Natal Dispersal, Habitat Selection and Mortality of North Island Brown Kiwi (*Apteryx mantelli*) at the Moehau Kiwi Sanctuary, Coromandel.

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Abstract

The Moehau Kiwi Sanctuary is one of five sanctuaries established in 2000 and managed by the Department of Conservation. The objective of the sanctuaries is to protect the most endangered kiwi taxa, and increase kiwi survivorship. Operation Nest Egg (ONE) is a programme utilised by the Moehau Kiwi Sanctuary for artificially incubating abandoned kiwi eggs, and captive rearing chicks until they begin to show a gain in weight. ONE chicks were then released back onto Moehau or adjacent protected areas.

Kiwi populations are declining on the mainland at an average of about 3% per year in areas where predators of kiwi are not controlled. The main cause for this decline is chick mortality due to predation by stoats (*Mustela erminea*). During natal dispersal kiwi are known to disperse significant distances of between 5–20 km, and this has influenced the size of management areas needed for the protection of kiwi (10,000 hectares). The type of forest-cover is an important element in determining where management areas are located, as kiwi have preferences for certain forest types over others.

This study conducted at Moehau, Coromandel, on the North Island Brown Kiwi advances our knowledge of kiwi by examining differences in rates and distances of dispersal among chicks, sub-adults, non-territorial and territorial adults, as well as between genders. This study investigates kiwi selective use of roost site types, ground-cover types, forest types and physiographical features. Addressed in this study are differences in dispersal, habitat selection and mortality among age-classes and between genders over the months of the year, and across elevations. Comparisons between ONE and wild-reared kiwi dispersal and mortality are included.

Data were collected between 2001 and 2008 from observations of kiwi located during daytime hours. The data recorded included the grid reference, elevation, ground-cover type, forest type, physiography, and the type of roost site. The sample size for this study was significantly larger than for any previous studies thus enabling a greater confidence in estimated dispersal rates and dispersal distances, habitat selection and factors relating to mortality.

All wild-reared kiwi displayed dispersal and were not philopatric to their natal area. Dispersal distances were found to be further than previously estimated, with the net distance of natal dispersal differing among age-classes, from an average of 834m (SE +/- 131) for kiwi chicks to 7,553m (SE = +/- 1167) for non-territorial adults. Female sub-adult kiwi dispersed further (7,215m) than male sub-adult kiwi (4,226m) (p = 0.04). The time taken to travel one km during natal dispersal ranged from an average of 131days/km (SE = +/- 9) for chicks to 89 days/km (SE = +/- 13) for sub-adults.

Habitat selection has been observed in other studies on kiwi but not specifically for Coromandel North Island Brown Kiwi, and selection for ground-cover types by kiwi when roosting on the surface has never been previously studied. Roost site selection of kiwi differed among age-classes (p <0.001), between gender (p <0.001), and across elevations (p <0.001). Female kiwi were found more often in surface roosts (64%) than hole roosts (32%), and male kiwi were found at similar frequencies in holes (46%) and on the surface (47%). Sub-adults used holes to a greater extent as elevation increased, and selected for sub-alpine forest over broadleaf forest (p <0.001). This study is the first to recognise that selection of ground-cover types by kiwi differs among age-classes (p <0.001). Kiwi chicks were more often found on the surface under dead fern fronds and debris (39%) than other ground-cover types.

The mortality rate was highest in chicks (33%), with predation responsible for 60% of these deaths; conservation management techniques were responsible for a further 20% of deaths; the remaining 20% of deaths were due to natural or unknown causes. Summer (December-February) was the season in which 81% of kiwi chick deaths occurred. The high proportion of deaths from monitoring techniques and the use of radio-transmitters (22%) indicates improvements need to be made to current management practices.

ONE chicks were found to disperse shorter distances and had a greater mortality rate than wild-reared chicks. Therefore, recommendations are made for changes to ONE management practices. Further recommendations are made for the enhancement of kiwi

habitat that could reduce kiwi mortality, and for increasing the habitat available to kiwi, thereby potentially increasing population sizes and/or densities.

Acknowledgements

Mostly I would like to dedicate this Thesis to my Darling Lilly and express my gratitude and appreciation for her patience and encouragement. This Thesis has been such a long project in progress and I have been unable to fulfil all the obligations I would wish to. Yet Lilly still hasn't kicked me out. Love you.

A special dedication goes to my mother Betty Daniels (deceased 29th July 1999), who inspired me, and whom I love and wish to make proud.

Another dedication goes to my sister Abby, and her beautiful daughter Equa who one day will hopefully get to experience kiwi in the wild, along with our other precious indigenous and currently endangered species.

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Lastly but certainly not leastly, I would like to give a big thank you to the kiwi of Moehau for the insights they have shown me. Although Kiwi are our national icon, their ecology and behaviour are still not well understood, only now are we beginning to appreciate how fortunate we are to have them. In the eight years spent working with kiwi I have found it a pleasure and privilege. As a species they are well deserving of their role as our icon. We may be wise to see them also as role models.

Table of Contents

Table of Figures

9

List of Tables

Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the qualification of any other degree or diploma of a University or other institution of higher learning, except where due acknowledgement is made in the acknowledgements.

Thesis Layout

CHAPTER ONE
An introduction of the subjects, study site and study species.

CHAPTER TWO
The general methods used in the monitoring of kiwi and their capture. Specific methods are included within the relevant Chapters.

CHAPTER THREE
This chapter addresses Objective One by quantifying the rate and distance of natal dispersal in kiwi and look at differences between gender, and age and any differences between months of year. Included are the methods used, results and discussion with regards to the relevant literature.

CHAPTER FOUR
This Chapter explores Objectives Two and Three and examines whether kiwi select for roost sites, ground-cover vegetation, forest-cover and physiographical features depending on the gender and age-class of kiwi. Any differences between months and elevation are also examined and discussed.

CHAPTER FIVE
This chapter focuses on Objective Four and examines the causes of mortality in kiwi depending on age, gender and the relationship with forest type, topography, and elevation, with discussion of the impacts of researcher disturbance.

CHAPTER SIX
This chapter provides a general discussion and summarises the findings on chapters three four and five and provides recommendations for further study. The implications of the findings for the conservation management of kiwi and on kiwi in general are also discussed.

Chapter 1.

Introduction

1.1 Kiwi

The study species of kiwi found at the Moehau Kiwi Sanctuary is the Coromandel variety of North Island Brown Kiwi (*Apteryx mantelli* Bartlett). Kiwi are endemic to New Zealand, and belong to the order of birds called Struthioniformes or ratites and are in the family Apterygidae. Ratites include rhea, ostrich, emu, and cassowaries, all of which are Gondwanan in origin (Sibley and Ahlquist, 1990). Kiwi are the smallest of the ratites with North Island Brown Kiwi weighing between 2–3.8kg (Colbourne and Kleinpaste, 1983; Miller, 1995). Kiwi are nocturnal and flightless with small vestigal wings, and like other ratites they are characterised by the lack of a breast bone keel to support their wing muscles. Although kiwi are nocturnal they do forage during the day, particularly in their most southern distribution on Stewart Island.

Presently, five extant species of kiwi are recognized, and the most recent unpublished genetic research of kiwi populations from Colbourne and Robertson (2005) identifies at least 11 distinct taxa. The species include: the North Island Brown Kiwi (*Apteryx mantelli*); the South Island Okarito Brown Kiwi or Rowi (*Apteryx rowi*); the Southern Tokoeka (*Apteryx australis*); the Great Spotted Kiwi (*Apteryx haastii*); and the Little Spotted Kiwi (*Apteryx oweni*). The latter are considered extinct in the wild on the three main islands, being found only on off-shore islands or in predator-free enclosures (Burbridge et al., 2003). The Haast Tokoeka is currently recognised as a variety of the Southern Tokoeka (*Apteryx australis 'Haast'*). The Okarito Brown Kiwi is more closely related to the North Island Brown Kiwi than to other species (Colbourne and Robertson, 2005).

There are four varieties of the North Island Brown Kiwi, with populations in Northland, Coromandel Peninsula, and two distinct population lineages around the Bay of Plenty/Ureweras, and Tongariro/Taranaki/Wanganui. Evidence also suggests that there

are three varieties of the Tokoeka, with a variety on Stewart Island, and two Fiordland populations now separated by a major river, and historically by glaciers (Colbourne and Robertson, 2005).

Kiwi occupy a wide variety of habitats, ranging from coastal sand dunes to high mountain tussock lands, and all forest types in between (Taborsky and Taborsky, 1992; Taborsky and Taborsky, 1995). Kiwi can also be found in exotic pine forest plantations (Colbourne and Kleinpaste, 1983). Kiwi breed at around a median age of 3.5 years, one to two times per year, and are thought to be able to live for up to 65 years (Robertson, 2004). Kiwi have low egg productivity, with around a 50% hatch rate in the wild (McLennan, 1988; de Monchy and Forbes, 2006). On Coromandel Peninsula of North Island the breeding season occurs from July through to April, they generally have two clutches per season with two eggs in each clutch, and the male excavate the nest and incubate the eggs (de Monchy and Forbes, 2006). In contrast Okarito Brown Kiwi (Rowi) have an average of one clutch per season with a single egg, and male and female share incubation (Robertson, 2005).

1.2 Conservation Management of Kiwi

Today there are an estimated 70,000 kiwi of all species combined in the wild, compared to an estimated 7 million before the arrival of humans and the mammalian predators they introduced. Kiwi are highly susceptible to predation by introduced mammalian predators because they have evolved in an environment without them for millions of years. Introduced predators of kiwi include ferrets, stoats, cats, possums, pigs and dogs (King, 1990; Miller and Pierce, 1995; McLennan, 1997). Only 5% of kiwi chicks in the wild survive to adulthood, and this is mainly due to predation of chicks by stoats (*Mustela erminea*), which kill approximately 60% of all kiwi weighing less than 1,000grams (McLennan et al., 1996; Basse et al., 1997; McLennan et al., 2004). Another factor contributing to the decline of kiwi populations is habitat loss and modification (McLennan et al., 1996; Basse et al., 1999; Robertson, 2003). With an annual population

rate of decline of between 3–6%, it is estimated that without predator control kiwi would become extinct on the mainland within 20 years.

1.2.1 Kiwi Recovery Programme

Up until the 1980's little was known about the status of kiwi populations, although it was suspected that, like other endemic New Zealand bird species, they were probably in decline. Kiwi certainly were disappearing from areas of previous distribution. A number of studies confirmed that most kiwi populations were in fact declining, with insufficient recruitment of chicks to maintain populations (McLennan, 1988; McLennan and Potter, 1993; Miller and Pierce, 1995; McLennan et al., 1996). The Kiwi Recovery Group (KRG) was established in 1991 to determine, and implement, strategies to ensure kiwi survival; the first Kiwi Recovery Plan was published this same year (Butler and McLennan, 1991).

As part of the Kiwi Recovery Programme strategy, the Department of Conservation (DOC) has established five kiwi sanctuaries since 2000. One objective of the sanctuaries is to prevent further decline and protect representative populations of the most threatened kiwi taxa. There are two sanctuaries in South Island (Okarito and Haast), and three in North Island (Northland, Coromandel and Tongariro).

The Moehau Kiwi Sanctuary was established on the Coromandel Peninsula, North Island for the protection and management of the Coromandel variety of North Island Brown Kiwi. Before its establishment there was a significant lack of knowledge on the Coromandel variety of North Island Brown Kiwi, or kiwi generally within the Waikato Region. Our knowledge of Coromandel NI Brown Kiwi has now substantially improved, although there is still very little published material available. (Unpublished reports on Coromandel NI Brown Kiwi at Moehau Kiwi Sanctuary, and cited in this study are located at the Department of Conservation, Hauraki Area Office, Waikato Conservancy).

1.2.2 Operation Nest Egg

Operation Nest Egg (ONE) is an integral part of the Kiwi Recovery Group's national kiwi recovery strategy, and encompasses captive rearing and breeding institutes nationwide in co-operation with the Bank of New Zealand (BNZ) and DOC (Colbourne et al., 2005). Captive breeding institutions now play a vital role in increasing wild populations, and they have developed the techniques that established ONE as a viable management tool. In 1995 the first captive-reared chicks, about one year old (over 1000 grams), were released on predator-free Motukawanui Island and unexpectedly began to breed the following year (Miller, 1995; Robertson, 2003). Then in 1996 the first captive-reared chicks were released back into mainland forests in areas throughout North Island and also at Okarito in South Island (Colbourne, 1998).

1.2.3 Kiwi Crèche's

In 1997 the first kiwi (Rowi) reared through ONE were transferred to Motuara Island in Marlborough Sounds, which was to act as a crèche site until kiwi were heavy enough (approximately 1kg) to defend themselves against stoats (Colbourne, 1995). Mainland predator-free enclosures also are being utilised for this purpose; one of the first such enclosures, established at Bushy Park, Taranaki in 1994, has since reared kiwi chicks that were hatched in captivity, and in the wild (Dew, 2002; Vesey, 2008).

1.3 Natal Dispersal in Birds

Most definitions of dispersal refer to two types: natal and breeding dispersal. Natal dispersal is the movement of juveniles from their place of birth, hatching or release site to the place where they reproduce or would have reproduced if they had survived and found a mate. Breeding dispersal is the movement between breeding attempts (Howard, 1960). Conversely, natal philopatry is the tendency to remain on or adjacent to the parent's home range past the age of adulthood, or to return to the parent's home range to breed; it can also refer to the tendency to remain near a release site (Massot and Clobert, 2000). Philopatry in breeding dispersal refers to the tendency to return to the same site to breed every season.

A review by Greenwood (1980) presented evidence to suggest that ecological factors, primarily the different mating systems, were a basis for the differences in dispersal between birds and mammals. Greenwood (1980) demonstrated that there was female-biased dispersal among birds, and that female birds dispersed further than males. This was supported by a review of avian dispersal studies that found 49–59% of species showed female-biased dispersal, 11–20% showed male biased dispersal, and 16–21% showed no sex bias. Mammals conversely had a male biased dispersal (Clarke et al., 1997). Greenwood (1980) suggested that for the largely monogamous birds (eg. kiwi) there is greater need for the males to establish territories, defend resources, and avoid the stress of moving to unfamiliar surroundings with unknown food resources and threats. In this mating system the dispersal of females is favoured, as they are free to choose the most suitable males by the resources they defend. In mammals it was observed that they are far more likely to be polygamous and that intrasexual competition forces a high proportion of breeding males in search of mating opportunities. Dobson (1982) had predicted that for monogamous mammal and bird species where intrasexual competition can be considered equal, dispersal distances should also be equal. However females of many monogamous species of birds dispersed further than males.

Reed et al. (1999) expanded on the explanation for natal dispersal of Greenwood (1980), suggesting that young birds are 'prospecting' for possible future breeding sites by actively gathering information on the distribution of territorial individuals, suitable food resources and potential mates with which to breed. It was more deliberate dispersal, rather than due to competition.

The Oedipus hypothesis (Liberg and von Schantz, 1985) sought to link Greenwood and Dobsons views. The hypothesis predicted whether an animal would leave its natal area (disperse) or stay in the natal area (philopatric) based on the mating systems. It was assumed that, from the point of view of young animals, dispersal will cost more than philopatry and therefore they must be prone to stay, and that it is the parents that are in the position to determine which offspring leaves (assuming any will show philopatric tendencies) — the one that disperses likely being the one that exhibits the most

competition towards the territorial adults. Pusey (1987) similarly considered inbreeding avoidance and intrasexual competition as debatably the two factors most responsible for sex-biased dispersal in birds and mammals. The sex that displays the greatest movement in natal dispersal also tends to display this in breeding dispersal. However, natal dispersal is far more extensive than breeding dispersal.

It is often assumed that a major cause of dispersal is population density. However studies such as that by Greenwood and Harvey (1979) on Great Tit (*Parus major*) showed there was no relationship between distance of dispersal, and density of males. Dispersal distance was more likely due to territory size, as males moved a greater number of territories as density of territories increased. Juveniles tended to disperse to a greater extent than adults. Territory size may be most important, as there was a strong correlation between distance moved and the number of territories traversed. For example, Great Tit juveniles moved an average of four to seven territory widths during natal dispersal while adult Great Tits returned to within one territory width of the previous breeding site. Arcese (1989) also found that the distance of dispersal in song sparrows was dependent on the density and size of territories. There were a similar number of territories traversed over each year of the study and a significant difference in distances moved by both sexes between years. Other factors which have been proposed as determinants for dispersal include the degree of fragmentation of habitat and spatial distribution of habitats. Goth and Vogel's (2003) study on the Australian Brush Turkey (*Alectura lathami*), a primarily ground-dwelling megapode (similar to kiwi in that they are flightless, precocial and independent after hatching), found that the number of thickets (dense scrub habitats) was the main factor in determining dispersal distances, with a decreased distance correlated with an increased number of thickets.

Studies on natal dispersal on kiwi and other birds generally use basic methods to determine the rate, distance and direction of dispersal, measuring the distance (in a straight line) between known points, and the time taken. This is sufficient given the difficulties in monitoring them (Gibbs, 2000; Grant, 2003; Small and Rusch, 1989). A study by Matthysen et al. (2005) on Great Tits (*Parus major*) found that determining the

rate of dispersal accurately was dependent on the degree of monitoring of the subjects and the effectiveness of the equipment used in monitoring them. A comprehensive analysis of the technical problems associated with estimating measures of dispersal is provided by Clobert et al. (2001).

1.4 Habitat Selection, and how habitat connectivity influences dispersal in birds.

Lack (1933) was among the first to emphasize the occurrence of habitat selection in birds, and habitat selection has since been demonstrated in many bird species (Nummi and Poysa, 1993; Ferrer and Harte, 1997), including kiwi (Taborsky and Taborsky, 1995; Miles et al., 1997), with differences in preference observed between age-classes. However, not all bird species are selective of the habitat they use (Ganey et al., 1998). Birds are known to select habitat on the basis of broad factors such as forest type, topography, terrain, substrate, or vegetation composition. Some studies have suggested that birds may not be 'selecting habitat' but may be influenced by availability of breeding partners, physical barriers, and behavioural or physical characteristics (Harris and Reed, 2002).

The relationships between habitat selection and dispersal in kiwi, and birds generally; and whether these factors are dependent or independent of one another are not well understood. However, the impacts of habitat modification and disturbance on bird species abundance and distribution and their dispersal or movements well documented (Hunt Jr, 1972; Rabenold et al., 1998; Zeitler, 2000; Frid and Dill, 2002). Habitat loss and fragmentation can affect populations of forest birds by limiting or preventing dispersal or movement among forest patches. Harris and Reed (2002) contended that although the effects of physical barriers to animal movement are well established the behavioural inhibition of individuals moving across habitat gaps, ecotones, and isolated patches of habitat, has received little attention. Examples of this were observed in a study by Belisle et al. (2001) on two migratory bird species (Quebec, Canada), the Black Throated Blue Warbler (*Dendroica caerulescens*) and the Ovenbird (*Seiurus aurocapillus*), and one

21

resident forest bird species, Black Capped Chickadee (*Poecile atricapillus*), which provided evidence that as forest-cover decreased the forest birds took more time to disperse.

Diamond (1984) considered how habitat fragmentation affects New Zealand's bird distributions on its oceanic islands; on islands that were previously linked to the mainland; and in isolated forest patches. Birds general ability of flight means they are often cited as a taxon in which movements should not be disrupted by gaps in landscape connectivity caused by natural or anthropogenic disturbances, with many species routinely crossing difficult and varied terrain. However, Diamond's (1984) evidence suggests that landscape-scale forest-bird movements during breeding and natal dispersal are constrained due to bird species having a 'dislike' of open areas. New Zealand bird species can be divided into two groups: those that cross water and those that don't. Long-distance colonisers from Australia have tended to evolve into species that can no longer migrate over open water, being unable to fly, or else acquiring 'a fear' of flying over water. Species unable to emigrate are mainly restricted to large land-bridge islands. Hugh Robertson (DOC, Science and Research Division) has speculated that the 'fear of silence/fear of crossing farmland' restricts the movement of kiwi in Northland where forested kiwi habitat is isolated in patches in a sea of farmland. However, anecdotal and physical evidence from Northland (H. Robertson and N. Coad, personal communication, 1999), and a study on kiwi in Northland by Chan (1999) indicate they do disperse over farmland

Terborgh's (1974) study on New Zealand bird species and how kiwi (*Apteryx* spp.) and saddleback (*Philesturnus carunculatus*) are examples of species unable to cross water, and therefore must have relied on landbridges to disperse to islands that were connected to North or South Island until the late-Pleistocene (e.g., Stewart Island, Great Barrier Island). Some absences of species from particular islands are attributed to man-induced extinctions, or unfulfilled habitat requirements. However, many absences have no apparent explanation and may simply represent local extinctions that have not yet been reversed by immigration. There are populations of flightless forest-bird species in

mainland New Zealand, that exist in forest patches that were formerly part of continuous forest but now form virtual islands, that are widely separated by open country which may not provide the habitat requirements or environmental factors that they 'prefer'.

In forest fragments throughout New Zealand the distributions and area requirements of bird species reflect their population density and dispersal ability. These patterns make it clear that the continued survival of New Zealand endemic bird species such as kiwi, which are confined to native forest, hinges on preserving large areas of native forest (Diamond, 1984). Limitations to dispersal may make isolated populations more vulnerable to extinction. Small and isolated populations are usually assumed to be at a high risk of extinction due to environmental or demographic changes, genetic problems, or lack of immigration (Dale, 2001). North Island Brown Kiwi (*Apteryx mantelli*) occupy mainland forest patches of 1–10 km² or smaller, but they have not survived on land-bridge islands smaller than Stewart Island (1735 km²). Perhaps kiwi are unlikely to persist in isolation for a long time in forest patches or islands, but can maintain themselves in a system of isolated patches if dispersing individuals can occasionally walk from patch to patch (Diamond, 1984).

A study on the importance of connectivity of habitat for North Island Robin (*Petroica longipes*) suggested that juvenile natal dispersal movements were greatly affected by the fragmentation of forest habitat and that movements between fragments increased as distances between fragments decreased. Most juvenile movements (52.1%) were observed between patches that were separated by less than 20m, and site occupancy was positively correlated with the degree of connectivity of the forest patches (Wittern and Berggren, 2007). Connectivity of habitat may not be as important for kiwi as they are known to traverse large distances across farmland to reach isolated patches of forest (Chan, 1999).

1.5 Mortality in Birds

All natural communities will experience disturbance and species mortality events at some spatial and temporal scale, often over intervals longer than the lifespan of the investigator or investigation, and spanning over geological time, therefore the effects of disturbance cannot necessarily be directly observed and most studies observe disturbance and mortality in species over periods of several years or less. There is a growing realization that disturbance may play as great a role in community dynamics as biological processes, and that the interplay between these may account for the high degree of the organizational and spatial patterning of natural communities (Sousa, 1984).

1.5.1 Human Disturbance and Bird Mortality

The extinction of the various endemic moa species of New Zealand after colonisation by Polynesians and associated mammals around 700–800 years ago (Worthy and Holdaway, 2003) demonstrates the radical consequences of human disturbance in the form of habitat loss and over exploitation of resources on the mortality of birds. Kiwi were exploited as a resource of feathers and possibly for food (Holdaway, 1989; Day, 1989). Human disturbance can take many forms and can impact directly and/or indirectly on wildlife. Some human activities have an obvious impact on mortality in birds while others can have more subtle effects and may not be noticed or directly linked with any particular disturbance event (Pierce and Sporle, 1997; Camphuysen et al., 2002; Ontiveros and Pleguezuelos, 2003; Sundar and Choudury, 2005). Zeitler's (2000) study on human disturbance, behaviour and spatial distribution of Black Grouse in skiing areas in the Bavarian Alps discovered that human presence in Black Grouse (*Tetrao tetrix*) habitats could cause short-term changes in individual behaviour, or changes in habitat use and distribution patterns, and even the decline and extinction of local populations. Zeitler (2000) stated that the causal relationships between the presence of humans and population dynamics in animals is difficult, if not impossible to prove analytically.

Habitat fragmentation and modification due to 'development', especially drastic habitat change such as that generated by timber harvest, is perhaps the greatest factor influencing, not just birds such as kiwi, but all animal and plant species distribution, and

24

is a well-studied cause of avian community changes (Fahrig and Merriam, 1994; Schmiegelow and Mönkkönen, 1997; Watson et al., 2005). In a survey of breeding birds in lake habitats of northern Wisconsin, USA, results showed little difference between developed and undeveloped lakes in bird abundance or species richness, although it was found that differences existed in the diets of birds between lakes; declines in insectivorous and ground-nesting bird species observed on developed lakes, with a corresponding increase in seed-eating and tree-nesting bird species, indicating that levels of development appear to affect the composition of bird species (Lindsay et al., 2002). Increased predation due to habitat modification, as well as direct anthropogenic disturbances from landscape maintenance (mowing, clearing, etc.) may have been responsible for the decline in ground-nesting birds around developed lakes.

Breeding colonial water birds are particularly susceptible to human disturbance because of their high-density nesting habits. Fifteen species of colonial water birds nesting at 17 colonies in north and central Florida were exposed to three different human disturbance mechanisms (walking, canoe, or motorboat). Detrimental affects to reproductive success from these disturbances included: egg and nestling mortality (including predation), nest evacuation, reduced nestling body mass and slower growth, premature fledging and modified adult behaviour (Rodgers Jr and Smith, 1995).

Other studies have also found an association with human habitat alteration and an increase in predation. Logging and development (e.g., clearing land, creating patches of habitat, thinning stands) within the Marbled Murrelet's (*Brachyramphus marmoratus*) range has resulted in increased numbers of predators and predation rates, this has made Murrelet nests easier to locate because of increased amounts of forest edge and limited numbers of platforms with adequate hiding cover (Nelson and Hamer, 1995). Marbled Murrelets have no protection at nest sites other than the ability to remain hidden. In addition, areas heavily used by humans for recreational activities (i.e., picnic and camping grounds) can attract predators and may increase the chance of nest predations within these areas. In a study of the reproductive success of Herring Gulls (*Larus argentatus*) on four islands in Maine, USA; hatching success decreased with the

frequency of disturbance by picnickers, evidently causing adults to leave their nests for longer periods, rendering the nests more vulnerable to predators (Hunt Jr, 1972).

The above studies could have implications for the management of kiwi populations on the Coromandel Peninsula and elsewhere in New Zealand, particularly for areas where kiwi occur in commercial pine forest plantations that are frequently disturbed through timber harvesting, and/or when kiwi are located adjacent to popular public recreational areas and towns (Colbourne and Kleinpaste, 1983; Marsh, 1993; Dew, 2002).

1.5.2 Researcher Disturbance of Study Species

Human disturbance from researcher monitoring of bird and other species can often cause mortality, and when dealing with rare and endangered species this can have significant consequences. Mortality events are often inevitable, and have to be weighed against the need for further information to contribute to saving a species from further decline or possible extinction.

Martin's (1981) study on Cave Swallow (*Petrochelidon fulva*) in Texas found that during a relatively wet year at a cavern-nesting colony, overall seasonal reproductive output and nestling survival was higher than during a drier year. Much of this difference was due to improved second clutch conditions for reproduction. However increased investigator disturbance of the cave colony during the first attempt at breeding for the year may have negatively affected hatching and survival of the first clutch.

Infanticidal behaviour on young in ground-nesting colonial seabirds can be a major cause of chick mortality, and studies have shown that investigator disturbance can subject chicks to aggressive attacks by neighbouring birds, and increase mortality (Fetterolf, 1983). In a study of the effects of investigator disturbance on chick mortality, at a ring billed gull (*Larus delawarensis*) colony near Port Colbourne, Ohio (Brown and Morris, 1995), no chicks were fatally attacked during investigator disturbance, but differences in the experimental procedures in this study compared to Fetterolf (1983) showed that awareness of and attention to the potential impacts of investigator activity can reduce such impacts.

Monitoring techniques for research purposes are also a form of researcher disturbance which can cause mortality in birds (Goth and Jones, 2001; de Monchy and Forbes, 2006). The need for information for conservation management purposes must be weighed against the threat any direct monitoring may pose, as it may in fact be more detrimental to the survival of the study species or population than using alternative monitoring methods. Mortality has occurred in kiwi (*Apteryx* spp.) by the transmitter attachment or metal identification leg-bands becoming entangled in vegetation so that kiwi then get entrapped, are unable to forage and die of starvation. Non-fatal injuries have also been caused particularly to kiwi chicks and these include abrasions and dislocation of limbs (Miles and McLennan, 1998; de Monchy and Forbes, 2006).

1.6 Objectives of Study.

The primary aim of this Thesis was to investigate the biological and environmental factors associated with dispersal, habitat selection and mortality of North Island Brown Kiwi (*Apteryx mantelli*).

There were four specific objectives in this study:

1. To determine the rate and distance of natal dispersal of kiwi and whether there are differences between gender, age and age-class and whether differences occur depending on the time of year.

2. To determine whether kiwi select for habitat types and roost sites by investigating the proportional use of different types of roost site, physiography, forest-cover, and ground-cover.

3. To determine if there are any differences between gender and age-class in the selection of habitat types and roost sites, depending on the time of year or elevation.

4. To identify and quantify the causes of kiwi mortality and whether there are differences depending on age-class, gender and time of year.

Knowing the rate and distances of dispersal of kiwi depending on age-class or gender is essential in accurately modelling population dynamics for conservation management purposes. This Thesis quantifies the rates and distances of dispersal over a longer period and with a larger population sample than other studies have managed to achieve. The effects of time of the year and elevation are also examined as well as differences between wild-reared and Operation Nest Egg kiwi (ONE).

Habitat selection is a subject of confusion in kiwi due to the variety of habitats in which they exist and the genetically distinct populations that are observed. There has not been any studies habitat selection and dispersal on the Coromandel variety of North Island Brown Kiwi, this is the first study to specifically observe this kiwi variety and population. This Thesis adds to the knowledge of kiwi habitat selection by examining selection of roost site types; ground-cover vegetation types used when in surface roosts; type of forest-cover; and physiography where roosts are chosen. When roosting on the surface, kiwi may select for particular types of ground-cover vegetation depending on their age-class and gender. Ground-cover selection has likely played an important role in kiwi survival and evolution, and therefore examining selection choices could help to determine optimum habitat for kiwi.

