactive
0	80	347.3	62.8	2-3600	222.3-472.3	491	94.3
1	167	11.7	0.8	1-76	10.1-13.3	149	21.8
2	17	9.9	1.6	2-27	6.6-13.3	191	1.5
1 and 2	184	11.5	0.8	1-76	10.0-13.0	340	10.4

From 75 occurrences of transmitter activity during behaviour class 0, maximum recorded length of continuous transmitter activity was about 3 minutes; and from 165

occurrences of transmitter activity during behaviour class 1, maximum recorded length of continuous transmitter activity was 5 minutes and 10 seconds. From 184 occurrences of transmitter inactivity during behaviour class 1 or 2, maximum recorded length of continuous transmitter inactivity was 1 minute 16 seconds (Table 2.10).

Based on these results and general observations, some generalised characteristics of the signal pattern during three major behaviours are suggested. Foraging (the main component of class 1) is characterised by active signals usually not lasting more than 60 seconds at a time but occasionally lasting up to about five minutes, and inactive signals usually lasting from one to about 30 seconds. Travelling is characterised by active signals lasting longer than about six minutes, with any inactive signal very unlikely to last longer than 30 seconds. Inactive behaviour is characterised by inactive transmitter signals lasting at least four minutes[2] at a time, with active signals unlikely to last more than one minute at a time.

System for Classifying Behaviour into Groups Based on Activity Transmitter Data

To quantify activity, it is necessary to identify precise points in time when behaviour changes from one state to another. However, when using the discrete automated data to classify behaviour, a system of assigning behaviour from the data of each minute in isolation is not appropriate because periods of transmitter activity occurred during observed inactive behaviour and vice versa. Therefore, to minimise the effect of short bouts of the non-dominant signal mode on classification, the seconds active data were smoothed using a moving average transformation (Figure 2.4). A moving average of five minutes was used as this was usually long enough for inactive transmitter signals to be detected during class 1 behaviour, while behaviour classes 0 and 2 generally had all inactive and active signals respectively over this period of time.

[2] Note that the calculation of the length of time transmitters spent in active or inactive mode often resulted in minimum values rather than exact values. This was because data collection often began when a particular behaviour was already underway and the time that it had started was unknown. For example, if the kiwi was in the burrow and the signal was inactive when monitoring began, and the signal remained inactive for 10 minutes, 10 minutes would be recorded as the time of signal inactivity during observed inactivity, but the actual time of signal inactivity could have been longer. Most of the values recorded for signal inactivity during inactive behaviour and signal activity during travelling behaviour are minimum values, therefore the means for these values are likely to be underestimations.

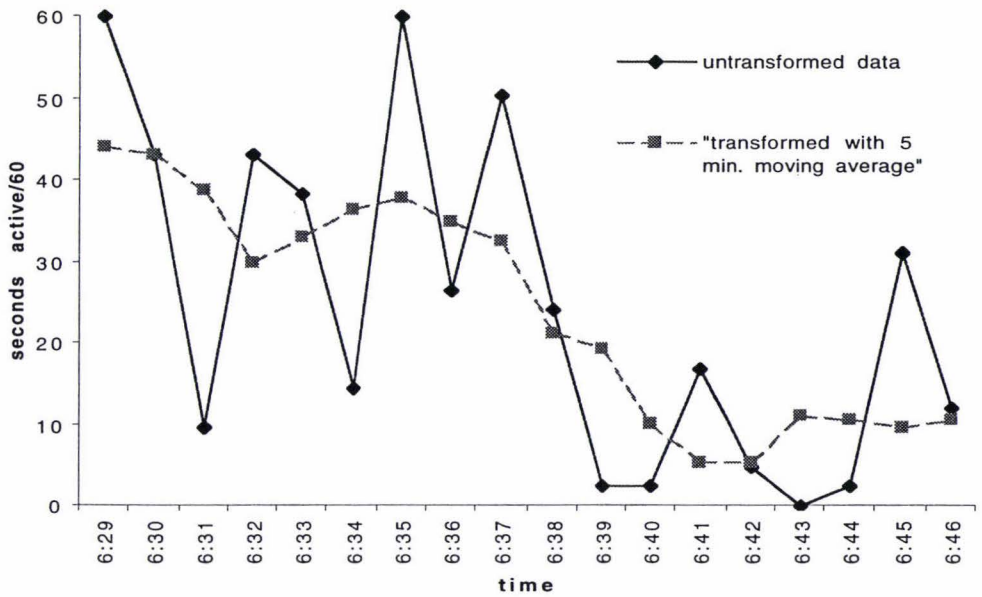

Figure 2.4 Seconds active/60 data from *Moenui* on 17 August 1999 06:29-06:46, untransformed (solid line) and smoothed with a moving average of five minutes (broken line).

Criteria for classifying moving average scores into behavioural classes were established according to mean and/or median moving average scores for each of behaviour classes 0, 1, 2, and active (1 and 2 pooled). Accuracy of the system was then checked by determining the proportion of observations classified correctly.

First, the accuracy of the system in classifying behaviour as inactive (class 0) or active (classes 1 or 2) was tested using automated data. For an independent test of the system, classification criteria were established from only half of the data set, and the proportion of correct classifications were then compared between the two halves of the data set. Behaviour was classified as inactive if the moving average score was below 26.42 (the midpoint between mean moving average scores of behaviour classes 0 and 1) and active if this score was 26.42 or above. There were no significant differences between the two halves of the data set ($\chi^2 = 2.069$, df = 1, $p = 0.15$) in the proportion of correct classifications. Within the whole data set, there was also no significant difference between data collected in 15- and 60-second periods, in the proportion of inactive ($\chi^2 = 1.590$, df = 1, $p = 0.207$) or active ($\chi^2 = 0.417$, df = 1, $p = 0.518$) observations correctly classified. In total, 94.29% of 3590 minutes were classified correctly, with active observations (98.01%) correctly identified more often

than inactive observations (93.46%) (χ^2 = 19.602, df = 1, p < 0.0001) (Table 2.11a). The same classification system was then checked against manual data, which gave slightly higher proportions of correct classifications (97.62% of 714), although proportions of inactive (χ^2 = 3.344, df = 1, p = 0.067) and active (χ^2 = 2.041, df = 1, p = 0.153) observations correctly identified were not significantly higher than those identified from automated data. Manual data also correctly identified periods of observed activity (99.40%) more often than periods of observed inactivity (96.03%) (χ^2 = 7.349, df = 1, p = 0.006) (Table 2.11b).

Table 2.11 Percentage of observations classified correctly as inactive or active for five individuals from (a) automated data and for 2 individuals from (b) manual data, with classification criteria: inactive < 26.42 ≤ active. N shows the number of times the behaviour (inactive or active) was observed in that individual, and % gives the proportion of those times that that behaviour was identified using this classification criteria. The sub-total row pools results from the four kiwi whose automated data was collected in 15-second periods. Data from the fifth individual (*Moenui*) was collected in 60 second periods.

A

kiwi	inactive		active		total	
	%	n	%	n	%	n
Iwa	97.17	353	100	1	97.18	354
Jake	89.46	351	100	3	89.55	354
Taz	92.60	608	100	34	92.99	642
Te Ngahere	92.97	498	100	20	93.24	518
sub-total	92.98	1810	100	58	93.20	1868
Moenui	94.24	1128	97.81	594	95.47	1722
Total	93.46	2938	98.01	652	94.29	3590

B

kiwi	inactive		active		total	
	%	n	%	n	%	n
Gonzo	100	56	-	0	100	56
Moenui	95.34	322	99.40	336	97.42	658
Total	96.03	378	99.40	336	97.62	714

Next, the accuracy of the system in classifying behaviour as class 0, 1 or 2 was tested from automated data. Again, classification criteria were established from class means of half of the data set, and the proportion classified correctly compared between the

two halves. Behaviour was classified in class 0 if the moving average score was below 26.42 (as above), class 1 if the moving average score was 26.42 or above and up to 54.6 (midpoint between mean moving average scores of class 2 and active), and class 2 if the moving average score was above 54.6. The proportion of correct classifications were not significantly different ($\chi^2 = 2.540$, df = 1, $p = 0.11$) between the two halves of the data set. Within the whole data set, there was a significant difference between data collected in 15- and 60-second periods in the proportion of class 2 ($\chi^2 = 6.809$, df = 1, $p = 0.009$) observations correctly classified, with 91.57% of 261 minutes correctly identified from 60-second periods, but only 75% of 32 minutes correctly identified from 15-second periods (Table 2.12). Therefore, the proportion of correct classifications from 15- and 60-second data were not pooled.

Table 2.12. Percentage of observations classified correctly as behaviour class 0, 1, or 2 for five individuals from automated data, with classification criteria: class 0 < 26.42 ≤ class 1 ≤ 54.6 < class 2. N shows the number of times the behaviour class was observed in that individual, and % gives the proportion of those times that that behaviour was identified using this classification criteria. The sub-total row pools results from the four kiwi whose automated data was collected in 15-second periods. Data from the fifth individual (*Moenui*) was collected in 60 second periods.

kiwi	0		1		2		1 & 2	
	%	n	%	n	%	n	%	n
Iwa	97.17	353	-	0	100	1	100	1
Jake	89.46	351	-	0	100	3	100	3
Taz	92.60	608	88.24	17	76.47	17	82.35	34
Te Ngahere	92.97	498	55.56	9	63.64	11	60.00	20
sub-total	92.98	1810	76.92	26	75.00	32	75.86	58
Moenui	94.24	1128	73.57	333	91.57	261	81.48	594

The proportion of correct classifications of behaviour classes 1 and 2 from data collected in 15- and 60-second periods could not be pooled, and sample sizes of 15-second class 1 (n = 26) and 2 (n = 32) observations were too small for a separate classification criterion to be adequately tested. Therefore, classification criterion separating class 1 from class 2 was re-established from half of the 60-second data-set only. Behaviour was classified in class 1 if the moving average score was 26.42 or above and up to 56.42 (midpoint between moving average score class 2 mean and active median), and class 2 if the moving average score was above 56.42. The

proportions of correct classifications for class 1 (χ^2 = 1.851, df = 1, p = 0.174) and class 2 (χ^2 = 2.746, df = 1, p = 0.098) observations were not significantly different between the two halves of the data-set. In total, a similar percentage of class 1 and 2 observations were correctly identified (81.65%) as in the previous classification, but there was a much smaller difference between the percentage of class 1 (81.98%) and 2 (81.23%) observations correctly identified than in the previous classification (Table 2.13a). This classification system was then checked against manual data, which correctly identified class 1 behaviour (93.75% of 144 observations, Table 2.13b) significantly more often than the automated data did (χ^2 = 10.321, df = 1, p = 0.001). There was no significant difference in the proportion of correct classifications of class 2 behaviour between automated and manual data (χ^2 = 1.83, df = 1, p = 0.176) (All Chi-square tables are presented in Appendix 8.)

Table 2.13. Percentage of observations classified correctly as behaviour class 0, 1, or 2, from (a) automated data collected in 60-second periods and (b) manual data, with classification criteria: class 0 < 26.42 ≤ class 1 ≤ 56.64 < class 2. N shows the number of times the behaviour class was observed, and % gives the proportion of those times that that behaviour was identified using this classification criteria.

A

0		1		2		1 & 2	
%	n	%	n	%	n	%	n
94.24	1128	81.98	333	81.23	261	81.65	594

B

0		1		2		1 & 2	
%	n	%	n	%	n	%	n
96.03	378	93.75	144	86.46	192	89.58	336

Correlation of Two Methods for Quantifying Activity Transmitter Signal Pattern

Seconds active out of five consecutive minutes showed a correlation between manual and automated recording methods of r^2 = 0.8056 (n = 490) (Figure 2.5a) for pooled 15 and 20 second automated data collection periods, and r^2 = 0.9684 (n = 178) (Figure 2.5b) for 60 second automated data collection periods.

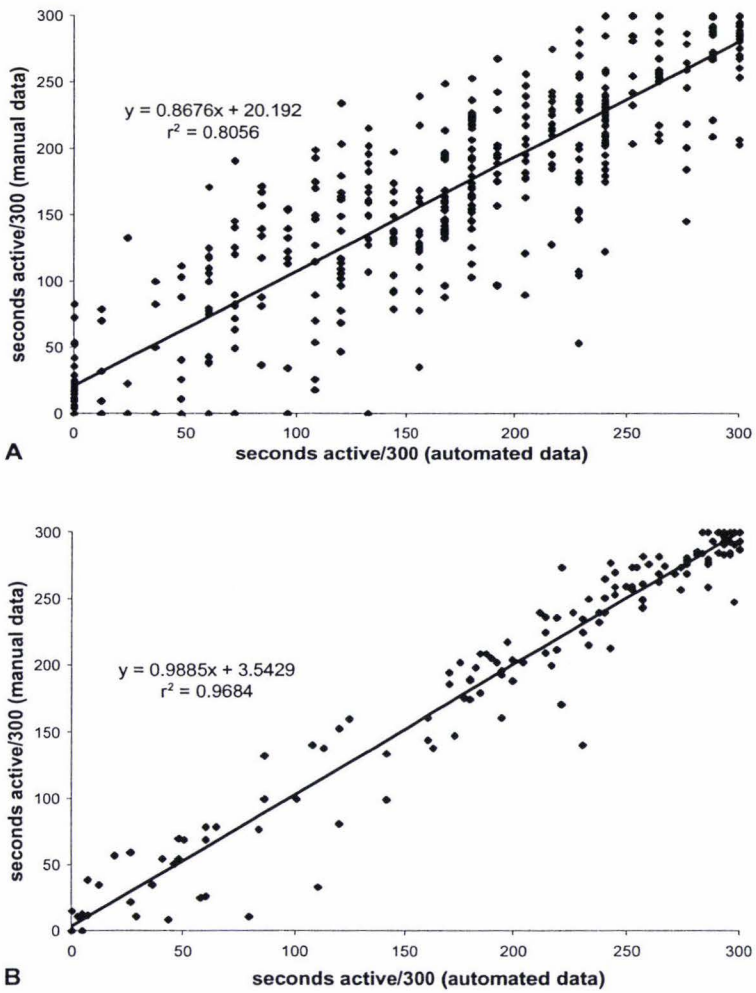

Figure 2.5 Correlation of manual and automated data recording methods in quantifying seconds active out of 5 minutes, when automated data collected in (a) 15- and 20-second periods and (b) 60-second periods.

2.4 Discussion

This study was intended primarily as a test of how well the motion-sensitive transmitters could indicate various behaviours in kiwi. However, a transmitter is only as useful as the data that are collected from it, therefore the transmitter's ability to give distinctive signal patterns during different behaviours, and the method of data collection, cannot be evaluated in isolation from each other. The reliability with which the kiwi activity transmitters in combination with the automated data collection system enabled behaviour to be correctly classified, is discussed first.

Using the system devised for classifying behaviour as active or inactive, classification from automated data was in accordance with the observed behaviour in over 89% of

cases for every individual. In total, over 94% of observations were identified correctly. This compares favourably with the study of Gillingham & Bunnell (1985) who found that proportion of time active in black-tailed deer (*Odocoileus hemionus columbianus*) could be estimated with about 90% accuracy from telemetry data using transmitters that emitted an inactive pulse after 12 minutes of inactivity.

Active observations were classified as such in over 98% of cases but inactive observations were correctly identified in a lower proportion of cases and this trend was consistent across individuals. Eighty-nine percent of all incorrectly classified inactive observations occurred either in the late evening up to 24 minutes before the earliest time the kiwi could have left the burrow, or in the early morning up to 24 minutes after the latest time the kiwi could have returned to the burrow. On three occasions (one of which was in the wild) kiwi could be seen inside the burrow before exiting at night and after re-entering in the morning, and movement inside the burrow for periods of 15, 18, and (at least) 5 minutes was noted. On one occasion the kiwi was seen probing inside its burrow. The minutes that kiwi were seen doing this were still classified as inactive. This classification was necessary to retain consistency, as most times that kiwi were in their burrow they could not be seen and were assumed to be inactive. Ward-Smith (1998) found through video monitoring of kiwi at the entrance to their nests, that kiwi sometimes shuffled around inside for periods of up to 12 minutes before emerging. It was also noted that one male frequently probed around in the nest entrance during this time and that most newly hatched chicks did some probing at the entrance to their nest before emerging for the first time. The adult kiwi were also seen shuffling around inside the nest after re-entering although none were recorded pulling material in over the entrance to the nest from inside, so this was not apparently a behaviour associated with nesting. In light of these previous findings and the observations made in the present study, particularly observations that kiwi sometimes begin foraging while still in their burrow, it seems appropriate that movement prior to leaving or after returning to the burrow is classified as active behaviour. Movement inside the burrow prior to leaving and after returning probably explains why active observations were correctly classified more often than "inactive" observations. This also suggests that the overall proportion of correct classifications from automated data of 94.24% is a conservative estimate as many of the "incorrectly

classified inactive observations" may actually have been correctly classified occurrences of activity. Therefore, data collected by this data-logging system from the motion-sensitive kiwi transmitters were reliable at indicating whether the bird was active or not.

Distinguishing between different active behaviours from transmitter data requires a higher level of sensitivity in the motion-detecting system, the data collection system, or both, than simply identifying behaviour as active or inactive. In the present study, two different sorts of active behaviours ((i) continuous walking/running and (ii) other active behaviours, primarily foraging) were correctly classified in 82% of cases by automated data collected in 60-second periods. Nams (1989) was able to identify three behaviours in striped skunks (foraging, walking, and eating) with 75% accuracy, from variations in pulse interval of non-motion-sensitive transmitters, due to changes in "capacitance" when an animal's body position changes relative to the transmitter. Nams (1989) suggested that behaviours should be able to be classified more readily using activity transmitters as they create much greater changes in pulse interval. While behaviour classes rather than single behaviours were identified in the present study, results show that continuous locomotor movement can be distinguished from other sorts of activity somewhat more readily than similar behaviour categories were distinguished in Nam's (1989) study.

Correct classification of different active behaviours was lower from automated data collected in 15-second periods than from data collected in 60-second periods. This may have been due to the small sample size of active observations during 15-second data collection, but could also have been due to a reduced sensitivity to subtle changes in the frequency of a particular transmitter signal, inherent in reducing the sample period. Manual data consistently showed the highest proportion of correct classifications, even though the classification criteria were established from the automated data. Manual data collected simultaneously with observation data were continuous in form and were collected for quite long periods from one individual. These data therefore very closely represented the complete pattern of the transmitter signal changes over time. Automated data collected in 15-second periods were possibly at the opposite end of the continuum from manual data, in that there was

more chance for the recorded data to not be truly representative of the transmitter signal pattern.

An artefact of the sampling procedure may also have contributed to the better results from manual data than from the automated data. Manual data were likely to have better time synchrony with observation data than did automated data because manual and observation data were recorded using the same watch while the data logger had an independent timekeeping mechanism that could not be precisely synchronised (to the second) with another timekeeper.

Some authors have used transmitter data to distinguish between foraging and non-foraging behaviour in birds. For example, Whittingham et al. (2000) classified 98% of 253 records in accordance with the foraging or non-foraging observation of golden plovers (*Pluvialis apricaria*) from the frequency of changes in pulse-pattern, Exo et al. (1996) classified five out of seven oystercatchers' (*Haematopus ostralegus*) behaviour correctly as foraging or non-foraging in 95% of cases, and Douglas & Pickard (1992) found that a particular pulse interval corresponded with blue duck (*Hymenolaimus malacorhynchos*) grazing behaviour in 96% of cases. In these studies, transmitters were mounted on the birds' backs, and pulse intervals programmed to change as the angle of the birds' back changed when they bent over to forage. These methods seemed to be accurate at identifying specific behaviours provided the activity switch was placed at a precise angle within the transmitter and the transmitter was placed correctly on the bird's back (Exo et al., 1996). However back-mounted transmitters are not used on kiwi because their lack of wings, poor pectoral development and their tendency to spend time in thick vegetation makes a harness attachment impractical and dangerous. Back-mounted transmitters attached with glue have been used on kiwi chicks in the past but most fell off within a few days (Miles & McLennan, 1998), and have been abandoned in favour of leg-mounted transmitters.

Regression values and correlation coefficients between manual and automated data were calculated on quantification of activity over five minutes. This was the same period as that used in the moving average transformation to classify behaviour, therefore should give the best indication of how consistent the two methods will be in

classifying the same behaviour in the same class. Regression values were high for both 60-second and 15- and 20-second automated data collection, but were higher for the 60-second period data collection.

Regression and correlation could be described as tests of how well the data from the data-logger represents the actual signal pattern from the transmitter. Differences between the automated and manual data for the same radio signals could have arisen in three ways. As the time-keeping mechanism on the data-logger could only be set to the nearest minute and therefore could not be synchronized precisely with an independent time-keeper, firstly, some signals could be recorded as having occurred in different minutes by the two methods, and secondly, for the automated data collected in 15 or 20 second periods, it was not possible to determine which 15 or 20 second period from the manual data this automated data corresponded to. Thirdly, the data logger could record false data by counting two pulses instead of one when the signal amplitude was too high or by not counting pulses when the signal amplitude was too low. The first two could be considered an artefact of the sampling method and do not actually imply that poorer quality information about what the transmitters were doing at the exact time that the data logger sampled, was collected. The third situation would be indicative of a problem with the automated data collection method. The fact that correlation coefficients were higher for data collected in 60-second periods shows that the second explanation above was having an effect, but the overall high correlations showed that any problems with the data logger did not cause large differences in the amount of activity detected over a five-minute period.