Although other studies have examined causes of mortality in kiwi and the impacts this has on kiwi populations, this Thesis examines the impact of intensive monitoring on mortality, the effects of elevation, and the time of year at which kiwi chicks are most vulnerable at Moehau. Differences in survivorship between age-classes and wild-reared and ONE kiwi are investigated.

This research will have implications for groups and organisations interested in the protection and management of North Island Brown Kiwi, and possibly other kiwi species. It will assist in determining what type of habitat is most suitable for young kiwi during dispersal and when establishing territories, and which areas need habitat enhancement to increase use by young kiwi. It will help to prioritise habitat for protection where kiwi are most vulnerable. This study will assist in determining the optimal size of intensively managed or predator-fenced areas for kiwi, and in predicting the carrying capacity of an area well in advance of it reaching its limits, thus allowing greater management flexibility.

Chapter 2.

General Methodology

The data for this study were collected by the kiwi sanctuary staff as required under the kiwi sanctuary research and monitoring plan and following the Moehau Kiwi Sanctuary best practice manual, and operating procedures. These data were collected between February 2001 and June 2008. The raw data (before modification for analysis and interpretation) was obtained from a total of 1641 observations of kiwi, with 346 of these observations being made by the author. The raw data is appended in a CD within the back of the Thesis.

2.1 Study Site - Moehau Kiwi Sanctuary

The Moehau Kiwi Sanctuary is located at the tip of the Coromandel Peninsula (36° 32´ S, 175° 24´ E) North Island, New Zealand; it is managed by the Department of Conservation (Figure 2.1). Together with the Kuaotunu Project Kiwi, and Whenuakite Kiwi Sanctuary, they make up the Coromandel Kiwi Sanctuary, each geographically isolated from the other (Robertson, 2003). The Moehau Kiwi Sanctuary encompasses approximately 18,000 hectares of Moehau Range, and is surrounded on three sides by Hauraki Gulf which acts as a barrier so that kiwi can only disperse south from the Sanctuary for distances greater than about five km. The Southern landward boundary is the Colville/Waikawau Bay road; here the peninsula is at its narrowest point at about five km across.

The main purpose of the Moehau Kiwi Sanctuary was to monitor kiwi chicks until they reached a weight of 1000g, and to determine their survival rate when predator populations were controlled and whether the trapping regime is sufficient to increase chick survival from around 5% (without trapping) to 20% or greater for the population to be maintained or increased. If the survival rate was insufficient then the predator control programme was modified (Roxburgh, 2001; Robertson, 2003). There is an extensive

predator control and habitat restoration programme on Moehau, which includes the establishment of nearly 1800 stoat traps (approx. 1 per 10 hectares), as well as localised cat trapping, possum control, and dog-kiwi aversion training to protect kiwi and other endangered wildlife.

Moehau Range is recognised internationally as a site with significant ecological values. Endangered and threatened species that are present include: locally endemic weta and stag beetle species, Archey's and Hochstetter's frogs, Coromandel Striped Gecko, Pateke (Brown Teal), Kaka, Kakariki (parakeets), Kiwi, and rare and threatened plants (Burns, 1985; McCraith, 2002). In places unbroken native vegetation exists from the coast to the sub-alpine zone (Burns, 1985). The significance of Moehau is acknowledged by its gazettal as an Ecological Area and as a Conservation Reserve of the International Union for the Conservation of Nature (IUCN). Moehau is also the highest-ranked forested habitat in the Waikato Conservancy for biodiversity by the Department of Conservation.

Moehau Range rises from sea level to an elevation of 892 metres, with contiguous forest from the summit to the sea on both the western and eastern sides of the mountain. Most of the forest-cover on Moehau is temperate forest with a much smaller area of sub-alpine forest around the summit and in patches along the summit range. Specific forest types identified include; podocarp/broadleaf, tawa/broadleaf, kauri/tanekaha, kanuka/manuka associations, and sub-alpine forest and sub-alpine meadow (Burns, 1985).

The topography of Moehau consists of well-defined ridges and spurs running off the summit ridge, which runs approximately north to south. It is steep and rugged terrain with slopes greater than 35˚. The summit ridge divides Moehau into a western and eastern side. The few relatively flat areas are around the mouths of streams and lower sections of the valleys, making up less than 10% of the area.
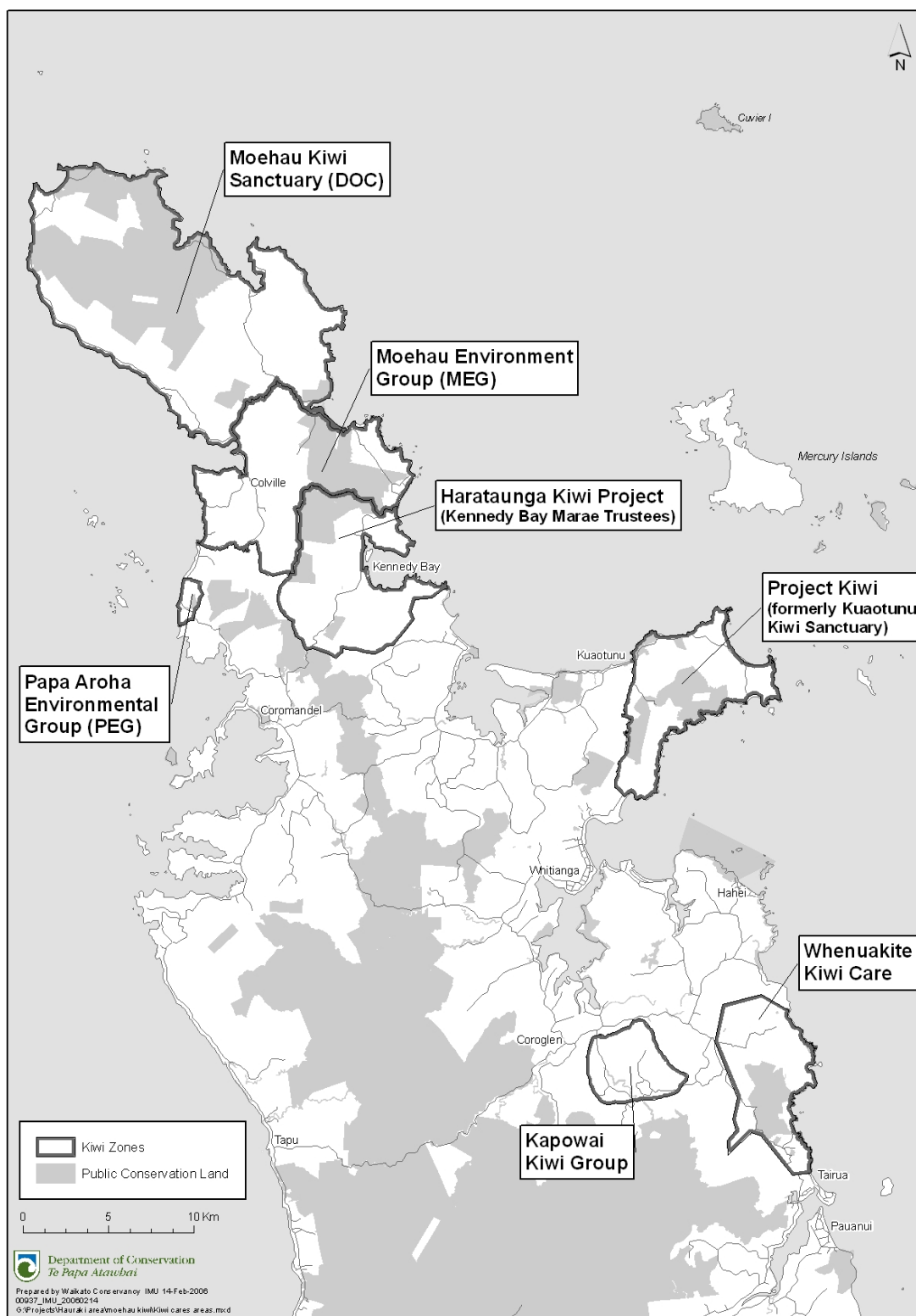
Figure 2.1. *Map showing location of Moehau Kiwi Sanctuary and other kiwi protection zones on Coromandel Peninsula, North Island, New Zealand.*

2.2 Monitoring of kiwi

Kiwi were monitored using radio-tracking technology including a Yagi aerial connected to a Telonics TR4 receiver. A radio-transmitter was attached to the kiwi above the 'knee' using the current method of best practice (Miles and McLennan, 1998; Wilks and Bramley, 2007; Wilks and Bramley, 2008). To accurately determine the location of kiwi without capturing or seeing kiwi, three to five bearings from different points as close to the bird as practical, with at least three of these bearings being 45˚ apart. The position of kiwi were given as the Easting and Northing grid references using a Garmin™ E-trex Global Positioning System. Another method to determine kiwi positions was to use a topographical map, or mapping programme and compass bearings of a kiwi from two or more known points, and then triangulating these to determine the kiwis approximate position. Kiwi that could not be located ground based telemetry, were searched for using either an aircraft or boat.

All spatial information and mapping data was displayed using the Mapinfo or Arcview mapping programmes with Microsoft Access database. Excel PHStat statistical tools were used for the data analysis.

Kiwi were captured at different intervals depending on their weight and age or breeding status. Kiwi chicks were captured monthly until they reached 1000g, sub-adult kiwi were captured every 4–6 months until breeding or until they had established territories, and adults were captured yearly. In Chapters four and five of this study, kiwi age cohorts were defined as either chick (up to 1000 grams), sub-adult (>1000 grams – 4.5 years or age at first breeding or age when bill grows less than 1.5mm in six months), or adult (from 4.5 years or age of first breeding, or age when bill grows less than 1.5mm in six months). In Chapter three the methodology divides the adult age-class into territorial and non-territorial adults (See Chapter 3.2 for definitions)

2.3 Capture of kiwi

Kiwi were either captured at the nest, or captured using a trained and certified kiwi dog. Moehau Kiwi Sanctuary staff that owned kiwi dogs regularly encountered kiwi at random and in dedicated searches. Kiwi were captured by dogs throughout the altitudinal range of Moehau and over most of the available habitat. However most were captured where staff access was easiest on the eastern side and summit ridge of the Moehau Range.

All kiwi that were captured weighing less than 1000g were fitted with transmitters. Kiwi over 1000g were fitted with transmitters only if they were breeding or territorial males, if they were to be included in research on dispersal, or if they occurred in areas where they could be particularly vulnerable to predation or exposed to human activities.

2.3.1 Kiwi Chicks Captured at Nest

Kiwi were never located in the same roost site in consecutive weeks other than when nesting, therefore kiwi were considered to be nesting when the male kiwi being monitored was found to be in the same roost for three consecutive weeks. The time of hatching was estimated by adding 75–85 days to the date when kiwi were found to be sitting on a nest, as this is the average period of incubation (Robertson, 2003). Nesting was also determined using Egg Timer and Chick Timer radio-transmitters developed by Wildtech™ that can detect changes in behaviour of NI Brown Kiwi and consequently the onset of nesting and the egg hatch date (Wilks and Bramley, 2007; Wilks and Bramley, 2008).

The exact location of the nest was established using telemetry gear. The nest was then marked, and GPS Easting and Northing co-ordinates were taken. The monitoring of nesting kiwi by Moehau Kiwi Sanctuary staff involves setting up a camp at least 50m from a nest site and marking a track to the nest with reflector tape that can be followed at night. When the strength of the radio transmitter pulse on the receiver indicated that the kiwi was leaving its nest, the staff monitoring the kiwi waited half an hour before quietly approaching and looking into the nest to see whether any kiwi chicks were present. Kiwi on Moehau generally leave the nest for around 10 minutes, and up to three hours each

night; and occasionally they do not appear to leave the nest at all (Moehau Kiwi Sanctuary Unpublished data, Department of Conservation, Hauraki).

Kiwi chicks that were found hatched at the nest were fitted with a 6 gram, Holohil radio transmitter (made in Canada) with the mortality function (an increase in the speed of radio pulses occurs if a radio-transmitter remains still for more than 12 hours). This allowed staff to determine with telemetry equipment if the chick was dead, or had lost its transmitter.

When eggs were found that hadn't yet hatched, the nest was monitored until the male either returned or abandoned the nest. The nest was considered to be abandoned if the male did not return the same night that it left the nest. If the nest was abandoned, the potentially viable egg(s) were taken to the Kiwi Encounter hatching and rearing facilities at Rainbow Springs, Rotorua. The kiwi chick was then kept at the facilities until it showed a gain in weight above its hatching weight. It was then taken back to the Moehau Kiwi Sanctuary and released back at, or within the vicinity of it initial nest site.

The extent and effectiveness of the predator trapping and control, and the survival rates of monitored chicks at the Moehau Kiwi Sanctuary is sufficient to allow the kiwi chicks to be released back into the wild before reaching 1000 grams. These kiwi were included in the population sample of young kiwi to be monitored. Other kiwi sanctuaries use captive facilities to rear their kiwi chicks until they reach over 1000g or more in weight and are deemed 'safe' from stoats (McLennan et al., 2004).

Chapter 3.

Natal Dispersal in Kiwi

3.1 Introduction

The dispersal of kiwi has only recently been the subject of research and few studies exist. Furthermore these studies lack statistical robustness due to insufficient sample sizes, and consequently many assumptions have had to be made relating to dispersal parameters (McLennan and Potter, 1993; Gibbs, 2000; Grant, 2003; Basse and McLennan, 2003). The main reasons for historically small sample sizes results from losses of radio-transmitters used to monitor kiwi, and an inability to locate kiwi out of the immediate study areas (Robertson, 2003).

Department of Conservation staff at the kiwi sanctuaries, and other independent kiwi practitioners have speculated, from anecdotal evidence, that male kiwi disperse further than female kiwi (H. Robertson, personal communication, 2003). The hypothesis formulated by Greenwood (1980) predicted that there should be little or no sex-bias in the distance of natal dispersal in kiwi, as both sexes of North Island Brown Kiwi are highly competitive in establishing and maintaining territories, and are generally monogamous (McLennan, 1997; Taborsky and Taborsky, 1999).

In modelling population growth rates in kiwi populations, two key elements are to assess immigration and emigration rates. This can be achieved by plotting the known distribution of birds through analysis of radio telemetry data on the dispersal of sub-adult kiwi monitored since fledging. No dispersal records have been established from 'banded' birds. To date only monitored kiwi that have radio-transmitters have provided knowledge on kiwi dispersal (Robertson, 2004).

Long-distance movements of young kiwi have been observed in Tongariro, Waikaremoana, Northland and Moehau. Kiwi have travelled distances of over 10km from one location to another (McLennan and Potter, 1993; Grant, 2003; de Monchy and

Forbes, 2006). At Moehau they have been found to disperse 20–50 km, to well outside the sanctuary boundary before establishing territories or were unable to be found (P. de Monchy, personal communication, 2006). At Trounson Park, Northland there are higher densities of kiwi present (Pierce & Westbrooke, 2003) than in other areas of the North Island. Several young radio-tagged kiwi have been recruited at the park where they hatched, while others have dispersed at least 25 km from the reserve to neighbouring Waipoua Forest (T. Herbert & N. Coad personal communications, 1998).

In a study on kiwi in Trounson (Chan, 1999), it was found that juvenile kiwi were capable of travelling many kilometres while dispersing from their natal area. Chan (1999) suggested rivers and streams may be obstacles to dispersal. By contrast Gibbs (2000) found that rivers (and fence lines) did not form barriers that juvenile kiwi were not prepared to cross. Others have also noted that "rivers prove not to be major obstacles" to dispersal (Cam Speedy, personal communication, 2000). Gibbs (2000) had a very small sample size of three juvenile kiwi at Trounson Park, and showed that over the period of about a year they travelled up to 1.5 km from their natal area, within an area of 450 ha of forested habitat isolated by surrounding farmland. Field studies at Lake Waikaremoana, Te Urewera National Park, showed that most sub-adult kiwi disperse from their natal area in large forest tracts, travelling up to five or more kilometres in a few weeks. The minimum mean distance of dispersal of 11 sub-adults was 5.24 km +/- 0.97 (S.E.). The actual mean is probably considerably higher, because four kiwi wandered out of the catchment and could not be located (Basse and McLennan, 2003).

Grant (2003) in her research on captive-reared kiwi dispersal at the Tongariro Kiwi Sanctuary, used similar measuring techniques to Basse and McLennan (2003) to determine dispersal distances from the release site. Captive-reared kiwi chicks were released into the wild at 1000 grams. There is evidence that captive-reared chicks show different dispersal characteristics than wild-reared chicks. The furthest distance any captive-reared kiwi was recorded to have travelled was 12 km (Grant, 2003).

Most long-distance dispersal of North Island Brown Kiwi appears to occur after birds are about 9 months of age, although kiwi chicks can travel several kilometres on leaving the nest between 1-4 weeks after hatching (Robertson, 2004). At Waikaremoana (North Island) sub-adult kiwi generally settled in areas bordering existing kiwi territories, travelling through territory without resident kiwi, which would otherwise appear to be suitable habitat (Basse and McLennan, 2003).

Grant (2003) found there was a significant effect on sub-adult kiwi dispersal from the interactions between month of year, sex, and area and Tongariro. Sub-adult females were found to be further away from their release site during May and June. The apparent difference in dispersal distance among males and not females, just before the breeding season, could suggest that males are more active in seeking out mates. The greater dispersal seen in all individuals released into habitat not previously occupied by kiwi compared to those kiwi released into habitat already occupied, suggests that conspecific attraction may be occurring. This has been recorded in many bird species (Stamps, 1991; Muller et al., 1997). There is a moderate density of kiwi within the Tongariro forest and therefore it should not necessarily be expected that kiwi would travel as far in higher density kiwi populations where the number of territories are limited by the available habitat.

This Thesis examines any differences in the distance and rate of dispersal of kiwi that were monitored on Moehau Range depending on the age-class and gender, and if there are any differences between months of the year or between wild-reared and captive-reared kiwi. If differences exist then our current modelling of populations for conservation management may be insufficient for enabling the long-term sustainable survivability of kiwi in mainland forests.

Knowledge on the rate and distance of dispersal in kiwi will have implications for the management of kiwi populations. Dispersal data makes it possible to determine emigration and immigration rates, the time taken to reach particular population targets and carrying capacity, and determine the optimum size for protected kiwi habitat. It will

provide the information needed for more efficient use of human and financial resources in the management of the Department of Conservation kiwi sanctuaries.

3.2 Methodology

See also Chapter Two: General Methodology.

Kiwi that were monitored from the chick age-class and included in the dispersal study included three chicks recruited from the 2000/01 cohort, 12 from 2001/02, 16 from the 2002/03, 17 from 2003/04, 18 in 2004/05, and four in 2005/06 cohorts. Also included were seven sub-adult kiwi of unknown hatch date. This provided a total sample size of 77. Comparisons were made between different age-classes, only if kiwi within a particular age-class (eg. adult) had been monitored since they were chicks.

3.2.1 Determining Kiwi Territoriality

It was decided that kiwi had established a territory if any of the following criteria were met:

1. The distance between two known locations was 500m or less and the time taken to travel between locations was greater than six months (for sub-adult or adult kiwi that were monitored from the chick age-class).
2. The kiwi was caught with a mate.
3. The female was gravid when caught.
4. Kiwi were sitting on eggs.
5. There was a 4% or less difference in the net distance of dispersal, between two consecutive locations and all previous locations of kiwi that were monitored since hatching or from within 50 days of age (Chapter 3.3 Figures 3.19 & 3.20).

3.2.2 Kiwi Dispersal

There were two measures of dispersal distance used: net dispersal and cumulative dispersal. The net distance of dispersal was the distance between the first and last capture or known location, measured in a straight line. The cumulative distance of dispersal was the sum of distances between the first capture and each subsequent capture up to when kiwi had established territories, died, could not be located, or were no longer monitored (Figure 3.1).

Dispersal rates were measured as the number of days taken to travel one kilometre (days/km), and estimated from the time taken to travel from the first point of capture (nest site or capture in natal area using kiwi dog during the day) to each subsequent capture point, until kiwi had either established territories, had the transmitter removed, died or been lost.

In this chapter the term 'month' is representative of a period of 31 days. The time period between one known location (data point) and any subsequent location of kiwi ranged from several days to months. The data collected on the distance travelled and time taken (rate) between one known location and a second subsequent known location for individual kiwi, was pooled depending on the age-class or gender, and the mean distance or rate of dispersal over 31 days determined. Reference to distances and rates of dispersal for a particular month (eg. June) indicates that the second subsequent known location or data point occurred in June.

Data was pooled over all years from 2001–2008. The distance and rate of dispersal was determined between age-classes and gender of kiwi, and differences between elevation and time of the year were examined. Statistical analysis using ANOVA followed by Tukeys pairwise comparisons, was used to determine which variables were the best predictors for the rate of dispersal, and the net and cumulative distance covered.
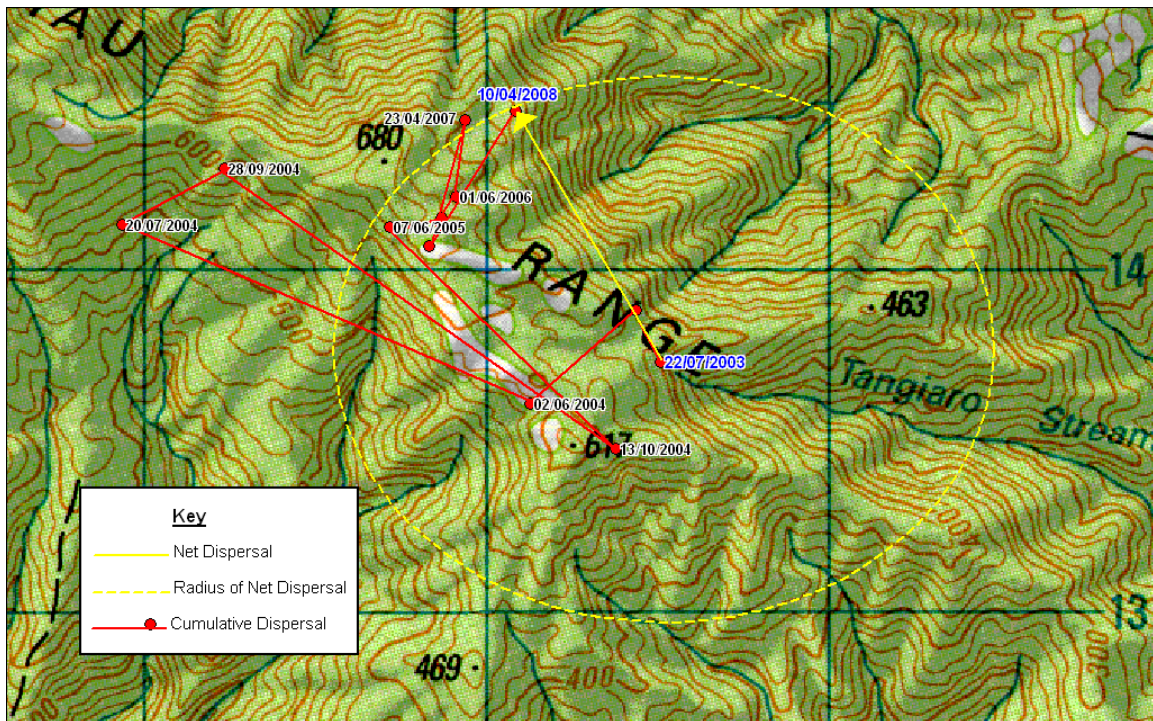
Figure 3.1. *The net distance of dispersal and cumulative distance of dispersal of a sub-adult male kiwi at Moehau Kiwi Sanctuary, from 2001–2008. (Dates in blue represent the first and last known locations).*

3.2.3. Detecting Dispersal in Kiwi

When kiwi were monitored from hatching until reaching the adult age-class, dispersal was determined to have occurred at the age when there was a 90% or greater difference in the net distance of dispersal between two consecutive locations and all previous locations (Figure 3.2). (See Chapter 3.3 Figures 3.19 & 3.20).
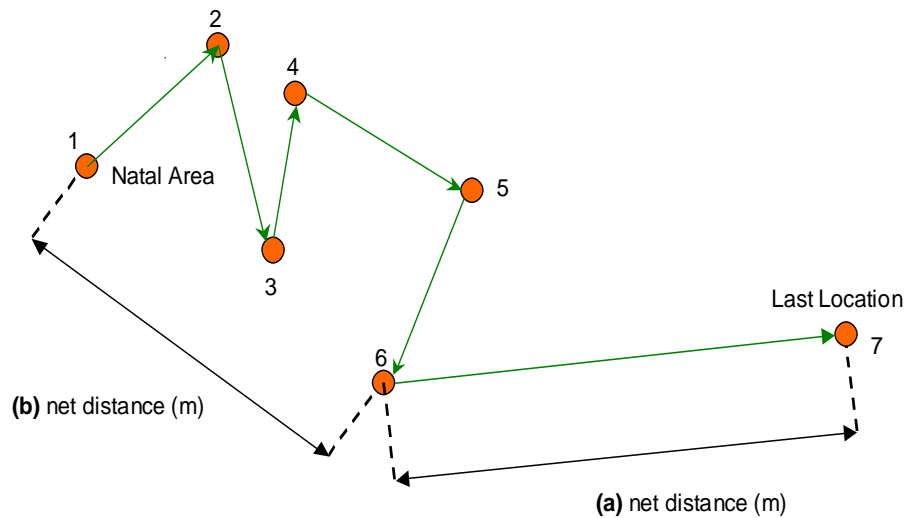
Figure 3.2. *Locations of a kiwi are depicted in chronological order by the orange circles (pts 1-6). The distances between locations were measured in metres. When the distance of (a) was > 90% of the net distance of (b) then dispersal was considered to have occurred (%difference = a/b*100). When the difference in net distance was less than 4% as a sub-adult or adult monitored from the chick age-class, a territory was considered to be established.*

3.2.4 The Role of Kiwi Gender and Age-class in Natal Dispersal

The gender of kiwi were determined from DNA analysis (Massey University, Hamilton), or morphology. Female North Island Brown Kiwi are significantly heavier than males (females 2–3.8kg, males1.7–2.8kg) and with longer bills (females 97–155mm, males 80–118mm) (Colbourne and Kleinpaste, 1983; McLennan, 1997; Robertson, 2003).

For the dispersal data analysis the different age-classes were defined as being a chick, sub-adult, non-territorial adults and territorial adults. . In this study kiwi age cohorts were defined as either chick (up to 1000 grams), sub-adult (from 1000 grams until 4.5 years of age, or age of first breeding attempt, or when bill grows less than 1.5mm in six months), non-territorial adults (from 4.5 years of age, or age of first breeding attempt, or when bill grows less than 1.5mm in six months), and territorial adults (adult kiwi that had established a territory).

The territorial adult kiwi age-class data analysis was determined from dispersal data collected from the natal area until they had established territories, (See Chapter 3.2.1) over all other age-classes. Kiwi chicks from the years 2006/07 and 2007/08 were not included in the dispersal analysis because kiwi from these cohorts were no longer monitored after being released at 1000 grams. Distances of dispersal were compared between the age-classes using ANOVA, followed by Tukeys pairwise comparisons.

The distances and rates of dispersal were compared between the genders of kiwi using an independent two-tailed t - test (assuming unequal variances).

3.3 Results

3.3.1 Dispersal Distances

A total of 77 kiwi were monitored for natal dispersal, 10 were captive-reared Operation Nest Egg kiwi chicks released back to the Moehau Kiwi Sanctuary. Kiwi were monitored for a minimum period of 68 days and up to a maximum of 2,359 days. The average number of days that kiwi were monitored for was 978 days (95% CI +/- 66).

Chicks had an average age of 149 days (95% CI +/- 14.3) and sub-adult kiwi an average age of 682 days (95% CI +/- 85.8), while non-territorial adult kiwi had an average age of 1526 days (95% CI +/- 150.4) or four years, and territorial adults 1298 days (95% CI +/- 135.1) or 3.5 years. Twenty eight of the monitored kiwi chicks and sub-adults established territories, one from 2000/01, seven from 2001/02, nine from 2002/03, six from 2003/04, and five from 2004/05.

The relationship between cumulative distance of dispersal and the net distance of dispersal of wild-reared kiwi monitored from all age-classes can be largely explained by the linear relationship net distance (m) = 396m + 0.401m*cumulative distance. (R^2 = 73.1%, n = 705, p = <0.0001), and indicated by the solid line (Figure 3.3). The linear relationship when all kiwi including ONE chicks were included was: net distance (m) = 363m + 0.4027m*cumulative distance (R^2 = 73.8%, n = 810, p = <0.0001). The relationship between net distance and cumulative distance was strongest when cumulative distances were less than about 20,000m, and after which the variation in standard error became too great. For territorial adult kiwi which had been monitored from 50 days of age or less until they had established a territory the linear relationship between the net distance travelled and cumulative distance was the strongest: net distance (m) = 0.423*cumulative distance (R^2 = 76.6%, n = 308, p = <0.0001).

The net distance travelled by dispersing kiwi over all age-classes from the natal area or point of first capture to each subsequent location was approximately 40% of the cumulative distance travelled (Figure 3.4). There was a maximum net distance travelled

of 22,203m by kiwi that were monitored from hatching until establishing a territory, and a minimum net distance of 2,052m (Figure 3.5). The maximum cumulative distance of dispersal recorded was 45,107m.

The total cumulative distance of dispersal differed among age-classes (one-way ANOVA: df = 3, F = 33.31, P = <0.0001). Tukeys pairwise comparisons identified a statistically significant difference between chicks and sub-adults and adults, and between sub-adults and non-territorial and territorial adults. Kiwi in the non-territorial adult age-class travelled 40 % further in cumulative mean distance from their initial capture point (20,345 km 95% CI +/- 4,475, n = 26) than sub-adult kiwi (12,197 km 95% CI +/- 2,461, n = 52), and territorial adult kiwi (17,846 km 95% CI +/- 4,688, n = 22) travelled 32% further than sub-adults (Figure 3.6). The average cumulative distance travelled by chicks was 2,052m (95% CI 696).

The net distance of dispersal differed among age-classes (one-way ANOVA: df = 3, F = 19.37, P = <0.0001). Tukeys pairwise comparisons identified a statistically significant difference between chicks and sub-adults or adults. The average net distance of dispersal in sub-adult kiwi was 85% further (5,487m, 95% CI +/- 1,204, n = 51) than chicks (834m, 95% CI +/- 265, n = 43) (Figure 3.7).

The average cumulative distance of dispersal of female sub-adult kiwi was 31% further (16,382m 95% CI +/- 4,321m) than male sub-adult kiwi (11,288m 95% CI +/- 4,563m) (two tailed t-test: p = 0.09, females n = 19, males n = 18, p = 0.09) (Figure 3.11). By contrast female sub-adult net distance of dispersal was 41% greater (7214m 95% CI +/- 2485m) than male sub-adults (4225m 95% CI +/- 1557m) (two tailed t-test: p = 0.04, females n = 19, males n = 17) (Figure 3.8)

Non-territorial adult female kiwi (9,167m, 95% CI +/- 3,694m, n = 19) dispersed 34% further in net distance than non-territorial male kiwi (6062m 95% CI +/- 3420m, n = 17), and territorial adult female kiwi (8,454m 95% CI +/- 4,202m, n = 9) 24% further than territorial adult male kiwi (6,435m, 95% CI +/- 3,647m, n = 12). However, these

differences were not statistically significant for non-territorial adults, (two tailed t-test, p = 0.19), and Territorial adults (two tailed t-test, p = 0.43) (Figure 3.9).

3.3.2 Age and Dispersal

The percentage difference in net dispersal was determined from kiwi that had been monitored since hatching until the adult age-classes, and was a measure of the difference in the net distance travelled between captures, so that from any given known location the following location was a % further or lesser in net distance from the natal area. When the difference in net distance of dispersal between known locations of kiwi monitored from the chick age-class is greater than 90% (See Chapter 3.3.2) it appears that most wild-hatched chicks (n = 191) begin to disperse significant distances from their natal area. The minimum age at which this occurred was at around 60–70 days old (8–10 weeks) (Figure 3.10). The average distance from the natal area when kiwi had shown dispersal was 3,443m (95% CI +/- 1,088) and at an average age of 301 (95% CI +/- 65) days (43 weeks).

The relationship between the age of territorial kiwi and the net distance of dispersal was best explained with the linear equation: net distance (m) = 6.4m*age (days) (R^2 = 40.4%, n = 297, p = <0.0001) (Figure 3.11).

3.3.3 Chicks and Dispersal Distances per Month

The average distance kiwi chicks travelled between monthly captures was 435m (95% CI +/- 63m), The least distance travelled between captures per month for chicks was 236m (January), and the greatest distance travelled was 644m (November). The greatest distance travelled in the period of one month for chicks was 2,986m. Chicks appeared to disperse a greater distances from March until May. The distance between captures per month was less in female chicks during the months of February to April compared with male chicks, with no obvious difference between gender during other months (Figure 3.12).

3.3.4 Sub-adults and Dispersal Distances per Month

The average distance all sub-adult kiwi travelled per month was 596m (95% CI +/- 118m) and the greatest distance travelled in the period of one month by a sub-adult kiwi

was 4,871m. They appeared to disperse greater distances from July to October and lesser distances from February to May. For female sub-adults the average distance in dispersal per month was 750m (95% CI +/- 227) (Figure 3.13) and for males 545m (95% CI +/- 193) (Figure 3.14). There appeared to be a very similar trend between male and female sub-adult kiwi in the distance they disperse per month, except that females generally dispersed further each month. Females travelled anywhere between 194–1,539m per month whereas males travelled 136–1119m per month.

3.3.5 Rates of Dispersal

The rate of dispersal of kiwi that were monitored from the natal area until they had established a territory was on average 91 days (+/- 14 days) to travel one kilometre. The rate of dispersal decreases as the total cumulative distance travelled increases (Figure 3.15).

The rate of dispersal differed among age-classes (one-way ANOVA: df = 3, F = 19.37, P = 0.012). Tukeys pairwise comparisons identified a statistically significant difference between chicks and sub-adults. The rate of dispersal between kiwi chicks and sub-adult kiwi differed, with kiwi chicks (n = 44) having a slower rate of dispersal at 135 days per km (+/- 19) compared to sub-adults (n = 35) at 89 days per km (+/- 27) (Figure 3.16).

Chick dispersal rates varied depending on the month of the year, with a minimum rate of around of 153 days/km and a maximum rate of 107 days/km. There was no difference in the rate of dispersal between female and male kiwi chicks (two tailed t-test: female n = 16, male n = 15, p = 0.64). However male kiwi appear to have a slower rate of dispersal than female chicks between May and September (Figure 3.17).

Sub-adult rates of dispersal over the year varied from 61 days/km to 129 days/km depending on month (Figure 3.18). However, there was no difference in the rate of dispersal between male and female sub-adult kiwi (two tailed t-test: females n = 19, males n = 16, p = 0.8).

3.3.6 Detecting Territoriality

One method used to assess territoriality in sub-adult or adult kiwi was to determine if the percentage difference in net distance of dispersal (% Difference) was less than 4% (Figures 3.19 & 3.20). The percentage difference was determined as the difference in distance (m) between two consecutive locations (a) and all previous locations (b). Whereby the percentage difference in net distance (% difference) = (b-a))/(a)*100 (See Chapter 3.2 Methods Figure 3.2).

This measure of % difference in net distance of dispersal (% difference) was consistent with other methods of determining territoriality in 79% of kiwi (n = 19) that were aged 50 days or less since first monitored (Table 3.1). This percentage increased to 82% (n = 21) when the sample included two kiwi aged 182 days (% diff = 2.03) and 134 days (% diff = 3.26) respectively when first monitored as chicks, and that were corroborated as being territorial through another method (ie. the distance between captures being less than 500m over a period of six months or greater). The % difference method was used exclusively to determine territoriality in only one kiwi (aged under 50 days when first monitored). A total sample of 22 wild-reared kiwi were identified as being territorial (n = 22).

Six of the 22 kiwi were found to be territorial through evidence of breeding behaviour, with two of these not corroborated as being territorial when the % difference in net distance of dispersal was <4% (Table 3.1).

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3.3.7 Operation Nest Egg Kiwi (ONE)

ONE kiwi of all age classes dispersed at a lesser rate than wild-reared kiwi, and except for ONE chicks all other age-classes dispersed for shorter distances. However, the sample size for ONE was too small for statistical testing (Tables 3.2 & 3.4). The average age of ONE kiwi chicks released back into the Moehau Kiwi Sanctuary was 39 days. Eight kiwi were monitored for more than 296 days, and seven dispersed more than 1,000m net distance from the natal area or release site (Figure 3.21). Four kiwi were identified as being territorial adults.
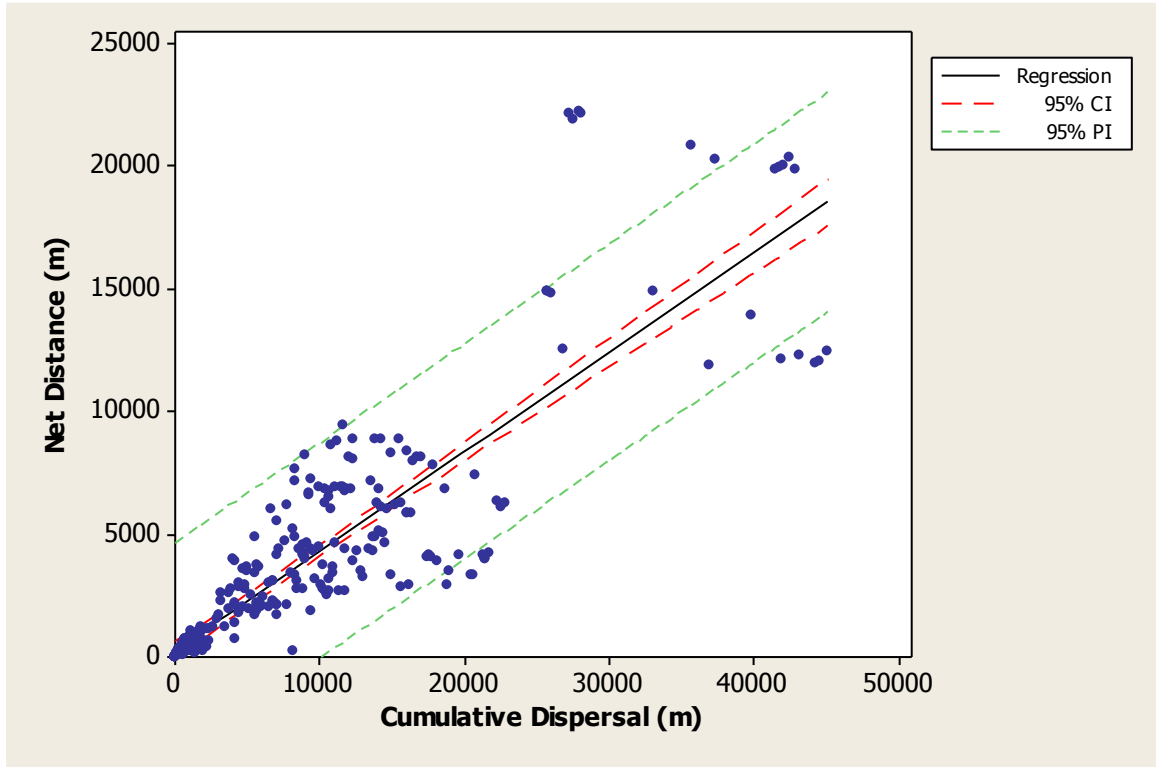
Figure 3.3. *The relationship between the total cumulative distance (m) and net distance (m) of dispersal from the natal area or release site to each consecutive location, for all wild-reared and ONE kiwi at Moehau Kiwi Sanctuary (n = 707). The solid black line indicates the linear relationship: net distance = 363 + 0.4027*cumulative distance.*
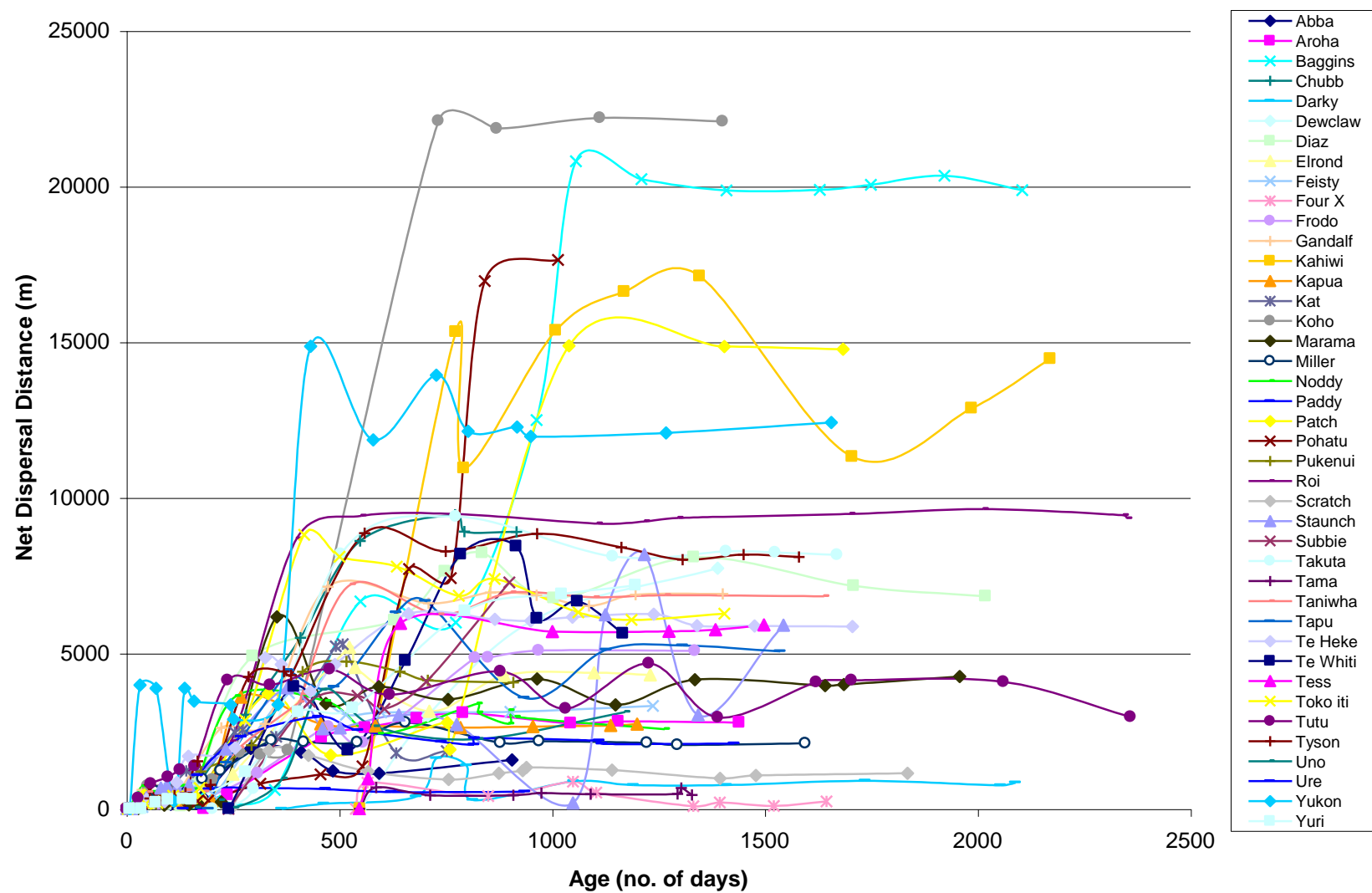
Figure 3.4. *The net dispersal distance travelled of all wild-reared kiwi from their natal area or first capture site.*
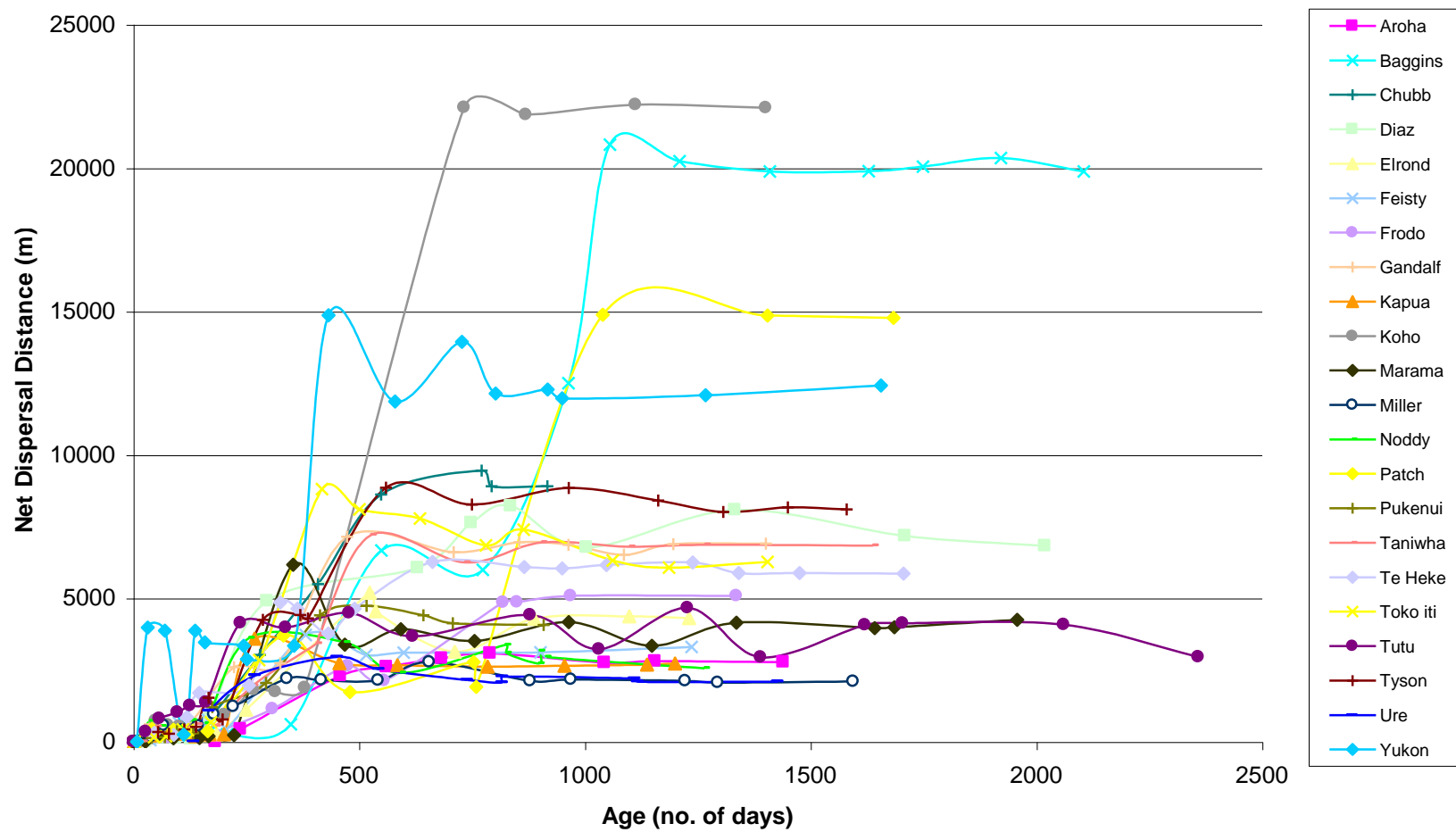
Figure 3.5. *Net dispersal of wild-reared territorial adult kiwi from the natal area until a territory was established.*
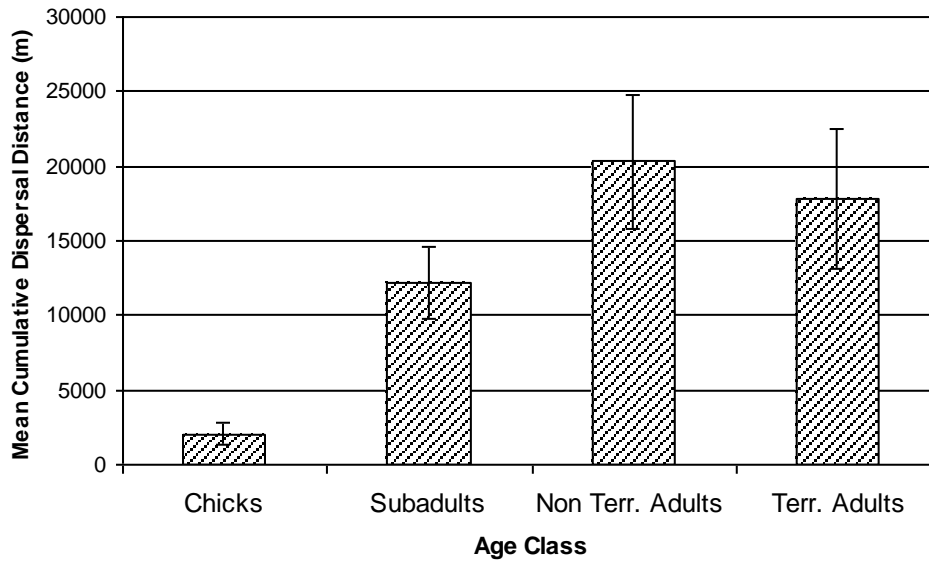
Figure 3.6. *The mean cumulative distance of dispersal (m) of chick (n = 44), sub-adult (n = 52), non-territorial adult (n = 26) and territorial adult (n = 22) kiwi age-classes, at the Moehau Kiwi Sanctuary from 2001–2008.*
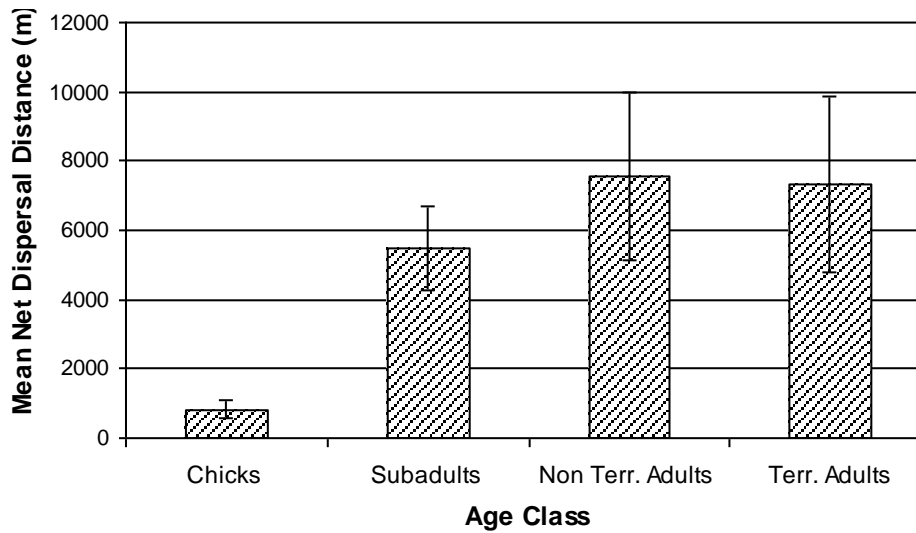
Figure 3.7. *The mean net distance of dispersal (m) of chick (n = 44), sub-adult (n = 52), non-territorial adult (n = 26) and territorial adult (n = 22) kiwi age-classes, at the Moehau Kiwi Sanctuary from 2001–2008.*
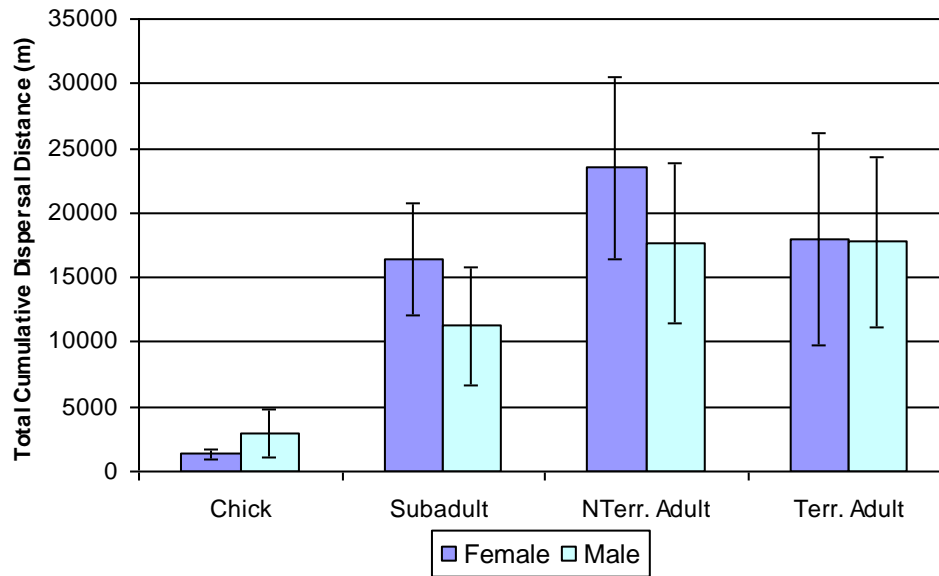
Figure 3.8. *The total cumulative distance of dispersal (m) of female and male kiwi respectively, within different age-classes (chicks n = 16, n = 15, sub-adults n = 19, n = 18, non-territorial adults n = 12, n = 14, and territorial adults n = 9, n = 13), at Moehau Kiwi Sanctuary from 2001–2008).*
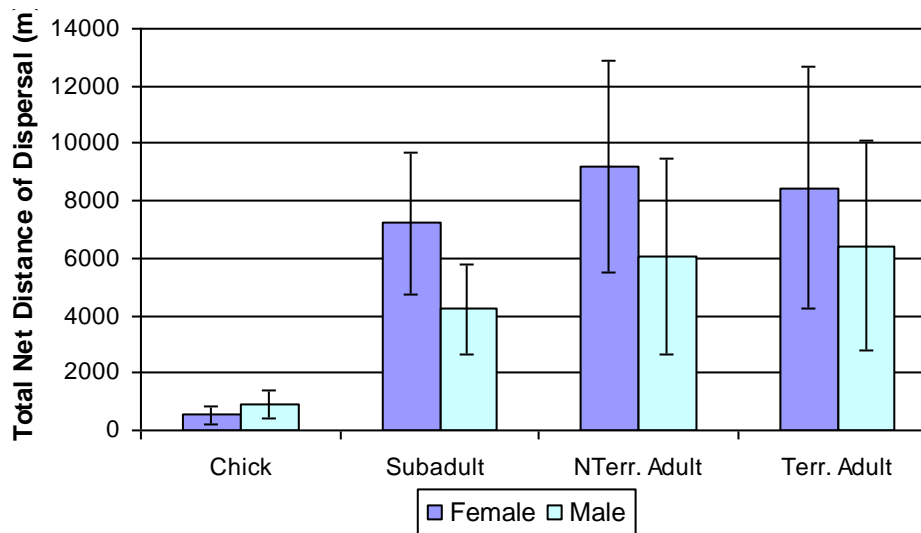
Figure 3.9. *The total cumulative distance of dispersal (m) of female and male kiwi respectively, within different age-classes (chicks n = 16, n = 14, sub-adults n = 19, n = 17, non-territorial adults n = 12, n = 13, and territorial adults n = 9, n = 12), at Moehau Kiwi Sanctuary from 2001–2008).*