Berger (1997) used observation to identify "minimum" probable time periods for activity or inactivity of red deer (*Cervus elaphus*). These minimums allowed the researchers to determine when it was possible to assume that behaviour had not changed during periods of missing data. Establishing minimum probable time periods for the three main behaviours in the present study would have helped to increase precision in interpreting the transmitter data, as apparent periods of a particular behaviour of a shorter duration than the established minimum time could be ignored. It would also be useful for monitoring kiwi in the wild as they sometimes wandered out of range of the receiving antenna. Unfortunately, minimum time periods of

inactivity at night were not able to be determined from observation (with the exception of standing, but this behaviour made up a tiny proportion of total inactive observations) as it could not be visually verified whether the kiwi was inactive or merely out of sight. Neither could minimum periods of activity be determined, as it would have to be verified that the kiwi was inactive at the beginning and end of each active period for it to have any meaning in terms of a minimum probable time of activity. Trials of different night viewing and recording techniques may enable development of a method that gives more continuous visual coverage. For example, infrared light emitting diodes (as used by Chan (1999)) on captive kiwi that are also wearing activity transmitters, may allow more continuous visual coverage of kiwi in captivity and therefore result in the ability to infer more detail about behaviour, from the transmitter data.

In conclusion, (a) the signal pattern from the motion sensitive transmitters used in this study made it possible to differentiate between an active and inactive kiwi with a high degree of reliability; but (b) it was not possible to differentiate among active behaviours with a high level of reliability using the data recording methods described here. Two types of active behaviour could be distinguished with moderate reliability when the transmitter signals from one individual were recorded repeatedly (with no time out in between repeats) rather than alternating between individuals. The continuous form of data collection appeared to produce data with more ability to discriminate between different behaviours, although this apparent difference may simply be the result of an artefact due to differences in time synchrony. Thus, (c) the different methods used to record the transmitter data were consistent in their ability to allow active and inactive behaviours to be differentiated, but were not consistent in allowing active behaviours to be differentiated among although it was not possible to determine how important this inconsistency was. Automated collection systems that collect data in a continuous format, combined with viewing techniques and environments that allow kiwi to be kept in sight for longer periods, would be useful in investigations of whether behaviours can be further differentiated by transmitter signal.

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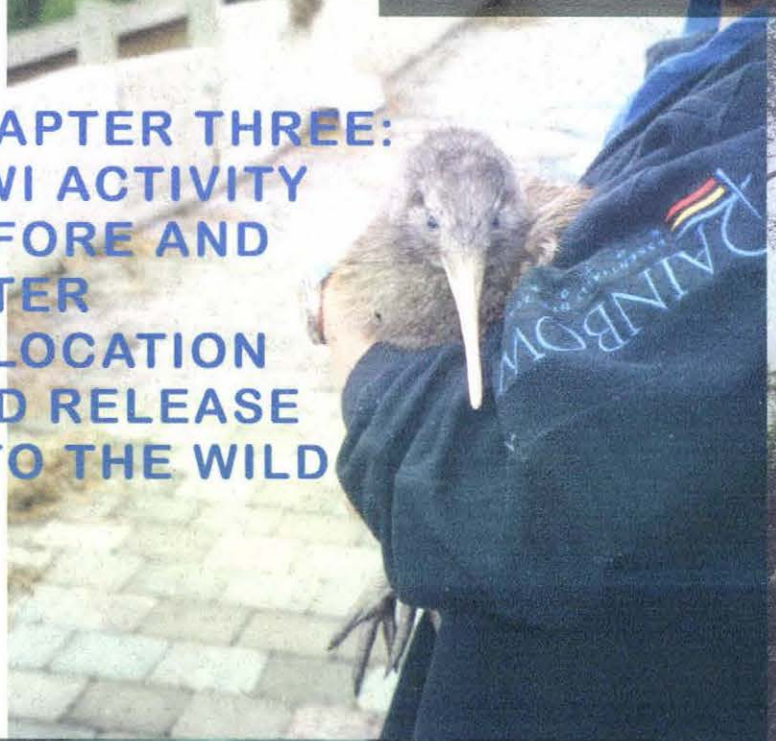
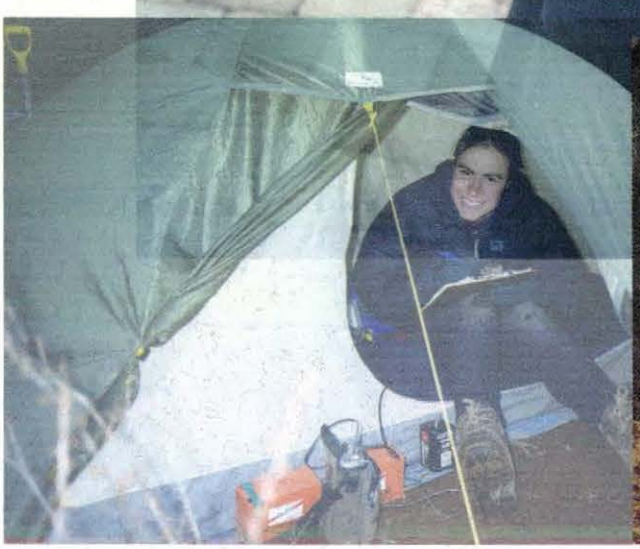
CHAPTER THREE: KIWI ACTIVITY BEFORE AND AFTER RELOCATION AND RELEASE INTO THE WILD





3. Kiwi Activity Before and After Relocation and Release into the Wild

3.1 Introduction

A large part of the active period of most free-living animals is spent searching for, capturing and consuming food. The proportion of its time that an animal spends foraging will affect both its energy intake and energy expenditure. The relationship between these factors is summarised in an energy budget model (Figure 3.1). Depending on an animal's rate of energy acquisition, its metabolic rate during foraging, at rest and during non-foraging activities, and its maximum capacity to assimilate energy from food, there are minimum and maximum limits on foraging time between which energy intake will balance energy expenditure (Weiner, 2000). An animal with activity levels outside these limits will be in deficit and need to metabolise stored energy.

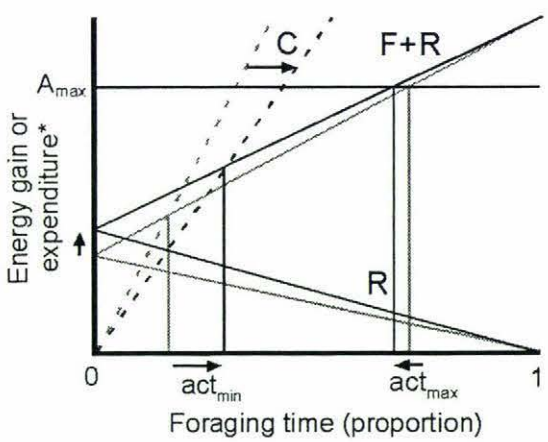


Figure 3.1. Energy Budget Model A_{max}: maximum daily energy assimilation, C: daily energy consumed, R: daily energy expenditure for rest and non-foraging activities, F: daily energy expenditure for foraging activity, act_{min} : minimum daily activity time at which energy gain from foraging may cover all energy expenditure, act_{max}: maximum daily activity time at which energy gain from food covers all energy expenditures. Arrows show predicted direction of change in kiwi activity budget from captivity to wild. *Energy expenditure when variables F and R are being referred to, energy gain when variable C is being referred to (Modified from Weiner, 2000).

When an animal is moved from one location to another, several of the elements making up the energy budget are likely to change. Kiwi that are moved from a captive situation where they are given their energy needs on a plate, to the wild where they immediately have to find all of their own food in a new forest habitat, are likely to face a decreased rate of energy acquisition, for two reasons. First, it will inevitably take any individual longer to obtain a given amount of energy by foraging than by feeding from a dish. Schekkerman & Visser (2001) found that energy used in activity and thermoregulation by chicks of two self-feeding precocial species was 53-58% higher in free-living individuals than in those provided with food ad libitum and kept in a thermally neutral environment, thus giving some indication of the differences in energy intake rate between a foraging individual and one provisioned with food.

Second, captive-reared sub-adult kiwi may have low levels of foraging proficiency. Sub-adult and juvenile kiwi were found to be less efficient than adults at capturing earthworms under the soil (Jenkins, 2001), implying that either kiwi learn to forage through experience, or that as they grow their morphological characters become better suited to prey detection and capture. Video-monitoring of adult kiwi that had various baits placed outside their nest or roost showed that captive kiwi were more inclined to feed on novel items than wild kiwi (Ward-Smith, 1998) raising the possibility that kiwi raised in captivity are less able to differentiate between inappropriate and appropriate food items. Wunderle (1991) cited attempts to feed on inappropriate prey or objects, as a behaviour often seen in young birds of species that improved in foraging efficiency as they got older. Therefore, captive-reared sub-adult kiwi may face an additional reduction in energy intake rate upon release if opportunity or incentive to forage for naturally occurring food while in captivity is limited, or if still at a relatively early stage of development. In the energy budget model, a lowered energy intake rate is represented by a reduction in the slope of line C, resulting in a higher minimum foraging time (Figure 3.1).

Thermoregulatory costs in birds within temperate zones tend to increase when temperatures decrease (Dawson & O'Conner, 1996). Costs of thermoregulation are a component of the line R in Figure 3.1, the daily energy expenditure for rest and non-foraging activities. McNab (1996) found that metabolic rate of North Island brown kiwi did not change at ambient temperatures between 10°C and 30°C, although it was not ruled out that their metabolism may remain unchanged at temperatures down to 7°C. Mean annual temperatures in Rotorua (where the kiwi in this study were kept prior to release) are between 12.5°C and 15°C, while in the Tongariro region (where they were released) mean annual temperatures are between 7.5°C and 10°C (Brenstrum, 1998). Therefore it is possible that the daily energy expenditure for rest and non-foraging activities will increase in these kiwi after release, particularly in those released in winter when temperatures will frequently be below 7°C. An increase in daily energy expenditure for rest and non-foraging activities increases the Y-intercept of line R/F+R in the energy budget model, resulting in a lower maximum foraging time (Figure 3.1).

The aim of this study was to quantify total nightly activity of sub-adult North Island brown kiwi in captivity and compare this with total nightly activity of the same kiwi after relocation and release into Tongariro or Karioi Rahui Forests. Based on the hypotheses that energy intake rate would be reduced and daily energy expenditure for rest and non-foraging activities would increase after release, it was predicted that following release mean time spent in foraging activity would increase and its among-night variability would decrease. Other factors potentially affecting activity times were also investigated in order to control for their influence. Results of this investigation are reported and discussed.

3.2 Methods

Seven brown kiwi between the ages of 4 and 17 months were used. All were raised at Rainbow Springs Wildlife Park, Rotorua, and were subsequently released into Tongariro Forest (from where they had been collected as eggs or chicks) or Karioi Rahui Forest (the

kiwi released into the Karioi Rahui had been collected as eggs from Waimarino Forest) as part of Operation Nest Egg (Chapter 1).

Four major blocks of pre-release and immediate post-release monitoring of kiwi activity took place during: 19 January-24 April 1999, 20 July-2 September 1999, 24 March-11 May 2000, and 24 June-10 July 2000. Additional periods of post-release monitoring took place from 28 June-3 July 1999, and 21-23 September 1999.

All individuals had a Sirtrack™ 20 g (2% of the minimum body weight of the kiwi used in this study) kiwi transmitter attached to either leg around the tibio-tarsus, using the standard attachment procedure (Miles & McLennan, 1998; Robertson & Colbourne, 2001). The transmitters contained mercury switch motion detectors, consisting of a mercury ball inside a vertically orientated tube. Activity detected in the transmitter changed the signal to the "active" pulse rate and after 10 seconds of no activity being detected it reverted to the "inactive" pulse rate. Each minute, a kiwi was described as active or inactive depending on the pattern of active and inactive pulse rates from the transmitter, using a classification procedure developed in Chapter 2. This procedure correctly classified behaviour as active or inactive on at least 94% of occasions.

Pre-release Monitoring

Four kiwi (named *Awhi*, *Gonzo*, *Waitangi*, and *Hot Chick*) were monitored from the 19 January up until the 23 March (*Awhi, Gonzo and Waitangi*) or the 21 April (*Hot Chick*) 1999. These kiwi were kept in 46.1 m^2-71.5 m^2 (Figure 2.1) enclosures at Rainbow Springs, Rotorua. The entire complex comprised eight enclosures, separated by corrugated iron and wooden fences. These enclosures were partly on the side of a hill, with enclosures 1-4 at the top, and enclosures 8 and 9 being on predominantly level ground. The enclosures had a soil base and vegetation consisting of some large trees and smaller shrubs and ferns. The vegetation was dense and overgrown in places. Burrows had been made in each enclosure using cavities covered over with logs, earth, branches, fern fronds and other plant material. Each enclosure had a water tray and a wooden box

where the kiwi's food dish was placed every evening. Kiwi could go into this box to feed ad libitum throughout the night.

One kiwi (named *Moenui*) was monitored from the 20 July-18 August 1999. *Moenui* was kept within a 478 m^2 area (Figure 2.2) enclosed by a corrugated iron fence. The whole complex comprised eight enclosures and an access pathway, separated by wooden fences. These enclosures were on the side of a hill with enclosures 1-3 at the top, and enclosures 4-8 sloping downwards from the access pathway. The enclosures had a soil base topped with leaf litter. Vegetation consisted of recently planted young native shrubs, trees and ferns and a few more mature trees. About three to four burrows in each enclosure had been made using cavities covered over with logs, earth, branches, fern fronds and other plant material. Each enclosure had a water tray and a wooden box where the kiwi's food dish was placed each evening. Kiwi could go into this box to feed ad libitum throughout the night. *Moenui* had enclosures 1, 2 and 3 to himself (ramp-doors in the fences separating enclosures allowed movement from one to another).

One kiwi (*Jake*) was monitored from 24 March-29 April 2000. *Jake* was in enclosure 8 (of Figure 2.2) and shared this enclosure with another sub-adult kiwi.

One kiwi (*Tuatea*) was monitored from the 24 June-5 July 2000. *Tuatea* was in enclosure 7 (of Figure 2.2).

Signals from the kiwi transmitters were received by an ATS DCCII scanning receiver and data logger, through a three-element Yagi antenna. When four kiwi were being monitored simultaneously (19 January-23 March 1999, and 24 March-23 April 2000), the data logger-receiver system was set to continuously log data from the four transmitters. For pre-specified time periods of 20- (19 January-4 February 1999) or 15- (4 February-22 March 1999, and 24 March-23 April 2000) seconds, the following information was stored: year, Julian day (1-365), time (hh:mm), transmitter frequency, and pulse count (number of pulses received during the period) (Table 2.1). At the end of each of these periods, the system would switch to the frequency of the next transmitter and the process

was repeated. When only one kiwi was being monitored, two alternative sampling regimes were used. From 23-29 April 2000 (*Jake*) and from 24 June-5 July 2000 (*Tuatea*), 15-second sampling every 60 seconds was used. From 13-21 April 1999 (*Hot Chick*) and from 20 July-18 August 1999 (*Moenui*), continuous monitoring by storing the number of pulses received during every 60-second period was used. Non-continuous sampling allowed the data-logger to continue running for a longer time without needing its battery changed, but provided less distinction between different types of active behaviours than continuous sampling (Chapter 2).

Pre-release monitoring continued up until one night (*Hot Chick*), two nights (*Awhi, Gonzo, Moenui* and *Tuatea*), six nights (*Jake*), or nine nights (*Waitangi*) before the kiwi's release. This variation was unplanned but unavoidable because of the logistics involved in attempting to monitor kiwi at two different locations (captivity and the wild) at the same time.

Data were downloaded from the data logger onto a computer and imported into excel files (Table 2.1). Data were then sorted by individual and chronological sequence. Number of pulses per time interval were converted to a number of seconds active per time interval, then seconds active out of 15 or 20 were multiplied by four or three to get a number out of 60. Each minute for each individual was then classified as active or inactive according to the system developed in Chapter 2.

Post-release Monitoring

Kiwi were released as outlined in chapter 1. Post-release activity monitoring began on the kiwi's first night in the wild for six individuals and on the second night in the wild for one individual. In the two weeks immediately after release, each kiwi was monitored on at least three nights and at most ten nights. In addition, some were monitored on one or two occasions any time between two weeks and four months after their release.

The sampling procedure was continuous night-long monitoring of a focal individual. Usually one, and at most two individuals were monitored in a single night. When

possible, data collection began before sunset and was continuous until dawn. Monitoring involved listening to the signal received by a Telonics TR4 receiver through a Yagi three-element antenna, from a high-point within reception range of the kiwi's transmitter. A record was kept of the times (hh:mm:ss) the signal mode changed from active to inactive and vice versa (see Appendix 1). At least two people were designated to collect data per kiwi/night to ensure that data could be collected continuously throughout the night provided the kiwi remained in range of the receiving point.

Seconds of active signal per minute were quantified for each minute of the night. Each minute was then classified as active or inactive according to the system developed in Chapter 2.

Data Processing and Analysis

Although we attempted to collect data continuously throughout the night, this was not always achieved during post-release monitoring because kiwi sometimes moved out of range of the receiver and it took time to find the signal again. Also occasionally recorders fell asleep! This was dealt with by not using the results from any kiwi/nights where data were not recorded for at least 75% of the minutes between sunset and sunrise. It was assumed that missing data on a smaller scale than this would not bias the results. Some nights of pre-release data were also discarded when it was obvious that the data logger had not been recording accurately (for example, when high activity readings during the daytime were implied by the data or when it recorded data beyond the range of possible numbers of transmitter pulses during a scan interval).

An estimate of total activity between sunset and sunrise each kiwi/night was reached using three steps: (1) the active minutes recorded between sunset and sunrise were summed; (2) this sum was divided by the number of minutes for which data were recorded for that individual between sunset and sunrise; and (3) the resulting proportion was multiplied by the number of minutes between sunset and sunrise on that night.

The estimated total activity time was used as a relative index of foraging time because foraging time could not be reliably estimated using all of the data collection methods used throughout this study. Foraging-dominated behaviour could be identified with about 82% reliability when continuous data collection methods were used, but interval sampling methods (as were used during most pre-release monitoring) were less able to differentiate this behaviour from other forms of activity (see Chapter 2). Therefore, to check that total activity time was a valid relative index of foraging time, individuals' estimated foraging times were regressed against their estimated total activity time for nights on which continuous sampling methods were used.

Factors potentially influencing pre-release nightly activity levels were analysed with a mixed model (SAS, version 8) type 3 test. The dependent variable was total minutes of activity. Categorical independent variables were 'year' (1999 or 2000), 'month' and 'moon phase' (new, half, or full); and continuous independent variables were 'night length' (minutes from sunset to sunrise), 'age' of the kiwi (in days on each monitored night), 'temperature' (°C) and 'rainfall' (mm). An interaction effect between 'rainfall' and 'moon phase' was also tested for, due to the reduced intensity of moonlight on a rainy night. (Interaction terms are denoted by two variable names joined with an asterisk.) The random independent variable 'kiwi' (nested within year because each kiwi was only monitored in one of the two years) was also incorporated into the model. Additional pre-release activity data of three individuals from whom data was collected for chapters 2 and 4 (but from whom post-release data was not collected), were included in the analysis of factors influencing pre-release activity levels.

A second mixed model type 3 test was run on kiwi post-release activity levels using the same variables as pre-release with the addition of the variable 'days since release' and the exclusion of the variable 'year' because there were zero degrees of freedom in the type 3 test for year due to the low sample size.

T-tests were used to compare the before and after release activity of each individual. This was done using both total minutes activity and minutes activity as a percentage of night

length. F-tests were used to compare the before and after release variability in activity of each individual. Patterns of activity throughout the night were qualitatively assessed and any notable features recorded. Time differences between sunset and activity commencement and between activity ceasing and sunrise were recorded.

A mixed model type 3 test was also used to compare activity levels before and after release. The same variables were used as for the pre-release analysis, with the addition of the categorical independent variable of time relative to release (from here on referred to as the variable 'prepost') which had three levels: pre-release; first night after release; and all other nights after release. 'Prepost' was also tested in interaction effects with 'night length', 'month', 'moon phase' and 'rainfall'. Fit statistics in all models were given by Akaike's Information Criterion (AIC) (Burnham and Anderson, 2002).

Three nights either side of each reported day of full or new moon were classified as full or new moon respectively and all other nights were classified as half moon (days of full and new moon were obtained from a Collins diary, which had obtained the information from the Carter Observatory, Wellington). Times of sunset and sunrise were provided directly by the Carter Observatory, for the specific sites according to latitude and longitude. Weather data were obtained from the National Rural Fire Authority website and from NIWA (National Institute of Water and Atmospheric Research) using data from the closest weather stations to each site; Rotorua Airport was used for Rainbow Springs, Rotoaira weather station was used for Tongariro Forest and Waiouru weather station for Karioi Rahui. As only midday temperatures were available from all sites, the mean of the preceding and following days' temperatures were used as a relative temperature index for each night. Rainfall data were provided in the form of a total over a 24 hour period (0000-2400), therefore the average of the day before and day after the relevant night was used as the value for that night.

3.3 Results

Relationship Between Foraging Time and Total Activity Time

There was a significant positive relationship between nightly foraging time and nightly total activity time, both before ($p < 0.001$) and after ($p < 0.0001$) release (Figure 3.2). There was a stronger correlation between these variables post-release ($r^2 = 0.7342$) than pre-release ($r^2 = 0.5092$).

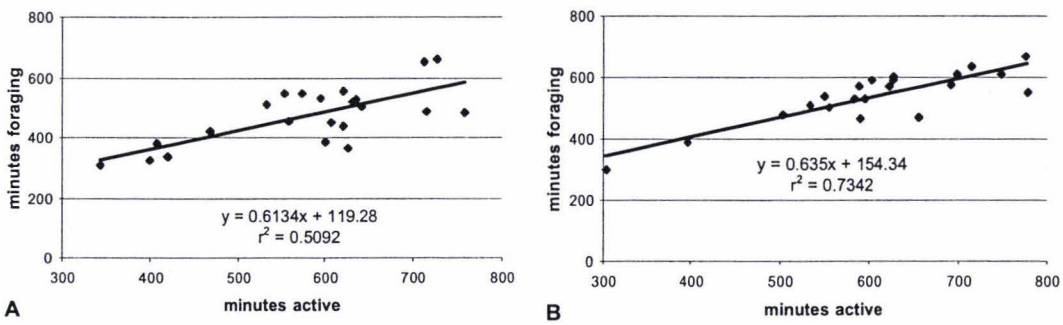


Figure 3.2 Nightly foraging time relative to nightly total activity time, (a) pre-release and (b) post-release. Each data point represents one kiwi/night of monitoring.