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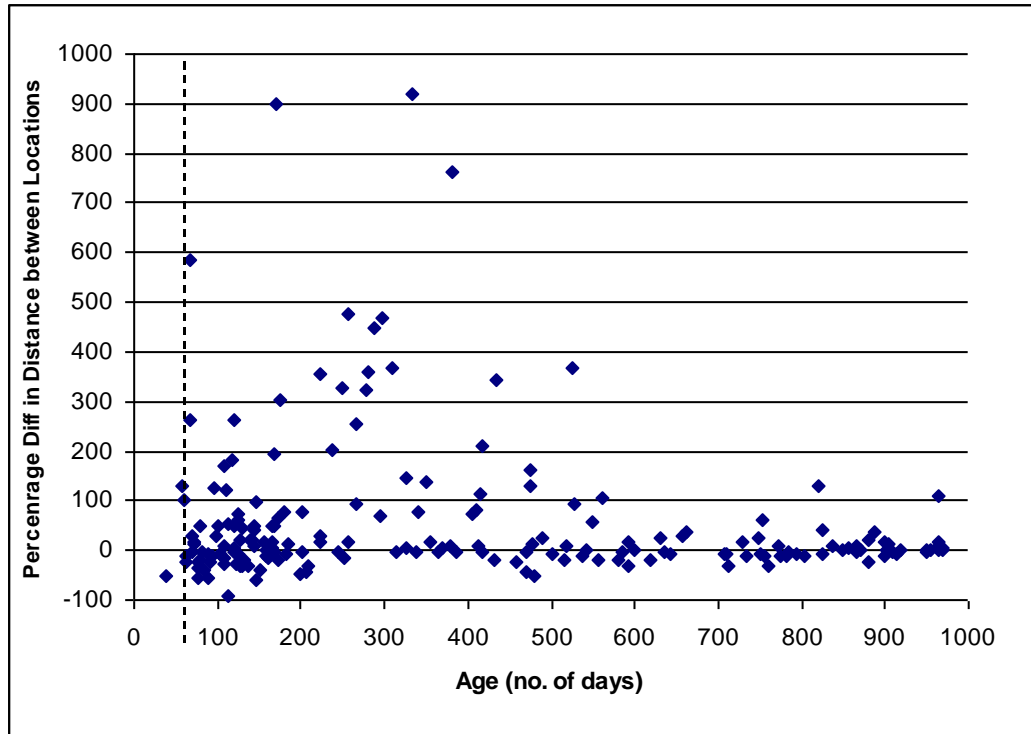
Figure 3.10. *The percentage difference in net distance of dispersal between known locations for kiwi monitored from the chick age-class until they had established a territory. The dashed line indicates the minimum age at which the net difference was greater than 90%, (when dispersal occurs from the natal area).*
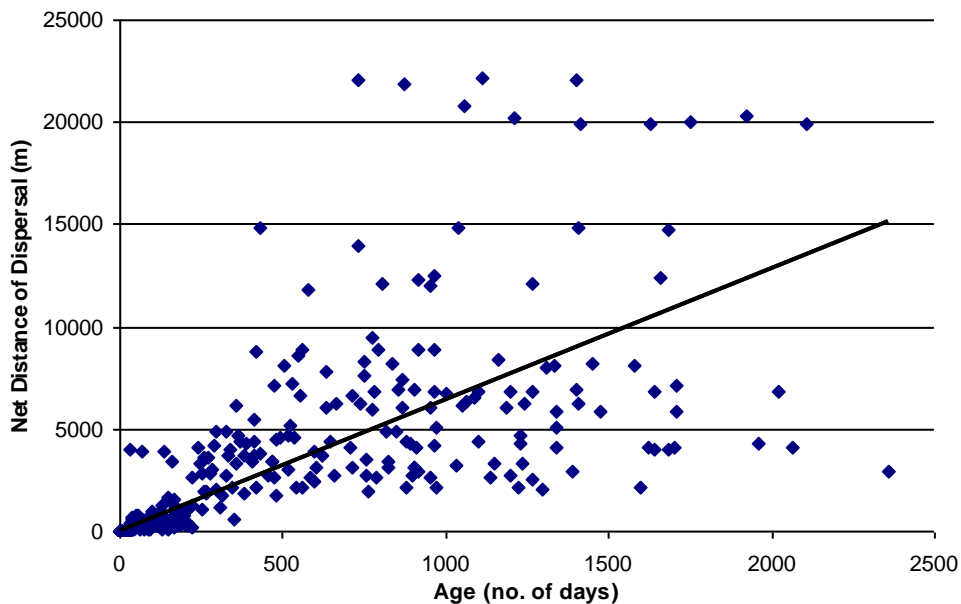
Figure 3.11. *The net distances of dispersal of kiwi that were monitored from hatching until they had established territories (n = 297). The solid line indicates the line of best fit for the relationship between age and net distance (m) of dispersal travelled by kiwi (Net distance (m) = 6.4*age).*
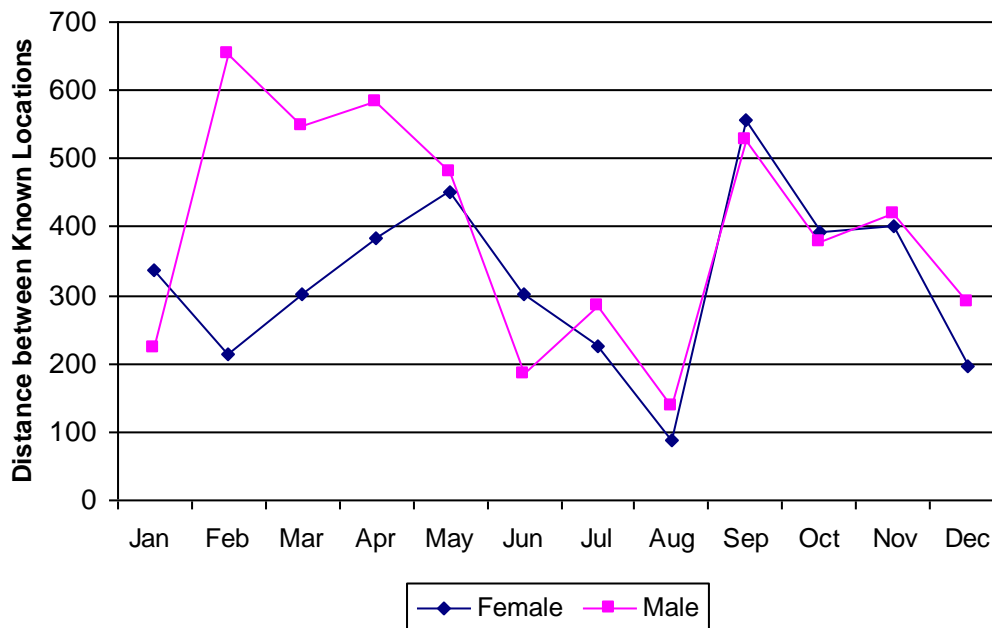
Figure 3.12. *The average distance travelled each month in metres (males n = 63, females n = 67) between known locations by male and female kiwi chicks over all years (2001 – 2008). The average number of days between known locations was 31 days.*
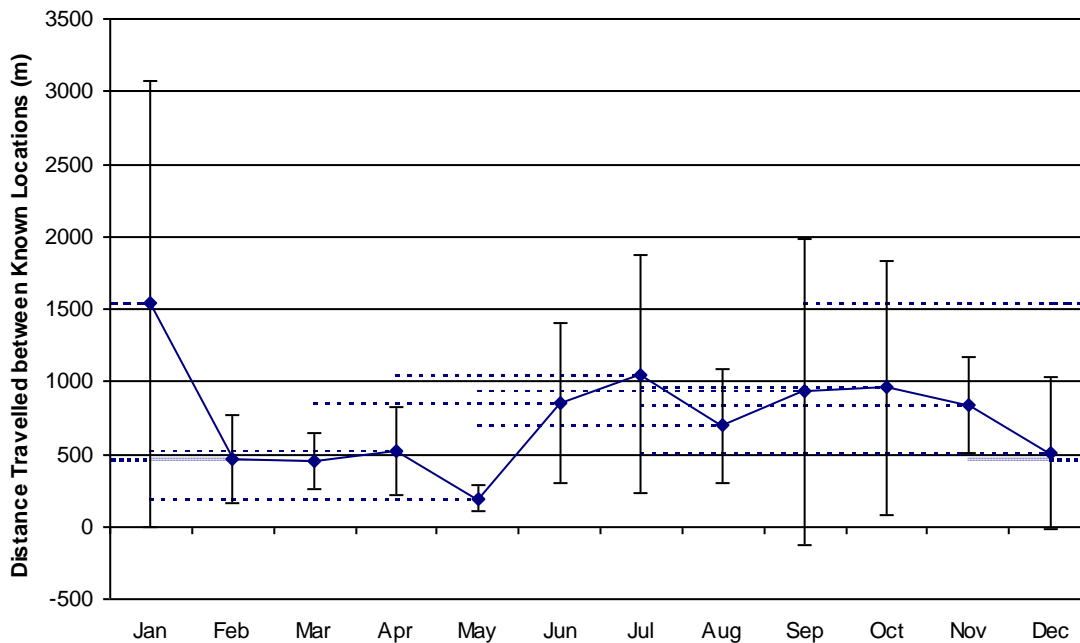
Figure 3.13. *The average distance (95% CI, n = 137) travelled each month and between captures or known locations for female sub-adult age-class kiwi at the Moehau Kiwi Sanctuary from 2001–2008 that were monitored from the natal area until they had established territories. Each month represents the date of capture or known location. The mean distance travelled was determined over a period of 31 days, and the dashed line represents the time between known locations (mean = 113 +/- 8 days).*
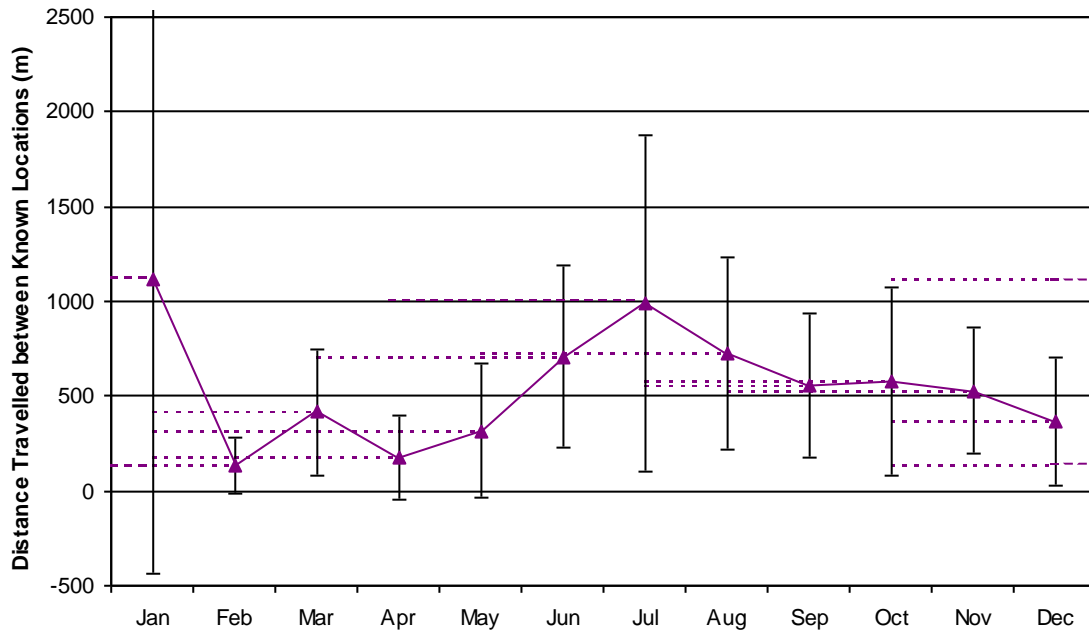
Figure 3.14. *The average distance (95% CI, n = 100) travelled each month and between captures or known locations for male sub-adult age-class kiwi at the Moehau Kiwi Sanctuary from 2001–2008, that were monitored from the natal area until they had established territories. Each month represents the date of capture or known location. The mean distance travelled was determined over a period of 31 days, and the dashed line represents the time between known locations (mean = 113 +/- 8 days).*
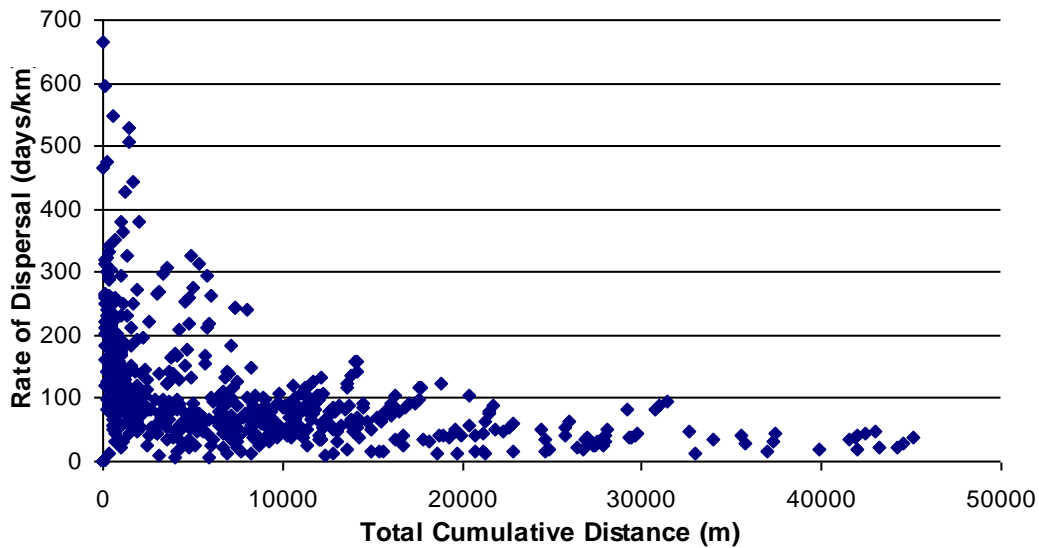
Figure 3.15. *The total cumulative distance travelled compared to the rate of dispersal between known locations of all wild-reared kiwi at Moehau Kiwi Sanctuary from 2001–2008 (n = 717). Log (Rate) = 2.066 – 0.000019*Distance (R² = 28.1%, p = <0.0001).*
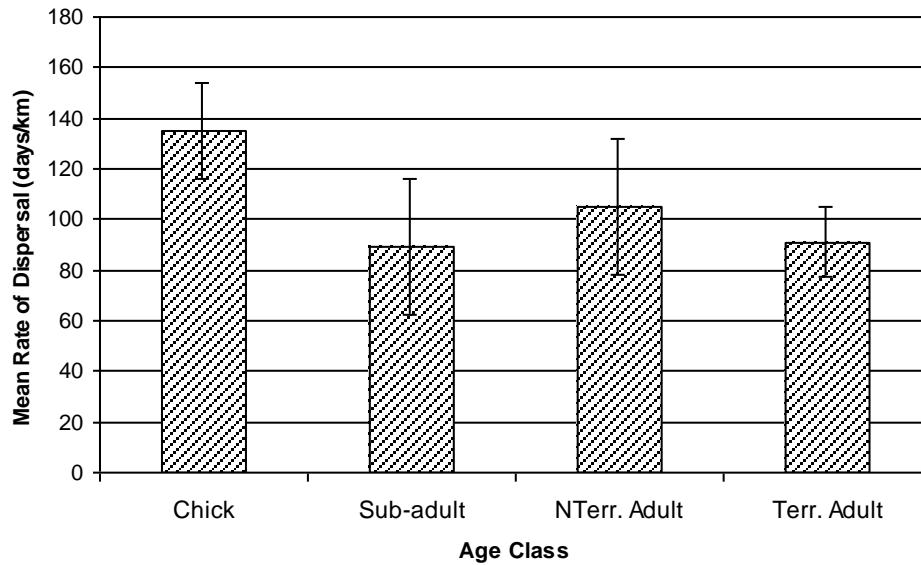
Figure 3.16. *The average rate of dispersal in days per kilometre (95% CI, n = 130) between known locations of each age-class and over all years (2001– 2008). The territorial adult age-class rate of dispersal was the average of all other age-classes.*
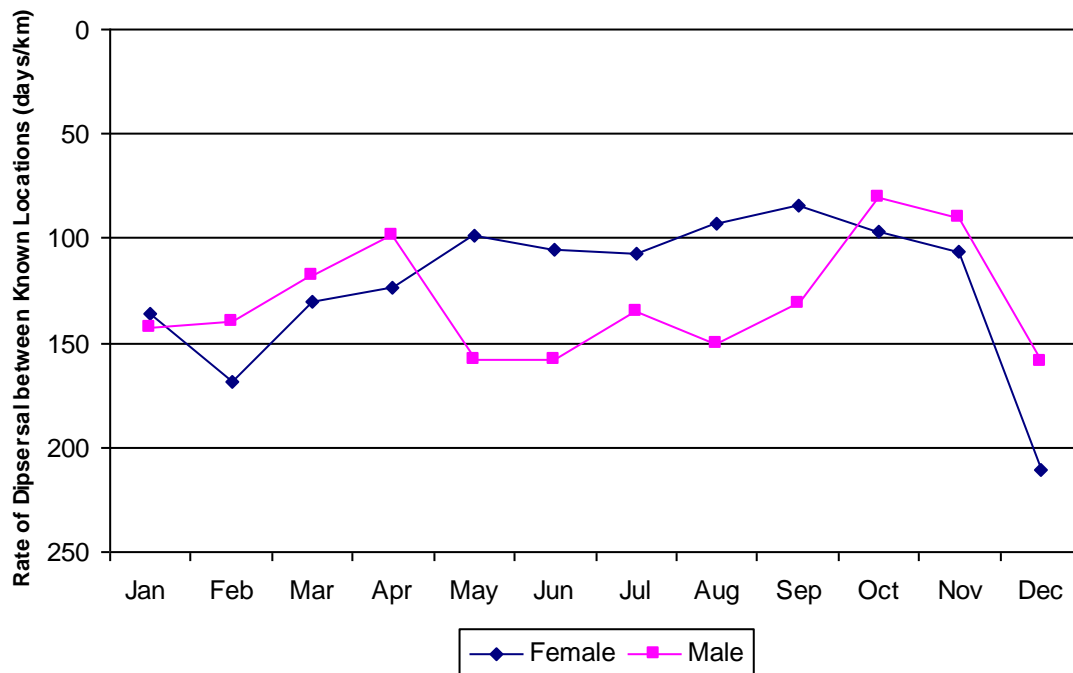
Figure 3.17. *The average rate of dispersal in days per kilometre travelled each month (males n = 63, females n = 67) between known locations by male and female kiwi chicks over all years (2001– 2008). The average number of days between known locations was 31 days.*
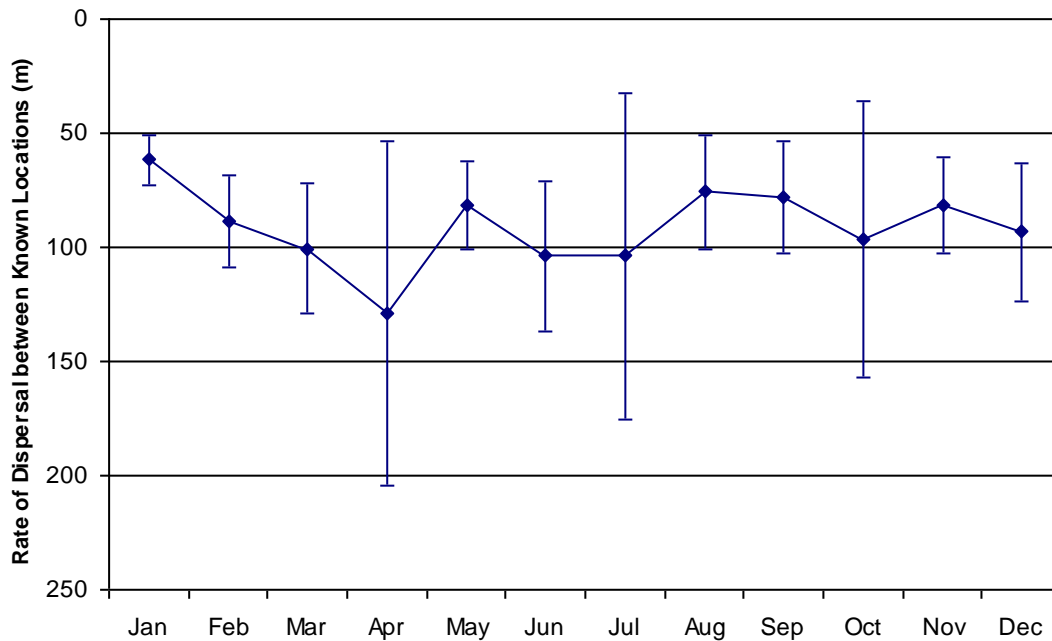
Figure 3.18. *The average rate of dispersal in days per kilometre for each month (95% CI, n = 237) and between captures or known locations for all sub-adult age-class kiwi that were monitored at Moehau Kiwi Sanctuary from 2001–2008. The average days since last capture of sub-adults was 113 days (95% CI +/- 8), or 3.8 months.*
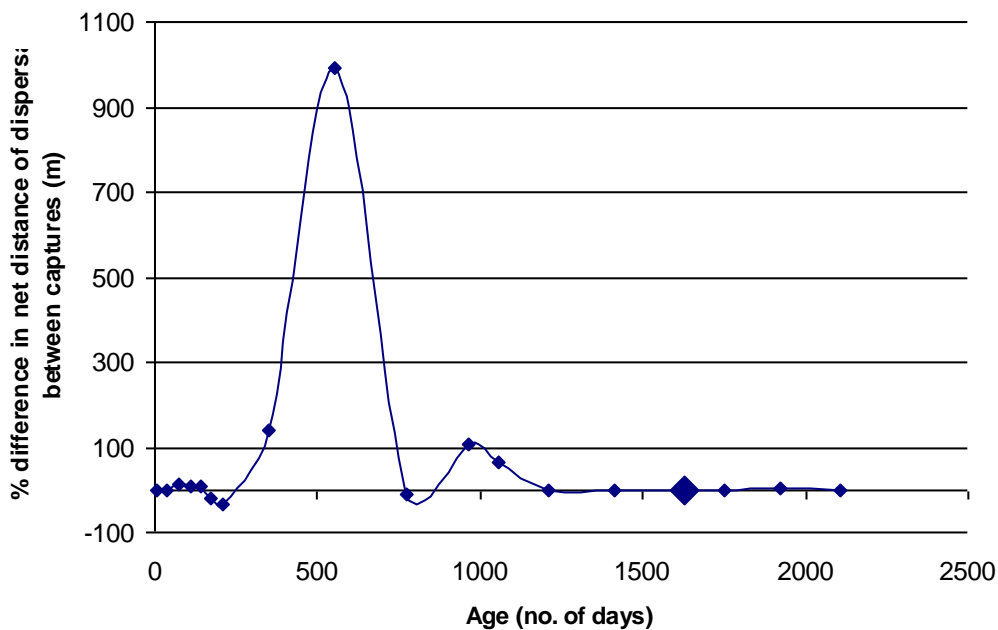
Figure 3.19. *The percentage difference in net dispersal between two consecutive locations and all previous locations of a female kiwi (Baggins) aged five years and monitored from hatching (March 2002) until a territory had been established. A territory was established when the percentage difference in Net distance of dispersal was <4% (1629 days).*
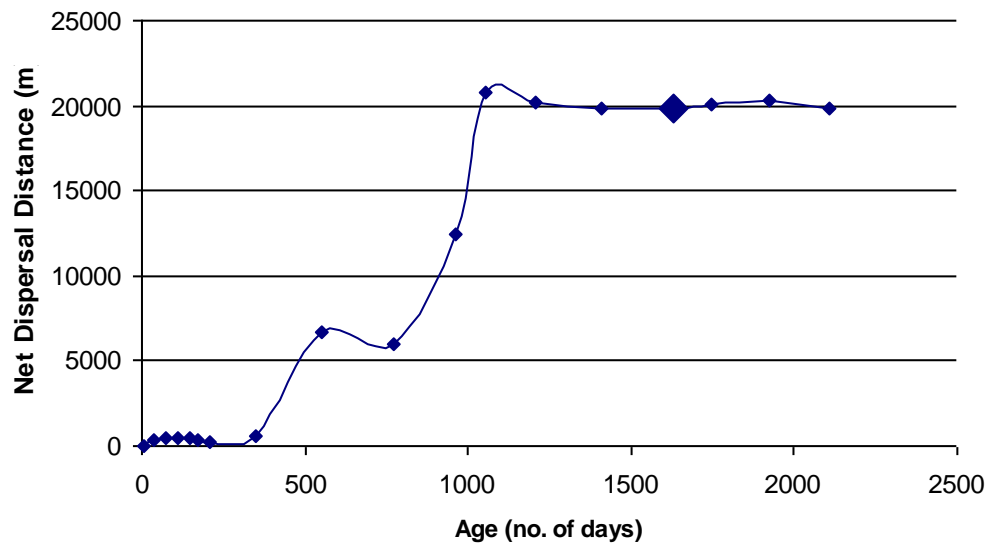
Figure 3.20. *The net distance of dispersal of a female kiwi (Baggins) aged five years, and monitored from hatching (March 2002) until a territory had been established at 1629 days (when the Percentage difference in Net distance was <4%).*

Table 3.1. *The methods used to determine territoriality (See Chapter 3.2.1) and the comparative results (in brackets) using the criteria of the percentage difference in net dispersal being less than 4% (n = 22) for kiwi monitored as chicks (age <50 days). (Highlighted results indicate where these criteria did not match). ONE kiwi results displayed in italics.*

With mate	With eggs/chick	Distance between captures <500m. Captures >six months apart.	Net Distance (<4% diff.).
		1 (0.08)	
		1 (**4.73**)	
		1 (1.48)	
		1 (0.48)	
1 (0.11)		1	
1 (**5.56**)		1	
		1 (1.31)	
	1 (0.51)	1	
		1 (0.92)	
	1 (**24.21**)		
		1 (2.20)	
		1 (**13.50**)	
		1 (0.17)	
		1 (1.57)	
1 (2.24)		1	
		1 (1.53)	
		1 (3.25)	
		1 (1.24)	
	1 (2.02)	1	
		1 (3.26)	*
		1 (2.03)	*
			1 (0.07)
		1 (0.97)	
		1 (2.75)	
		*1 (**27.5**)*	
		1 (1.29)	

* Age when first monitored > 50 days.

61
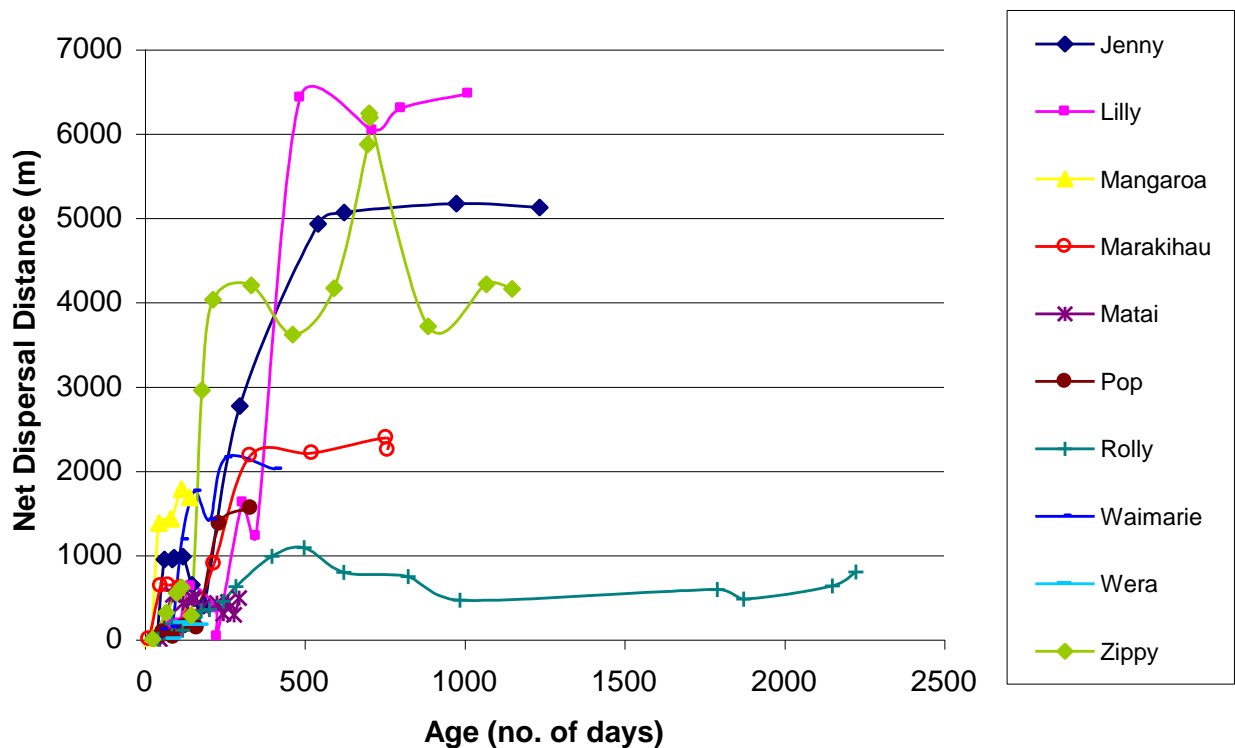
Figure 3.21. *Net distance of dispersal of Operation Nest Egg (ONE) kiwi released back into Moehau Kiwi Sanctuary after hatching in captivity once they had exceeded their hatch weight.*

Table 3.2. *The average rate and distance of natal dispersal in the different age-classes of Operation Nest Egg kiwi (ONE) released at Moehau from 2001–2008. The rate is measured between known locations as the number of days taken to travel one kilometre.*

Age Class	Mean Age (days)	95% CI	Mean Net Distance (m)	95% CI	Mean Rate (days/km)	95% CI	n
Chick	175	29	877	638	161	81	10
Sub-adult	641	233	3067	2075	113	56	8
Non-territorial adult	1537	1484	3356	5637	232	572	3
Territorial Adult	1160	693	4084	4002	151	142	4

Table 3.3. *The average rate and distance of natal dispersal in different age-classes of wild-reared kiwi at Moehau Kiwi Sanctuary from 2001–2008. The rate is measured between known locations as the number of days taken to travel one kilometre.*

Age Class	Mean Age (days)	95% CI	Mean Net Distance (m)	95% CI	Mean Rate (days/km)	95% CI	n
Chick	149	14	834	265	135	19	44
Sub-adult	682	86	5487	1204	89	27	52
Non-territorial adult	1526	150	7552	2407	105	27	26
Territorial Adult	1298	135	7300	2539	91	14	22

Table 3.4. *The median rate and distance of natal dispersal in the different age-classes of Operation Nest Egg kiwi (ONE) released at Moehau from 2001–2008. The rate is measured between known locations as the number of days taken to travel one kilometre.*

Age Class	Median Age (days)	Median Net Distance (m)	Median Rate (days/km)	n
Chick	164	536	109	10
Sub-adult	664	2130	80	8
Non-territorial adult	1236	4155	136	3
Territorial Adult	1160	4637	140	4

Table 3.5. *The median rate and distance of natal dispersal in different age-classes of wild-reared kiwi at Moehau Kiwi Sanctuary from 2001–2008. The rate is measured between known locations as the number of days taken to travel one kilometre.*

Age Class	Median Age (days)	Median Net Distance (m)	Median Rate (days/km)	n
Chick	148	542	116	44
Sub-adult	625	4470	75	52
Non-territorial adult	1488	5861	91	26
Territorial Adult	1252	6250	88	22

3.4 Discussion

The greater distance travelled in cumulative distances of dispersal by non-territorial adults compared to sub-adult kiwi was most likely due to the longer average monitoring period for non-territorial adults. The net dispersal distance of sub-adult compared to non-territorial adult or territorial adult kiwi was similar. The greater distance in net distance of dispersal and rate of dispersal by sub-adults compared to chicks is indicative of natal dispersal occurring primarily during sub-adulthood in kiwi.

Sub-adult female kiwi dispersed further in net distance than did males, but not in the cumulative distance. Rates of dispersal were similar. Other studies of natal dispersal in bird species have also found a bias toward females in the net distances travelled, as well as in the rate of dispersal (Small and Rusch, 1989; Morton, 1992). The difference in kiwi may suggest that perhaps females are avoiding inbreeding and intrasexual or intersexual competition (Pusey, 1987). Greenwood suggests ecological factors such as intrasexual competition as being the main driver in dispersal but Reed et al. (1999) explain that natal dispersal is probably a more deliberate prospecting for mates and food sources. However, intersexual or intraspecific competition in kiwi is unlikely to occur due to differences in behaviour and in their morphology. Differences in bill length between genders and age-class mean that food availability is not a source of conflict, as kiwi can feed at different soil depths and so avoid competition (Reid et al., 1982; Gibbs, 2000; Robertson and Colbourne, 2003; Cunningham, 2006).

Although there was no statistically significant difference in the net distance of dispersal between males and females of non-territorial adult (nta) and territorial adult (ta) kiwi which would be expected given the differences between male and female sub-adult kiwi, this may be due to the small sample size of each gender, as the average net distance of female kiwi (nta = 9,166m, ta = 8,454m) away from the natal area was substantially further than adult males (nta = 6,022m, ta = 6,435m).

Previous studies have suggested that conspecific attraction may occur in kiwi as has been found in a range of other bird species (Stamps, 1988) and that this may influence kiwi dispersal. This conclusion has come from observations of greater dispersal distances of juvenile kiwi released into areas where no resident kiwi were present (Grant, 2003). However, the results of this study demonstrate that sub-adult kiwi will disperse similar or greater distances (median = 4470m) (Tables 3.4 & 3.5) than those observed by Grant (2003) (median = 3,459) through areas known to have territorial kiwi present and into areas with comparatively fewer kiwi present (de Monchy, 2004; de Monchy and Forbes, 2006). Assuming call rates of kiwi are an indication of the abundance and density (Pierce and Westbrooke, 2003), kiwi call survey data from Moehau Kiwi Sanctuary in 2005 showed and average call rate of 3.6 calls per hour (3.2 in 2004) from an estimated 40 birds and yet of the call rate in areas outside of MKS in 2005 had call rates of 0.62 calls per hour from an estimated eight birds (Stewart, 2007).

Adult kiwi are territorial (Colbourne and Kleinpaste, 1983; McLennan et al., 1987; McLennan, 1988) with territory sizes of North Island Brown Kiwi breeding pairs ranging anywhere between 19–74 hectares (McLennan et al., 1987; McLennan, 1997; Miles et al., 1997), except in Northland where territories are much smaller at 5–6 hectares (Taborsky and Taborsky, 1992). The maximum width of adult kiwi territories is about 800–900m (Miles et al., 1997). All 44 of the wild-reared kiwi chicks or sub-adult kiwi that were monitored from the chick to adult age-class dispersed at least 1,574m in net distance from the parental home territory or natal area, and therefore displayed dispersal and not philopatry. Coromandel North Island Brown Kiwi do not display the same aggressive behaviour as other Brown Kiwi species such as the Okarito Brown Kiwi which are known to deliberately kill unrelated chicks that stray in to their territory (Colbourne, 1998) and therefore this threat is unlikely to be a factor influencing dispersal in Coromandel kiwi.