Variables Affecting Pre-release Activity

Rainfall showed a significant effect and moon phase a close to significant effect on pre-release activity (Table 3.1; Appendix 9). Unadjusted regression showed rainfall to be positively correlated with activity (Figure 3.3). Least squared mean activity was significantly higher during a new moon than during a full or half moon (Figure 3.4).

Post-release Activity

When post-release activity was analysed alone, its variation was not significantly accounted for by any of the fixed variables used in the model (Table 3.2).

Table 3.1 Likelihood statistics of factors relating to kiwi pre-release nightly activity. AIC = 1967.0 Variables joined by an asterisk denote an interaction term. df: degrees of freedom; f: f statistic; p: p value. *indicates p value < 0.05.

Effect	df	f	p
Year	1,7	0.00	0.9627
Night length	1,158	0.06	0.8096
Month	6,158	1.15	0.3381
Age	1,158	0.23	0.6337
Moon phase	2,158	2.99	0.0533
Temperature	1,158	1.64	0.2024
Rainfall	1,158	4.25	0.0409*
Rainfall*moon phase	2,158	0.27	0.7664

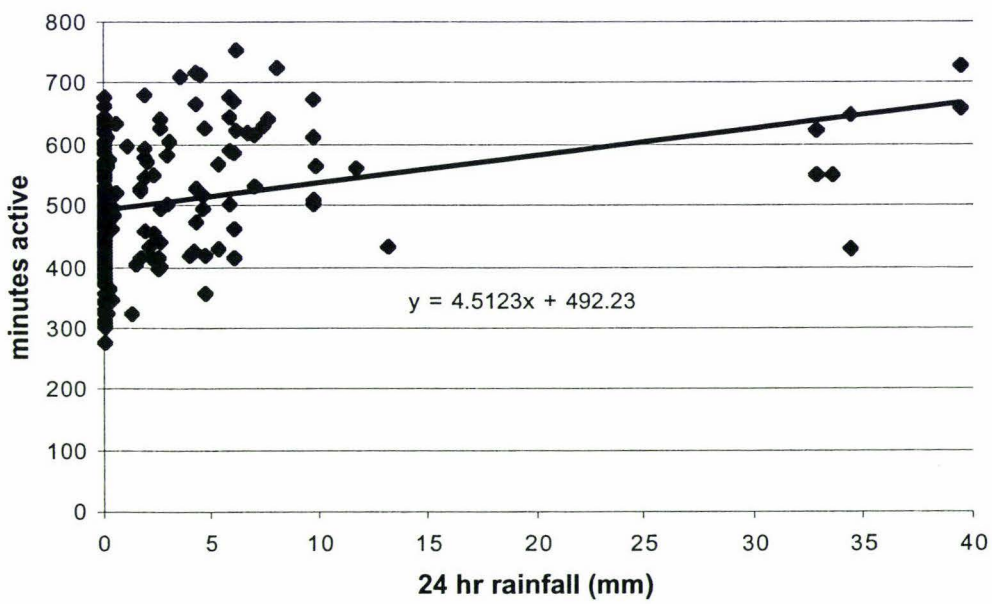


Figure 3.3 Unadjusted regression of pre-release activity against rainfall.

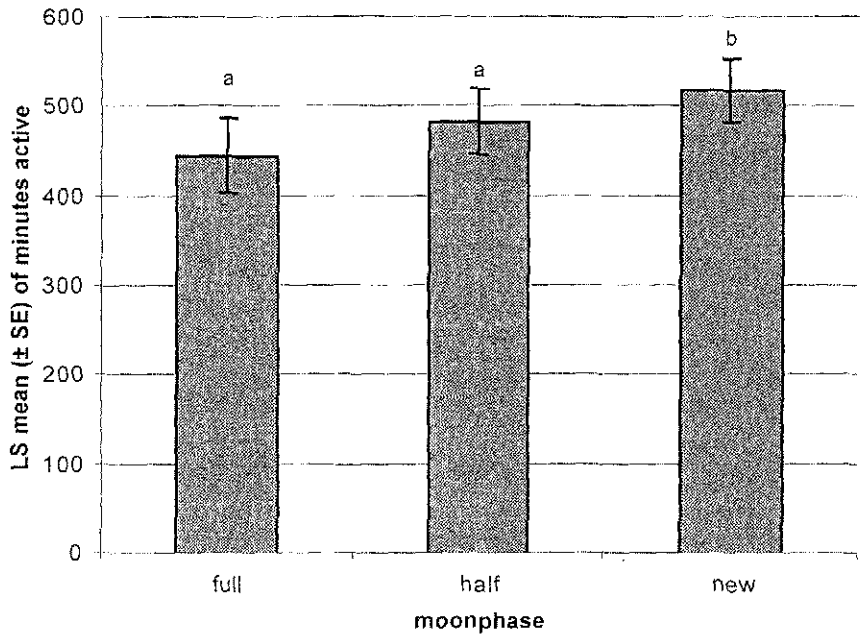


Figure 3.4 Least squared means of kiwi pre-release nightly activity times, during different moon phases. Bars with different letters above them have significantly different LS means.

Table 3.2. Likelihood statistics of factors relating to kiwi activity after release (first night after release is excluded from analysis). AIC = 384.2 Variables joined by an asterisk denote an interaction term. df: degrees of freedom; f: f statistic; p: p value. * indicates p values < 0.05.

Effect	df	f	p
Night length	1,25	0.09	0.7612
Month	7,25	1.22	0.3279
Age	1,25	0.19	0.6670
Days since release	1,25	1.39	0.2492
Moon phase	2,25	0.08	0.9206
Temp	1,25	0.14	0.7090
Rainfall	1,25	0.16	0.6888
Rainfall*moon phase	2,25	0.24	0.7919

Pre- and Post-release Activity of Individual Kiwi

Six of the seven kiwi were monitored on their first night after release. Two of these kiwi had low activity levels on their first night relative to their pre-release activity (*Moenui* and *Tuatea*; Figure 3.5 e&f), and two had activity levels similar to their pre-release activity but low relative to subsequent nights' activity levels (*Hot Chick* and *Waitangi*; Figure 3.5 c&g). Of the six kiwi, only *Moenui* and *Tuatea* did not have significantly higher nightly minutes of activity after release than pre-release. When activity was expressed as a percentage of night length however, *Moenui*'s activity was higher after than before release (Table 3.3).

When night one was excluded from analysis, both *Moenui* and *Tuatea* had significantly higher activity after release than before release, and *Jake* (who was not monitored on night one in the wild) was the only kiwi to show no significant increase after release (Table 3.3).

Nightlong activity patterns in captivity tended to be characterised by several bouts of activity separated by rest periods often lasting from about 30 to 90 minutes. Time delays between sunset and commencement of activity or between cessation of activity and sunrise were always less than one hour in the evening and no more than one and a half hours in the morning. In contrast, first night in the wild activity patterns of three of the four kiwi who had low activity on this night were characterised by longer and fewer rest periods, and in the case of two kiwi there were very long delays before activity began in the evening or activity ceased a long time before sunrise. *Moenui* did not become active until five hours and 42 minutes after sunset on his first night after release (several times longer than the longest delay seen in any kiwi before release). *Tuatea* became active 61 minutes after sunset (a longer sunset till activity delay than was seen in any kiwi before release) and ceased activity two hours and eleven minutes before sunrise (longer than any activity cessation to sunrise gap seen in any kiwi before release) on his first night after release. *Hot Chick* was released late in the day (22 minutes after sunset) and became active only eight minutes later, but had an inactive period lasting three hours and 20 minutes during the night on this first night after release. After the first-post-release-night,

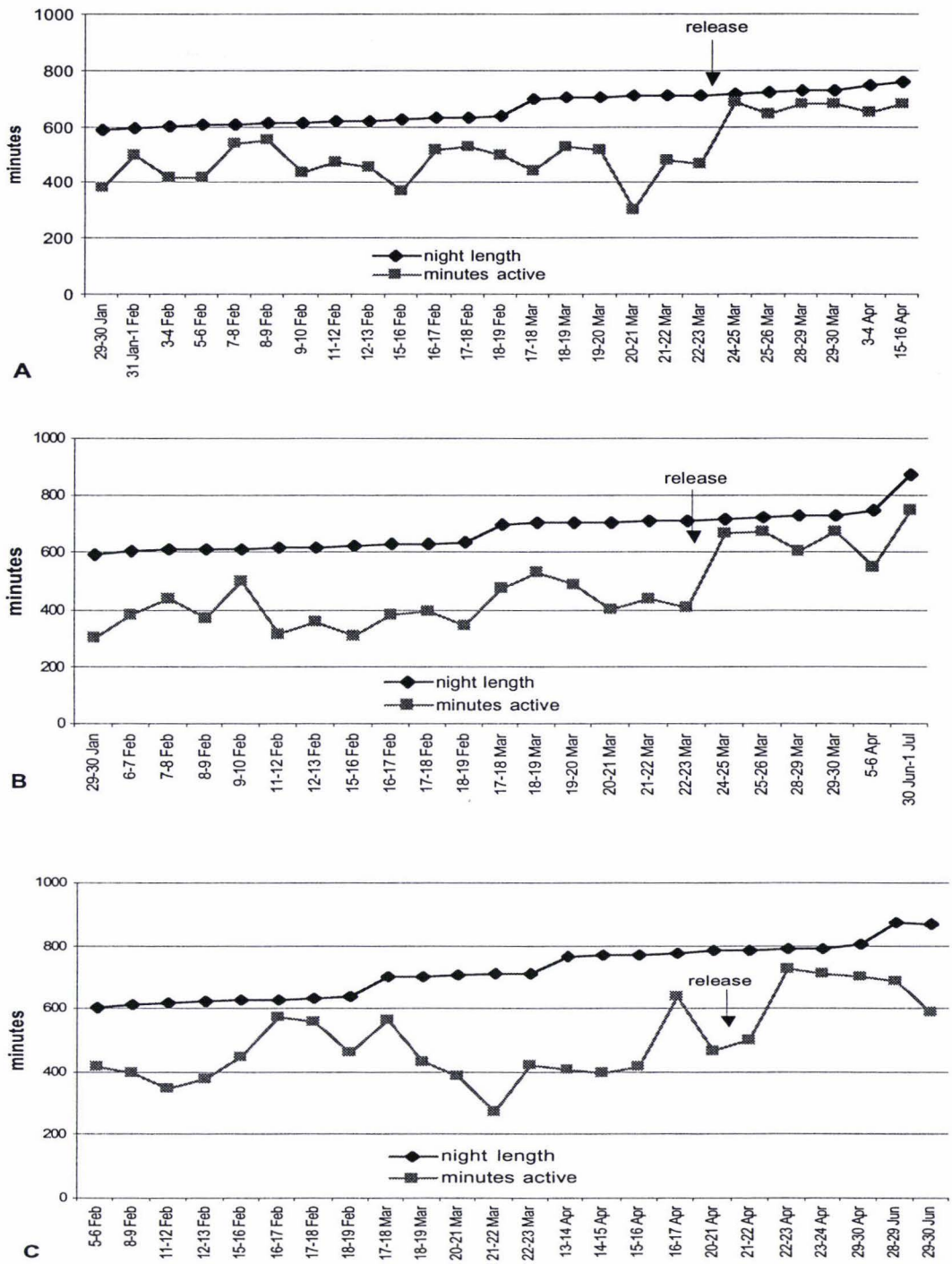


Figure 3.5 Timeline of nightly activity levels of each kiwi pre and post-release. (a) *Awhi*, (b) *Gonzo*, (c) *Hot Chick* (continued over)

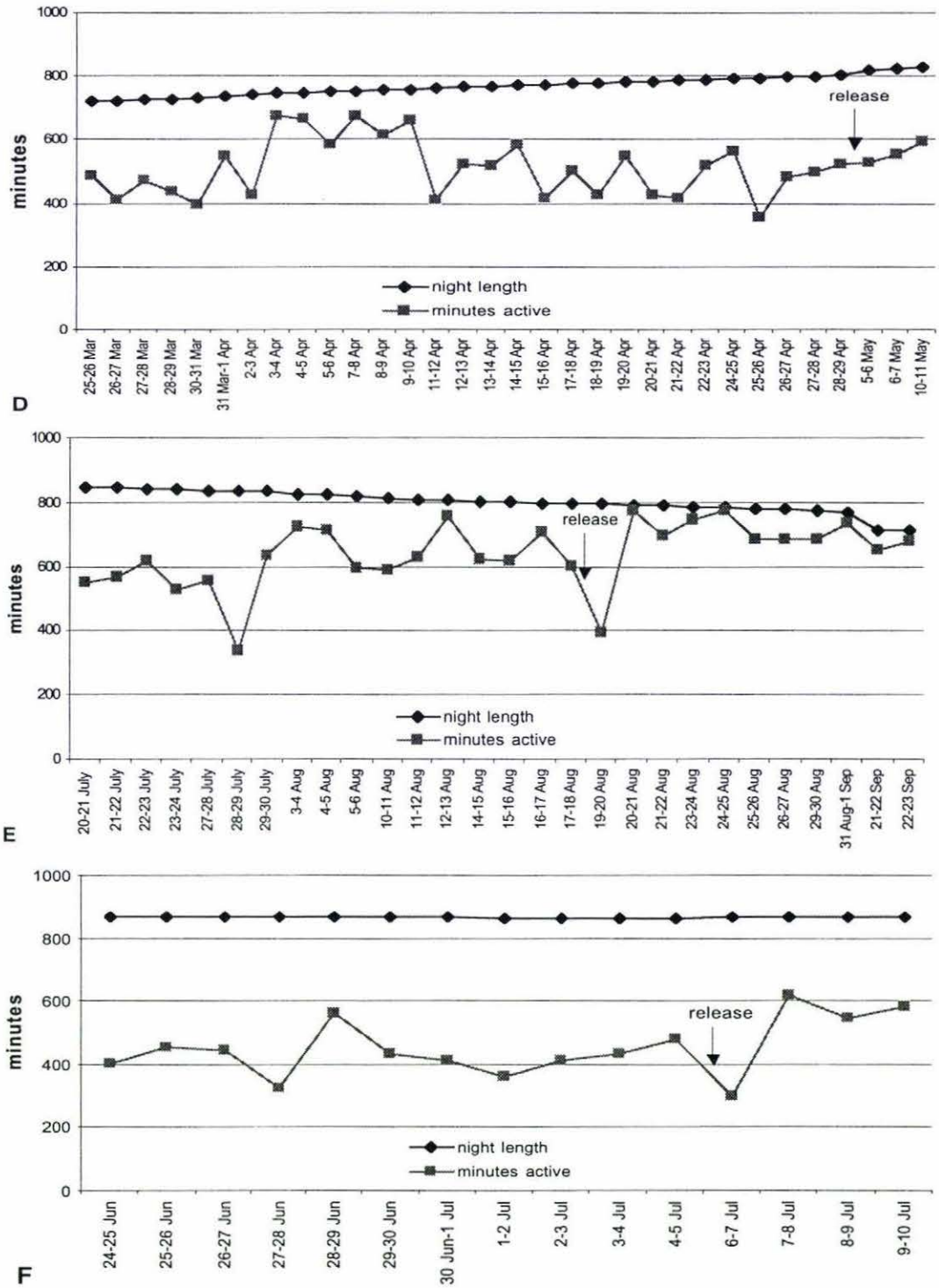


Figure 3.5 (cont.) Timeline of nightly activity levels of each kiwi pre and post-release. (d) *Jake*, (e) *Moenui*, (f) *Tuatea* (continued over).

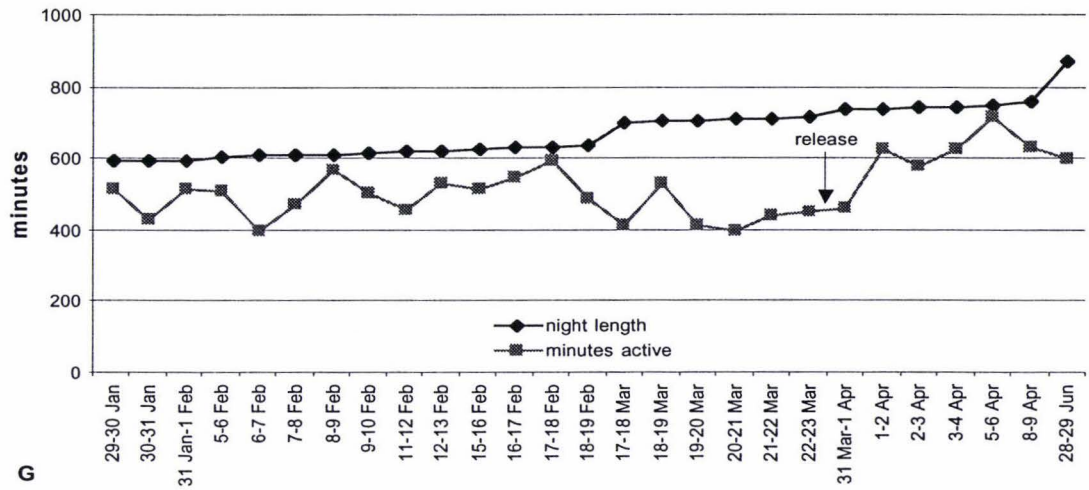


Figure 3.5 (cont.) Timeline of nightly activity levels of each kiwi pre and post-release. (g) *Waitangi.*

Table 3.3 Comparisons between pre- and post-release activity in individual kiwi. The minutes columns report comparisons made using absolute number of minutes active, while the % columns report comparisons made using minutes of activity as a proportion of nightlength. Comparisons excluding the first post-release night are reported because several individuals showed considerably lower activity on their first night in the wild than on subsequent nights. *Jake* was not monitored on the first night post-release. Every significant comparison involved a higher mean activity after release than before release. df: degrees of freedom; t: t statistic; p: p value. * indicates p values < 0.05.

kiwi	minutes			%			minutes (excl. night 1 post-release)			% (excl. night 1 post-release)		
	df	t	p	df	t	p	df	t	p	df	t	p
Awhi	23	-12.08	<0.001 *	23	-6.54	< 0.001*	21	-11.54	< 0.001*	22	-6.34	<0.001*
Gonzo	8	-7.72	< 0.001*	19	-5.56	< 0.001*	6	-6.56	< 0.001*	7	-5.60	<0.001*
Hot Chick	9	-4.95	<0.001*	10	-2.52	0.0305*	11	-7.37	< 0.001*	9	-3.25	0.0099*
Jake	-	-	-	-	-	-	7	-1.97	0.0898	10	-0.33	0.7505
Moenui	20	-1.87	0.0761	20	-2.85	< 0.01*	24	-3.80	< 0.001*	21	-5.59	<0.001*
Tuatea	3	-1.14	0.3386	3	-1.12	0.3442	6	-5.59	0.0014*	6	-5.62	0.0014*
Waitangi	13	-12.51	< 0.001*	11	-0.73	0.4833	10	-6.39	< 0.001*	11	-1.46	0.1736

total nightly activity tended to be higher and therefore was characterised by fewer and/or shorter periods of inactivity.

The first night after release was excluded from analysis of pre- and post-release activity variance. *Awhi* and *Moenui* both showed a significant decrease in activity variance after release (Table 3.4).

Table 3.4 Comparison between pre- and post-release activity variance in individual kiwi. The higher variance column shows which had the higher variance of pre and post-release, while the p value shows whether this difference was significant. df: degrees of freedom; f: f statistic; p: p value. * indicates p values < 0.05.

kiwi	higher variance	df	f	p
Awhi	pre	18, 4	10.93	0.0161*
Gonzo	post	16, 4	0.83	0.3461
Hot Chick	pre	17, 4	2.64	0.1792
Jake	pre	28, 2	8.30	0.1130
Moenui	pre	16, 9	4.95	0.0098*
Tuatea	pre	10, 2	2.84	0.2881
Waitangi	pre	19, 5	1.59	0.3209

Variables Affecting Pre- and Post-release Activity

When all nights before and after release were considered, 'prepost' and month had significant effects on activity. Month was also significant in interaction with 'prepost', showing that the months of higher activity pre-release differed from those post-release. Night length was significant in interaction with 'prepost'. In contrast to when pre-release activity was considered alone, rainfall did not have a significant effect and moon phase was not close to significance in the combined pre-and post-release dataset (Table 3.5). As 'prepost' was included in significant interaction terms, its least squared means could only

be estimated after these interactions were removed from the model. Removing these interactions resulted in a reduced fit to the model (AIC increased from 1720.8 to 1865.3). Least squared mean of activity more than one night after release was significantly higher than that of both pre-release and first night after release activity (Figure 3.6).

Table 3.5 Likelihood statistics of factors relating to kiwi activity before and after release.
AIC = 1720.8. Variables joined by an asterisk denote an interaction term. df: degrees of freedom; f: f statistic; p: p value. * indicates p values < 0.05.