Kiwi were shown to disperse through all forest types and open pasture during natal dispersal (See Chapter Four). Other endemic bird species, such as North Island Robin (*Petroica longipes*) have also demonstrated this. Robin were not dependent on

undisturbed old growth forest during natal dispersal, and found in all forest habitats (Wittern and Berggren, 2007). Habitat selection is one mechanism that might explain dispersal distance. Previous studies have suggested that kiwi appear to disperse shorter distances in intact forest habitats than in fragmented and mosaic forest habitats (McLennan, 1997; Grant, 2003), and yet other studies have suggested that the distance of natal dispersal may be related to the number of territories traversed as discussed in a study by Matthysen et al. (1995). It was concluded in the study by Matthysen et al. (1995) that forest fragmentation caused an increase in the distance of natal dispersal of nuthatches (*Sitta europaea*), but that there was no change in the number of territories that were crossed. Therefore the number of territories may be more of a factor to dispersal than the degree of habitat fragmentation (Greenwood and Harvey, 1979; Arcese, 1989).

Determining the percentage difference in the net distance of dispersal between captures appeared to be a robust method of detecting territoriality in sub-adult or adult kiwi that were monitored from the chick age class, or more specifically, from hatching or within 50 days of age or (Table 3.1). This is useful if territoriality of kiwi cannot be otherwise determined using other methods. Current methods of determining territoriality in kiwi primarily depend on finding evidence of breeding behaviour, such as when they are found with a mate, on a nest with either a chick or egg(s); and in the case of female kiwi, when they are found to be gravid (Robertson, 2004). The criteria for determining territory establishment, using the distance travelled being greater than 500m between captures over a period greater than six months, corresponded with evidence of breeding behaviour for five out of the six birds where evidence of breeding behaviour was detected.

In this study it was determined that 21 kiwi had established territories and only six of these were confirmed as territorial through evidence of breeding behaviour (Table 3.1). This may suggest that factors other than having a mate (potential breeding partner) determine whether kiwi establish a territory. Factors such as habitat selection, or conspecific attraction cannot be precluded as a possible contributing element (Muller et al., 1997; Grant, 2003).

When the percentage difference in net dispersal between captures was greater than 90% (for kiwi that eventually established territories), this tended to coincide with greater dispersal distances from the natal area. This occurred on average at around 302 days or 43 weeks of age, similar to the age range of 30–40 weeks recorded by McLennan (1998) for NI Brown Kiwi at Waikaremoana.

The rate of dispersal of kiwi in this study was erratic over the year, (all years pooled) and there was a wide variation in dispersal distances between individual kiwi within each age-class. However, the lack of any difference in the rate of dispersal between female and male sub-adults, despite the difference in distances, may suggest that sub-adult female kiwi dispersal is more direct than sub-adult males.

Rates of dispersal were estimated as the number of days to travel one kilometre between known locations. Estimates of how far kiwi of each age-class and gender disperse could be calculated for North Island kiwi that are monitored in other kiwi-management areas based on the rate of dispersal, and estimated age of kiwi. This information could be useful in providing information on possible locations of kiwi that cannot be found due to remote and/or otherwise inaccessible terrain. If the rate of dispersal between captures of a kiwi is known then the corresponding total cumulative distance of dispersal can be interpolated for kiwi of known age-class, however the relationship between the rate of dispersal and total cumulative distance is weak (Figure 3.15). With the total cumulative distance known then the net distance of dispersal of a kiwi can then be established (Figure 3.2). Net distance can also be more easily estimated if the age in days or the age-class is known by using the linear equation net distance (m) = 6.4 * age (days) (Figure 3.11).

3.4.1 Operation Nest Egg Kiwi
This study found similar results to a study by Grant (2003) on ONE North Island Brown Kiwi released at Tongariro Kiwi Sanctuary. Grant (2003) monitored 21 chick and sub-adult kiwi for more than 36 weeks after being released at between 15–75 weeks of age, and found that all kiwi travelled more than 1,000m net distance from their release site. In this study on ONE kiwi released at Moehau, seven of the eight kiwi monitored from 42

weeks of age had moved more than 1,000m in net dispersal distance from the natal area or release site, and the average net dispersal of sub-adults was over 3km (n = 8). However, one of the eight ONE chicks that was monitored for more than 42 weeks did not display natal dispersal and remained philopatric to the natal area, and probably still within the parental territories right up until monitoring ceased at six years of age. Kiwi dispersed less distance and at a slower rate than wild-reared kiwi (except for ONE kiwi in the chick age-class); this may be explained by possible behavioural differences due to the captive-reared environment. For example kiwi that are captive-reared are unable to move or forage as they would in the wild. There may also be genetic differences, as kiwi that are captive-reared are often in need of assistance during hatching and may not have otherwise survived in the wild. Those kiwi that receive assistance during hatching may be passing on genes that are in some way deficient.

3.4.2 Limitations and Bias

There were limitations in determining the monthly rates and distances of dispersal in sub-adults. As sub-adult kiwi were only captured on average every 113 days (95% CI +/- 8), any interpretation of data from figures (13,14 & 18) on monthly dispersal distances and rates needs to take into consideration that the means reflect the average monthly results derived from the distance or rate travelled over an average of 113 days (95% CI +/- 8) between known locations. However imprecise the results are in estimating rates and distances travelled on any specific month, it does provide an indication of the average rates and distances travelled within a period of a month and the range between months.

Accurate dispersal figures depending on age had to be determined from kiwi that were monitored from hatching, or that were in the chick age-class and therefore likely to be within the natal area. However, figures on the rate of dispersal depending on 'age-class' were only determined if kiwi were monitored throughout any particular age-class as they were defined in this study.

Dispersal figures at Moehau, although greater than other studies on North Island Brown Kiwi may still be underestimated due to the confined nature of the peninsula, with the Hauraki Gulf surrounding it on the northern, western, and eastern sides, and its maximum

width of around 10km. This idea is supported by the finding in this study that kiwi which dispersed southward had the greatest net distances of dispersal.

The majority of studies are unable to measure the distance of natal dispersal accurately due to a lack of verification of reproduction or inability to monitor until reproduction (Howard, 1960). In most dispersal studies reliable quantitative data on sex-biased natal dispersal in birds is difficult to obtain, much of it coming from small sample sizes, limited study areas, and incomplete data sets (Wolff and Plissner, 1998). Studying variation in dispersal requires datasets on a large spatial scale with a large sample of individuals of known gender and age class (Mathysen et al., 2005). This study fulfils the above requirements with most samples, except those regarding gender within age-classes, being above n = 30, and the study spanning a period from 2001–2008. However due to the small sample sizes in regard to gender of each age-class there is limited value in the results regarding differences in distances and rates of dispersal, particularly differences between months. Only a few kiwi chicks of known gender were included (n = 31), with gender being determined through genetic analysis or from when they had reached adulthood. Gender can also be determined in sub-adults and adults through physiological differences in weight and bill length (Robertson, 2003; McLennan et al., 2004).

Differences in the rates and distances of dispersal between years depending on the gender or age-class were not examined due to the lack of comparable data between years for individual kiwi. Individual kiwi were caught at random times of the year and at intervals ranging from days to months. Also determining differences between years could not be examined as confounding factors were not identified and included in the data set.

Chapter 4.

Habitat and Roost Selection in Kiwi

4.1 Introduction

At Moehau Kiwi Sanctuary anecdotal evidence from kiwi capture notes recorded by staff, and baseline call survey data collected in 2000, suggests that kiwi were usually found in forest types with the densest vegetation cover such as in manuka/kanuka forest or sub-alpine scrub (Stewart et al., 2000). North Island Brown Kiwi in Tongariro forest were found more often than expected in unlogged and broadleaf/scrub compared with logged forest and toe toe (*Cortaderia* spp.), given the relative proportions of these habitat types in each region (Miles et al., 1997). Chan (1999) concluded that juvenile kiwi in Trounson Park in Northland demonstrated a preference for seral vegetation (successional vegetation - scrub and regenerating bush such as manuka and kanuka forest) over mixed podocarp/broadleaf and kauri-dominated forest communities. McLennan (1997) also noted that young kiwi at Waikaremoana in the Urewera selectively inhabited dense regenerating forest, and Taborsky and Taborsky (1995) found kiwi selected for seral vegetation and native forest over pine forest and other habitat types with kiwi roosting selectively in seral vegetation and marshes.

It was suggested by Chan (1999) that further research into the dispersal, distribution, and habitat use of juvenile kiwi should concentrate on the reasons for habitat selection. Chan (1999) found no evidence of adult kiwi excluding juvenile kiwi from their territory. However, juvenile and adult kiwi were observed to have substantially different habitat use. One factor that may influence the distribution and habitat use of juvenile kiwi and adults could be intra-specific interactions (Gibbs, 2000).

The study on kiwi and habitat selection at Trounson Park in Northland by Gibbs (2000) found that juvenile kiwi that utilised all three main habitat types present (kauri forest, podocarp/hardwood forest, and kanuka/manuka scrub) had a higher survival rate and

faster growth rate than those juvenile kiwi that utilised only one or two of these main habitat types. This was interpreted as evidence that differences in resources such as food, and shelter from predators, existed among habitat types.

Gibbs (2000) established that habitat use by juvenile kiwi was different from that of male parents. This difference appeared to be due to adult kiwi selecting for podocarp/broadleaf forest more than juvenile kiwi, while juvenile kiwi selected for pasture, possibly due to a seasonal food source. The apparent difference between the habitat use of adult and juvenile kiwi could be due to their different beak length resulting in different food availability for different cohorts in the same areas (Swennan et al., 1983; Gibbs, 2000; Cunningham, 2006). It may also be due to the density of ground-cover in a habitat or forest type (Taborsky and Taborsky, 1995; Chan, 1999).

4.1.1 Roost Site Selection in Kiwi

McLennan (1987) noted that North Island Brown Kiwi that were monitored in Hawkes Bay spent 36% of daytime hours in burrows and the rest of the day on the surface under vegetation or in hollow logs. Male kiwi were found significantly more often in burrows than females. Other studies have concluded that the type of roosts used is highly dependent on the habitat type (Taborsky and Taborsky, 1995; Miles et al., 1997). Miles et al. (1997) observed that surface roosts were being used almost exclusively under native toe toe and exotic pampas grass (*Cortaderia* spp.), and far more often in unlogged and broadleaf/scrub than in logged forest. Males used surface roosts more than expected and females preferred roosts associated with hollow logs. The type of roost site was also dependent on the season, with surface roosts tending to be used most in summer, while excavated roosts were used more in winter and spring. Both McLennan (1987) and Miles et al. (1997) established that kiwi generally roosted in a different place each day but did return to previously used roost sites.

Although previous studies have examined habitat selection and preferences for roost sites and forest type, no studies have investigated selection for ground-cover vegetation types when kiwi roost on the surface. If preferences for ground-cover types exist, then encouraging these types of ground-cover in kiwi habitat may increase the area of habitat

71

available to kiwi and decrease competition for holes as roost sites. Conversely, if holes are selected for, artificial holes might be of use as a management tool. In this chapter, kiwi selective use of roost sites, ground-cover, forest-cover and physiography are tested. In addition, selection differences between age-classes, gender, months and elevation are explored.

4.2 Methodology

See also Chapter Two: General Methodology.

There were a total of 1347 observations from 228 kiwi at capture sites or known locations from 2001 and 2008. The first captures of each individual kiwi were removed from the initial data set because the first captures of sub-adult and adult kiwi were usually made by dogs finding them on the surface, and the first captures of chicks were usually made when the chick was in a nest (usually in a hole). Data was pooled over all years from 2001–2008. Any differences in association between age-classes and gender of kiwi and the location characteristics were tested using Chi-square tests, as well as differences among months and across elevations.

The observations of kiwi were made from 228 monitored individuals, and varied between 1–17 observations per individual (average = 6), and although the observations were temporally divided, there may be bias in the sampling method due to individual preferences, so any future studies should attempt to eliminate this bias or include individual preferences in the data analysis. To mitigate the possibility of bias in this study the first captures of kiwi were removed from the data set, and then the second captures of kiwi were compared with all subsequent captures. From this comparison there was found to be no difference in the proportion of roost site types selected between the two samples (in both samples, kiwi selected for roost site types in similar proportions), therefore it could be assumed that there was independence in observations among captures and that individual preferences did not unduly influence the results (Chi-square test df = 2, n = 1347, p = 0.83). Individual kiwi roost site selection was independent of the number of observations, therefore regardless of the number of observations kiwi did not significantly change their behaviour.

In this study there was no differentiation between ONE kiwi and wild-reared kiwi. It was decided to include ONE kiwi in the total sample due to initial investigation which showed no difference in roost site selection between the ONE (n = 110) or wild-reared chicks (n = 173) (Chi-square test df = 2, p = 0.8), and because of the low number of observations of ONE sub-adults (n = 39) and adults (n = 8).

4.2.1 Kiwi Recovery Sites

Whenever kiwi were captured or the location was known, the location was grid referenced, and habitat factors recorded. These factors included: forest-cover; ground-cover vegetation (fern fronds, grasses, ground ferns, rushes, logs and mixed cover); elevation; month of capture; whether they were caught in a burrow, a hollow log, or on the surface; whether they were alone or with another kiwi; and the topography (ridge, gully, stream or face/slope).

4.2.2 Ground-cover Selection

The ground-cover vegetation determined from within a one metre radius of burrow or surface roost of a kiwi. The vegetation classifications are general representations of a more complex plant species composition. A more detailed description of species and genera are provided below:

1. Fern Fronds – dead fern fronds and debris

Ponga (*Cyathea dealbata*), mamaku (*Cyathea medullaris*), smiths tree fern (*Cyathea smithii*), wheki (*Dicksonia squarrosa*)

2. Ground ferns:

Blechnum spp., *Lycopodium* spp. *Gleichenia* spp. *Aspidium* spp. mangemange (*Lygodium articulatum*), bracken (*Pteridium aquilinum*)

3. Grasses:

Both exotic and native grass spp.

4. Rushes:

Juncus spp., *Typha* spp., etc

5. Mixed cover:

A variety of broadleaf shrubs and vines as ground-cover.

6. Logs:

Any association with logs, fallen or standing.

4.2.3 Forest-cover Selection

Forest types were determined and categorised using landcover information gathered from aerial photographs. GIS information was gathered from Land Information New Zealand (LINZ) and Department of Conservation landcover databases, as well as from on the ground observations of where kiwi were found.

The main forest types were divided into three categories: manuka and kanuka forest, broadleaf forest and sub-alpine scrub (Figure 4.1). The proportions of forest types are based on data available in 2006. Out of the total forest-cover, manuka/kanuka covered approximately 47%, broadleaf 46% and sub-alpine scrub 5%. Pine plantations covered the remaining 2%. Pine forest and exotic pasture were excluded from the analysis for forest-cover selection by sub-adult kiwi, due to the low occurrence of sub-adult kiwi in this forest type and its low availability. Chi-squared tests were used to test forest-type selection among age-classes and between genders, and whether sub-adult kiwi selected for different forest-types. Other studies on kiwi habitat preferences or selection have also used Chi-squared analysis for similar data (Taborsky and Taborsky, 1995; Miles et al., 1997) (Figure 4.1).
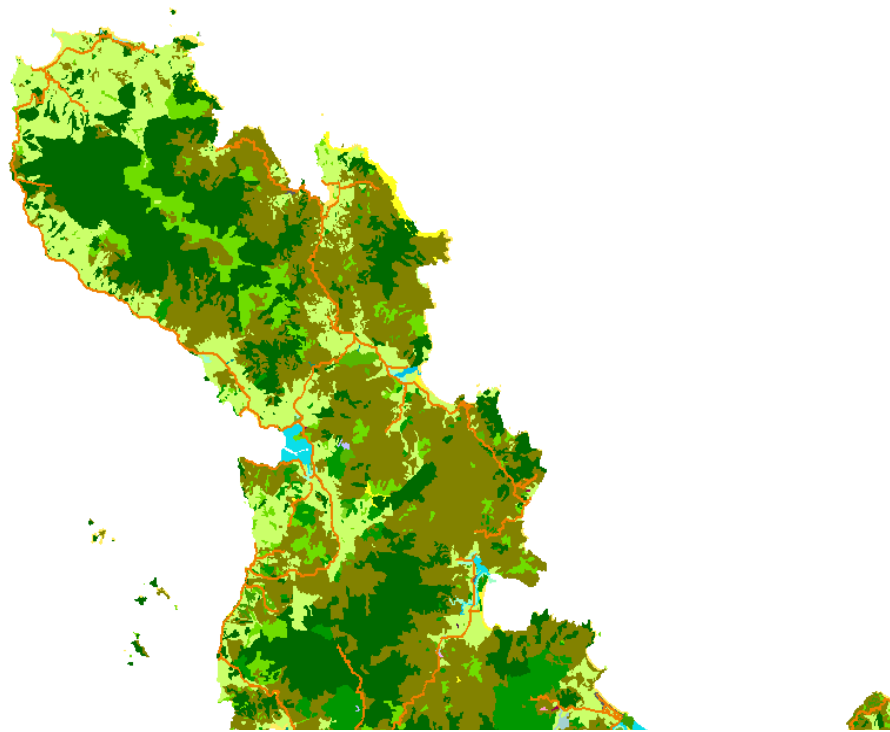
Key

■ Broadleaf / Podocarp
■ Pine plantation
■ Broadleaf
□ Exotic grassland
■ Kanuka / manuka

Figure 4.1. *Map of Moehau Range depicting different types of vegetation cover.*

4.2.4 Elevation

Moehau Mountain is the central geographical feature of Moehau Kiwi Sanctuary and has an elevation of 892 metres above sea level (asl.), with only 5% of the total land area of approximately 18,000 hectares being above 600m. In this study elevation data was categorised into 100m contour intervals (eg. 0–100m, 200–300m above sea level), and highlighted in Figure 4.2. Depending on the elevation at which kiwi were observed, they were then allocated to the 100m elevation interval that this fell within. See Figure 4.21 for a representation of the relative proportions of forest-cover types as elevations increase.
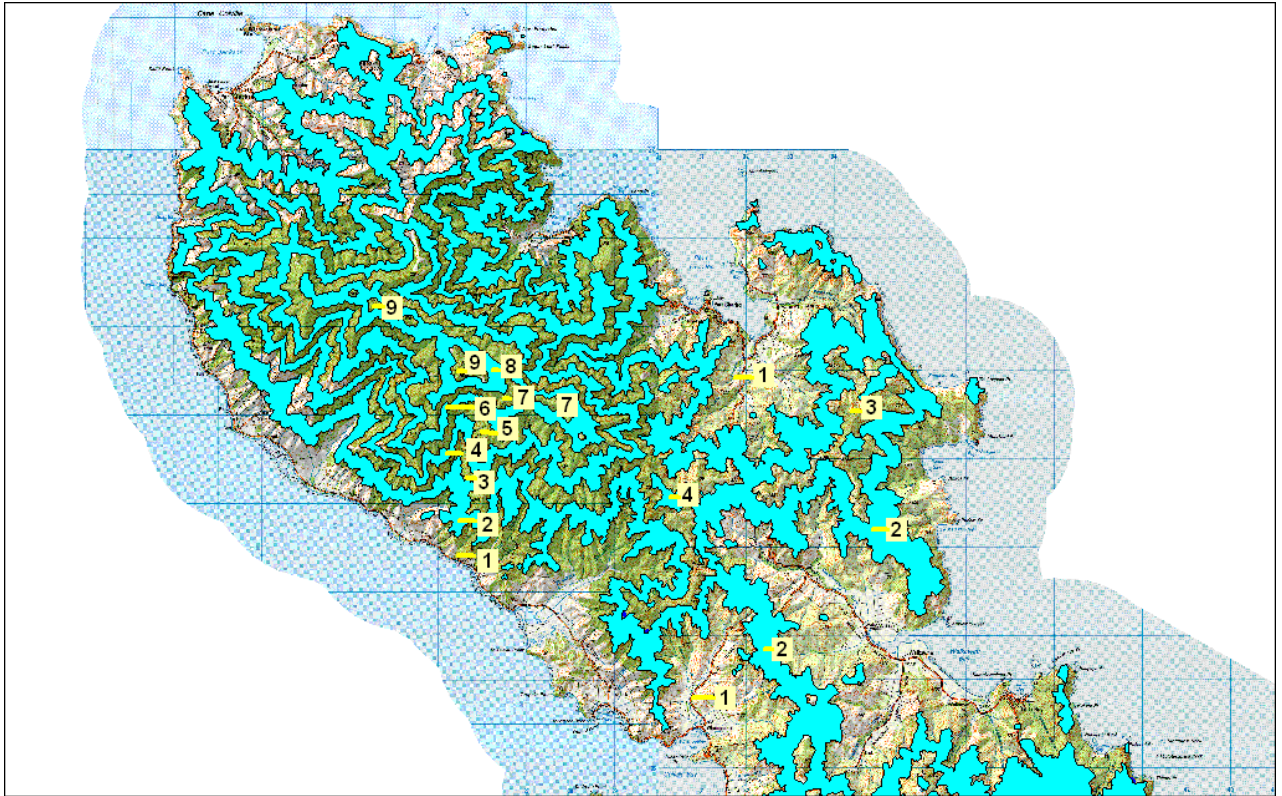
Figure 4.2. *Moehau Range showing elevation contour intervals of 100m represented by numbers 1-9 (1=0–100m, 2=100–200m…), beginning at sea level. Alternate 100m elevation bands are highlighted and labelled.*

4.3 Results

4.3.1 Roost Site Selection

For kiwi of all age-classes that were located at the Moehau Kiwi Sanctuary, 60 % roosted on the surface, 34% in holes and 6% in hollow logs.

The different age-classes of kiwi selected for different roosting sites (Chi-square test df = 4, n = 1347, p = 1.06E-63). Chicks and sub-adults selected for different of roost site types (Chi-square test df = 1, n = 410, p = 4.06E-7), with chicks found in surface roosts 91% of the time and 22% more than sub-adults. Adult kiwi selected roosting sites in holes more than other age-classes. Adult kiwi were found in holes 58% of the time and 32% more often than sub-adults (Figure 4.3).

Female kiwi and male kiwi selected for different roost site types (Chi-square test df = 2, n = 991, p = 4.33E-08). Female kiwi were found at a surface roost 65% of the time. Male kiwi roosted equally often on the surface (46%) as in a hole (47%). Adult females used a surface roost 17% more often than adult males (Figure 4.4) The differences in roosting site selection among all age-classes, was due to the differences observed in both adult female and male kiwi (Chi-square test, df = 2, n = 566, p = P = 0.011), as there was little difference between male and female kiwi in the chick and sub-adult age-classes (Figure 4.5). There was no difference in the type of roosting site selected for by male and female kiwi, between different seasons or months of the year and no differences between different age-classes of known gender.

In Spring (September-November) chicks were found on the surface 72% of the time, and were found at least 17% more often in holes compared to other seasons (Chi-square test df = 3, n = 448, p = 0.0003) (Figure 4.6). There was no statistically significant difference in the use of holes or surface roosts for sub-adults or adults between seasons or months of the year.

Kiwi were found more often in holes than on the surface at elevations above 600m asl (54% of captures) than below 600m asl (33% of captures) (Chi-square test df = 2, n =

1263, p = 7.02E-8) (Figure 4.7). Sub-adult kiwi were found more often in holes (64% of captures) at elevations above 600m asl, than below 600m asl (19% of captures) (Chi-square test df = 2, n = 296, p = 2.84E-13) (Figures 4.8). Kiwi chicks were also found more often in holes (39% of captures) at elevations above 600m asl, than below 600m asl (8% of captures) (Chi-square test df = 2, n = 448, p = 1.64E-12) (Figure 4.9). By contrast adult kiwi did not select for holes more than the surface at elevations above 600m asl.

There was no statistically significant difference for male (Chi-square test df = 2, n = 567, p = 0.19) and female kiwi (Chi-square test df = 2, n = 262, p = 0.16) in roost site selection at different elevations (Figures 4.10 & 4.11). However, both did tend towards a greater use of holes as elevation increased. Females used surface roosts more often than holes at all elevations except above 800m asl when they used holes and surface roosts the same amount of time, and male kiwi used surface roosts more often than holes at elevations less than 500m asl. (except between 200–300m asl when holes were used more often).