Effect	df	f	p
Year	1,4	0.33	0.5945
Night length	1,137	1.56	0.2141
Month	8,137	2.18	0.0329*
Age	1,137	0.34	0.5599
Moon phase	2,137	0.92	0.4001
Prepost	2,137	3.16	0.0455*
Temp	1,137	0.07	0.7942
Rainfall	1,137	0.28	0.5985
Rainfall*moon phase	2,137	1.04	0.3573
Night length*prepost	2,137	7.3	0.0078*
Month*prepost	5,137	4.23	0.0013*
Moon phase*prepost	2,137	0.36	0.6958
Rainfall*prepost	1,137	2.45	0.1202

Removing the first night after release from the analysis resulted in an improved fit to the model (AIC decreased from 1720.8 to 1704). The significant effects were the same as in the previous analysis but 'prepost' increased its significance from $p = 0.0455$ (Table 3.5) to $p = 0.0151$. Significant interaction terms involving 'prepost' had to be removed from the model before 'prepost' least squared means could be estimated, which reduced the fit to the model (AIC increased from 1704 to 1760.3). There was still significantly more activity after than before release (Figure 3.7). No months were significantly different from each other pre-release but there were some differences post-release with May and July having significantly lower activity than March and April. March showed an

increased activity least squared mean after release (Figure 3.8). Night length was slightly positively correlated with activity before release but showed a very weak negative correlation with activity after release (Figure 3.9).

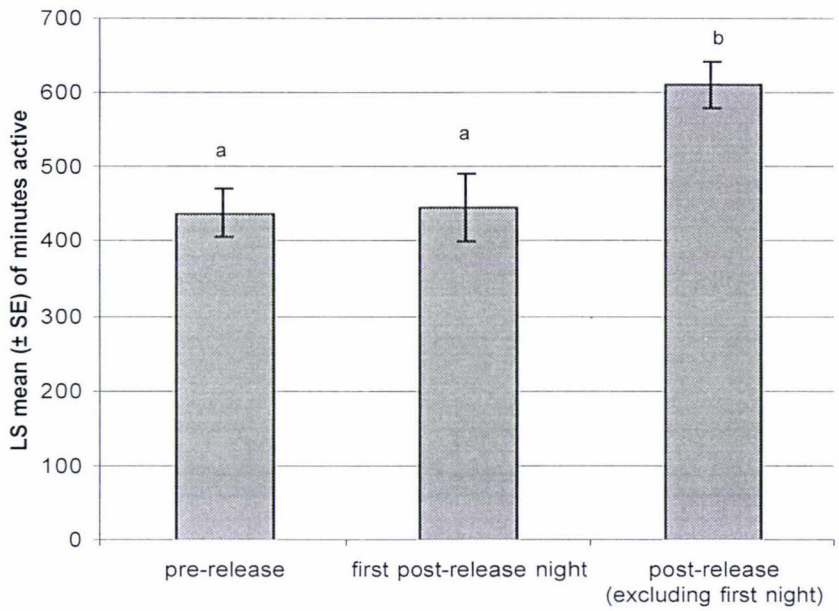


Figure 3.6 Least squared means of kiwi nightly activity during different time periods relative to release. Bars with different letters above them have significantly different LS means.

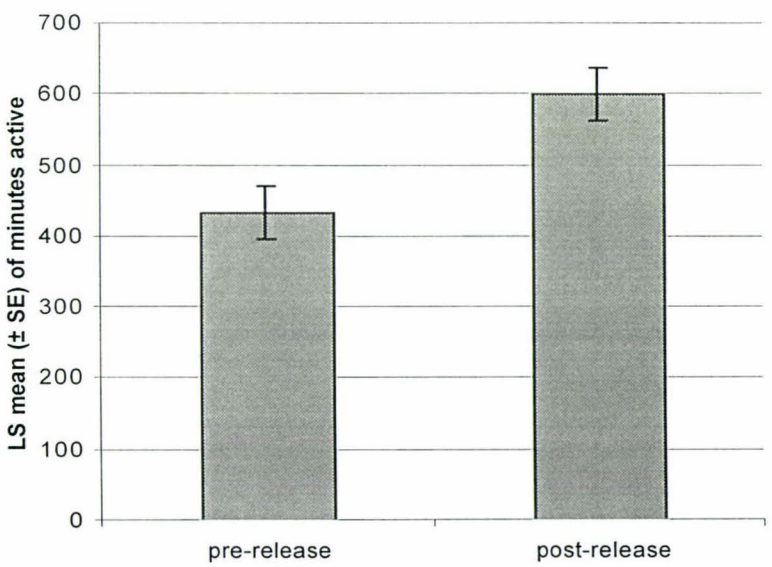


Figure 3.7 Least squared means of kiwi nightly activity times pre-release and post-release (excluding the first night after release).

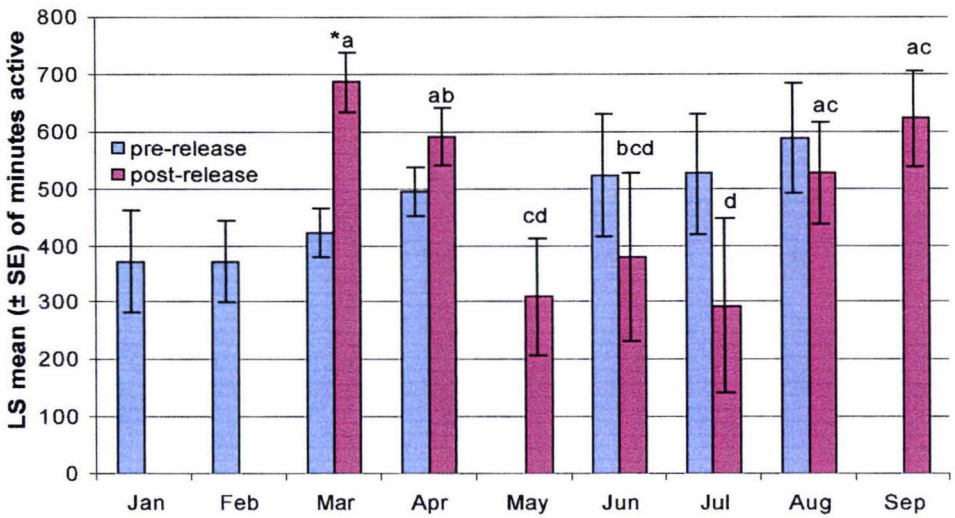


Figure 3.8 Least squared means of nightly minutes active pre- and post-release (excluding the first night after release) during different months. *signifies a month with significantly different pre- and post-release values. There were no significant differences among months pre-release. Bars with different letters above them have significantly different post-release values.

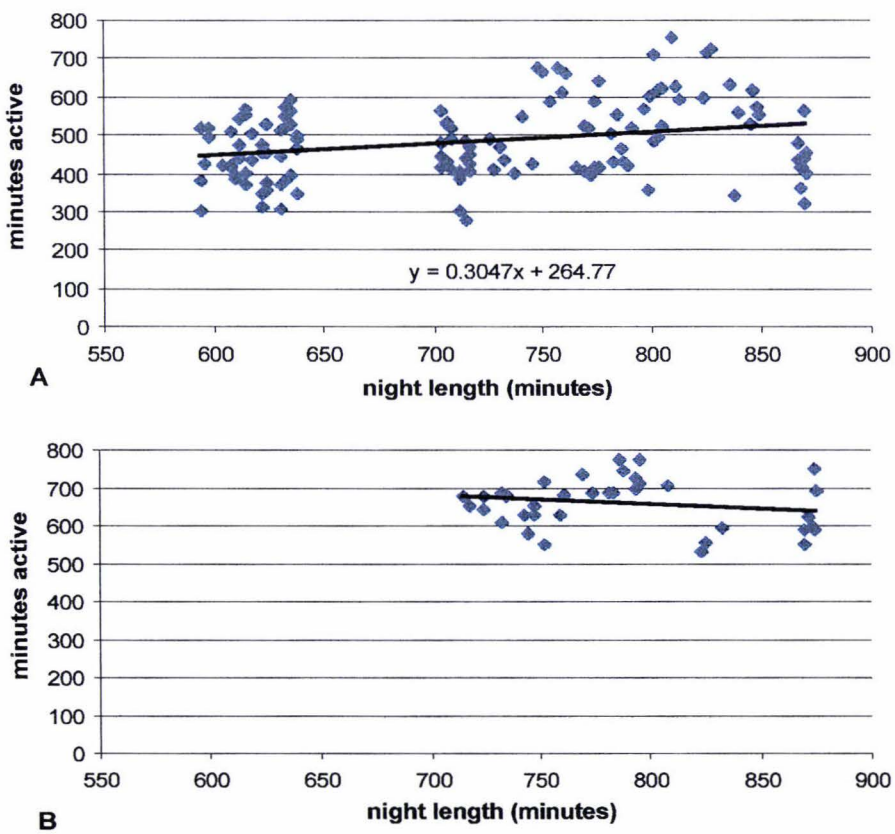


Figure 3.9 Unadjusted regression of activity against night length (a) pre-release and (b) post-release (excluding the first night after release).

Mean Nightly Activity Pre- and Post-release

Least squared mean (± SE) of nightly minutes active before release, was 434 minutes (7.23 hours) ± 36 minutes. After release this value was 601 minutes (10.02 hours) ± 36 minutes.

3.4 Discussion

The significant correlation between foraging time and activity time allowed testing of the prediction that mean foraging time would increase after release of captive-reared kiwi into the wild. After one night in the wild, kiwi activity was high relative to previous levels. This was shown by a significant increase in activity by six out of seven kiwi, and by a general increase in activity from the second night in the wild onwards when all kiwi were considered and the effects of other factors such as rainfall and time of year were taken into account. The prediction of an increased foraging time after release is therefore supported.

The prediction that among-night variance in foraging time would decrease after release was not upheld. Only two out of seven kiwi showed a significant reduction in activity variance after release. According to the energy budget model (Weiner, 2000) this tends to imply that there was not an increase in energy expenditure for rest and non-foraging activities including thermoregulation. However, the small number of post-release nights sampled for most individuals could have limited the potential for a difference in variance to be found. There was no indication that kiwi released in winter had tighter constraints on their activity variability than others, as might have been expected if thermoregulation costs were higher in winter than at other times of year. Again, potential to find such an effect was limited by the number of nights sampled and by the fact that all kiwi monitored were released in either autumn or winter, so the full range of possible thermoregulatory effects may not have been experienced.

Kiwi showed significantly lower activity on their first night in the wild than on subsequent nights. While length of nightlong activity did not differ significantly between pre-release and post-release-night-one, there were differences in the pattern of activity throughout the night. Typical kiwi activity, both in captivity and the wild, consistently began with the onset of darkness and ceased with the approach of dawn. However, on the first night after release two kiwi had a notable delay in the onset of their activity, one was inactive for an exceptionally long time in the middle of the night, and one became inactive more than two hours before dawn. Instances of kiwi not becoming active shortly after nightfall have also been noted in pairs of little spotted kiwi after a relocation from Kapiti Island to Tiritiri Matangi Island (Boyd, 1993). At least three out of ten pairs had not left their burrow by two hours after nightfall and one pair probably did not leave their release burrow at all on their first night after release. Elevated corticosterone levels have been found to reduce activity in birds when under non food-limiting conditions (Wingfield et al., 1997). Adams (2000) found elevated corticosterone levels in captive North Island brown kiwi for at least six hours after handling and confinement in a box (as occurs during relocations), therefore high corticosterone levels may be responsible for suppressing activity in some kiwi soon after their release.

Although there appeared to be a positive relationship between night length and activity before release, this was not significant when the effect of other factors was taken into account. After release there was no apparent relationship between activity and night length. For a relationship between night length and activity to be detected a larger range of night lengths may need to have been sampled because activity time versus day/night length has been found to form an S-shaped rather than a linear relationship in many animals (Daan & Aschoff, 1975). Time of first and last calls of Tongariro kiwi has previously been used to infer relative activity times throughout the year, and appeared to show that there was some increase in activity as the nights got longer (Miles, 1995).

Some differences in activity among months were seen post-release. However, given the unpredictability of the changes from one month to the next and the small sample of

individual kiwi during several months, these differences are more likely to be representative of differences among individual kiwi than due to external influences.

Activity of kiwi before release increased with rainfall and was lower on moonlit nights but neither rainfall nor moonlight appeared to have any effect on post-release activity. While Buller (1888) commented that "on dark and wet nights they (the kiwi he kept in captivity) were particularly active and noisy", few reported studies have quantified kiwi activity during different weather. Some studies have investigated the effect of weather on kiwi call rates. For instance, Miles (1995) found that call rates were significantly higher on fine nights than on nights with rain in Tongariro Forest and McLennan & McCann (1991) found that call rates of great spotted kiwi in Kahurangi declined during wet and windy weather. Calling in kiwi is considered to serve a mainly reproductive function through its involvement in maintaining the pair-bond and territory defence (Colbourne & Kleinpaste, 1983; Colbourne & Kleinpaste, 1984; Taborsky & Taborsky, 1992; Miles, 1995), and such behaviour that is non-essential in the short-term may be dispensed with at times of stress during severe weather (Wingfield et al., 1997). Short-term survival behaviour such as foraging may however remain unaffected at such times. Many studies have found that behaviour of nocturnal animals is influenced by the moon's cycle (e.g. Bouskila, 1995; Brigham et al., 1999) but studies of kiwi during different moon phases have produced varied results. It has long been considered that kiwi are more likely to call on non-moonlit nights than when the moon is bright, and some authors have suggested that kiwi activity in general is suppressed during a bright moon (Buller, 1888; Taylor & Calder, 1983; Colbourne & Kleinpaste, 1984; Kayes and Rasch, 1985 (cited in McLennan, 1992)). However, a quantitative study by Miles (1995) found no effect of moon phase on kiwi calling rates in Tongariro Forest. As post-release weight losses are commonly seen in Operation Nest Egg kiwi (Colbourne, 1998; Whakapapa Department of Conservation, Unpublished data), a possible explanation for the altered response to both rainfall and moonlight after release is that in the first two weeks after release (when most post-release monitoring was done) kiwi needed to spend all available time foraging in order to retain a positive energy budget, and therefore had little choice of restricting activity. Habitat differences between the pre- and post-release environments could also

account for the different responses. Kiwi were released under closed canopy forest where rain and moonlight intensity will be reduced once it reaches the ground, whereas the enclosures at Rainbow Springs had a completely open canopy.

No effect of temperature on activity was detected. However, since daytime rather than nighttime temperatures were used, it is not possible to rule out a temperature effect. Daytime temperatures are not always a good indicator of relative night-time temperatures because during fine weather it can be very warm during the day but very cold at night. Effect of temperature would be best to be studied using a logger at the site that takes temperatures throughout the night.

Age at release has been suggested as an important factor in determining the ability of captive-reared individuals to adjust to living in the wild (Snyder et al., 1994; McLennan, 1998). No effect of age on activity levels or their degree of change after release was noted in this study, but as only seven individuals were studied, an age effect cannot be ruled out.

The energy budget model predicts that when energy intake rate is reduced, foraging time will increase (Figure 3.1, Weiner, 2000). Thus, the increase in activity, and presumably in foraging time, observed after release in this study is consistent with the hypothesis that energy intake rate was reduced below that prior to release. This would not be a surprising finding, as the kiwi were shifted from a situation where their energy needs were provided to one where their total energy intake had to be obtained by foraging for naturally occurring food. Foraging is considered to involve five main components: (1) site selection, (2) search, (3) food selection, (4) prey capture and (5) prey handling and consumption (Wunderle, 1991). For each of these components, either there is evidence that adults show greater competency than sub-adults in various bird species (e.g. Mueller & Berger, 1970; Buckley & Buckley, 1974; Davies & Green, 1976; McLean, 1986; Sutherland et al., 1986; Beauchamp et al., 1987; Sullivan, 1988; Wunderle & Lodge, 1988; Jenkins, 2001), or there are aspects of kiwi behaviour suggesting that wild individuals are likely to have advantages over recently released captive-reared individuals

(Colbourne & Kleinpaste, 1983; Taborsky & Taborsky, 1995; Ward-Smith, 1998; Gibbs, 2000; Jenkins, 2001). In addition, young kiwi may be more likely to take invertebrates from the litter or ground surface (Chan, 1999) than adults who take many invertebrates from beneath the ground as well as from the surface and litter layers (Buller, 1888; Gurr, 1952; Bull, 1959; Watt, 1971; Reid et al., 1982; Kleinpaste & Colbourne, 1983; Miles, 1995; Miles et al., 1997), suggesting that young kiwi are restricted in their diet due to their relatively short bills. Therefore, there may be a number of morphological and experiential factors contributing to a low foraging efficiency in young kiwi after release from captivity. Foraging efficiency describes the energy intake rate an individual achieves in the absence of competitors (Goss-Custard & Sutherland, 1997), but energy intake rate is likely to reduce further in the presence of competitors (e.g. Ulfstrand, 1979).

Although most kiwi showed a sudden increase from their pre-release activity levels, the levels of activity seen in the wild were within the ranges of those detected in wild non-incubating adult North Island brown kiwi at other sites. Average nightly activity in the wild in the present study (after adjustment for influence from external factors) was 10.02 hours, while at Waitangi, Paerata and Hawke's Bay, average nightly activity of kiwi was estimated at 11.5, 8.5, and 7.4 hours respectively (Taborsky & Taborsky, 1999). This suggests that post-release kiwi are not compensating for their low energy intake rate to the point of adopting activity levels beyond those normally seen in wild kiwi. However, the post-release weight losses commonly seen in Operation Nest Egg kiwi (Colbourne, 1998; Whakapapa Department of Conservation, Unpublished data), suggest that their post-release activity increase is unable to compensate for their reduced rate of energy acquisition. There is also a possibility that high corticosterone levels at release contribute to weight loss, as high corticosterone levels were found to coincide with a slow growth stage in the young of another precocial species (Frigerio et al., 2001).

Weight loss and a low energy intake rate are of concern for three reasons. Firstly, if weight-loss continues indefinitely, starvation will occur. Secondly, weight is commonly used as a gauge of when a kiwi should be resistant to stoat predation and thus when it can be released into an area without high intensity stoat control. If it is assumed that most

kiwi will lose weight after release, the minimum release weight should be higher than the "stoat safe" weight. Thirdly, the more time an animal spends looking for food due to a low energy intake rate, the more exposed and less ready to escape or defend itself against a predator it may be (Krebs, 1980; Hegner, 1985; Wunderle, 1991; Koivula et al., 1995; Green et al., 1998).

Determining the change in activity levels of kiwi after release has allowed some insight into the process of adjustment that the kiwi undergo after release. Kiwi tend to have unusual and low activity patterns on their first night after release, possibly as a result of stress, but exhibit their highest recorded activity levels from then on. The increased activity levels are thought to be due to a reduced rate of energy intake, and the weight loss typically seen in kiwi after release seems to support this interpretation. Further investigations could look at the relationship between amount of weight loss and the extent of change in activity. It may be possible to reduce the change in activity levels after release by providing incentive and opportunity for kiwi to forage while in captivity.

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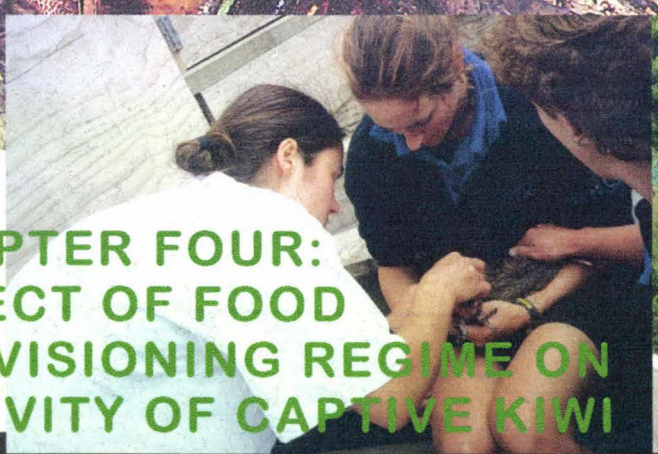

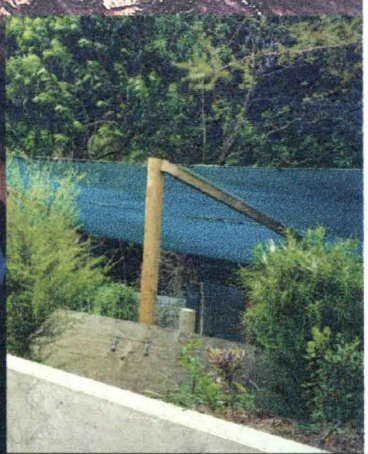

CHAPTER FOUR: EFFECT OF FOOD PROVISIONING REGIME ON ACTIVITY OF CAPTIVE KIWI

4. Effect of Food Provisioning Regime on Activity of Captive Kiwi.

4.1 Introduction

Captive-rearing for release into the wild is often used as a tool in species recovery programmes. In the hope of increasing survival of animals once they are in the wild, pre-release training is sometimes undertaken (e.g. Zwank et al., 1988; Powell & Cuthbert, 1993; Powell et al., 1997; McLean et al., 1999; Brown & Laland, 2001). Training usually consists of conditioning the animals to be vigilant towards predators that may be encountered in the wild (Carpenter et al., 1991; McLean et al., 1995; Griffin et al., 2000), providing foraging experience in a naturalistic setting (Maxwell & Jamieson, 1997; Powell et al., 1997; Burke et al., 2001), exposing the animals to foods that the species feeds on in the wild (Snyder et al., 1994; Kuehler et al., 1995; Berry, 1998), or presenting food in a manner that promotes active searching and normal food handling behaviour (e.g. Wallace & Temple, 1987).

The form in which food is presented to captive animals has been found to affect their activity budgets. For example, harbour seals (*Phoca vitulina concolor*) and gray seals (*Halichoerus grypus*) increased their exploratory behaviour when presented food along with various novel objects (Hunter et al., 2002). Captive black and white ruffed lemurs (*Varecia variegata variegata*) increased their time spent foraging to the equivalent of that of their wild counterparts, when their food was provided on the roof of their cage so that they had to suspend from the roof and reach through the mesh roof to pick it up (Britt, 1998). Stereotypic behaviours such as pacing and head swinging were reduced and feeding behaviour took up more time in big cats when they were provided whole carcasses rather than processed dog-food (McPhee, 2002). Captive elephants that had a portion of their usual hay ration replaced with freshly harvested foliage browse increased their time spent feeding and decreased inactivity time (Stoinski et al., 2000). Feeding enrichment, including putting food in holes and in branch piles, increased time spent foraging by spectacled bears (*Tremarctos ornatus*) (Fischbacher & Schmid, 1999). Thus,

it appears that when food is presented in such a way that the animal has to perform at least some of the searching, food detection, accessing or handling behaviour that it would have to do in the wild, time spent in feeding-related activities tends to increase.

Higher levels of activity were seen in sub-adult North Island brown kiwi after release into the wild than before release (Chapter 3). It was hypothesised that this increase in activity post-release was a result of a reduced rate of energy acquisition and the kiwi therefore needing to spend more of their time foraging to meet their energy needs. The aim of this chapter is to test this hypothesis by measuring and comparing activity of captive kiwi under two different food-provisioning regimes. It was predicted that activity would be higher when the kiwi's food supply was distributed in many small portions around the enclosure than when food was provided in one portion.

4.2 Methods

Four brown kiwi (*Iwa*, *Jake*, *Taz*, and *Te Ngahere*) aged from 19 to 25 weeks at the start of the study, were used. All were raised at Rainbow Springs wildlife park, Rotorua, and were subsequently released into Tongariro or Whirinaki Forest (from where they had been collected as eggs or chicks) as part of Operation Nest Egg.

The kiwi were kept within a 478 m^2 complex (Figure 2.2) enclosed by a corrugated iron fence. The complex comprised eight enclosures and an access pathway, separated by wooden fences. These enclosures were on the side of a hill with enclosures 1-3 at the top, and enclosures 4-8 sloping downwards from the access pathway. The enclosures had a soil base topped with leaf litter. Vegetation consisted of recently planted young native shrubs, trees and ferns and a few more-mature trees. About three to four burrows in each enclosure had been made using cavities covered over with logs, earth, branches, punga fronds and other plant material. Each enclosure had a water tray and two wooden boxes or shelters where the kiwi's food dishes were placed (there were two food dishes and feedboxes per enclosure because there were two kiwi in each enclosure). *Taz* and *Te Ngahere* were kept together in enclosure 3 (56 m^2) while *Iwa* and *Jake* were kept together

in enclosure 8 (42 m^2). Before the study, the four kiwi were in four individual enclosures, but to make room for younger kiwi that were being moved outside from indoor brooders, Jake was moved from enclosure 1 to 8 and Te Ngahere was moved from enclosure 7 to 3, on the 24 March 2000. Activity monitoring began on the 25 March 2000.

Data Collection

All individuals had a Sirtrack™ 20 g (2% of the minimum body weight of the kiwi in this study) kiwi transmitter attached to either leg around the tibio-tarsus, using the standard attachment procedure (Miles & McLennan, 1998; Robertson & Colbourne, 2001). The transmitters contained mercury switch motion detectors, consisting of a mercury ball inside a vertically orientated tube. Activity detected in the transmitter changed the signal to the "active" pulse rate (60 pulses/minute) and after 10 seconds of no activity being detected it reverted to the "inactive" pulse rate (30 pulses/minute).

Signals from the kiwi transmitters were received by an ATS DCCII scanning receiver and data logger, through a three-element Yagi antenna. The data logger-receiver system was set to continuously log data from the four transmitters. For pre-specified time periods of 15 seconds, the following information was stored: year, Julian day (1-365), time (hh:mm), transmitter frequency, and pulse count (number of pulses received during each 15 second recording) (Table 2.1). At the end of each 15 second period, the system would switch to the frequency of the next transmitter and the process was repeated. Due to a short time-out period each time the data logger switched to a different frequency, there was a maximum of 56 scans per kiwi per hour. Data were collected on each night of the experiment from before sunset till after sunrise.

Kiwi were weighed by Rainbow Springs staff at intervals of between 6 and 18 days during the study. The quantity of prepared food eaten each night was also recorded, as described below.

Experimental Procedure

The experiment was run over four weeks, and was divided into two periods: pre-treatment (first 14 nights) and treatment (last 14 nights) (Table 4.1). During the pre-treatment period, all kiwi were provided with a dish of their prepared food (minced ox heart, porridge, wheat germ, cat biscuits, premix, banana) every night. This dish was placed inside the wooden feed box or shelter about two hours before night-fall. The kiwi could feed from the dish ad libitum throughout the night. During the treatment period, a new food provisioning regime was used for the two kiwi in enclosure 3. The new provisioning regime involved separating the two kiwi's usual quantity of prepared food into 30 separate portions. Each portion was put in a plastic tube (47-52 mm deep, 20 to 28 mm in diameter across the top and the bottom 10-16 mm tapered so that the bottom inside diameter was 6-15 mm). These tubes were pushed into the soil, so that the top edge of the tube was flush with or slightly lower than the ground surface, at random points within the enclosure and covered with a thin layer of soil or leaf litter. In order to find all the tubes again the next morning, it was necessary to place the tubes underneath, beside or between particular landmarks that could be recorded, but attempts were made to vary the positions as much as possible from one night to the next and to not leave any obvious visual signs of the tubes' positions. The two kiwi in enclosure 3 (*Taz* and *Te Ngahere*) are thus referred to as "treatment kiwi" (TK). The other two kiwi (*Iwa* and *Jake*) continued having their food provisioned in a single dish during the treatment period, and are referred to as "control kiwi" (CK).

Food of a known quantity (grams) was provided to the kiwi each night. The following day the food remaining in the dish or tubes was weighed, to determine how much food had been eaten by the kiwi in each enclosure.

Data Processing and Analysis

Activity data were downloaded onto a computer and imported into excel files (Table 2.1). Data were sorted into a day/time sequence for each individual. Number of pulses per 15 seconds were converted to a number of seconds active, and then multiplied by four,

Table 4.1. Design of experiment testing effect of food provisioning regime on kiwi activity. Dish or tube refers to which days each pair of kiwi was provided with prepared food in a single portion (dish) or divided into 30 portions (tubes).

	Day of experiment	Control kiwi		Treatment kiwi	
		Iwa	Jake	Taz	Te Ngahere
Pre-treatment period	1	Dish	Dish	Dish	Dish
	2	Dish	Dish	Dish	Dish
	3	Dish	Dish	Dish	Dish
	4	Dish	Dish	Dish	Dish
	5	Dish	Dish	Dish	Dish
	6	Dish	Dish	Dish	Dish
	7	Dish	Dish	Dish	Dish
	8	Dish	Dish	Dish	Dish
	9	Dish	Dish	Dish	Dish
	10	Dish	Dish	Dish	Dish
	11	Dish	Dish	Dish	Dish
	12	Dish	Dish	Dish	Dish
	13	Dish	Dish	Dish	Dish
	14	Dish	Dish	Dish	Dish
Treatment period	15	Dish	Dish	Tubes	Tubes
	16	Dish	Dish	Tubes	Tubes
	17	Dish	Dish	Tubes	Tubes
	18	Dish	Dish	Tubes	Tubes
	19	Dish	Dish	Tubes	Tubes
	20	Dish	Dish	Tubes	Tubes
	21	Dish	Dish	Tubes	Tubes
	22	Dish	Dish	Tubes	Tubes
	23	Dish	Dish	Tubes	Tubes
	24	Dish	Dish	Tubes	Tubes
	25	Dish	Dish	Tubes	Tubes
	26	Dish	Dish	Tubes	Tubes
	27	Dish	Dish	Tubes	Tubes
	28	Dish	Dish	Tubes	Tubes

giving an estimate of seconds active out of 60 for every minute in which data were recorded. Each recorded minute for each individual was then classified as active or inactive according to the system developed in chapter 2. An estimate of nightly activity each kiwi/night was reached using three steps: (1) the active minutes recorded between sunset and sunrise were summed; (2) this sum was divided by the number of minutes for which data were recorded for that individual between sunset and sunrise; and (3) the resulting proportion was multiplied by the number of minutes between sunset and sunrise on that night. Times of sunset and sunrise were supplied by the Carter Observatory, Wellington, according to longitude, latitude and date.

Activity data were analysed with a mixed model (SAS version 8) type 1 test. The dependent variable was nightly minutes of activity. The fixed independent variables were experimental group (treatment or control kiwi) and time (pre-treatment or treatment period), with their interaction being used to indicate whether the treatment influenced activity. Random independent variables were night nested within time, because each night of the study occurred either during the pre-treatment or the treatment period, and kiwi nested within experimental group, because each kiwi was either a treatment or control kiwi.

Average daily weight gains were compared among kiwi and different time periods during the study. An attempt was made to compare weight gains between times of different food provisioning regimes but a precise comparison could not made because weight data was collected on dates independent of the time-frame of the study.

The quantity of prepared food eaten was analysed with a mixed model, using the dependent variable grams of food eaten. Fixed independent variables were experimental group, time (three periods were used, defined by the times between which weight data were collected) and their interaction. This interaction effect was the indicator of whether treatment influenced the kiwi's food intake. A random independent variable was night.

4.3 Results

Effect of Treatment on Activity

Time (df = 1,25, f = 6.79, p = 0.0152) and the interaction between experimental group and time (df = 1,69, f = 36.82, $p < 0.0001$; Appendix 10) both showed significant effects on activity. Least squared mean activity showed a significant increase from the pre-treatment to treatment period in the treatment kiwi, and showed no significant change in the control kiwi (Figure 4.1).

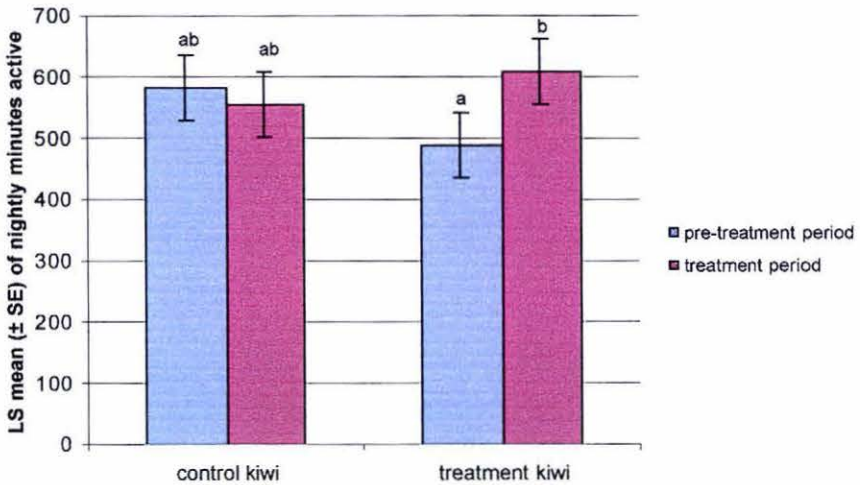

Figure 4.1. Least squared mean of nightly minutes active by control and treatment kiwi, during the pre-treatment and treatment periods. Bars with different letters above them have significantly different LS means.

Weight Gains and Food Intake

All kiwi continued to gain weight throughout the study. The rate of weight-gain fluctuated for all kiwi from the 14 March through till the kiwi's release (Figure 4.2a). Both treatment kiwi showed a lower rate of weight gain during the treatment period than during other periods. Jake (CK) showed large fluctuations in rate of weight gain.

Both treatment and control kiwi showed their lowest intake of prepared food during the treatment period (Figure 4.2b). There was no significant effect of the experimental group and time interaction on food intake ($df = 2,29, f = 1.97, p = 0.1579$).

Mean Activity When Food Distributed

Least squared mean (± SE) of nightly minutes active by treatment kiwi during the treatment period was 610 (± 52) minutes (10.17 hours).

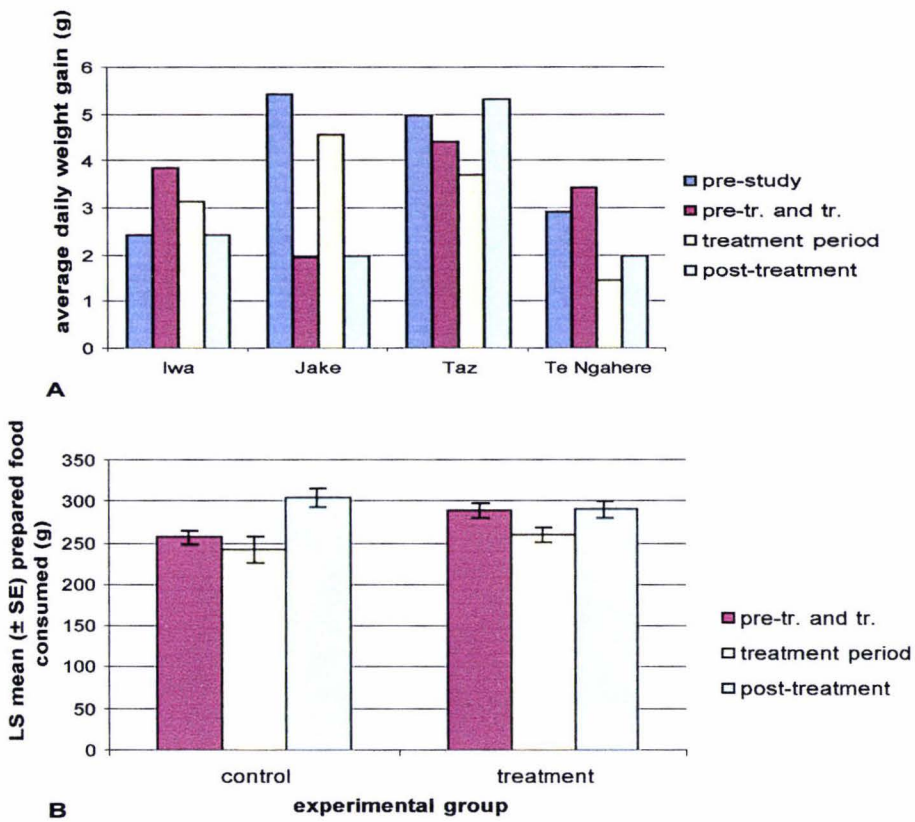

Figure 4.2 (a) Average daily weight gain of each kiwi, during four consecutive time periods before, during and after this study. (b) Least squared mean of prepared food consumed each night by treatment and control kiwi, during three consecutive time periods during and after this study. Note: grams of food consumed refers to the total amount eaten by two kiwi.
Pre-study: 14-25 March;
Pre-tr. and tr: 25 March-11 April (*Iwa* and *Jake*) or 25 March-12 April (*Taz* and *Te Ngahere*). This included all of the pre-treatment activity monitoring period plus the first two (*Iwa* and *Jake*) or three (*Taz* and *Te Ngahere*) nights of the treatment period;
Treatment period: 11-25 April, which included all of the treatment period except the first two nights plus the first two nights after the treatment period, for *Iwa* and *Jake*; and 12-23 April, which included all of the treatment period except the first three nights, for *Taz* and *Te Ngahere*;
Post-treatment: 25 April-4 May (day of release) for *Iwa* and *Jake*; and 23-29 April (day of release) for *Taz* and *Te Ngahere*.

4.4 Discussion

The way that food was provisioned appeared to have an effect on kiwi activity. As was predicted, activity was higher when food was distributed around the enclosure than when food was provided in one portion.

It may have been expected that the increase in activity when the kiwi's food was dispersed, would result in a lower rate of weight gain. However, while the treatment kiwi showed lower rates of weight gain during the treatment period than they did at other times, it was not possible to establish a causative link between this lower weight gain and the treatment, because all four kiwi fluctuated in their weight-gain rates.

If the scattered distribution of food resulted in an increase in activity, it is likely that the extra activity times were spent looking for food. A possible side-effect of this could have been that kiwi found more naturally occurring food items. If this were the case, it may be expected that intake of prepared food would decrease. However no reduction in intake of prepared food (when food was dispersed), above that occurring randomly, was detected.

The increase in activity seen when food was distributed in many small portions provides tentative support for the hypothesis that kiwi activity increase after release into the wild was due to their need to spend more time foraging in order to meet their energy needs. However, due to the small sample size in the present study, it is impossible to confirm that the activity increase seen was not due to other factors or a result of random variation. Moreover, other hypotheses for an increase in activity after release have not been ruled out. For example, the post-release activity increase may also reflect a change in behaviour related to the relocation process and an unfamiliar habitat. The effect of an unfamiliar habitat on activity could also be tested in a captive setting, by moving individuals from one enclosure to another and monitoring their activity before and after this shift.

The utility of pre-release foraging training for captive-reared kiwi warrants further investigation. An increased level of activity prior to release may be beneficial in itself if it

provides appropriate physical conditioning for the higher levels of activity that are likely to be adopted after release (e.g. Bernal & Packard, 1997). The mean nightly activity of the kiwi in this study when food was dispersed was 10.17 hours, which is similar to the 10.02 mean hours of activity seen in sub-adult kiwi after release into Tongariro and Karioi Rahui Forests (chapter 3), thus this food provisioning regime may have been sufficient to stimulate activity levels appropriate for kiwi soon to be released. However, determining whether there are other benefits of this type of feeding regime, such as an increasing intake of naturally occurring prey, requires further research and an increased sample size.

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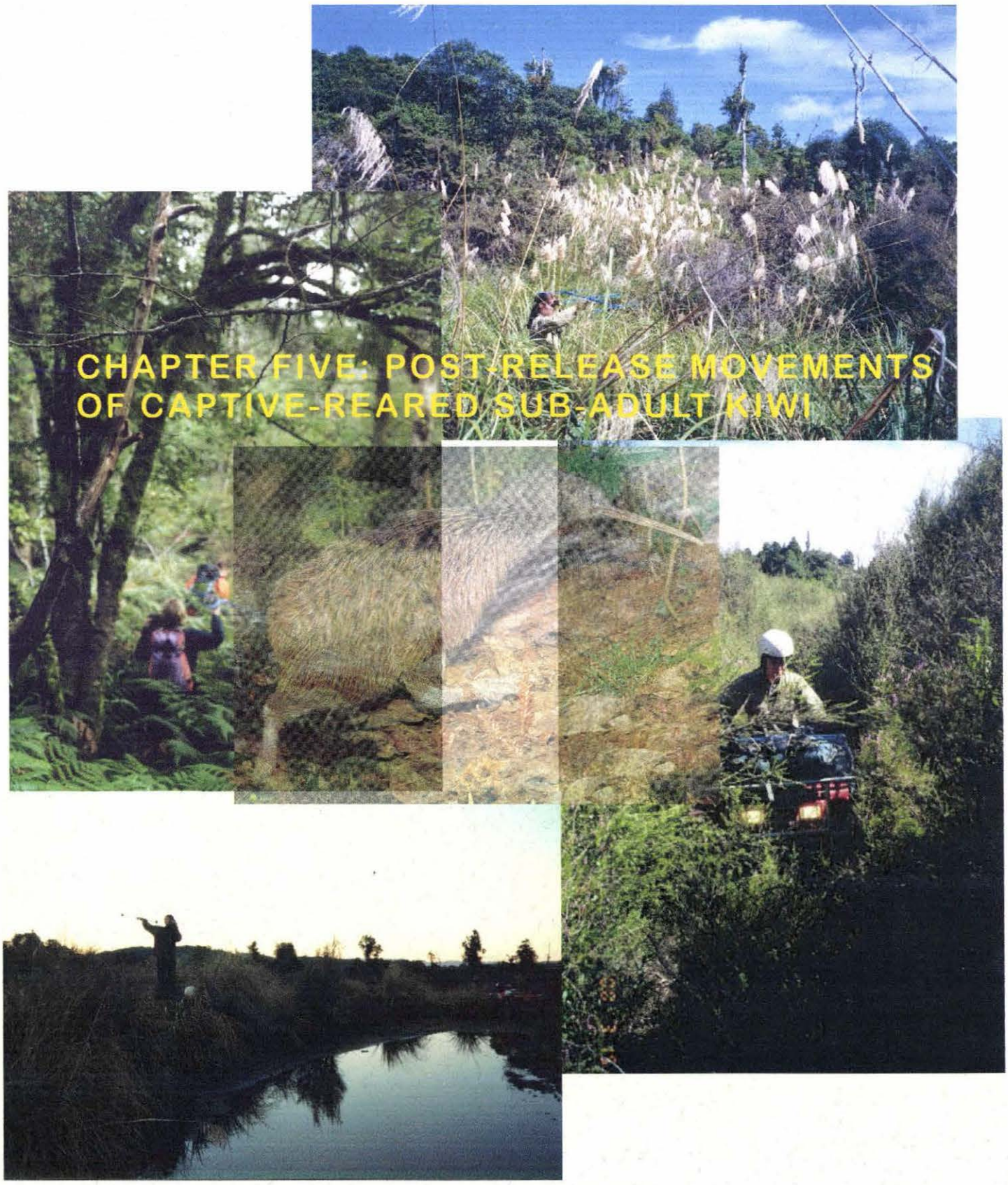

CHAPTER FIVE: POST-RELEASE MOVEMENTS OF CAPTIVE-REARED SUB-ADULT KIWI

5. Post-release movements of captive-reared sub-adult kiwi

5.1 Introduction

When animal relocation is used to maintain or increase the viability of a population, it is useful to know how far individuals tend to move from their release site. The distance and rate of individuals' movement may have consequences for their survival (e.g. Metzgar, 1967; Ambrose, 1972; Woolard & Harris, 1990; Altwegg et al., 2000), their chances of breeding (Johnson & Gaines, 1987; Boyce & Boyce, 1988; Forero et al., 2002), the level of genetic structuring within the population (Anthony & Blumstein, 2000) and the area of land that will need to be managed to protect the population (Goss-Custard & Sutherland, 1997; McLennan, 1998b). The ability to predict the extent of post-release movement, and a knowledge of the factors that can govern it, can therefore help with the selection of optimum release sites and times as well as the planning of the resource allocation necessary to protect a population.