Chicks and sub-adults of unknown gender appear to have had the most influence on the trend toward greater use of holes as elevations increased. There were 353 chicks and sub-adults for which the gender could not be determined and 425 whose gender were known. All adult kiwi were identified as either male or female.
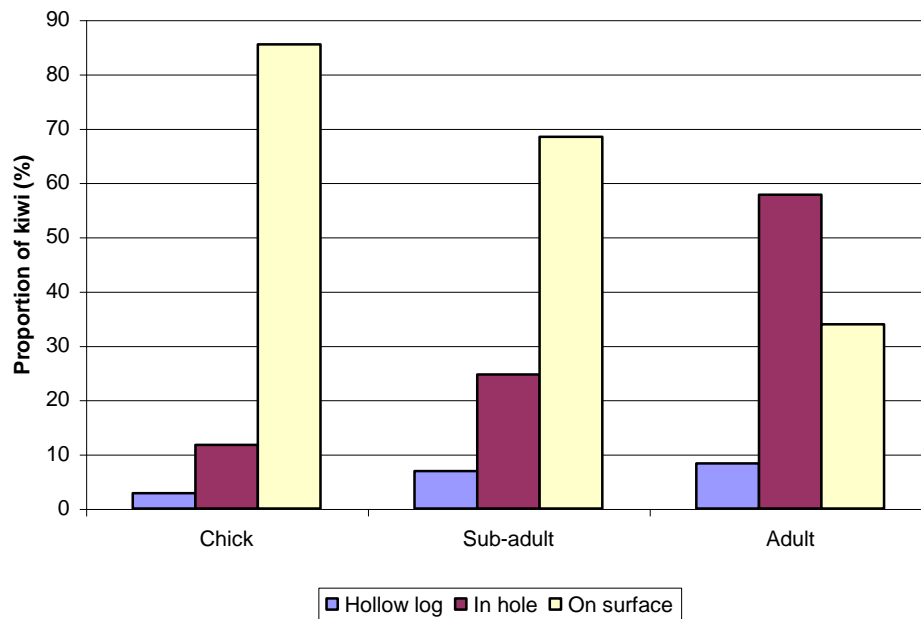
Figure 4.3. *The proportion kiwi from the chick, sub-adult and adult age-classes (n = 1347) that were observed in a hollow log, in a hole, or on the surface when located at Moehau Kiwi Sanctuary from 2001–2008.*
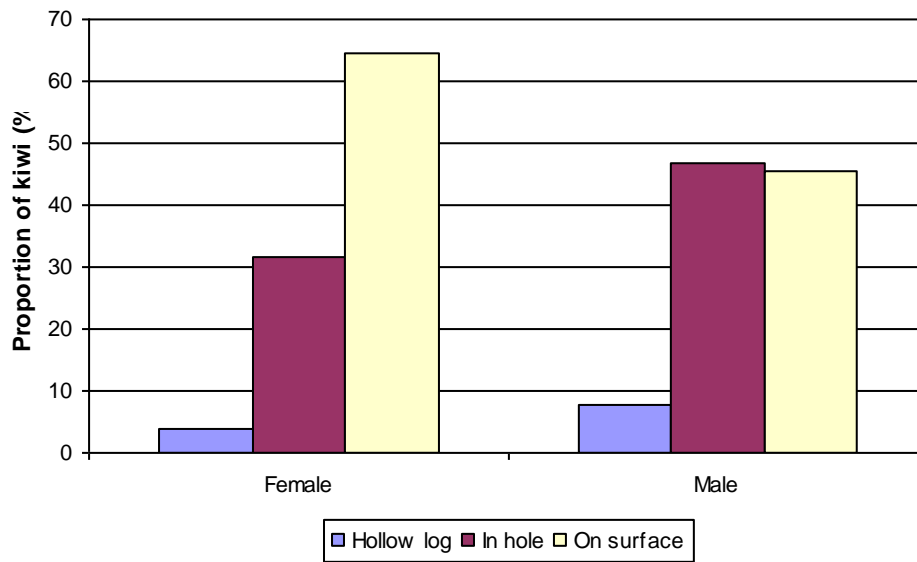
Figure 4.4. *The proportion of female and male kiwi (n = 991) of all age-classes that were observed in a hollow log, in a hole, or on the surface when located at Moehau Kiwi Sanctuary from 2001–2008.*
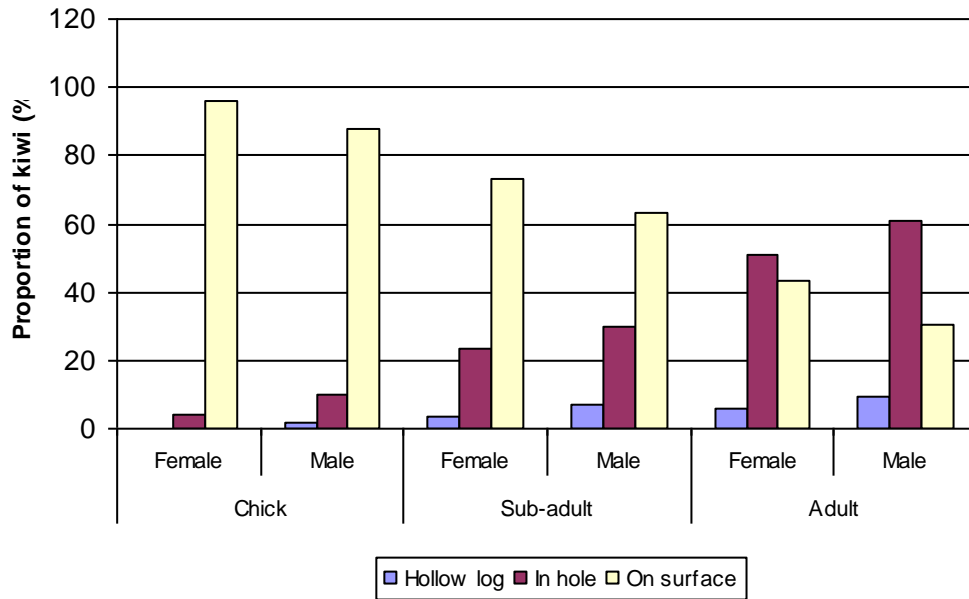
Figure 4.5. *The proportion of female and male kiwi from the chick, sub-adult and adult age-classes (n = 991) that were observed in a hollow log, in a hole, or on the surface when located at Moehau Kiwi Sanctuary from 2001–2008.*
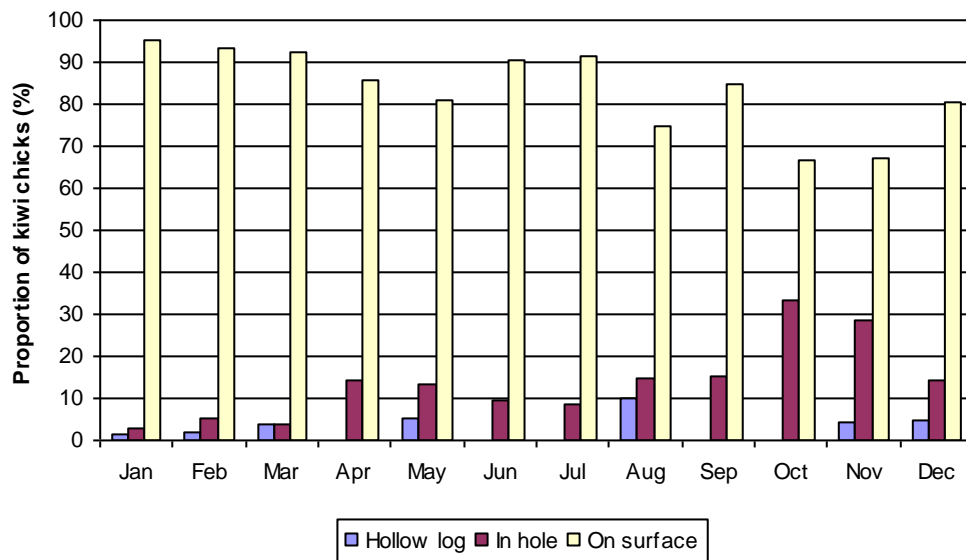
Figure 4.6. *The proportion of kiwi in the chick age-class (n = 461) that were observed in a hollow log, in a hole, or on the surface for each month when located at Moehau Kiwi Sanctuary from 2001–2008 (*Summer = Dec-Feb, Autumn = Mar-May, Winter = Jun-Aug, Spring = Sep-Nov).*
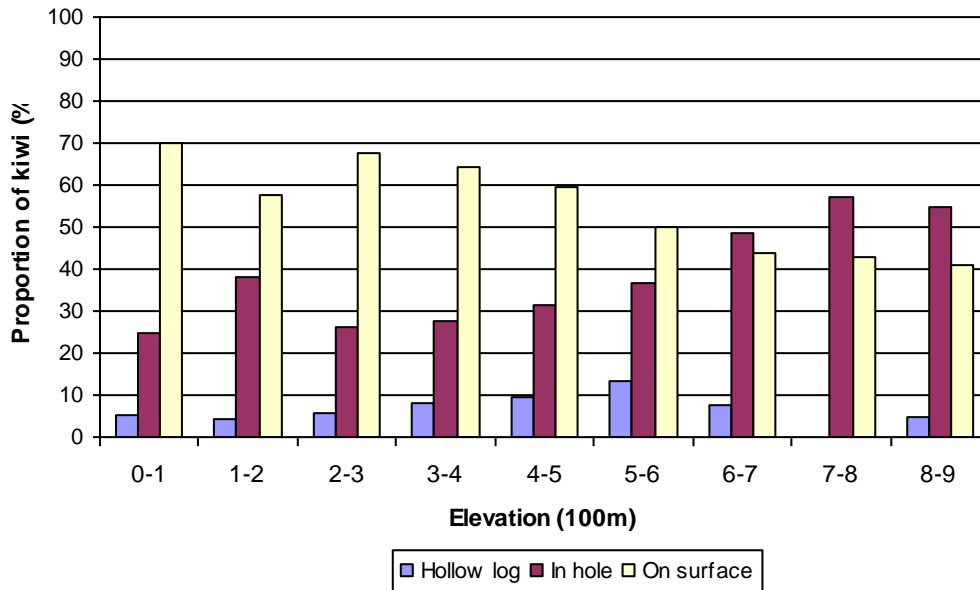
Figure 4.7. *The proportion of kiwi from all age-classes (n = 1344) that were observed in a hollow log, in a hole, or on the surface at different elevations when located at Moehau Kiwi Sanctuary from 2001–2008.*
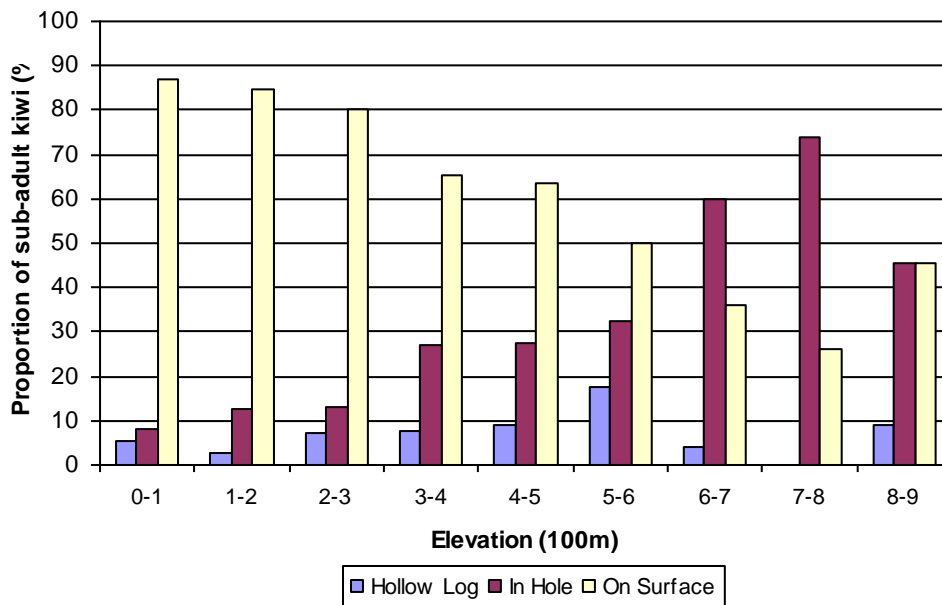
Figure 4.8. *The proportion of sub-adult kiwi (n = 317) that were observed in a hollow log, in a hole, or on the surface at different elevations when located at Moehau Kiwi Sanctuary from 2001–2008.*
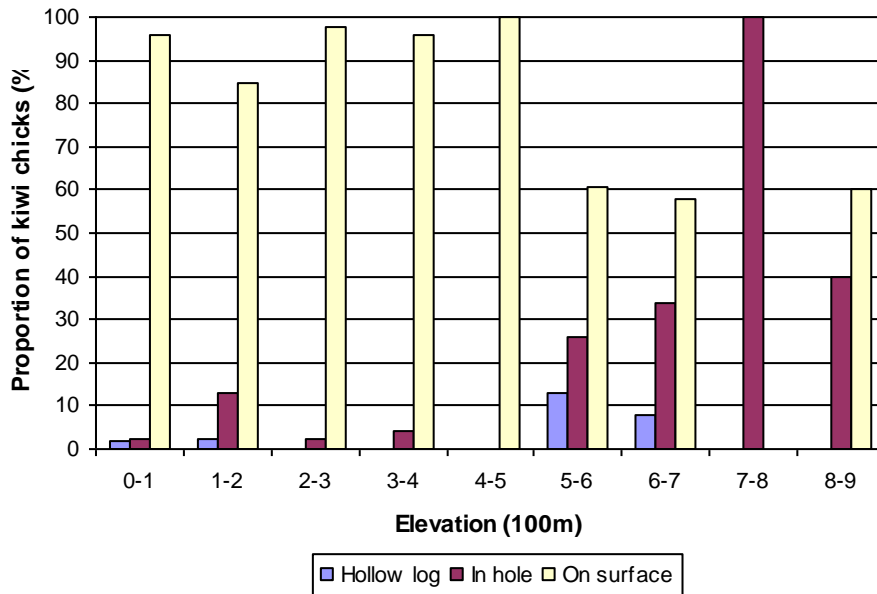
Figure 4.9. *The proportion of kiwi chicks (n = 461) that were observed in a hollow log, in a hole, or on the surface at different elevations when located at Moehau Kiwi Sanctuary from 2001–2008.*
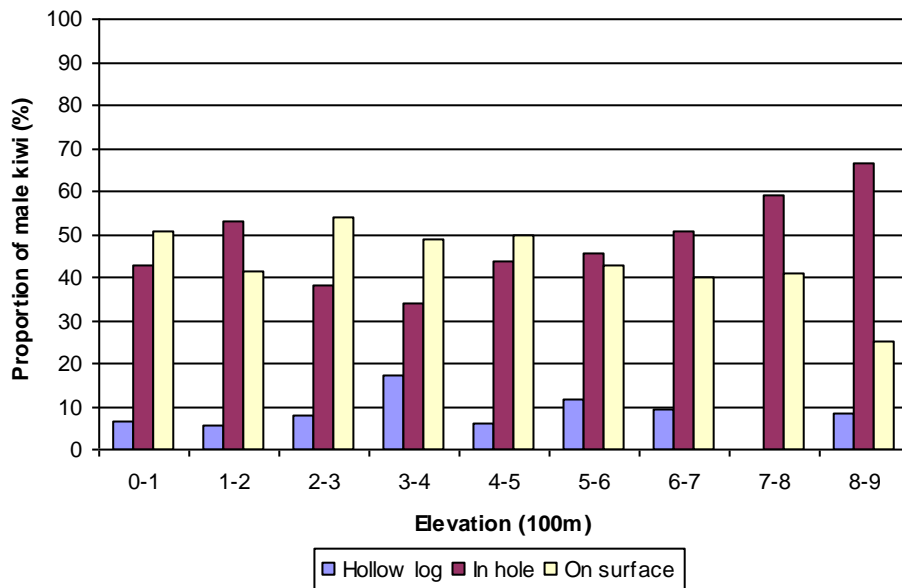
Figure 4.10. *The proportion of male kiwi from all age-classes (n = 614) that were observed in a hollow log, in a hole, or on the surface at different elevations when located at Moehau Kiwi Sanctuary from 2001–2008.*
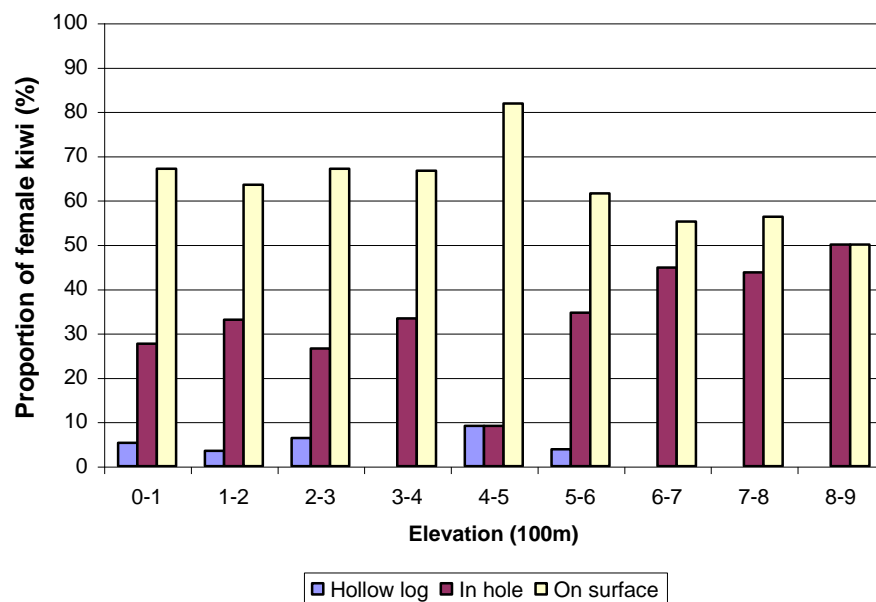
Figure 4.11. *The proportion of female kiwi from all age-classes (n = 377) that were observed in a hollow log, in a hole, or on the surface at different elevations when located at Moehau Kiwi Sanctuary from 2001–2008.*

4.3.2 Ground-cover

Kiwi were associated with different ground-cover types depending on whether they were found in a hole or on the surface (Chi-square test df = 5, n = 671, p = 1.65E-22) (Figures 4.12 & 4.13). When located in holes, the ground-cover consisted of mixed vegetation 56% of the time and fern fronds 16% of the time, however when found on the surface the ground-cover under which they roosted consisted of fern fronds on 30% of occasions and mixed ground-cover 16% of the time. There was no difference in the type of ground-cover used between males and females (Figures 4.14a & b).

Depending on the age-class of kiwi they selected for different ground-cover vegetation types (Chi-square test df = 10, n = 565, p = 1.18E-5). The selection of fern fronds decreased from the chick age-class to adulthood. Chicks were found on the surface under fern fronds on 39% of recoveries (Figure 4.15), sub-adults (26%, Figure 4.16) and adults (14%, Figure 4.17).

In Hole
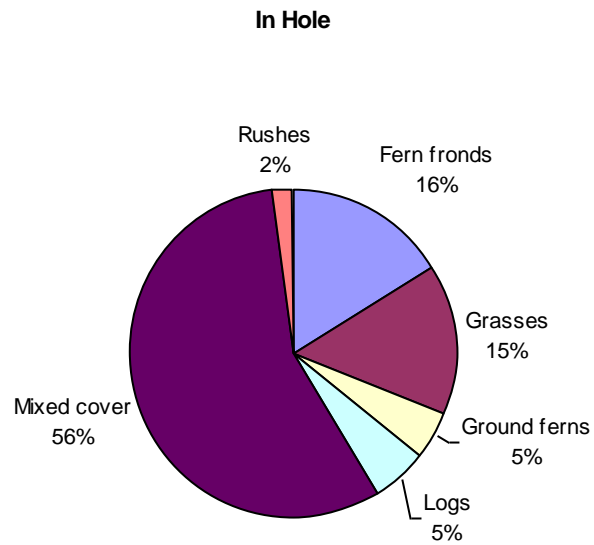
Figure 4.12. *The proportion of different types of ground-cover (n = 106) that kiwi were observed to be using after being located roosting in a hole at Moehau Kiwi Sanctuary from 2001–2008.*
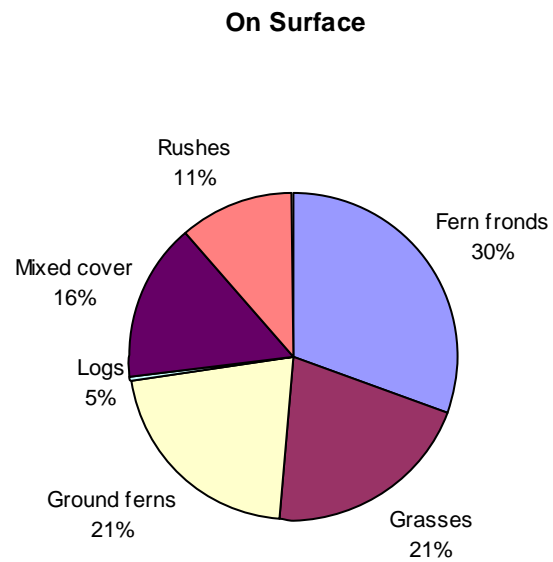
On Surface

Figure 4.13. *The proportion of different types of ground-cover (n = 565) that kiwi were observed to be using after being located in a surface roost at Moehau Kiwi Sanctuary from 2001–2008.*
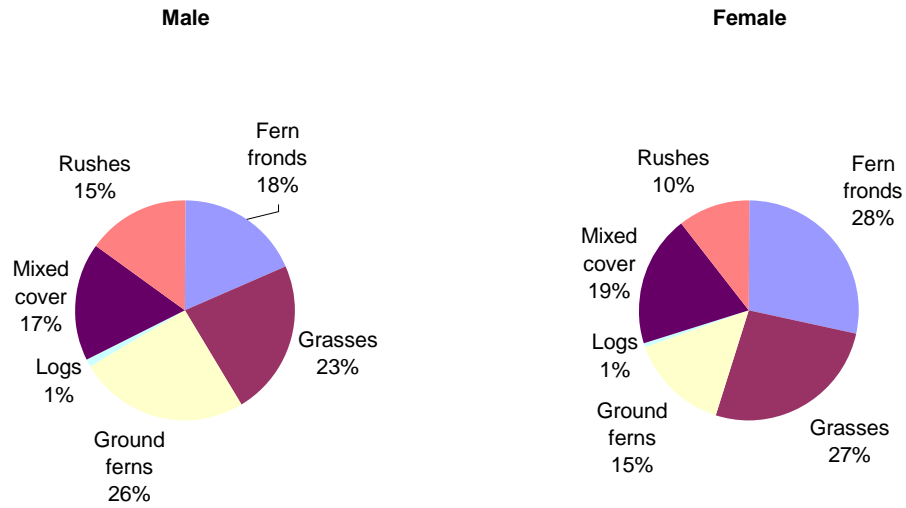
Male

Female

Figure 4.14a & b. *The proportion of different types of ground-cover that male (n = 186) and female kiwi (n = 162) were observed to be using after being located in a surface roost at Moehau Kiwi Sanctuary from 2001–2008.*
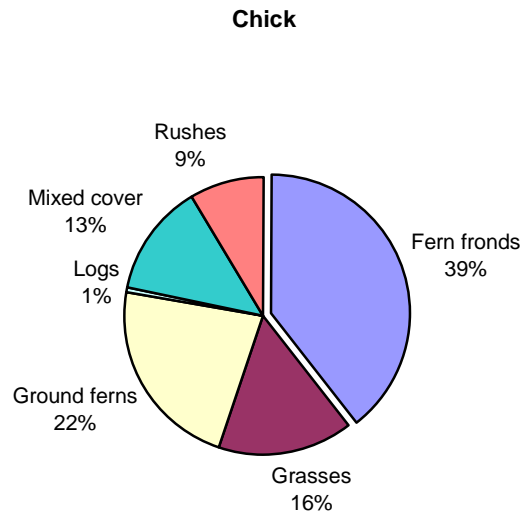
Chick

Figure 4.15. *The proportion of different types of ground-cover that kiwi in the chick age-class (n = 287) were observed to be using after being located in a surface roost at Moehau Kiwi Sanctuary from 2001–2008.*

Sub-adult
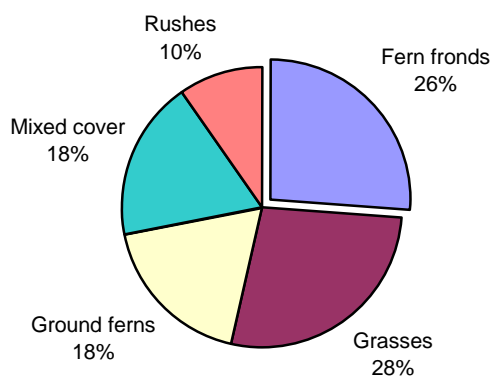
Figure 4.16. *The proportion of different types of ground-cover that sub-adult kiwi (n = 164) were observed to be using after being located in a surface roost at Moehau Kiwi Sanctuary from 2001–2008.*

Adult
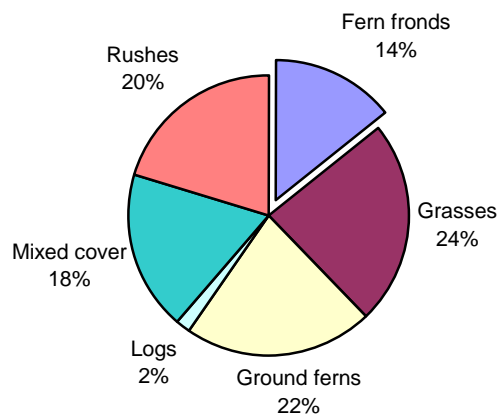
Figure 4.17. *The proportion of different types of ground-cover that adult kiwi (n = 114) were observed to be using after being located in a surface roost at Moehau Kiwi Sanctuary from 2001–2008.*

4.3.3 Forest-cover

Kiwi selected for different roost sites depending on forest-cover types (Chi-square test df = 4, n = 1334, p = 3.28E-15). Kiwi were more often found on the surface in manuka and kanuka forest compared to other forest types (Figure 4.18). In manuka and kanuka forest kiwi were observed in surface roosts (69%) more often than in holes (28%). There were similar proportions of kiwi located in roost sites in holes or on the surface in broadleaf forest and sub-alpine scrub. Broadleaf forest was the only forest type in which hole roosts (46%) were used more often than surface roosts (43%).

Sub-adults selected for particular forest types above what would be expected given the proportion of the forest type available (Chi-square test df = 1, n = 250, p = 1.35E-16). Although sub-alpine scrub only covers 5% of the available habitat, 17% of sub-adult kiwi were located within it (Figure 4.19). There was no difference in the proportion of captures of sub-adults in manuka and kanuka compared to the amount of available manuka and kanuka forest-cover and sub-adult kiwi were found in broadleaf forest 36% of the time when it represents 46% of the available forest-cover.

Of the kiwi that were located on the surface under fern fronds, 77% were in manuka and kanuka, and for kiwi found under the most frequently selected ground-cover types, such as ground ferns grasses and rushes, more than 60% of kiwi located were in manuka and kanuka forest (Figure 4.20).
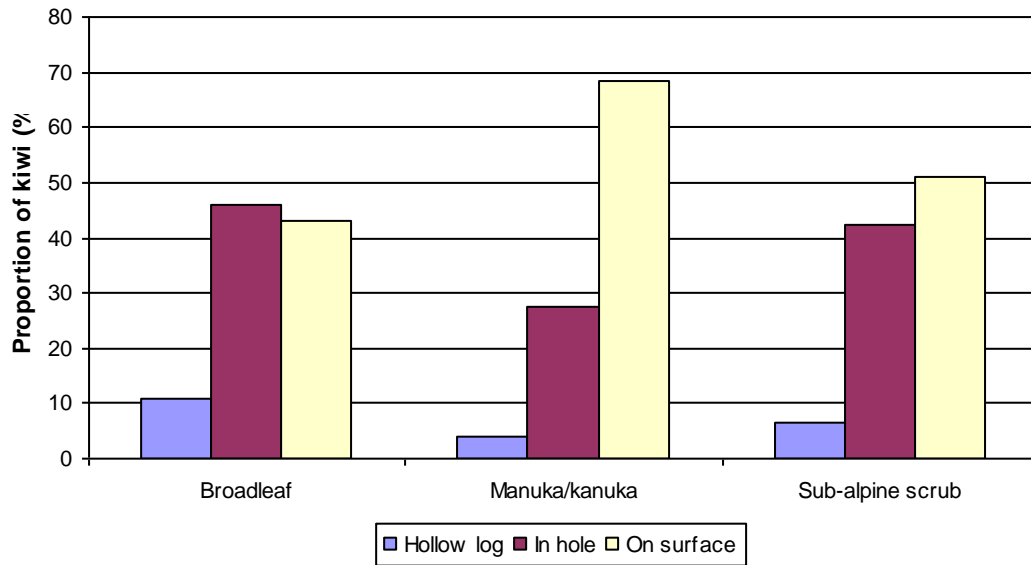
Figure 4.18. *The proportion of kiwi (n = 1334) observed in different forest-cover types and roosting in either a hollow log, in a hole or on the surface at Moehau Kiwi Sanctuary from 2001–2008.*
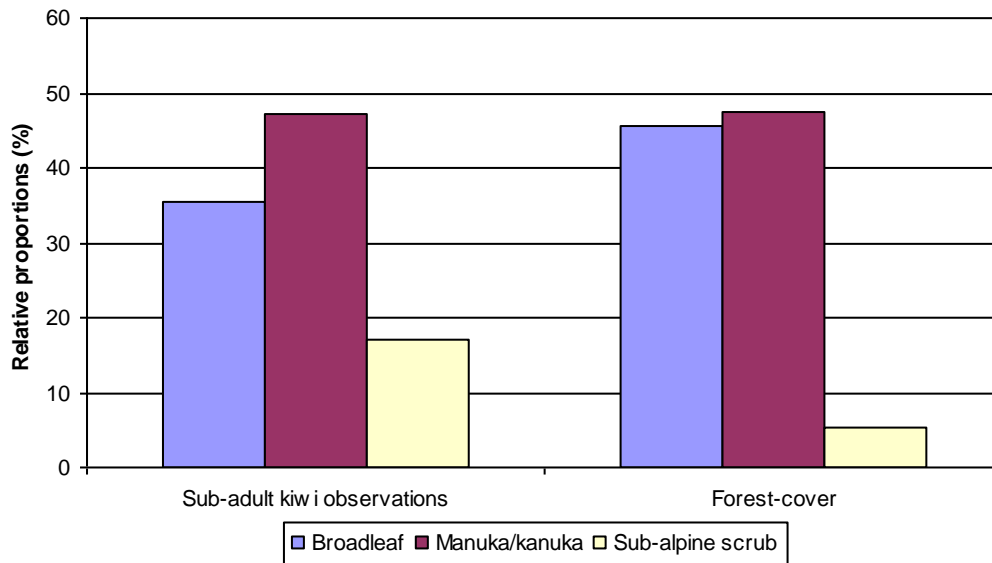
Figure 4.19. *The proportion of sub-adult kiwi (n = 981) observed in different forest-cover types compared with the actual proportion of forest-cover type available at Moehau Kiwi Sanctuary from 2001–2008.*
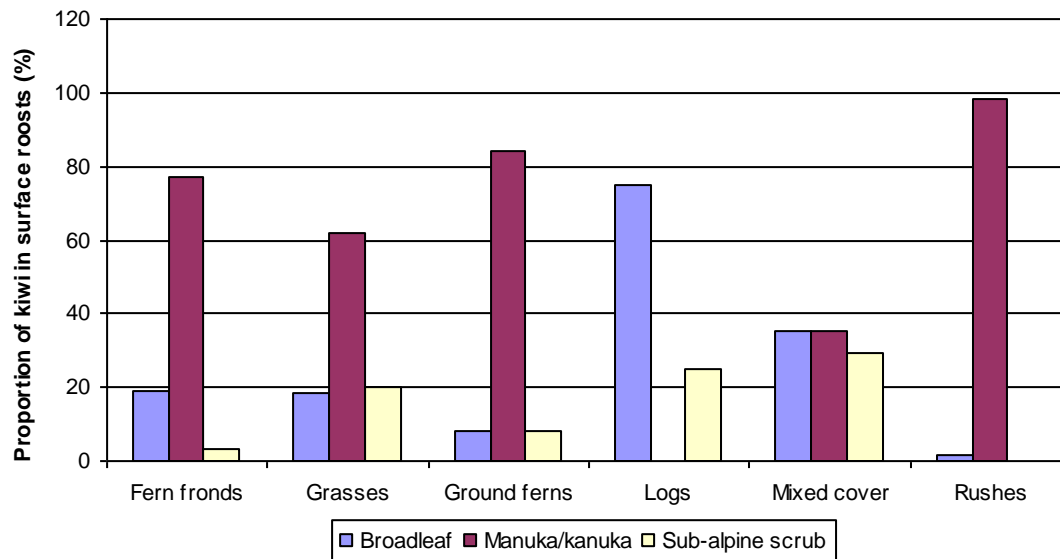
Figure 4.20. *The proportion of kiwi (n = 555) observed roosting on the surface within different types of ground-cover in the main forest-cover types at Moehau Kiwi Sanctuary from 2001–2008.*
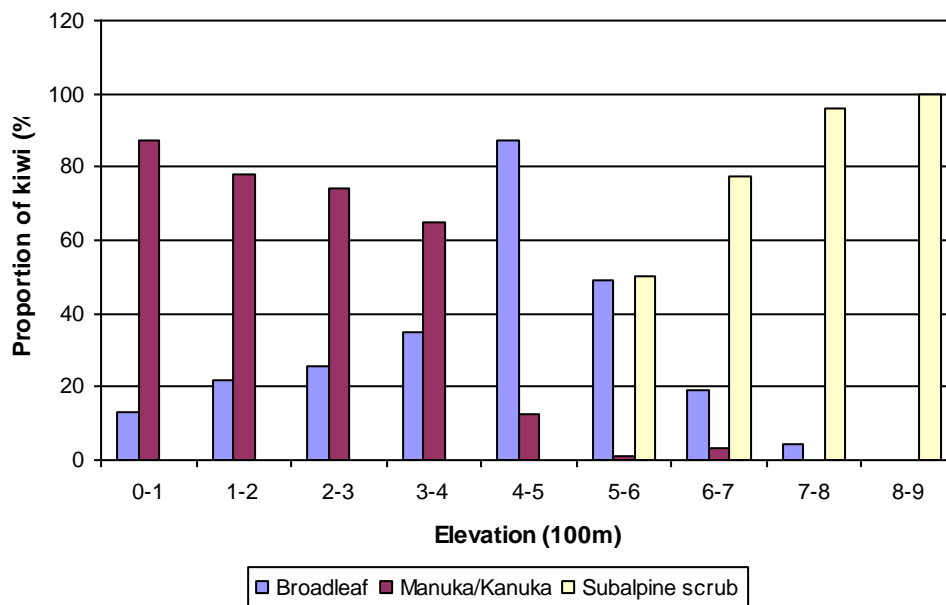
Figure 4.21. *The proportion of kiwi (n = 1610) observed in different forest-cover types within 100m altitudinal gradients at Moehau Kiwi Sanctuary from 2001–2008. This graph best demonstrates the proportion of forest types at different elevations.*

4.3.4 Physiography

Sub-adult kiwi were captured more often on ridges (58% of captures) than adults (42%), and adults were captured more often in gullies (40% of captures) than sub-adults (24%) (Chi-square test df = 6, n = 1360, p = 4.35E-9) (Figure 4.22). There was little difference in the type of roost site selected depending on the physiography (Figure 4.23).
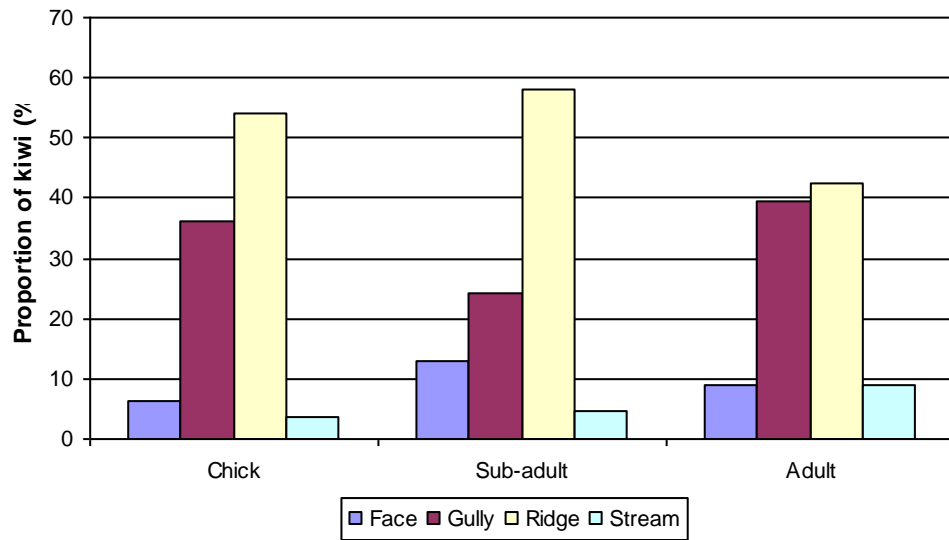
Figure 4.22. *The proportion of kiwi (n = 1360) from the chick, sub-adult and adult age-classes observed on different physiographical areas when located at Moehau Kiwi Sanctuary from 2001–2008.*
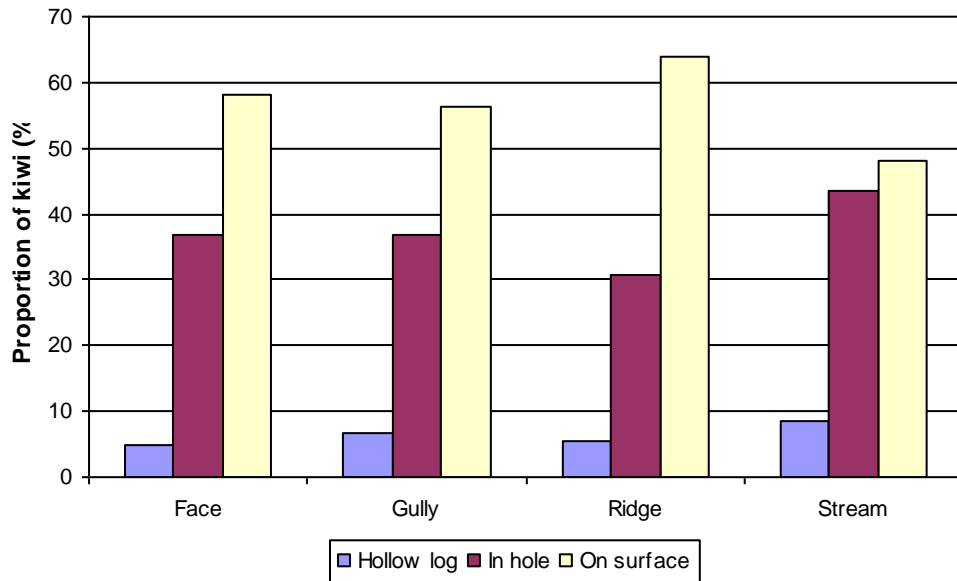
Figure 4.23. *The proportion of kiwi (n = 1344) observed in different physiographical areas and the type of roost that was used at Moehau Kiwi Sanctuary from 2001–2008.*

Figure 4.24. *Kiwi sheltering under dead ponga fronds after being released from a capture for a health check, Moehau Kiwi Sanctuary.*

Figure 4.25. *Kiwi chick hiding under dead ponga fronds and debris after being released at Moehau Kiwi Sanctuary. Kiwi is in centre of figure.*

The figures above demonstrate the similarity in colouration between dead ponga (*Cyathea dealbata*) fronds and debri, and the cryptic colouration of kiwi feathers.