Animal use of space tends to differ between adults and sub-adults/juveniles. In many species adults tend to stay on or return to the same home range each year (e.g. Greenwood, 1980; Greenwood & Harvey, 1982). The juveniles/sub-adults of these species exhibit either natal philopatry or natal dispersal between independence and first breeding. Natal philopatry is remaining on the parent's home range past the age of independence or returning to breed on the parent's home range (Waser & Jones, 1983; Reed & Oring, 1993; Thibault, 1993). Philopatry has also been referred to in terms of a tendency to stay near a release site (Massot & Clobert, 2000). Natal dispersal is defined as "the movement the animal makes from its point of origin [birth or hatch] to the place where it reproduces or would have reproduced if it had survived and found a mate" (Howard, 1960; cited in Greenwood, 1980). In many species, one sex is the predominant natal disperser while the other is philopatric (e.g. Pusey, 1987; Rohwer & Anderson, 1988; Wolff, 1993; Wolff & Plissner, 1998; Massot & Clobert, 2000). Amongst bird species, natal dispersal has often been found to be more common in females than males

(Greenwood, 1980; Greenwood & Harvey, 1982; Strickland, 1991; Giesen & Braun, 1993), with 49-59% of the avian species in which dispersal has been studied showing female-biased dispersal, 11-20% showing male-biased dispersal and 16-21% showing no sex-bias (Clarke et al., 1997).

Post-release dispersal of relocated individuals (both adults and sub-adults/juveniles) has also been reported in a range of species (Boyd, 1993; Graeme & Graeme, 1994; Soderquist, 1994; Clarke & Schedvin, 1997; Berry, 1998; Carrie et al., 1999; Mosillo et al., 1999; Pierre, 1999; Cowan, 2001). Differences between movement distances of translocated individuals and control groups of captured, non-translocated individuals have indicated a direct link between the act of translocation and subsequent dispersal (Mosillo et al., 1999).

Presence of established conspecifics may influence movement and dispersal behaviour of individuals (Stamps, 1988; Muller et al., 1997; Stewart et al., 1997; Zuri et al., 1997). An example of conspecific attraction was seen in captive-reared brush-tailed phasgocale (*Phasgocale tapoatafa*) when male dispersal distances were significantly lower when released into areas where females had occupied a home range for at least two weeks (thereby leaving their scent) than when they were released at the same time as females (Soderquist, 1994). However, negative consequences of releasing individuals where conspecifics are already established have been seen in Okarito brown kiwi, where several released sub-adults have been killed by resident kiwi (Colbourne, 1998). McLennan (1998a) advised that captive-reared kiwi be released before they develop dispersal and territorial behaviour at 30-40 weeks of age, to increase their chances of being tolerated by adults. The tolerance of resident kiwi towards newly released kiwi may vary throughout the year in response to seasonal changes in plasma testosterone levels (Potter & Cockrem, 1992). Therefore, the presence of resident kiwi at the release site, and time of year are additional factors potentially influencing dispersal.

Most kiwi populations have a territorial structure with adult pairs occupying relatively stable year-round home ranges (Colbourne & Kleinpaste, 1983; McLennan et al., 1987;

Jolly, 1990a & b; McLennan, 1990a, b, & 1996; Taborsky & Taborsky, 1992). Dispersal of juvenile/subadult kiwi from their natal area has frequently been reported when young kiwi have been radiotracked for several weeks (McLennan, 1996; Miller, 1996; Gibbs, 2000; Department of Conservation, Whakapapa, unpublished data), but quantified accounts of the distances and rates with which this dispersal occurs have not been documented. Prior to Operation Nest Egg, few relocations of kiwi on the mainland have been documented, and when they have been (e.g. Macmillan, 1990) little information on post-release movements could be gained as kiwi were not fitted with transmitters. Adult male little spotted kiwi translocated from Kapiti Island to Tiritiri Matangi Island tended to disperse widely from their release site in their first few days, even though they were released with their former pair and each pair was released in a different part of the island (Boyd, 1993).

The aim of this chapter is to provide a quantitative account of movement of sub-adult North Island brown kiwi from a release site within a large (>15 000 ha) forest tract with no barriers to movement. As dispersal in kiwi has been seen both in juveniles from a nest-site and in adults after relocation, any dispersal shown by captive-reared sub-adult kiwi after relocation and release could represent an innate urge to disperse from a natal site, and/or be associated with the relocation. If post-release dispersal of kiwi is a representation of natal dispersal, it may be age- and possibly sex-dependent. Dispersal may also depend on what season and where the release takes place. Therefore, relationships between dispersal and sex, age, season, and area of release are examined. The consequences of dispersal in kiwi are also investigated by looking for a relationship between dispersal and likelihood of being preyed on.

5.2 Methods

Twenty-one sub-adult kiwi were released into Tongariro Forest Conservation Area (TFCA) between the 19 January 1997 and the 6 September 2000 (13 in East TFCA, eight in West TFCA). Ten sub-adult kiwi were released into the Karioi Rahui between the 1

May 2000 and the 27 April 2001. All kiwi had been fitted with Sirtrack™ radiotransmitters, weighing 10 g, 15 g or 20 g depending on the size of the kiwi, prior to release, using the standard attachment procedure (Miles and McLennan, 1998; Robertson and Colbourne, 2001). Data on their daytime locations have been collected since their release.

Kiwi were tracked from the ground using a Telonics TR4 receiver and a Yagi 3-element directional antenna. Initially it was attempted to locate each kiwi once a week, but the frequency of locations fluctuated over the course of the study depending on how many kiwi there were to locate and how readily a signal could be found for each bird. Individuals' locations were determined either (a) from intersections of a number of directional signal bearings taken from known points, or (b) by walking in the direction of the strongest signal until between zero and about 20 m from the kiwi's location. Throughout most of the study, individuals were located at least once a month using the second of these two methods. Locations were recorded and stored as eight-digit grid references (four northings and four eastings). An estimate of the maximum error (in metres) of each location was made, depending on the method used to determine the location and other characteristics of the signals and site (e.g. Macdonald & Amlaner, 1980).

When a signal could not be found for an individual for a number of weeks, searches from the air were used to find their approximate location. This was done using a Telonics TR2 receiver or an ATS DCCII scanning receiver, attached to antennas mounted on the outside of a Cessna fixed-wing aeroplane. The aircraft flew over the region until a signal was received. The approximate location was then determined by repeated flyovers from different directions with the "gain" on the receiver being progressively reduced.

Data Analysis

For each recorded location, the distance between it and the kiwi's release site was calculated. This distance was recorded along with the location's error estimate and the number of days since release. The distance from release site of the most precise location

for every four-week post-release interval (with the first four-week post-release interval being days 1-28 etc, where day 1 is the day after release) was then identified.

Factors potentially influencing (or in the case of depredation, potentially being influenced by) the distance moved were analysed with a mixed model (SAS, version 8), type 3 test. The dependent variable was the natural log of distance from release site. Categorical independent variables were sex, release season (spring, summer, autumn, winter), release area (East TFCA, West TFCA, or Karioi Rahui), month, and fate, and continuous independent variables were time since release and age (in days) at release. Tests were also conducted for seven 2-way and two 3-way interaction effects. Random variables were year nested within area, and kiwi (each individual) nested within area*sex*season*fate. Sexes were assigned to kiwi based on bill length as a function of age, or by autopsy. As sexes could not be assigned with confidence to five kiwi, data from these kiwi (most of whom were only monitored for a short time) were not included in the model. Year and month variables refer to the time of each observation, not the time of the individual's release. The fate variable contained two levels: preyed on and not preyed on. Individuals were assigned as preyed on if they were found dead over the course of the study and their remains had signs that were consistent with having been killed by a predator. Fate was only tested for in an interaction with time since release, because of the inherent tendency for individuals that died to be monitored for a shorter time, and the apparent relationship between time since release and distance.

Analysis was restricted to the first 96 weeks (i.e. the 93-96 week interval) since release, to allow representation of all levels of season, sex, and area variables, at each value of time since release. Inherent increases in distance from release site over time with random movement were accounted for by using the covariance parameter SP (POW), which assumes that consecutive locations for an individual will be strongly correlated. The time since release variable was analysed using a polynomial, which tested the linear, quadratic and cubic trends in distance, over time since release. Least significant terms were removed progressively from the model and Akaike's Information Criteria (AIC) fit statistic (Burnham & Anderson, 1998) was used to assess the fit of each model.

5.3 Results

Twentynine of the 31 kiwi were monitored for periods ranging from nine weeks to more than two years. Monitoring is ongoing for 15 individuals (at August 2002), while the other 14 kiwi are no longer monitored due to deaths, or transmitters failing or falling off.

Movement Patterns of Individual Kiwi

Individual kiwi varied considerably in the distance and timing of their post-release movements (Figure 5.1a). For example, Te Aukaha and Koha were between 1 and 1.5 km from their release site more than three years after release, while Tiakariti was more than 7 km from his release site after only 28 weeks. Periods of major rapid dispersal occurred as soon as six weeks post-release in one individual (Tua), while one kiwi (Speedy) showed rapid dispersal about 98 weeks (almost two years) after release. The furthest distance any kiwi was known to travel from its release site was close to 12 km (Komutu).

Twentyone kiwi were still being monitored 36 weeks after release and all were eventually located more than 1000 m from their release site (Figure 5.1b). Of the eight kiwi not monitored for 36 weeks or more after release, only four were still within 1000 m of their release site when last located (Figure 5.1c).

Factors Correlated with Dispersal

Data from 24 kiwi were able to be used in the model (Appendix 11). The initial model (Table 5.1a) had an AIC of 888.5, but this improved to 738.3 after the majority of non-significant terms were removed (Table 5.1b). Distance of kiwi from their release site differed among months and in both the linear and quadratic components of time since release. There were significant differences among release areas in the linear component of distance from release site over time and a close to significant effect in its quadratic component. There were also significant differences between kiwi that were and were not eventually preyed on, in the linear component of distance from release site over time and a close to significant effect in its quadratic component. There was a significant effect of the interactions between month and area, and between month, sex and area (Table 5.1b).

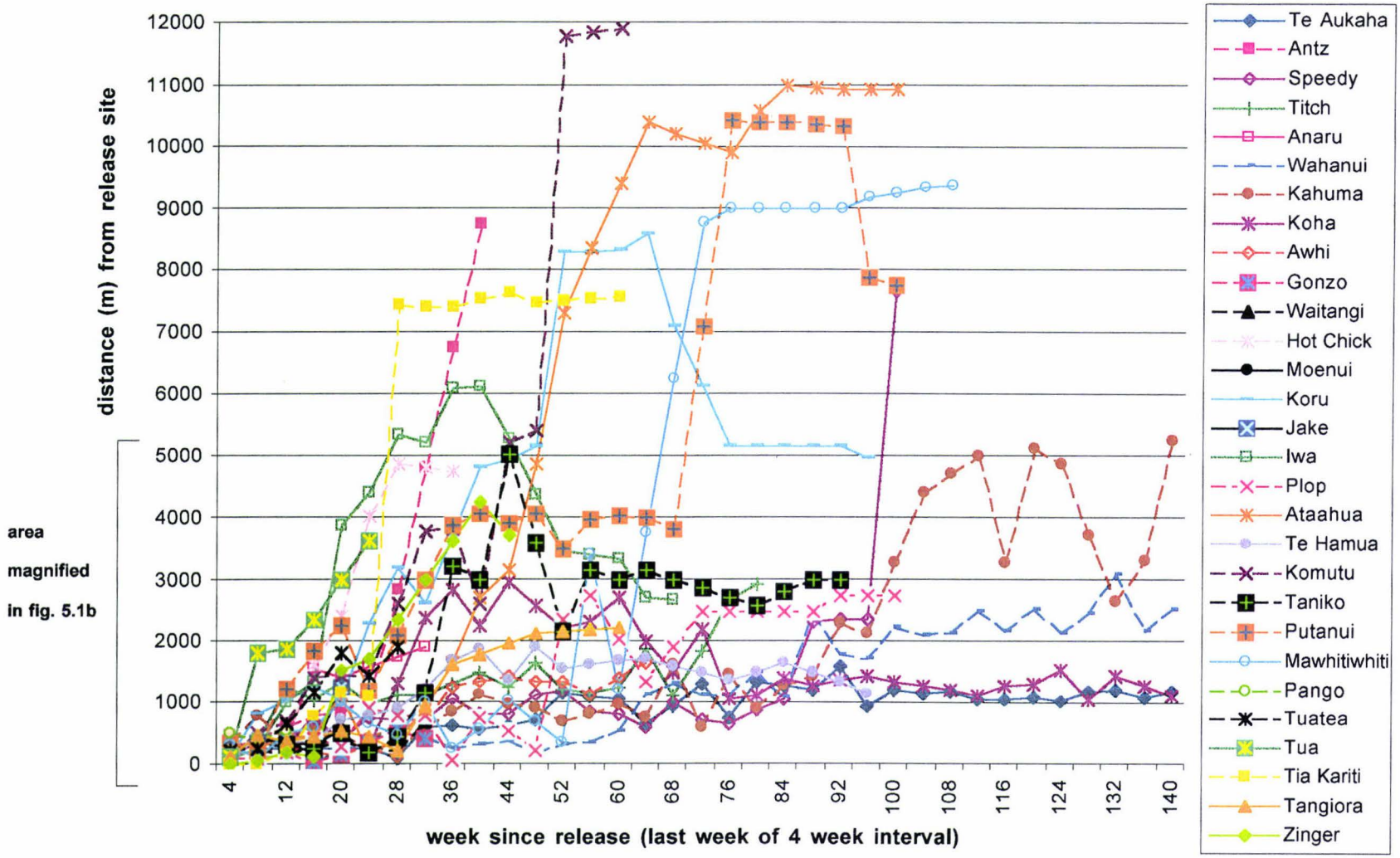

Figure 5.1(a) Distance of each kiwi from their release site over time since their release.

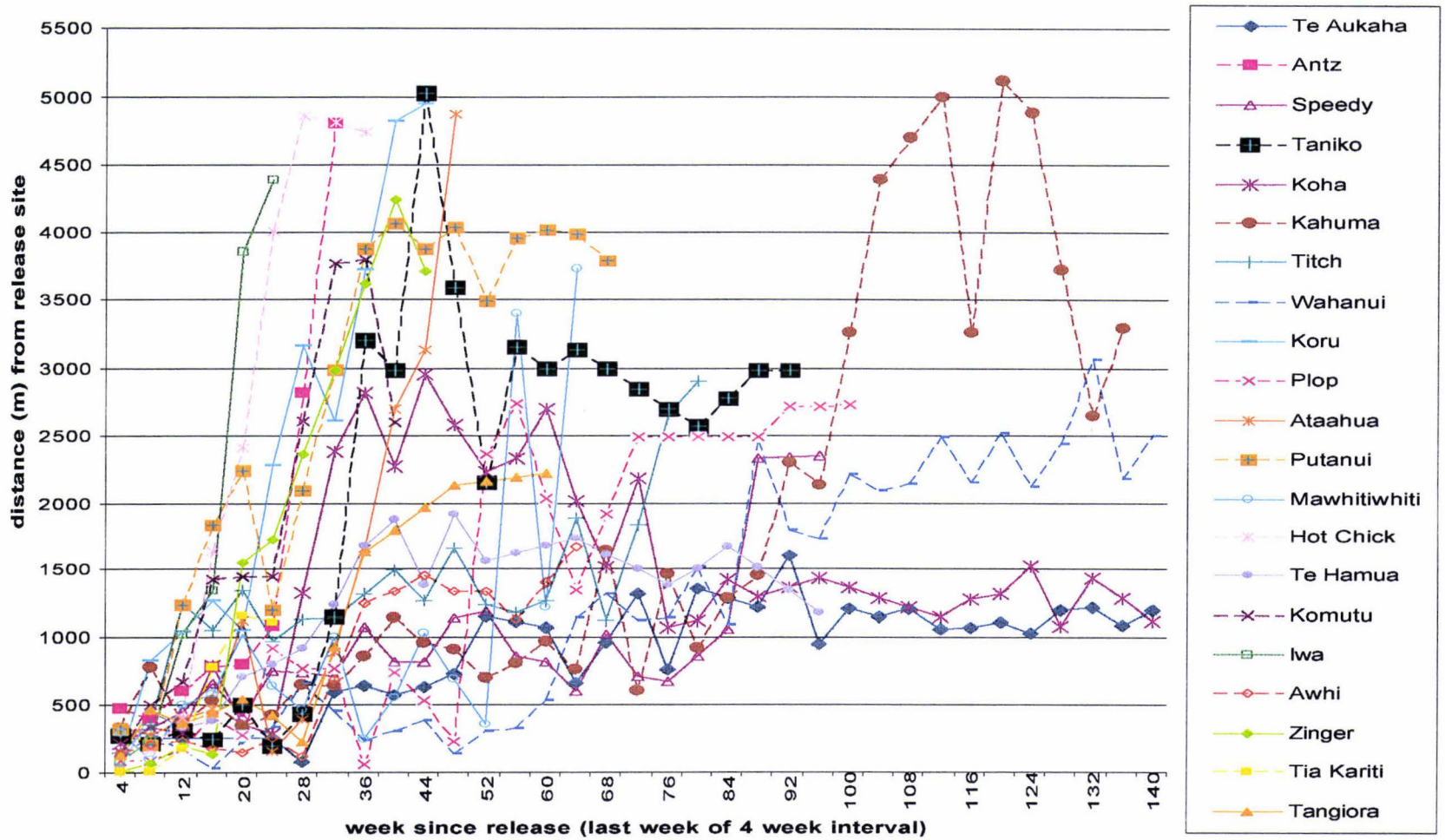

Figure 5.1(b) Distance from release site over time since release, for each kiwi still being monitored 36 weeks after release. Note that data are not shown for individuals once they had moved beyond 5500 m. These data are also shown in Figure 5.1(a).

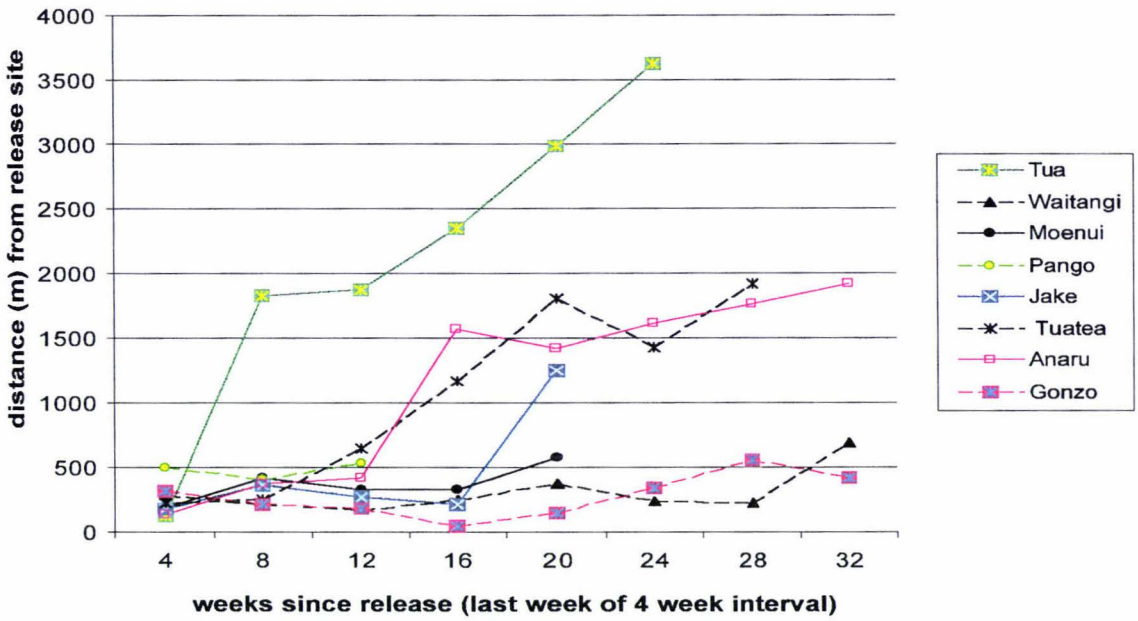

Figure 5.1(c) Distance from release site over time since release, of kiwi not monitored beyond 32 weeks post-release. These data are also shown in Figure 5.1(a).

Distance from release site increased after release in all release areas but in East TFCA this increase began to level off sooner than in the other two areas. From week 28 till week 76 East TFCA kiwi were closer to their release site than West TFCA kiwi. East TFCA kiwi were closer than Karioi Rahui kiwi to their release sites from week 60 till week 84 (least square means were non-estimable for Karioi Rahui kiwi from week 20 to week 56) (Figure 5.2).

West TFCA kiwi dispersed more than East TFCA kiwi from June till October, and Karioi Rahui kiwi dispersed more than East TFCA kiwi from July till November. Karioi Rahui kiwi had highly variable dispersal through the year with the greatest distances in the spring months and the smallest distances in April. West TFCA kiwi had less variability with their only significant pairwise comparison being greater distances in June than in April, while East TFCA kiwi had no significant differences among months (Figure 5.3).

Table 5.1. Likelihood statistics of factors relating to kiwi distance from release site. (a) Initial model (AIC = 888.5); (b) after stepwise removal of least significant terms (AIC = 738.3). df: degrees of freedom; f: f statistic; p: p value. * indicates p value < 0.05

A

Effect	df	f	p
Sex	1,11	0.84	0.3780
Release season	3,11	1.82	0.2014
Release area	2,7	0.90	0.4479
Release age	1,221	3.09	0.0802
Month	11,221	1.53	0.1215
Time since release (linear)	1,221	1.34	0.2476
Time since release (quadratic)	1,221	7.09	0.0083*
Time since release (cubic)	1,221	0.31	0.5794
Month*sex	11,221	1.28	0.2374
Time since release (linear)*sex	1,221	0.18	0.6752
Time since release (quadratic)*sex	1,221	1.87	0.1724
Time since release (cubic)*sex	1,221	0.30	0.5845
Time since release(linear)*fate	1,221	1.94	0.1649
Time since release(quadratic)*fate	1,221	0.84	0.3598
Time since release(cubic)*fate	1,221	0.10	0.7529
Month*Release season	33,221	0.69	0.8951
Time since release(linear)*Release season	3,221	1.33	0.2669
Time since release(quadratic)*Release season	3,221	1.87	0.1349
Month*Release area	22,221	1.37	0.1313
Time since release(linear)*Release area	2,221	1.79	0.1686
Time since release(quadratic)*Release area	2,221	2.54	0.0813
Time since release(cubic)*Release area	2,221	0.09	0.9137
Month*Release area*sex	21,221	1.74	0.0269*
Release area*sex*fate	3,11	0.44	0.7318

B

Effect	df	f	p
Month	11,265	2.40	0.0076*
Time since release (linear)	1,265	18.77	<0.0001*
Time since release (quadratic)	1,265	18.34	<0.0001*
Time since release (linear)*sex	1,265	1.49	0.2229
Time since release (quadratic)*sex	1,265	2.98	0.0857
Time since release(linear)*fate	1,265	4.77	0.0299*
Time since release(quadratic)*fate	1,265	3.80	0.0524
Month*Release area	24,265	1.99	0.0047*
Time since release(linear)*Release area	2,265	10.32	<0.0001*
Time since release(quadratic)*Release area	2,265	2.86	0.0592
Month*Release area*sex	35,265	1.72	0.0094*

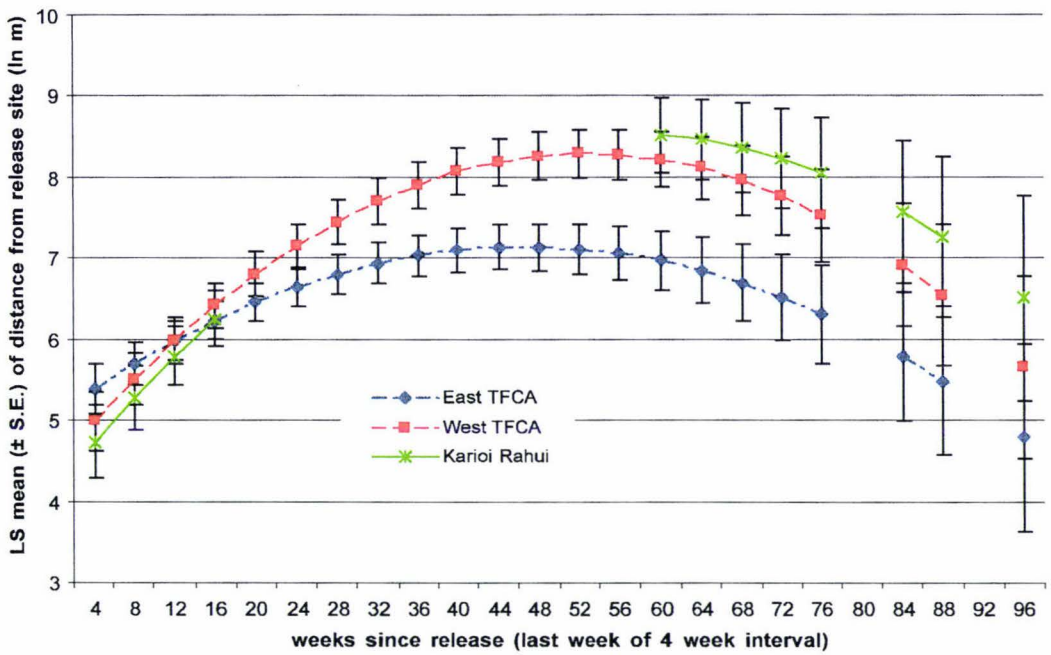

Figure 5.2. Least squared means of kiwi distance from release site over time since release, in the three release areas.

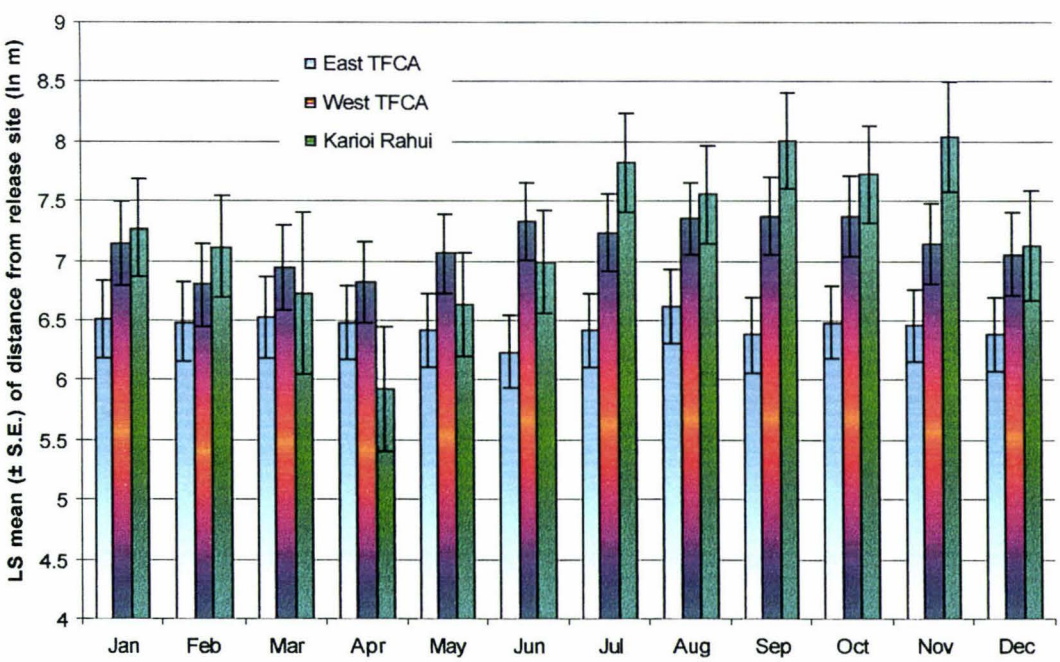

Figure 5.3. Least squared means of distance from release site during each month of the year in the three release areas.

The differing dispersal among areas during the late winter/spring months was more attributable to differences among different areas' males than to differences among different areas' females (Figure 5.4). Karioi Rahui males were further from their release sites than East TFCA males in June, July, September, October and November; and West TFCA males were further away than East TFCA males in June and October. Although the pattern of East TFCA having lower winter/spring dispersal than the other areas was still apparent when only females were considered, there were fewer differences than when only males were considered. West TFCA females were further from their release sites than East TFCA females in only June and September, and Karioi Rahui females were further away than East TFCA females in September and November. There were only two monthly differences between males and females within areas: in June in East TFCA and in May in the Karioi Rahui, with females being further from their release sites than males in both cases.

Kiwi that were later known to be preyed on tended to be further from their release sites than kiwi that were not known to be subsequently preyed on. This difference was significant for the period from 16 till 24 weeks after release (Figure 5.5).

Median Distances Moved from Release Sites

Median distances from release sites one year after release (about when least square mean values for distance stopped increasing) were 1187 m for East TFCA kiwi (n = 7) and 3459 m for West TFCA and Karioi Rahui kiwi (n = 11).

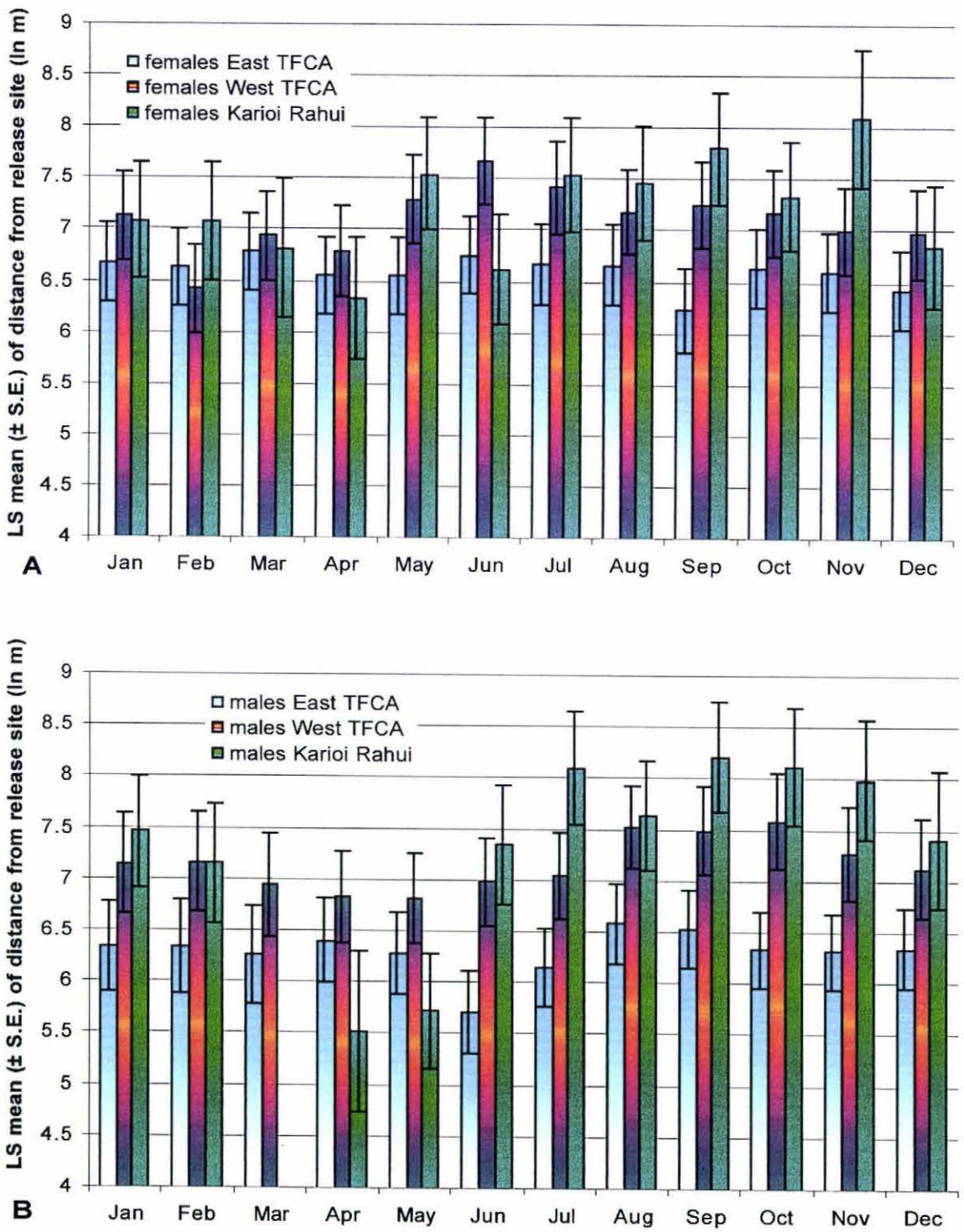

Figure 5.4. Least squared means of (a) female and (b) male distance from release site during each month of the year, in the three different release areas.

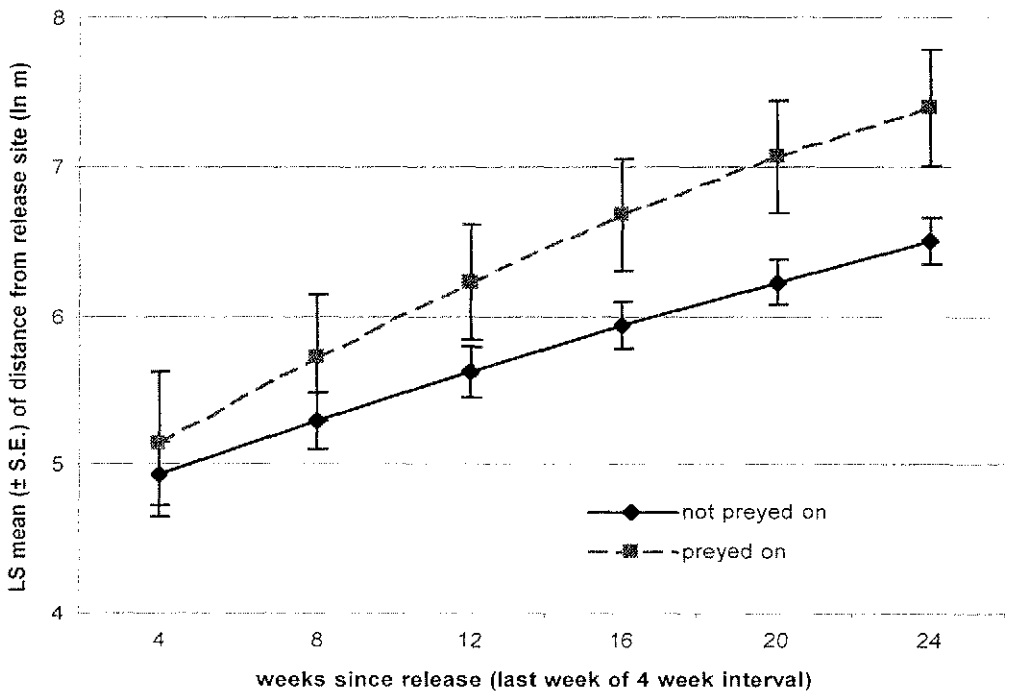

Figure 5.5 Least squared means of distance from release site over time since release of kiwi that were eventually preyed on (n = 4) and those that were not preyed on (n = 20 up till week 20, n = 19 up till week 24). Only the first 24 weeks are shown because least square means were non-estimable for weeks 28-48 and after week 48 sample size of preyed on kiwi was n = 1.

5.4 Discussion

All kiwi monitored for 36 weeks or more after release in the present study moved at least 1 km from their release site. Kiwi released into West Tongariro Forest and the Karioi Rahui tended to move greater distances than those released into East Tongariro Forest, and this difference was most apparent during the winter and spring months. There were more monthly differences among areas in males than in females. There was a tendency for greater dispersal in kiwi that were later known to be preyed on than in those not preyed on.

Philopatry to a release site has been defined as moving a smaller distance than the population mean home range diameter (Massot & Clobert, 2000). The mean home range

diameter of adult Tongariro Forest kiwi has been calculated to be about 800 m (from Miles, 1995). Therefore none of the 21 kiwi still being monitored 36 weeks after release were philopatric to their release site according to this definition (assuming home range sizes of Karioi Rahui kiwi are similar to those of Tongariro Forest kiwi). This suggests that dispersal from a release site is the norm in relocated sub-adult North Island brown kiwi of both sexes. This does not necessarily suggest that dispersal from a natal site is also the norm in all juvenile kiwi. Factors that were absent in the current study, such as any influence that parents have on their offspring (e.g. Liberg & von Schantz, 1985), might affect dispersal patterns of young kiwi growing up in the wild. However, since relocation and release is becoming a common kiwi management technique, understanding the factors that influence dispersal in relocated kiwi is important regardless of whether it is informative about factors influencing kiwi dispersal from their natal site.

Two variables are often referred to in studies of dispersal: (1) whether individuals are philopatric or disperse; and (2) dispersal distance (of individuals that do disperse) (Clarke et al., 1997). It has been pointed out that the same factors do not necessarily govern both variables (Liberg & von Schantz, 1985). Although almost all kiwi in the present study showed dispersal rather than philopatry, dispersal distances were variable among individuals and this variation was correlated with a number of factors. Kiwi released in the Karioi Rahui and on the western side of Tongariro Forest tended to disperse further than those released in East Tongariro Forest. Determining whether this differential dispersal among areas is likely to be due to habitat factors such as availability of food or suitable shelter, would require detailed analysis of specific habitat variables at consistent distances from each release site. This is outside the scope of the present study, however personal observation and a review of literature (Scientific Advisory Committee, 1980; Atkinson, 1981; McSweeney & Smith, 1984; New Zealand Forest Service, 1986) describing the habitat within each area suggests that the two Tongariro Forest areas are far more similar to each other in terms of geology, topography, altitude and vegetation composition than either is to the Karioi Rahui (Chapter 1 contains general descriptions of the habitat in the three areas and specific descriptions of release sites).

The most likely explanation for differences in dispersal patterns between areas is the distribution of resident kiwi, with dispersal distances being smaller when kiwi were already present. Resident kiwi were known to be within 1 km of all release sites in eastern Tongariro Forest whereas release sites in western Tongariro and the Karioi Rahui had no known resident kiwi in the vicinity (Figures 1.3, 1.4; pers. obs.; pers. comm. Ross Martin; pers. comm. John Luff). Conspecific attraction is a phenomenon that has been noted in a variety of species (e.g. Stamps, 1988; Muller et al., 1997; Anthony & Blumstein, 2000). Many of the far dispersing kiwi in this study moved towards localities known to already contain kiwi. Four of the West Tongariro released kiwi have since been found on the eastern side of Tongariro forest and three of the Karioi Rahui kiwi have been located - and two appear to have settled - around the upper tree-line on the southern side of Mt Ruapehu (unpublished data, Whakapapa and Ohakune Department of Conservation; Specht, 2002) - one of the localities in the Karioi Rahui with resident kiwi prior to the ONE kiwi being released (Oates, 2001). These observations combined with the higher dispersal seen in individuals released into habitat previously not containing kiwi, suggest that conspecific attraction occurs in kiwi. Different densities of conspecifics might influence dispersal tendencies in different ways however (Stamps, 1991), therefore if conspecific attraction does occur in low to moderate density kiwi populations such as in Tongariro Forest, it should not necessarily be expected that it will have a similar influence in higher density kiwi populations.

The presence of conspecifics might act as a cue to the presence of suitable habitat for naïve individuals (Muller et al., 1997) or individuals may be attracted to the residents themselves as prospective partners (e.g. Ramsay et al., 1999). Dispersal of sub-adult kiwi released into areas without resident kiwi began to increase in June, which roughly coincides with the first breeding period in Tongariro Forest kiwi (estimated from unpublished data on times of first eggs hatching of monitored Tongariro Forest kiwi). This suggests that motivation to find a mate led to the increase in movement. The more apparent seasonal difference among areas in males than in females could also suggest that males are more active in seeking out mates than females. There was no evidence suggesting that aggression from resident kiwi during the breeding season, when male

testosterone levels rise (Potter & Cockrem, 1992), led to increased dispersal, as the only area with release sites already containing resident kiwi showed no monthly variation in dispersal.

McLennan, (1998a) stated that kiwi develop dispersal behaviour at 30-40 weeks of age. In the present study kiwi were released at ages ranging from 16 to 75 weeks and no effect of age on their dispersal was detected. It is possible that age is less of a predictor of when dispersal will begin in captive-reared released kiwi than in wild-reared kiwi, or that any effect of age was masked by other factors in these kiwi due to some confounding between age, season and area variables (Chapter 1).

Kiwi that were later preyed on appeared to be faster dispersers than kiwi that were not preyed on. Faster dispersing individuals probably have less time to become familiar with any particular site that they inhabit. Lack of site familiarity has been shown to increase predation risk in some animals and suggested explanations for this are that transient individuals are more active and therefore more exposed, or residents may become aware of danger more quickly, or residents are more familiar with escape routes (e.g. Metzgar, 1967; Ambrose, 1972). Stamps (1995) noted that individuals may learn site-specific serial motor programmes that enhance their ability to move rapidly, safely, and efficiently around obstacles and barriers in familiar areas. Colbourne & Kleinpaste (1983) commented that kiwi they tried to catch in Waitangi State Forest seemed to know exactly where to go at a fast pace without crashing into obstacles, and usually ran straight to the nearest thick cover. Thus the lack of familiarity with the immediate environment and its escape routes could have contributed to an increased risk of predation for dispersing kiwi. In addition, far dispersers increase their chance of reaching human modified habitat where predators such as ferrets are more common than in forests (Lavers & Clapperton, 1990). However, there is also the possibility that characteristics that make kiwi disperse also make kiwi prone to predation, but that dispersal does not cause predation risk.

Reducing dispersal in released kiwi is likely to be beneficial for two reasons. Firstly, analysis of the present data suggests that more rapid dispersal heightens predation risk.

Secondly, in the absence of evidence to the contrary, it is assumed that direction of kiwi movements are random and kiwi simply decide whether to stay where they are or shift. Therefore, if kiwi disperse very long distances after being released into a habitat containing a localised kiwi population within part of that habitat, their chances of meeting up with another kiwi and breeding will be fairly low. Similarly, when a number of kiwi are released into a habitat not previously containing kiwi, and most of them disperse a long way in random directions, their chances of meeting up with each other will be reduced. Where kiwi are released to supplement a population, choosing release sites adjacent to existing territories may be one way to lower levels of dispersal. Reducing dispersal from a release site when reintroducing kiwi to an isolated patch of habitat may be more difficult and alternative management techniques may need to be used.

Quantifying the distances moved of sub-adult kiwi from a release site and relating these distances to a number of variables, has allowed some insight into what factors influence kiwi dispersal. Almost all kiwi showed dispersal from their release site. Kiwi released at sites lacking resident kiwi showed more dispersal than those released into an area with several resident kiwi near their release sites. It is suggested that the different dispersal tendencies among areas are a result of conspecific attraction. Kiwi that were later preyed on showed more dispersal than kiwi not preyed on, possibly due to increasing dispersal leading to lower site familiarity or a greater likelihood of encountering habitat edges that harbour a higher predator density. Implications for management are considered in the next chapter.

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CHAPTER SIX: IMPLICATIONS AND SUMMARY

6. Implications and Summary

6.1 Introduction

The aim of this thesis was to identify factors influencing activity patterns and dispersal in captive-reared sub-adult North Island brown kiwi released into the wild, and how these influence survivorship and vigour. Thirty-one sub-adult kiwi were studied either before, after, or both before and after their release from captivity into the wild. Activity levels of individual kiwi were compared before and after their release in order to investigate their behavioural response to the relocation and release. The influence of different food provisioning regimes on the activity of captive kiwi was examined. Distances moved from release sites over time since release were quantified and compared among kiwi released in different areas, at different times, at different ages, and between males and females.