Figure 4.26. *A Breeding Pair of North Island Brown Kiwi using an artificial burrow at the Russel Peninsula kiwi protection area, Northland.*

4.4 Discussion

4.4.1 Habitat and Roost Site Selection

When found on the surface, North Island Brown Kiwi selected for particular roosting sites and ground-cover types. At Moehau the proportions of kiwi found on the surface (60%), in a hole (34%), or in a hollow log (6%) were similar to those presented by McLennan et al. (1987) who observed that 64% of NI Brown Kiwi at Hawkes Bay used surface roosts, and 36% used burrows[1]. The low use of hollow logs in this study could be due to the limited availability of these logs in manuka and kanuka forest (which represents 47% of the available habitat on Moehau) as there are few trees of adequate size and that have fallen over. McLennan et al. (1987) found that for NI Brown Kiwi the use of roost sites in hollow logs increased with the availability of these sites.

Miles et al. (1997) found that adult NI Brown Kiwi used holes between 30–50% of the time depending on the forest type, similar to the results of this study which showed that for all kiwi, hole use varied between 25–46% depending on the type of forest-cover. However, converse to findings by Miles et al. (1997), who found that males used surface roosts more than expected compared to females, this study found females used surface roosts more often than males; males also used holes as roost sites more than the surface. Adult kiwi will nearly always use holes for nesting activities (Colbourne, 2002) although they have been known to nest on the surface under thick vegetation (Diane Prince personal communication, 2005). The selection for hole roosts by adults may be directly related to the necessity of providing a suitable nest site. Physiological and behavioural differences may be determining factors in the greater use of holes by adults than chicks or sub-adults, as the greater size of adult kiwi means they are able to more easily create holes, and familiarity with their home territory may make it easier for them to locate existing holes.

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[1] The reason there is a distinction between burrows and holes is that burrows suggest that the cavity has been excavated by kiwi, whereas holes might not have been (possibly a natural formation).

Adult female kiwi were found more often on the surface than in holes, so they may be more susceptible to predators such as dogs. Holes may provide better protection by preventing scent from drifting due to wind, and allowing kiwi (with their large clawed feet) to deter predators from entering the small hole entrance (personal observation). As kiwi are known to utilize artificial holes (Figure 4.26), they should be considered for use in conservation management of kiwi to reduce mortality of kiwi in surface roosts. Artificial holes may have the added benefit of providing more roosting sites for kiwi and thereby increasing the habitat available, and increasing population sizes and densities (See Chapter Five).

Kiwi chicks were found more often in holes during Spring (September-November) but there was no difference detected for adult and sub-adult kiwi. Miles (1997) found kiwi sheltered in excavated roosts more often in Spring and Autumn. The difference detected in this study could be due to the need for shelter from environmental factors such as weather and there being less or more rainfall occurring during months of this season compared to other months (Forbes and Todd, 2000). It could equally be due to a few chicks remaining in the natal burrow for periods greater than one month (the average period between chick captures), as the months from October until December were when most of the kiwi chicks for the season hatched (de Monchy and Forbes, 2006).

Kiwi roosted on the surface more often than in a hole in manuka and kanuka forest compared to other forest types, and were more often in a hole than on the surface in broadleaf forest. One explanation for this may be that kiwi use surface roosts in manuka and kanuka more than in forest types due to the relatively dense ground-cover within manuka and kanuka providing the necessary shelter and roosting sites, whereas in broadleaf forest the ground-cover is more sparse (de Monchy and Hurst, 2000) meaning that kiwi must find alternative roosting sites in holes or hollow logs. Alternatively, perhaps there is a harder more compact soil under manuka and kanuka forest-cover preventing the excavation of burrows so that kiwi have to roost on the surface under any vegetation available, or that natural holes and hollow logs are less available for roost sites in manuka and kanuka than in other forest types.

The relatively greater abundance and density of ground-cover types in manuka/kanuka, may be represented by the observations of kiwi that roosted on the surface and that were associated with the ground-cover types that they selected most frequently (fern fronds, ground ferns and grasses) (Figure 4.13). Most kiwi that were observed roosting on the surface in fern fronds (77%), ground ferns (84%), and grasses (62%) were found in manuka/kanuka forest, (Figure 4.20). The recent eradication of goats from Moehau Range (de Monchy, 2007) will encourage understory and ground-cover growth in all forest types (de Monchy and Hurst, 2000), and this in turn will increase the availability of ground-cover for surface roosts, thereby potentially increasing kiwi selection of surface roosts over hole roosts.

Although kiwi on Moehau were found roosting on the surface more often under fern fronds than other ground-cover types, and that if found under fern fronds they were most likely in manuka and kanuka forest, this does not necessarily reflect historic preferences. Manuka and kanuka forest currently cover over a third of the area on Moehau. However, the availability of manuka and kanuka forest was much less before the land was modified by Polynesians and then Europeans (Holdaway, 1989; Poole and Adams, 1990). Therefore different proportions of forest types would have dominated and kiwi likely used other types of dead vegetation in the absence of fern fronds.

When located on the surface, kiwi on Moehau were found under dead fern fronds and debris (mainly dead ponga, *Cyathea dealbata*) 30% of the time and kiwi in the chick age-class 39%, more often than under any other ground-cover vegetation. It may be coincidental or not but the colouration of dead fern fronds and debris is virtually indistinguishable from the colouration of kiwi feathers (Figures 4.24 & 4.25). Unless an observer is aware that kiwi are under this vegetation they are difficult to see and field workers monitoring kiwi can be within a metre or less of a kiwi and still not see it. Before the introduction of exotic mammalian predators to New Zealand, birds of prey were the main predators of kiwi (Worthy and Holdaway, 2003), and the cryptic colouration of kiwi with their variations of brown to grey pigmentation enabled them to avoid these predators that primarily use sight to locate their prey. Unfortunately the cryptic camouflage of kiwi

does not provide protection against mammalian predators that primarily use smell to find their prey (King, 1990). It is suggested that selection for fern fronds may be due to natural selection and the need to avoid avian predators, and that chicks use this ground-cover for roost sites more than sub-adults and adults due to their smaller size and therefore limited ability to defend themselves, or to create their own burrows (Figure 4.25).

Another possible explanation for the selection of dead fern fronds and debris for ground-cover when roosting on the surface may be that it provides the next-best substitute to a hole that they do not have to excavate. The dead fern fronds and debris often create an enclosed tent-like structure around the base of the ponga (*Cyathea dealbata*) or other tree ferns, and these provide a ready-made shelter with similar dimensions to that of a burrow and entrance (personal observation). Grasses and rushes that were also selected for by kiwi as ground-cover, forms dense vegetation in which hollows and tunnels could easily be created.

Miles et al. (1997) and Taborsky and Taborsky (1995) both observed that the choice of roost site for NI Brown Kiwi was highly dependant on the type of forest habitat. This was also observed in this study, with kiwi selecting for surface roosts more than hole roosts in manuka and kanuka and hole roosts more often in broadleaf forest. Manuka and kanuka forest and sub-alpine forest on Moehau both have a relatively dense ground-cover compared to broadleaf forest, with sub-alpine scrub being significantly more dense than manuka and kanuka (Burns, 1985; de Monchy and Hurst, 2000). Maybe sub-adult kiwi at Moehau were selecting forest types or areas within the different forest types that provided the densest ground-cover for surface roost sites. Another theory as to the observed selection of sub-alpine scrub by sub-adult kiwi is that it may be due to dispersal patterns and not necessarily to any particular factor relating to sub-alpine scrub habitat. Sub-adult kiwi may be dispersing to higher elevations as they follow ridges.

Studies on habitat selection in kiwi have identified a preference for manuka and/or kanuka forest associations over other forest types (Taborsky and Taborsky, 1995; Chan,

1999; Gibbs, 2000) This study observed that sub-adults selected particular forest types, although the methodology prevented determining any difference in selection between adults and chicks. The forest type that sub-adults selected for was sub-alpine scrub rather than broadleaf forest, and manuka and kanuka was used as much as would be expected given the availability of this forest type. Previous studies did not include sub-alpine forest. Taborsky and Taborsky (1995) suggested it could be assumed that due to the high feeding requirements of kiwi that capture sites relate directly to the habitat in which they prefer to forage. It was also found that kiwi preferentially used marshes (rushes) and seral vegetation such as manuka and kanuka forest for roosting sites more than expected, but suggested this may be due to the selection of denser ground-cover vegetation, compared with other forest types.

Sub-alpine scrub is the dominant vegetation type at elevations above 600m asl on Moehau, with thick ground-cover vegetation and areas dominated by the native grass (*Microlaena avenacea*) that have no canopy. It is heavily influenced in plant species composition by the incessant wind and relatively cold temperatures (Moore and Cranwell, 1934; Cranwell and Moore, 1936; de Monchy and Hurst, 2000). Figure 4.21 provides an accurate depiction of the relative proportions of forest types at different elevations.

Sub-adult kiwi were found in holes more often than on the surface above 600m asl. This could indicate that environmental factors such as temperature (Taylor and Wilson, 1990), rainfall, wind or availability of suitable ground-cover may be influencing roosting site selection. The study of Wilson et al. (1988) on the effects of topography on the seasonal distribution of a range of South Island bird species, including Great Spotted Kiwi, found the main factor determining the spatial and altitudinal distribution was temperature. This does not appear to be the case for NI Brown Kiwi on Moehau as call-survey analysis has shown that there are higher densities of kiwi at the lowest and highest elevations, with lower densities in the middle elevations (Stewart et al., 2000), and this roughly corresponds to the distribution of forest types with manuka and kanuka, broadleaf and sub-alpine scrub forest types, each respectively being dominant as elevation increases.

Kiwi at Moehau selected for roost sites on ridges over other physiographical features (stream, gully or face/slope). Sub-adults were located on ridges (58%) more often than adults (42%). These differences observed between age-classes may be due to sub-adult natal dispersal and the relative ease in movement along ridges rather than through gullies. Ridges often remain relatively open and marked with animal tracks even when not used by humans (personal observation). Kiwi are likely to use the easiest access ways as they search for potential territories. If this is the case then kiwi dispersal distances may depend on the forest type, topography, terrain and presence of other ground-dwelling animals.

4.4.2 Limitations and Bias

The proportions of available forest-cover types were determined over an area of approximately 12,000 hectares, and due to the methodology used to determine the proportions of forest types over such a large area, it was not possible to determine forest-cover types within the relatively small area of adult kiwi territories or within the area ranged by kiwi chicks. Adults were often restricted to one particular forest type within their home territory.

Although hollow logs are similar in purpose and function to holes as roost sites and therefore should probably be considered as a form of hole, they were not included under a general category of holes given that the use of hollow logs depends on their availability and this may be different to the availability of holes on Moehau. Also hollow logs were generally natural formations due to the decomposition of the centre of the trunk before the outer layers, whereas holes were often excavated by kiwi.

Further statistical analysis of similar data sets should be undertaken using the Bonferroni z statistic in conjunction with Chi-square analysis testing, which more accurately evaluates preference, or avoidance of specific habitat types or characteristics depending on availability (Neu et al., 1974; Miles et al., 1997).

Data was pooled over all years from 2001 until 2008. There appeared to be a difference in the proportion of kiwi that selected roost sites either in holes or on the surface depending on the year (Figure 4.27). However, no comparisons were made to determine

annual differences in roost site selection, depending on gender and age-class of kiwi, due to insufficient or unavailable environmental temporal data such as rainfall, humidity and temperature that may confound or influence habitat selection. The relative proportion of kiwi from different age-classes or gender that were monitored in each year will also influence any variation between years and any investigation of this was beyond the scope of this study.
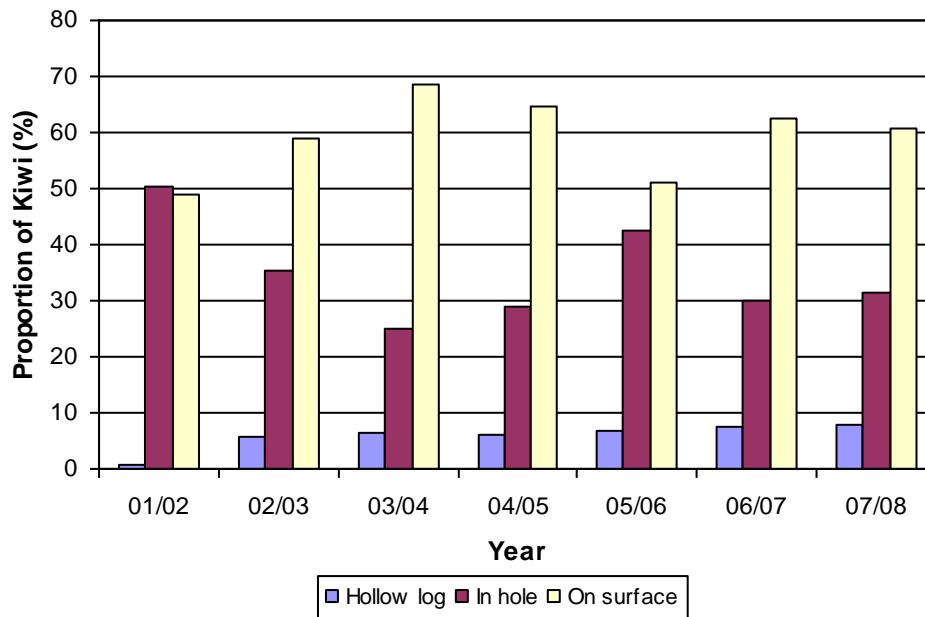
Figure 4.27. *The proportion of kiwi (n = 1347, annual mean = 192 +/- 15 (95% CI)) that were observed in different roost site types each year, from 2001–2008 at Moehau Kiwi Sanctuary*

Chapter 5.

Kiwi Mortality

5.1 Introduction

At the time when Polynesians discovered New Zealand approximately 700 years ago (Worthy and Holdaway, 2003), 78% of the land was covered in forest while only around 5% was grassland. By the time Europeans arrived in the late 1700's, about 53% of New Zealand was covered by forest, with a consequent increase in grassland to 30%. In the early 1990's forest-cover stood at around 23% with grasslands increasing to almost half (47%) the total area (Blackwell, 2005). As a consequence of habitat modification through logging, mining, fires and agricultural practices, and the effects of introduced mammals, and combined with the fact that 90% of New Zealand's birds have adapted to living in old growth forests, endemic species were steadily reduced and became more vulnerable to decline and extinction (Stevens et al., 1995).

Bennet and Owens (1997) suggested certain lineages of birds that have low productivity (such as the kiwi) are predisposed to extinction, as these species take longer to recover and are more likely to go extinct if they are reduced to small population sizes, either due to human or natural disturbances. Increases in extinction risk were independently associated with an increase in body size and decrease in productivity.

Many studies have documented impacts of human and natural disturbances on the mortality of birds and other fauna (Hunt Jr, 1972; Sousa, 1984; Brown and Morris, 1995; Rodgers Jr and Smith, 1995; Rabenold et al., 1998; Zeitler, 2000; Frid and Dill, 2002). In these studies some authors have argued that prey have evolved anti-predator responses to generalized threatening stimuli, such as loud noises and rapidly approaching objects, eg. vehicles (Hunt Jr, 1972; Zeitler, 2000; Frid and Dill, 2002), so that when encountering disturbance stimuli animal responses are likely to follow the same economic principles used by prey encountering predators and attempt to escape.

Kiwi have evolved without mammalian predators and have consequently developed alternative strategies, namely 'freezing' to avoid predation, with escape only being employed when the stimuli is virtually upon them. This makes them susceptible to injury or death from farming and other heavy equipment used in developing occupied kiwi habitat.

Pierce and Sporle's (1997) study on 194 kiwi deaths in Northland reported eight (4%) of the kiwi deaths to be attributed to human influences, with seven kiwi killed by possum traps, and one kiwi found to have died due to cyanide poisoning from a possum control operation. Other kiwi died from: falling down an historic fortification ventilation shaft, drowning in a swimming pool, being caught under a cattle stop, shredded by a rotary slasher, shot by a .22 rifle, and killed by a Harrier Hawk after being flushed out during a stock muster. Studies on kiwi that rely on observations from the public and Department of Conservation field staff create a bias toward kiwi deaths from human-related causes. Natural causes of death are always difficult to establish and inherently hard to detect unless the kiwi have transmitters attached, and are monitored.

Domestic and feral dogs were found to be responsible for the greatest proportion of adult kiwi deaths in Northland, accounting for 135 (70%) of 194 kiwi deaths reported between 1990 and 1995. Vehicles were the second most common cause of death, accounting for 6% of deaths. One kiwi died naturally from being caught in tree roots, and another was found sick and starving (Pierce and Sporle, 1997). There are likely to have been many more deaths due to dogs that have gone unreported, or not detected. For example, in 1987 a stray dog was found to be responsible for an estimated 400–500 kiwi deaths in Waitangi forest in Northland, however only 23 carcasses were actually found. The kiwi population virtually disappeared over the period these carcasses were found (Taborsky, 1988). Reid et al. (1982) established that 28% of kiwi deaths in Northland and Taranaki were due to dogs.

Possum control operations have caused numerous deaths of kiwi although relatively few get reported or are included in scientific publications. During the 1970s and 1980s a report by Gardiner (1993) indicated that at least 17 kiwi were caught in leghold traps during possum operations in Northland, New Zealand. Most of the kiwi survived and were released, often with injuries and fates unknown. During the late 1980s and early 1990s possum control operations using leghold traps on Moehau Range, Coromandel Peninsula, resulted in the injury and deaths of many kiwi (T. Ames and K. Mouritzen, personal communication, 2006). There was evidence of injuries caused from a leghold capture in at least two of around 200 individual kiwi monitored at the Moehau Kiwi Sanctuary showed (T. Herbert, personal communication, 2006).

In New Zealand mortality of endangered species due to conservation management techniques has been an ongoing issue. Mortality in kiwi has primarily been due to radio-tracking monitoring techniques, and more specifically from radio-transmitters and the attachments becoming entangled in vegetation, resulting in starvation. There have been various attempts to develop transmitters that will not cause injury or death (Miles and McLennan, 1998). Data collected from 12 different kiwi management sites from throughout New Zealand (Pim de Monchy, unpublished data, 2006) showed that from a total of 2,491 transmitter years (the collective amount of time transmitters have been attached to kiwi for monitoring purposes) a total of 26 deaths were recorded that were related to management techniques, most due to transmitter attachments becoming entangled in mangemange (*Lygodium articulatum*). This equates to one death per 96 transmitter years.

This Thesis seeks to expand on the knowledge of the causes of death in kiwi, and examines differences in mortality depending on gender and age-class. The importance of the time of year and elevation, and the impact of humans are also examined as factors that may influence mortality. It is hoped this study will provide information to create greater awareness of threats to kiwi at Moehau, and to assist conservation managers in protecting kiwi. Most importantly it demonstrates the impacts of management techniques

on endangered species. The results imply that improvements are needed, not only to prevent mortality but also to safeguard the "well-being" of individual kiwi.

5.2 Methodology

See also Chapter Two: General Methodology.

Mortality of monitored kiwi was detected using a radio transmitter and receiver. The transmitter emits different signals depending on whether it can detect movement or not. The mortality signal was emitted when the transmitter was still for 12 hours, and therefore indicating that either the transmitter had fallen off, was faulty, or the kiwi carrying it had died. Deaths from unmonitored kiwi had to be confirmed from carcasses that were recovered or reported by members of the public, DOC staff and contractors. For each mortality event data recorded included the date, weight, gender, age-class (at death), age cohort, geographic location, physiography, forest-cover type, ground-cover vegetation, and elevation.

Necropsies of fresh carcasses were undertaken by staff at Massey University to try to determine the cause of death. Other deaths were attributed to the most probable cause, or recorded as death unknown depending on the particular circumstances and evidence.

5.2.1 Kaplan-Meier Procedure

Survivorship data was calculated using the Kaplan-Meier survivorship analysis model (Kaplan and Meier, 1958) modified to allow for new animals to be added during the study (Pollock et al., 1989), and then adapted for analysis of kiwi survivorship (Robertson and Westbrooke, 2005). The Kaplan-Meier procedure calculates the probability of death depending on the age and length of time animals were monitored, with allowance made for when an animal is lost due to the transmitter having failed or fallen off, or the animal having emigrated from the study area.

Chi-square tests were used to determine the statistical significance of associations between the age-class, time of year and elevation, with that of mortality rates.

5.3 Results

A total of 310 individual kiwi were identified and banded during the monitoring at the Moehau Kiwi Sanctuary from 2001–2008. Each kiwi either had transponders inserted; were fitted with a radio transmitter; or were recovered dead from the field. Of these 90 kiwi died: 11 female deaths, nine male, and 70 of unknown gender.

5.3.1 Age-class of Kiwi and Mortality

For kiwi from all age-classes predation by mustelids (stoats) was the greatest cause of death, followed by dog predation, then transmitters and attachments becoming entangled in mangemange (Table 5.1). Most kiwi deaths (59) were of kiwi in the chick age-class (66% of mortalities); the main cause being due to stoats and secondarily entanglement in mangemange (*Lygodium articulatum*). There were a similar number of deaths among sub-adults (16 deaths, 18% of mortalities) and adults (15 deaths, 16% of mortalities).

All adult (n = 15) and sub-adult (n = 16) carcasses were found on the surface (not in a hole), compared with chicks of which 82% (n = 59) of carcasses were recovered on the surface and 18% in a hole.

Predation was the cause of 60% of all kiwi deaths. Almost a quarter (24%) of kiwi deaths during the study period were caused from human influences and conservation management techniques, with an average of one death for every 28.4 transmitter years. There were a total of 21 human-induced deaths with 19 of these directly due to management techniques. Furthermore 17 of the 19 deaths due to management techniques were caused from entanglement of the transmitters or the attachment in vegetation, and in one case the metal identification leg band (Figure 5.1). There were two natural deaths of kiwi that were found entangled in mangemange by the leg and not by any attachment. Of the 59 chicks that died during the study period, 10 (20%) died due to transmitter entanglement.

The month in which most kiwi deaths (both monitored and unmonitored kiwi) occurred was January with 22 deaths recorded, 18 of them chicks, and eight of these attributed to

stoats. There were no deaths of kiwi during July (Figure 5.2 & 5.3). The number of kiwi that died depended on the month of the year and this relationship could be largely explained by the polynomial equation: number of deaths = $0.4466*month^2$ - $6.735*month$ + 27.09 (n = 90, R^2 = 84.2%, p = <0.0001) (the months are valued as 1–12 = January-December.).

There were 259 kiwi of all age-classes out of a total of 310 different kiwi recorded that were monitored for at least one day from 2001–2008 (kiwi not monitored for a day were excluded from the data set due to the bias of unmonitored kiwi more likely to be reported dead than alive). Of the kiwi monitored for at least one day there were 77 deaths, with 55 in the chick age-class, 11 as sub-adults and 11 as adults. A greater proportion of chicks (61%) died compared to sub-adults (18%) and adults (11%) (df = 5, n = 259, p = 4.96E-15). There was little difference in the proportion of deaths between adults and sub-adults (Figure 5.3). Adult female kiwi had twice the rate of mortality (16%) as adult male kiwi (8%), although this was not statistically significant (Chi-square test df = 1 adult female n = 38, adult male n = 67, p = 0.18).

There were 167 kiwi chicks that were monitored for at least one day in Moehau Kiwi Sanctuary from 2001 and 2008, of which 55 died (33%). There was a strong association between the seasons of the year and the number of chicks that died relative to those that hatched or were released and survived (Chi-square test, df = 3, n = 167, p = 5.36E-16). Of all the deaths of monitored kiwi chicks over the year, 60% died during Summer (December-February) (mortality rate 81%), and 31% died during Autumn (March-May) (mortality rate 45%). No chicks died during Winter (June-August) and there was a 7% mortality rate in Spring (September-November) (Figure 5.4). None of the chicks were found dead between May and September. There was a lag period in the proportion of kiwi deaths compared to the proportion of chicks that hatched each month, with the proportion of kiwi chick deaths increasing as the number of chicks that hatch increased. Most kiwi chicks hatched, or were released between October and April, but a greater proportion of them were died from December to February (Summer) than in other months (Figure 5.4).

The rate of mortality in kiwi chicks was similar across elevations (100–300m, 300–600m, 600m–900m) and was in proportion to the number of kiwi chicks that hatched or were released and survived (Chi-square test df = 2, n = 167, p = 0.67) (Figure 5.5), therefore there was no greater chance of death depending on the elevation at which kiwi chicks hatched.

The difference in the number of chicks monitored in this section (n = 167) when compared with the results below on survival statistics (n = 162), is due to the inclusion in this section of five chicks that were monitored outside of Moehau Kiwi Sanctuary boundaries, but still within an area that receives predator control of a similar standard (de Monchy and Davies, 2005).

5.3.2 Kaplan-Meier Kiwi Survival Analysis

There were 93 radio-tagged adult kiwi monitored for a total of 238.5 bird-transmitter-years; six of these died during the study (2001–2008). Using the Kaplan Meier survivorship analysis method (Robertson and Westbrooke, 2005) this gave an average annual mortality rate of 2.52%, suggesting a mean life expectancy of 39.75 years for adult kiwi in Moehau Range. This mortality rate excludes those kiwi that were outside of the kiwi sanctuary, and the 2 deaths caused by mangemange entanglement of the transmitter or its attachment.

There were 110 kiwi in the sub-adult age class that were monitored for 118 bird-transmitter years, during which time a total of 16 deaths occurred, 10 within the Moehau Kiwi Sanctuary and the rest outside of the Kiwi Sanctuary. Excluding those deaths due to human influence and entanglement in mangemange, and assuming an annual emigration rate of sub-adult kiwi from the Moehau Kiwi Sanctuary of 6.8% (8 sub-adult kiwi dispersing out of Moehau Kiwi Sanctuary in 118 transmitter years), the data suggest an annual mortality rate for sub-adults of 3.4%. Deaths due to mangemange entanglement were excluded as these deaths would not have otherwise occurred had the transmitter not been attached.

A total of 162 kiwi chicks (including ONE chicks) were radio-tagged and monitored for a total of 27.1 transmitter years. Fifty of those within the Sanctuary died. Excluding those deaths due to mangemange entanglement (Figure 5.6), human influence or that were outside of the Sanctuary, the average annual mortality rate was 33%, with 81% of kiwi chick deaths occurring within 50 days of age.