This chapter includes: (1) an investigation of post-release weight changes and their relationships with activity changes and distance moved after release; (2) a summary of the main findings of this thesis; (3) suggestions for further research that might produce more definitive findings to some of the questions addressed in this thesis; and (4) suggestions of management regimes that may enhance kiwi survival and recruitment.

6.2 Post-release Weight Changes and their Relationship to Activity and Distance Moved

All kiwi were weighed at Rainbow Springs prior to relocation, on the day of or one or two days before release, using digital scales that weigh to the nearest gram. After release kiwi were weighed using pesola spring balance scales that weigh to the nearest 5 g (weight data are presented in Appendix 12). Pre-release weights were therefore rounded to the nearest multiple of 5 g to make the two methods comparable. Kiwi were first weighed in the wild between two weeks and one month after release. A post-release

average daily weight change (up until the time of their first post-release weighing) was calculated for the seven individuals monitored in the activity studies. After the first post-release weight, kiwi were weighed at intervals ranging from one to four months. A weight change up until the second, third, and fourth months in the wild was calculated for each kiwi that was weighed in its second, third or fourth month after release.

All of the seven kiwi monitored before and after release showed increases in their nightly activity level after release and the increase was significant for six of these. An index of activity change for each of these seven kiwi was calculated by subtracting their mean pre-release minutes of activity from their mean post-release minutes of activity (excluding night 1 and any night after the kiwi's first post-release weighing).

The index of activity change was regressed against the mean post-release daily weight change for each individual. There was a positive (close to significant: $p = 0.0535$) correlation between activity increase and weight loss after release (Figure 6.1). Although the sample size is small, it is possible that this indicates a link between activity increase and weight decrease.

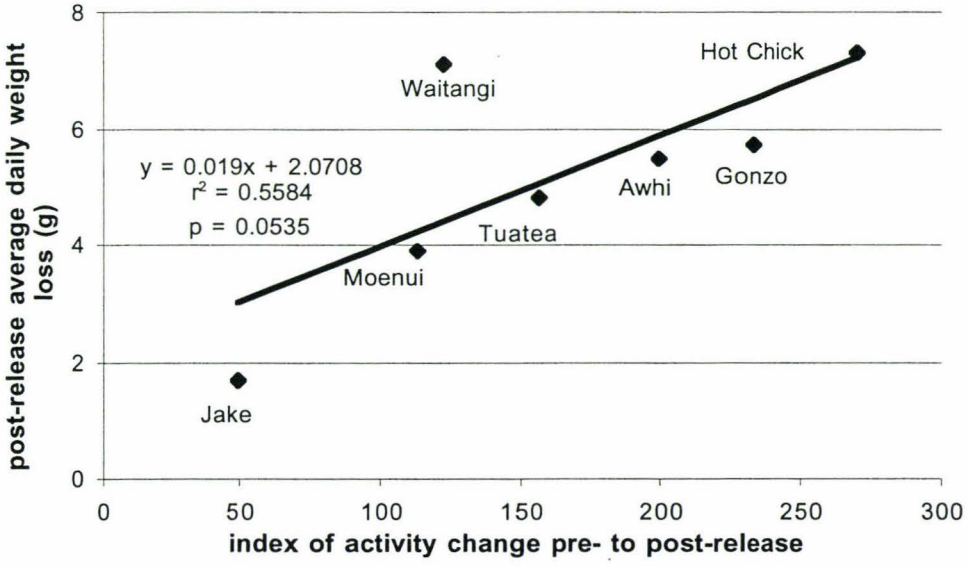

Figure 6.1 Post-release activity increase versus post-release average daily weight loss.

Some kiwi showed very low activity levels on their first night in the wild. An index of activity suppression on the first night in the wild was calculated by dividing each individual's first night activity value by the mean of their subsequent nights' activity values. The resulting value was also regressed against the mean post-release daily weight change for each individual. There was no evidence of a relationship between first night activity as a proportion of subsequent activity and post-release average daily weight loss (Figure 6.2).

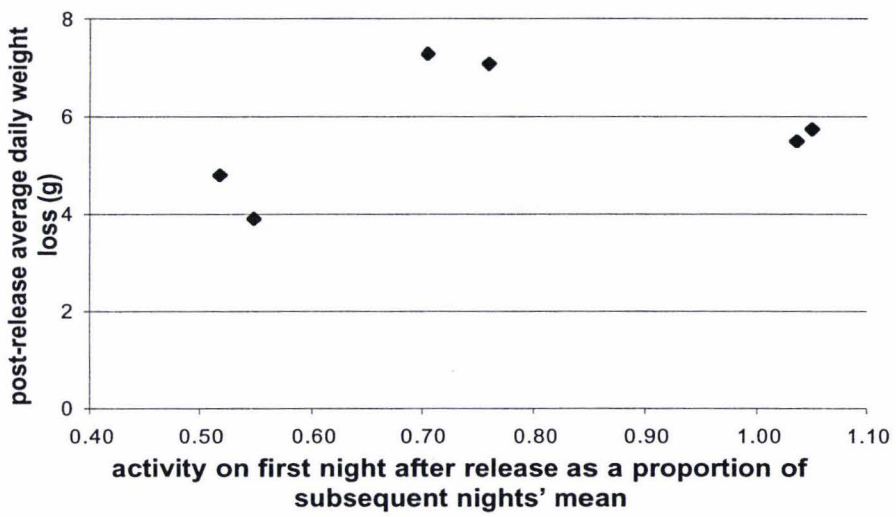

Figure 6.2 Activity on first night in the wild as a proportion of subsequent activity versus post-release average daily weight loss. There was no significant relationship.

Distance of kiwi from their release site in the second, third, and fourth months after release was regressed against change in weight from release up until each of these times. There was a positive but non-significant ($p = 0.0909$) relationship between distance from release site and weight increase after two months in the wild. However, when one individual was removed from this analysis, any indication of a link between distance and weight change disappeared (r^2 decreased to 0.0623 and $p = 0.3028$; Figure 6.3a). No relationship between growth rate and distance moved was seen after three or four months (Figure 6.3 b & c).

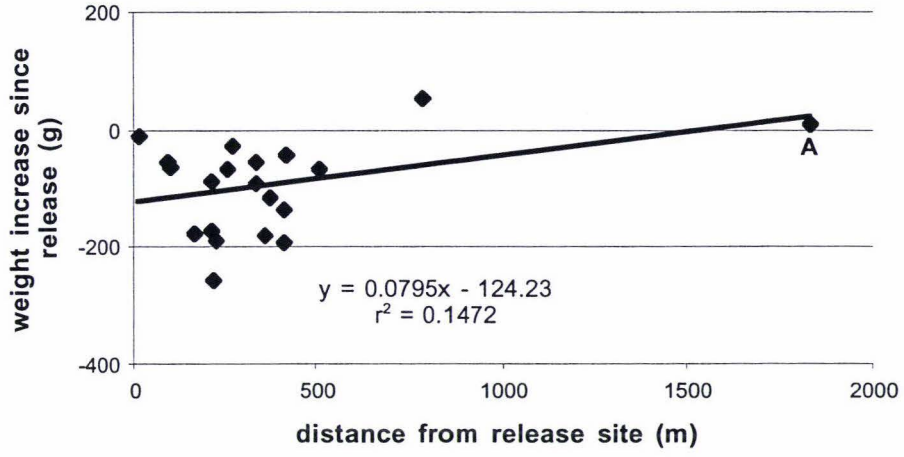

Figure 6.3(a) Weight change since release versus distance from release site, in the second month after release. $p = 0.0909$, but when individual A was removed, r^2 decreased to 0.0623 and $p = 0.3028$.

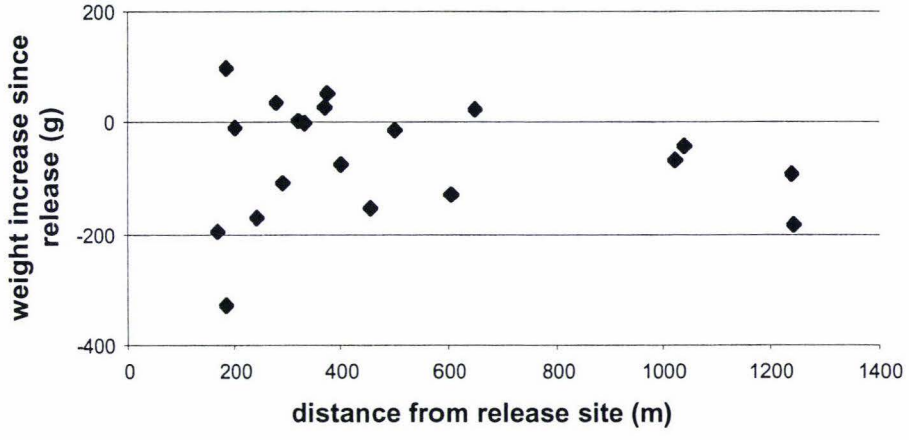

Figure 6.3(b) Weight change since release versus distance from release site, in the third month after release. There was no significant relationship.

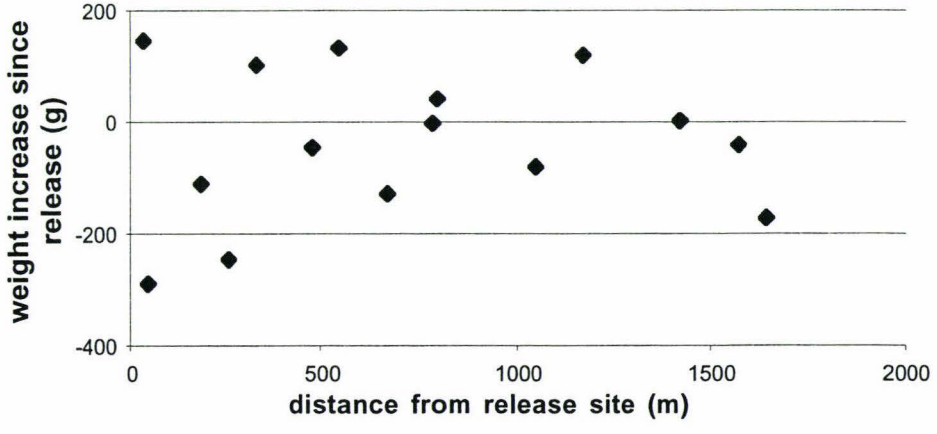

Figure 6.3(c) Weight change since release versus distance from release site in the fourth month after release. There was no significant relationship.

In general, kiwi lost weight for considerable periods after release. Eighteen out of 20 kiwi (90%) weighed during their second month in the wild had not regained their release weight. In the third month in the wild, 13 out of 20 (65%) had not regained their release weight, and eight out of 15 (53.3%) had not got back to release weight in their fourth month in the wild. On average it took about two and a half months after kiwi were released for them to begin re-gaining weight and four to five months for them to get back up to their release weight (it was not possible to determine a precise mean time taken to regain weight due to variation among individuals in the frequency that weight data were collected).

6.3 Summary of Findings

The signal pattern from the motion sensitive transmitters used in this study made it possible to differentiate between an active and inactive kiwi with a high degree of reliability. Foraging type behaviour could be distinguished from continuous walking or running with moderate reliability, but only when the signal from the transmitter of one kiwi was recorded continuously (Chapter 2).

On the first night after relocation and release into the wild kiwi tended to have unusual and low activity patterns relative to other nights after release. This may have been a result of stress associated with the transportation and release (Chapter 3). However, no relationship between level of activity suppression on the first night in the wild and post-release weight loss was detected (this chapter).

After their first night in the wild kiwi exhibited higher levels of activity than had been recorded before release. It was hypothesised that this increase in activity levels was due to a lower rate of energy intake in the wild than in captivity (Chapter 3). In support of this hypothesis, activity of captive kiwi increased when prepared food was distributed around the enclosure in tubes pushed into the ground (Chapter 4). There was a positive correlation between level of pre- to post-release activity increase and weight loss within

one month of release (this chapter). However, the certainty of conclusions in the activity studies was limited by small sample sizes and the low number of replications of post-release activity monitoring.

Almost all of the sub-adult kiwi showed dispersal from their release site. Kiwi released at sites lacking resident kiwi tended to disperse further than those released into an area with several resident kiwi near their release sites. I suggested that the different dispersal tendencies among areas could be a result of conspecific attraction but any definite conclusions were prevented due to some confounding among variables. Kiwi that were later preyed on dispersed further than kiwi not preyed on. This relationship may be due to further dispersing individuals having low site familiarity or a high likelihood of encountering habitat edges and their associated predators (Chapter 5). No relationship between distance moved and weight change was detected at two, three or four months after release (this chapter).

Kiwi tended to lose weight for considerable periods after release. After release it took on average about two and a half months for kiwi to begin re-gaining weight and four to five months for them to get back up to their release weight (this chapter).

6.4 Further Research

This research showed that a kiwi activity transmitter can give a remote observer reliable information about when a kiwi is active or inactive. The results also suggested that different types of active behaviour could be distinguishable using activity transmitter data. However, it was not possible to confirm these suggestions because of limitations in the viewing technique and the environments in which kiwi were observed. Studies using continuous format automated data collection and viewing techniques and environments that allow kiwi to be kept in sight for longer periods may enable determination of whether kiwi behaviours can be further differentiated by transmitter signal.

Activity levels of captive animals have been compared between those in small and large enclosures (e.g. Kreeger, 1996) and enclosure size may have had an effect on kiwi activity in the present study. However, it was unable to be taken into account because one kiwi had a far larger enclosure than any of the others. The results from this individual would therefore have had a disproportionately large effect on the analysis. Further studies of kiwi activity in captivity could look at effect of enclosure size using deliberate manipulations. Another factor that may have influenced captive activity in the present study was whether kiwi were alone or shared their enclosure with another kiwi. However, any effect of this factor possibly interacts with the size of the enclosure therefore it was not taken into account either.

It was hypothesised that kiwi activity increase after release into the wild occurred because they needed to spend more time foraging in the wild than in captivity in order to meet their energy needs. The increase in activity by captive kiwi when food was distributed in many small portions provided tentative support for this hypothesis. However, the post-release activity increase may also reflect a change in behaviour related to the relocation process and an unfamiliar habitat. The effect of an unfamiliar habitat on activity could be tested in captivity by moving individuals from one enclosure to another (with a similar supply of naturally occurring food and the same feeding regime applied) and monitoring their activity before and after this shift.

It is not known whether consumption of naturally occurring food increased during the dispersed feeding regime. This could be investigated by collecting faecal samples from the kiwi before and during such a feeding regime and comparing the presence of invertebrate remains between the two periods.

The hypothesis that conspecific attraction was a major factor in kiwi dispersal behaviour was generated based on correlational evidence of higher dispersal in kiwi released in areas without nearby resident conspecifics. However, as correlation does not necessarily imply causation, and there was confounding between variables in the present study (see Chapter 1 for explanation), experimental manipulation may be required to confirm this

hypothesis. Relocations can be designed as experiments by manipulating one variable and keeping others the same (Armstrong et al., 1994). To test the hypothesis that conspecific attraction was the mechanism behind the observed variation in dispersal, multiple replicates of releases of two or more kiwi would be used. Each replicate would consist of kiwi of a similar age being released at the same time, but each at a different location. Some of these locations would have resident kiwi nearby and the others would not, but in other respects the locations would be as similar as possible. After sufficient replicates, the conspecific attraction hypothesis should be either able to be rejected or not (but see next section (6.5)).

Analysis of factors influencing dispersal was restricted to the first 96 weeks after release. However, some kiwi have been monitored for much longer than 96 weeks and a few showed considerable dispersal after this length of time. Therefore, once enough data have been collected from kiwi that have been in the wild for two years or more, a different picture could emerge about factors that influence movement.

6.5 Management Recommendations

The large increase in nightly activity levels after release that might be linked to weight loss, could probably be minimised. The simplest approach would be to release kiwi at times when they have naturally higher activity levels. Pre-release activity was higher during a new moon than during other moon phases, therefore releasing kiwi near the end of a new moon phase might allow a smoother transition into the wild. Furthermore, dispersing the food that captive kiwi are provided with so that they have to perform some of the foraging behaviours that they would use in the wild also appears to increase activity. Therefore it may be beneficial to implement a dispersed feeding regime for Operation Nest Egg (ONE) kiwi before release.

The time that it takes kiwi to begin regaining weight after release may be an indication of how long it takes them to achieve the energy intake rate that they had achieved in

captivity. As the average time taken to begin regaining weight was about two and a half months, this may be the optimum period over which to use a dispersed feeding regime before release. The weight loss and in particular the prolonged period after release over which weight gain was stalled is a concern. It may be important to know whether post-release weight losses last a shorter time when kiwi have to search for their food before release.

Where ONE is used to supplement existing North Island brown kiwi populations of low to moderate density, it may be beneficial to release kiwi within about 1 km of current kiwi territories. It was hypothesised that releasing kiwi near conspecifics reduces their dispersal rates. There are probably two benefits of moderate rather than high dispersal distances of kiwi in this situation. First, most individuals will end up settling within the locale of other kiwi and therefore increase their chances of pairing up and breeding. Second, kiwi dispersing smaller distances may be less likely to be preyed on. Where kiwi are released near concentrations of kiwi territories within a large piece of potential kiwi habitat, moderate dispersal distances should result in the kiwi population spreading out over generations to colonise empty habitat. No evidence of aggression from residents to ONE kiwi was found during this study, however social systems and expressions of territoriality can be different in different kiwi populations (e.g. Colbourne & Kleinpaste, 1983; Mclennan et al., 1987; Potter, 1989; Taborsky & Taborsky, 1992; Miller & Pierce, 1995; Miller, 1995; 1996; Miles et al., 1997; Taborsky & Taborsky, 1999). Therefore, the likelihood of resident aggression occurring should be evaluated in each population before releasing sub-adults next to adult territories.

It should be noted that the hypothesis that kiwi released near resident conspecifics will have lower dispersal rates was generated from correlational evidence and has not been specifically tested (see previous section (6.4)). However, a tentative conclusion from this thesis is that releasing kiwi away from resident kiwi is not the best method of supplementing a population. Therefore, whether to base management decisions based on this tentative conclusion or whether to deliberately vary release sites to attempt to arrive at more definite conclusions, will depend on the characteristics of each kiwi population.

A compromise between these two approaches could be applied in Tongariro Forest by releasing kiwi near residents but continuing to collect monthly location data and adding it to the current dataset. As individuals are now being released at younger ages than those previously released into East Tongariro Forest, confounding between variables will be reduced over time.

When releasing near adult territories, it is recommended that kiwi be released at least 2 km from the nearest edge of the reserve. Results from this study suggest that a buffer of more than 2 km should allow more than half of the kiwi released to stay within the reserve if their direction of movement is random. This implies that the reserve needs to be at least 1600 ha in area. However, because a proportion of those released will probably disperse more than 2 km, in larger reserves kiwi should be released as far from edges as is practical.

When ONE is used in kiwi reintroductions there is no option to release sub-adults near resident kiwi. If kiwi are simply released upon relocation into empty habitat with no follow-up of their movements, it seems likely that many would disperse and never meet up with another kiwi. At Boundary Stream Mainland Island, a small reserve of 800-900 ha, kiwi are currently being reintroduced using ONE. After release, movements of the kiwi at Boundary Stream are monitored and when individuals move a long way outside the reserve they are tracked, picked up and brought back to the reserve (pers. comm. Tamsin Ward-Smith; pers. obs.). While this probably exposes the kiwi to additional stress, it has eventually resulted in the pairing up of two kiwi within the reserve, one of whom had left and been brought back to the reserve several times. If conspecific attraction does occur in kiwi it is probable that one of the ways kiwi detect the presence of other kiwi is by hearing their calls, therefore the recent emergence of a pair of kiwi calling to each other in Boundary Stream may lead to lower dispersal by the other sub-adults in the reserve. If so, the need for such a hands-on approach will be reduced over time. Another possible kiwi-reintroduction technique is to raise juvenile kiwi in captivity at their release site. In other species it has been found that individuals held at their release site for some time moved smaller distances after release than those released immediately

after relocation (e.g. Bright & Morris, 1994). Attempting to attract individuals towards each other by playing calls of a kiwi of the opposite sex from the direction of a kiwi that is out of calling range, is another technique that could be tested.

If immediate release is used in kiwi re-introductions, median dispersal distances of 3-4 km could be anticipated. Therefore about 5 km between the release site and the closest edge of the reserve may be sufficient to provide good habitat in the long term for more than half of the kiwi released. This means that reserves need to be very large (minimum of about 10 00 ha) to be viable kiwi reintroduction sites, unless much time and effort can be invested to trial methods to keep kiwi in the reserve or threats including kiwi predators can be controlled beyond the reserve boundaries.

Summary of Recommendations

- Plan releases to take place at the end or just after a new moon.
- Make kiwi search for their food for two to three months before release and compare their change in weight after release with those who were not made to search for food before release.
- Release near resident kiwi when releasing to supplement a population of North Island brown kiwi of low to moderate density where there is reason to believe resident aggression is unlikely to occur OR use controlled experiments to test the influence of resident conspecifics on sub-adult dispersal.
- Release at least 2 km from reserve edge when releasing near resident kiwi.
- When re-introducing kiwi, methods aimed at reducing dispersal distances such as raising kiwi in an enclosure at the release site or encouraging kiwi to move towards each other by simulating calls, could be tested. If immediate release is to be used, either the reserve should be 10 000 ha or more in area and release sites should be at least 5 km from the edge of the reserve, or it must be feasible to control threats including kiwi predators beyond the reserve boundary. Monitor kiwi after release.

6.7 References

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