5.3.3 Operation Nest Egg Kiwi

A total of 23 kiwi chicks were released through ONE and monitored in Moehau Kiwi Sanctuary. A total of 10 ONE chicks (38%) died during the study, nine after being released back onto Moehau and one during captivity. No ONE chicks that became sub-adults or adults died. A greater proportion of ONE kiwi (77%) in the chick age-class died compared to wild-hatched kiwi (Chi-square test df = 1, n = 259, p = 0.013). Out of the 236 wild-hatched kiwi that were monitored for at least one day, 49 (21%) were found dead. There was no difference in the proportion of ONE kiwi of all age-classes killed compared to wild-hatched kiwi (Chi-square test df = 1, n = 310, p = 0.16).
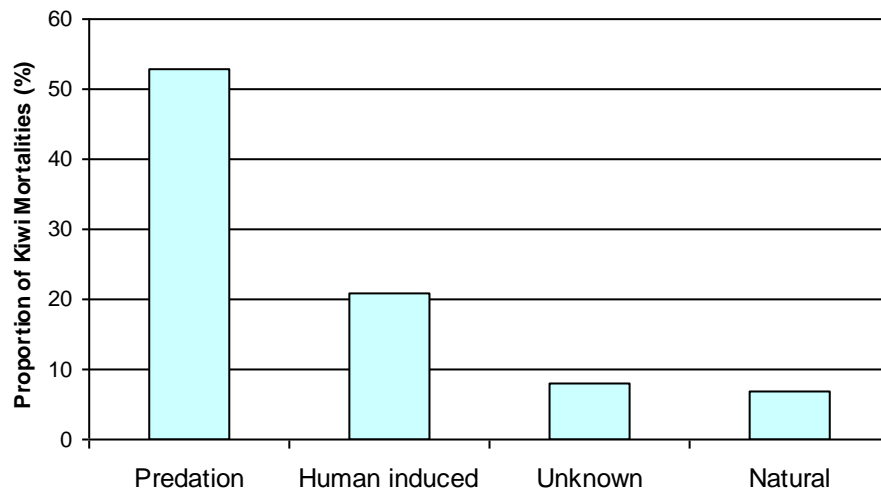
Figure 5.1. *The cause of mortality of kiwi at Moehau Kiwi Sanctuary from 2001 – 2008.*
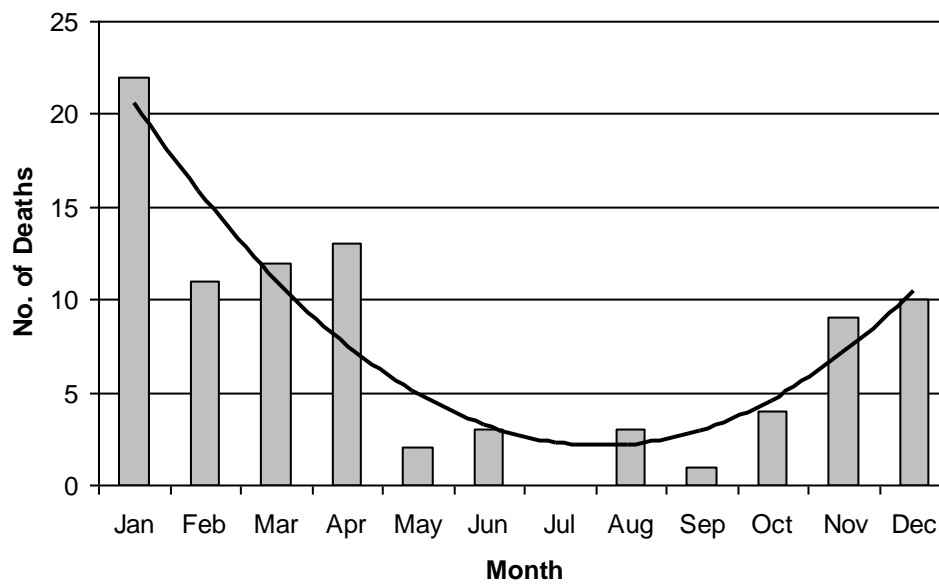
Figure 5.2. *The total number of deaths of kiwi for each month recorded for all age-classes from 2001–2008 at Moehau Kiwi Sanctuary. * Solid line represents number of deaths = 0.4466*month² - 6.735*month + 27.09.*
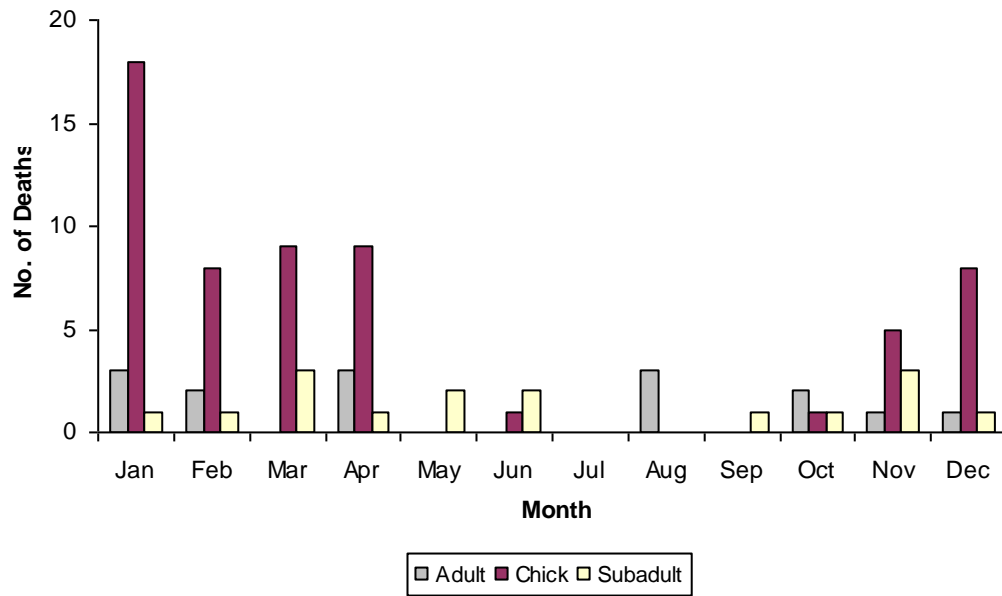
Figure 5.3. *The total number of deaths of kiwi for each age-class recorded at Moehau Kiwi Sanctuary from 2001–2008.*
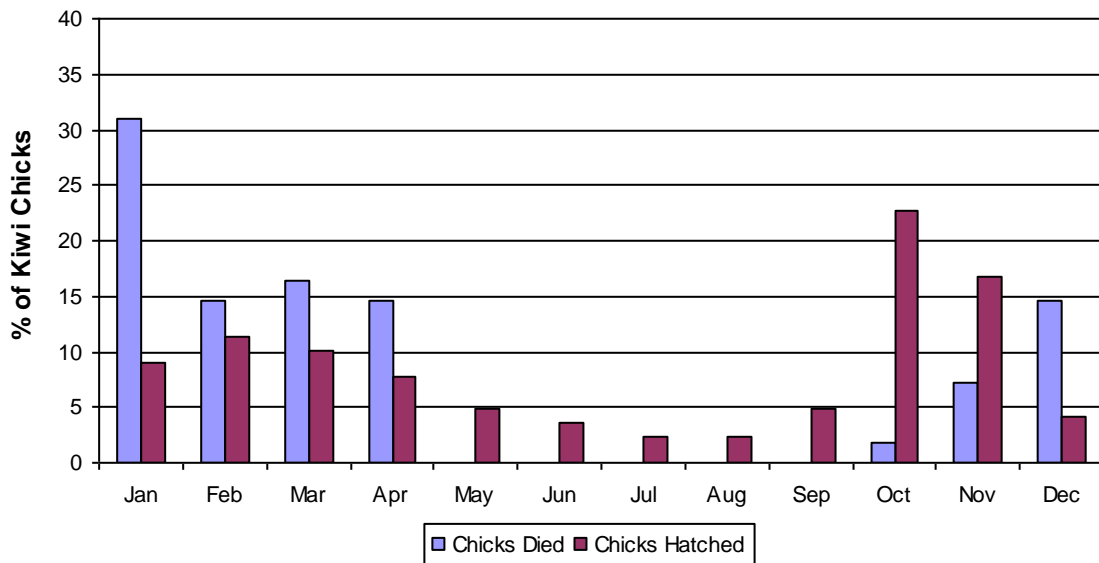
Figure 5.4. *The percentage of kiwi chicks that died each month (n = 55) and the total percentage of chicks that hatched or were released (Includes chicks that later died, n = 167) each month and over all years at Moehau Kiwi Sanctuary, 2001–2008. *(Summer Dec-Feb, Autumn = Mar-May, Winter = Jun-Aug, Spring = Sep-Nov)*
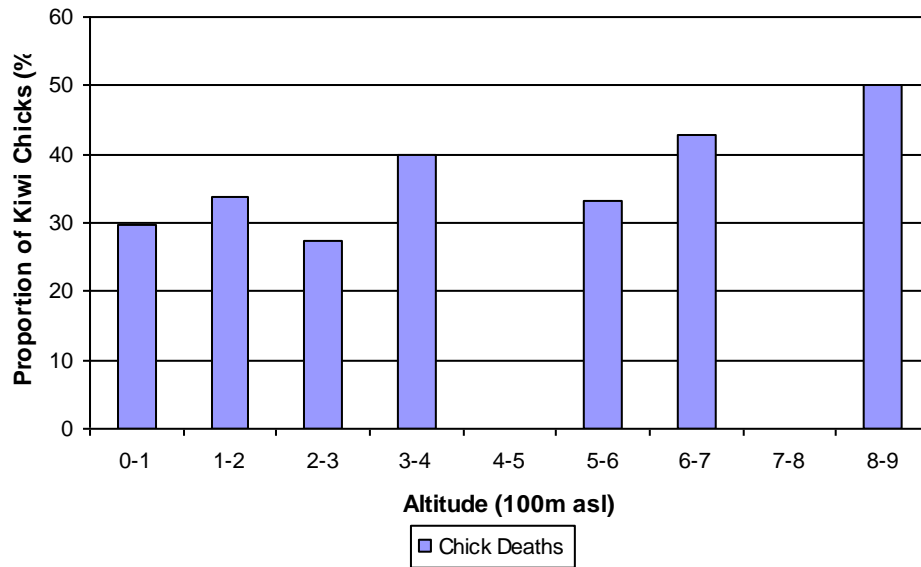
Figure 5.5. *The proportion of kiwi chicks that died (n = 55) at each altitudinal level, at the Moehau Kiwi Sanctuary from 2001–2008.*

Figure 5.6. *Kiwi chick found dead after entanglement of transmitter in mangemange (Lygodium articulatum).*

Table 5.1. *The causes of death recorded for all kiwi from 2001–2008 at Moehau Kiwi Sanctuary.*

Cause of Death	Chick	Sub-adult	Adult	Total
Mustelid predation	16			16
Probable mustelid predation	9			9
Mangemange* (band)			1	1
Mangemange* (natural death)		1	1	2
Mangemange* (transmitter)	10	4	2	16
Dog predation	4	2	7	13
Probable dog predation	3	2	1	6
Cat predation	3			3
Natural	1	1	1	3
Operation trauma	1			1
Road kill		1		1
Unknown	5	1	2	8
Unknown predation	8			8
Cyanide poisoning			1	1
Deformed	1			1
Infection	1			1
Total	59	16	15	90

* Mangemange entanglement.

5.4 Discussion

No kiwi were found dead in July. This might be because most kiwi chicks that had hatched in the previous breeding season were over 1,000g and therefore not as vulnerable to predation. July is when male and female kiwi are preparing nests in burrows and laying the first eggs of the season and so are not on the surface as often and exposed to predators (McLennan, 1988; de Monchy and Forbes, 2006). The month in which greatest number of kiwi were found dead was January, with the majority of these deaths being chicks. This was probably due to there being a higher proportion of chicks under 1,000 grams (Figure 5.3) when they were most vulnerable to predation, and becoming entangled in mangemange. There was a chick mortality rate of 81% during Summer months (December-February), coinciding with a peak in stoat abundance (King, 1990; de Monchy and Forbes, 2006).

Summer was when most kiwi chicks that had hatched the preceding year died (60%), and when the mortality rate was highest (81%). Of all the kiwi chicks that died, 90% died during summer and autumn. The increase in the proportion of chicks that hatch (spring) precedes an increase in the proportion of deaths in summer (Figure 5.4), and therefore the proportion of deaths may be a reflection of a greater abundance of chicks. There was still a greater proportion that died than would be expected during the summer months (81%) compared to autumn (45%) winter (0%) or spring (7%) and this is most likely explained by the increase in stoat abundance, conversely the reason there were no deaths between May and September could also be due to a relatively low abundance of stoats at this time of year (King 1990; de Monchy and Forbes). The current predator-trapping regime at Moehau Kiwi Sanctuary means that predator traps are checked every 5–6 weeks during winter and spring, and at approximately twice the frequency during summer and autumn. It is proposed that an even greater intensity of trapping during summer and/or autumn could substantially increase kiwi chick survival, and that this may also be applicable to other areas where predator control is undertaken to protect kiwi, and stoat abundance and density is similar to that on Moehau.

Kiwi chick survival at Moehau Kiwi Sanctuary was greater than at any other Department of Conservation managed kiwi sanctuary that monitor kiwi through radio-tracking methods (Robertson, 2005). However, there was also a greater rate of kiwi mortality due to management techniques at Moehau compared to other kiwi protection programmes monitoring kiwi with transmitters. There was a rate of one death for every 28.4 transmitter years compared to other kiwi management sites with one death per 96 transmitter years (Pim de Monchy, unpublished data). This may be due to mangemange being less abundant at other management areas in the North Island where it occurs, and absent from the rest of New Zealand where monitoring has occurred. It is possible that kiwi mortality due to predation has been overestimated by current management techniques, as the use of transmitters and identification bands as monitoring tools of kiwi may increase the chance of predators encountering them when they become entangled in mangemange or other vegetation.

Mangemange only occurs in the upper half of North Island (Dodsworth-Smith and Brownsey, 1989), and at Moehau Kiwi Sanctuary has been responsible for 24% of all kiwi deaths and 20% of chick deaths. Around six more kiwi were found entangled and released, or were taken to Rotorua Rainbow Springs Kiwi Encounter to recover due to injuries. Consideration should be taken of the presence of this plant species when establishing new populations of endangered ground-dwelling birds such as kiwi (*Apteryx* spp.) and weka (*Gallirallus australis*), and when monitoring them using traditional techniques, including the use radio-transmitters. There have been suggestions of releasing South Island kiwi species, in particular the Okarito Brown Kiwi (*Apteryx rowi*), numbering around 300 birds, to North Island offshore islands (Colbourne, 1995). A mortality rate equivalent to that of North Island Brown Kiwi at Moehau Kiwi Sanctuary due to entanglement of monitored kiwi would have a significant affect on the viability of the introduced population, should this be done where mangemange is present.

Adult North Island Brown Kiwi annual mortality rates at Waikaremoana were found to be 2.49% (McLennan et al., 2004), similar to that at Moehau (2.52%). Other management areas for NI Brown Kiwi show adult mortality rates of 4.6–7.3% (Robertson, 2005).

However, each population faces different threats. The similarity between Moehau and Waikaremoana in the mortality rate and range of threats (McLennan et al., 2004; de Monchy and Forbes, 2006) would indicate that other populations of kiwi in the North Island that face similar threats will have mortality rates between 2–3%.

All adult and sub-adult deaths occurred when the birds were on the surface, with similar numbers and rates of mortality for male and female kiwi. Considering that sub-adult and adult female kiwi were found on the surface more often than in holes (See Chapter Four), this would suggest that these groups are particularly vulnerable to predation or disturbance. Males may be less vulnerable as they generally nest in holes and incubate the eggs. Any increase in mortality of each group will have significant effects on the population dynamics and may possibly create a sex bias toward more males. If artificial burrows were used in kiwi habitat this might promote their use over using surface roosts and therefore reduce the likelihood of predation in these age-groups. It would probably not assist kiwi chick survival to the same degree as they would still be vulnerable to stoats which have no difficulty in investigating and entering holes (King, 1990).

5.4.1 Operation Nest Egg

Operation Nest Egg kiwi (ONE) at Moehau were more likely to die compared to wild-reared kiwi. This may be due to the eggs that are removed being 'less fit' than eggs that were allowed to hatch naturally. Eggs or chicks that are incubated and raised artificially, receive assistance that wild-reared chicks do not and therefore eggs and chicks that might have died in the wild are now able to survive (Colbourne, 1998; Colbourne et al., 2005). One chick named Rolly, the only kiwi not to display natal dispersal (See Chapter 3.4.1), was so named because he had an unnatural tendency to roll his head around; when released as a chick and by the age of six years still had not bred when all monitored kiwi of a similar age had. Another chick called Matai generally lacked energy and never grew at the same rate as other ONE kiwi before eventually dying from unknown causes before reaching 1000g (Moehau Kiwi Sanctuary, unpublished data, 2007).

Another reason for the higher proportion of deaths in ONE kiwi may be stress and weight loss after release from captivity to the wild. Grant (2003) noted that kiwi initially lost

weight after release, and began to increase weight after an average of two and half months, it took four to five months to regain their initial release weight. In this study seven of eight ONE kiwi died within four months of release although there was no evidence of significant weight-loss (Moehau Kiwi Sanctuary, unpublished data).

5.4.2 Limitations and Bias

In recording the deaths of the total number of kiwi at Moehau Kiwi Sanctuary there was a bias toward kiwi deaths that have been observed or reported by people and often when domestic dogs encountered kiwi and killed them, or when kiwi had been found on a road. Very rarely are kiwi encountered alive or dead, but when they are found it is usually when people find carcasses; therefore there is a tendency to overestimate the number of deaths in proportion to the population. There were also difficulties in establishing the cause of death of kiwi with any certainty even when carcasses were sent to Massey University for a necropsy (Moehau Kiwi Sanctuary, unpublished material).

There was no determination of any annual differences in mortality rates between age-class, or between gender of kiwi, due to the low number of deaths per year preventing robust statistical analysis. There was a maximum of 19 deaths (2007/08), and a minimum of three deaths (2002/03) of kiwi from all age-classes that had been monitored for at least one day from 2001–2008. Over all years combined there was a total of 77 deaths.

Further complicating any determination of annual differences in mortality rates was the differences in the proportion of kiwi of different age-classes and gender in the monitored population each year, depending on the management requirements of the Moehau Kiwi Sanctuary. There was a concerted effort to catch only adult male or female kiwi during the first few years of management (Figure 5.7), (females were only captured so that they could then be tracked and the male partner captured in a shared burrow). Conversely, in the latter two to three years there was a focus on removing adult female and non-breeding adult males from the monitored population. The main focus of the management was to get a representative and robust sample of kiwi chicks and sub-adults to determine kiwi chick survival rates, and sub-adult dispersal and emigration rates.

The different focus of the Moehau Kiwi Sanctuary management between years is reflected in Figure 5.7, which shows the proportion of deaths of kiwi that were monitored for at least one day, out of the total number of kiwi monitored each year. There was a low proportion of deaths in the first two years when there were few chicks or sub-adults, compared to adults in the monitored kiwi population sample (chicks have the highest mortality rate Figure 5.3), and a high proportion of kiwi deaths in the last year when adult male and female kiwi were being removed from the sample.
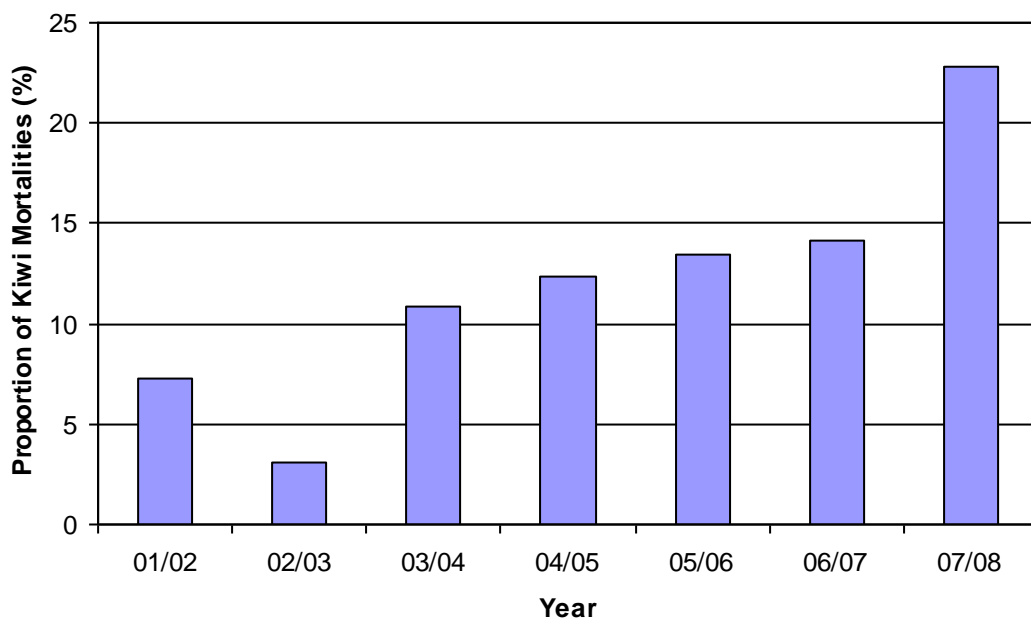
Figure 5.7. *The proportion of kiwi of all age-classes that died (n = 77) out of the total number of kiwi that were monitored each year from 2001–2008 (all years n = 642, annual mean = 92).*

Chapter 6.

General Discussion and Conclusions

6.1 Natal Dispersal

In the past when releasing kiwi into areas on the mainland where they had been extirpated, post-release dispersal of chick, sub-adult and adult kiwi, and natal dispersal of chick and sub-adult kiwi, has not been taken into account. Consequently, areas of protection were too small to encompass all sub-adult kiwi once they dispersed and eventually established territories (MacMillan, 1990). The estimated size of 10,000 hectares for a protected area is necessary to support a self-sustaining population based on survivorship and immigration and emigration rates (natal dispersal) (Basse and McLennan, 2003). However this study demonstrates that the estimated emigration and immigration rates may have underestimated dispersal distances.

Protected areas may not necessarily have to be as large as 10,000 hectares if predator-free enclosures are use eg. Islands. Where this is not feasible, a population model presented by Rhys Burns from the Department of Conservation, Opotiki (Neil, 2006) suggests that protected areas for kiwi need only be as large as 4000 hectares as long as sub-adult recruitment is greater than the rate of mortality in the population. The model assumes that sub-adults that disperse into an unprotected 'sink' area from a protected 'source' area are generally large enough to avoid most predators and will establish territories, and that these birds should be considered part of the managed population regardless of how low the consequent chick survival. There needs only to be a sufficient 'source' population and agreement on how large this population should be (proposed to be a minimum of 200 breeding pairs in the draft Kiwi Recovery Plan 2006–2016 (Butler and McLennan, 2003) but since amended to not include specific population targets. Given kiwi net dispersal distances as demonstrated in this study, this model could be modified to allow for several management areas (4000 hectares or less), separated by no more than the average sub-

adult dispersal distance, thereby allowing greater genetic flow between managed populations, and increased recruitment and population distribution.

The net distance and cumulative distance of natal dispersal can be estimated for chick and sub-adult kiwi if the age or age-class, and rate of dispersal between locations are known. This may prove useful for determining the optimum sizes of protected areas for Kiwi (Basse and McLennan, 2003). For example, if the net distance of dispersal of sub-adult kiwi in North Island kiwi populations is around 4,500m, as they were for wild reared kiwi in this study (Tables 3.3 & 3.5), then protected areas of at least 2025 hectares are required for half of all sub-adult kiwi that disperse to remain within the 'source' area and increase recruitment. The other half of sub-adult kiwi will disperse into the unprotected 'sink' area, where they are unlikely to produce chicks that reach adulthood and breed. This model presumes sub-adults originate from near the centre of the 'source' area, otherwise the actual size of the protected area would have to be a lot bigger for half of dispersing sub-adults to remain within it.

6.2 Habitat Selection

Kiwi select for particular forest types, and the selection of a particular type may be due to specific feeding requirements, to avoid detection by predators, con-specific attraction, or as a result of a lack of other suitable habitat (Taborsky and Taborsky, 1995; Chan, 1999; Gibbs, 2000; Grant, 2003). It is suggested in this study that an important contributor to forest-type selection could be the availability and/or type of ground-cover available for surface roosts. At Moehau surface roosts were used by kiwi on 60% of observations, and of all kiwi located in manuka and kanuka forest 68% were in surface roosts, more than in other forest types which had very similar proportions of kiwi using surface and hole roosts. However, this may be due differences between forest types in the availability of holes; soil substrates in which to excavate holes; or ground cover type and density.

A significantly greater proportion of kiwi selected for surface roost sites in ground-cover types of fern fronds (77%), ground ferns (83%) and grasses (61%) in manuka and kanuka

than in broadleaf or sub-alpine scrub and call surveys have identified manuka and kanuka forest types as harbouring a higher density of kiwi (Stewart et al., 2000) than broadleaf forest. However to determine if the availability of ground-cover determines the proportion of kiwi using surface roost sites under different forest types, it would be necessary to index ground-cover density and abundance under each forest type and consider other factors such as the substratum type and hardness, both of which may prevent kiwi excavating holes.

Encouraging the growth or abundance of ground-cover types used by kiwi when roosting on the surface, could increase the available area of habitat and increase population densities. Kiwi will often select roost sites and nest sites close to or in forest types that provide the greatest amount of foraging opportunities (Taborsky and Taborsky, 1995), and chicks and sub-adults use surface roosts most of the time. So if these forest types happen to have no, or very little ground-cover they may not be used by chicks or sub-adults as frequently as they otherwise would be.

Sub-adults selected for hole roosts over surface roosts as elevation increased; adult male kiwi used hole roosts more than half the time; and there was an increasing tendency to use hole roosts as age increases. This may infer that hole use is only limited by availability and the ability to create and utilise them, so promoting their use in wild populations may be beneficial to kiwi by providing shelter from weather events, and decreasing intraspecific competition for this resource.

The tolerance of kiwi to a wide variety of habitats (See Chapter Four) infers that they are able to disperse through different forest types, and are not inhibited by the forest type. Similar studies on the Emu (*Dromaius novaehollandiae*) (Ratite) and the endemic New Zealand Robin (*Petroica longipes*) also found forest type does not limit dispersal distances (Calvino-Cancela et al., 2006; Wittern and Berggren, 2007).

6.3 Mortality

McLennan et al. (2004) states that there is no bias in the proportions of each sex in populations of North Island Brown Kiwi, as female kiwi are not exposed to the same risk as other native birds in which females sit on the nest (male kiwi excavate the nest and incubate the eggs). The results of this study show that females were found more often on the surface than males and therefore it is reasonable to suggest that they are more vulnerable to predation from stray and pig-hunting dogs (Reid et al., 1982; Taborsky, 1988) and mustelids. This may create a sex bias toward males and may explain why the rate of mortality in females (16%) was twice that of males (8%). Sex bias in kiwi populations has been identified through call surveys. However, this was explained as being due to the greater difficulty in identifying and hearing female calls (Stewart et al., 2000; Corfield, 2005).

Safer methods of monitoring endangered species other than using radio-transmitters are needed. Nearly a quarter of kiwi chicks at Moehau succumbed to entanglement of their transmitter in mangemange vine. This degree of mortality could have negative consequences on the survival and sustainability of populations of other endangered or critically endangered species.

There are potential benefits of artificial burrows in reducing mortality (See Chapter 5.4) in kiwi and increasing the available habitat. Artificial burrows have been known to host wild kiwi and so may be used as readily as natural burrows (Figure 4.26). On Motuara Island eight chick and sub-adult Rowi (*Apteryx rowi*) of different parentage were found together in the same burrow (M Potter, Massey University, 2004). Kiwi in Northland (*Apteryx mantelli*) have been known to use concrete culverts or terracotta pipes as artificial shelters on at least 7 occasions (T Herbert, Department of Conservation, 2004). Kiwi on Moehau used hole roost sites on 34% of observations and adult kiwi on Moehau used hole roosts 58% of the time. It could be argued that it may be the ability of kiwi to create holes that determines the proportion of their use compared to surface roosts, and that increasing the availability of holes will increase their use.

6.4 Operation Nest Egg Kiwi

A greater proportion of ONE chicks died than wild reared kiwi chicks, with approximately 10% more ONE kiwi chick (under 1,000 grams) deaths than wild-reared chicks. ONE kiwi were slower to disperse, went shorter distances than wild-reared kiwi, and one individual did not display natal dispersal. These comparisons may indicate that ONE kiwi were generally lower in 'fitness' than wild-reared kiwi. An implication of dispersal of ONE kiwi from the release site, is that they could disperse out of kiwi protection areas and then be more likely to die than wild-reared kiwi. Perhaps therefore in relatively small protected areas, dispersal in ONE kiwi should be inhibited or prevented.

Once released into the wild ONE kiwi will unlikely be familiar with their natal area (where they were originally obtained as eggs or chicks) or with kiwi from which they inherited genes (parents), and therefore there is a greater potential for inbreeding, particularly when populations are small. To avoid this, the release site for ONE chicks and sub-adults should be near the parental territory or natal area so that when dispersal occurs there is less likelihood parent and offspring will meet. If released away from the natal area as sub-adults, random dispersal means there will be a greater probability ONE kiwi will encounter the parents as breeding adults. When populations are large, the affect of unfit individuals on the genetic health of a population is minimal, however when populations are small the impact on the genetic health of populations is magnified due to the limited availability of mates. Ideally ONE kiwi should be released into populations other than the population from which they were originally sourced.

Releasing ONE kiwi into the wild may be inappropriate considering the possible implications for the long-term genetic and behavioural health of kiwi populations if these individuals are 'unfit', particularly when traditional pest control and management methods are already sufficient to increase kiwi survivorship. The ONE programme may be more appropriate where species exist in small populations; where traditional management methods do not work; or when establishing new populations through translocations, with careful consideration to the need for increasing genetic diversity.

6.5 Main Conclusions:

Natal Dispersal

- Female sub-adult kiwi dispersed greater net distances than male sub-adults.

- The greatest rates and distances in natal dispersal occurred during sub-adulthood, while chicks on average remained within 834m of the natal area.

- The mean net distance dispersed by sub-adult kiwi was 5,487m, and the median was 4,470m (SE +/- 599).

- The distances in natal dispersal of chick and sub-adult kiwi can be estimated if the age or age-class, and the rate of movement between locations are known.

- Operation Nest Egg (ONE) kiwi dispersed at slower rates and for shorter distances than wild-reared kiwi.

- Can detect territoriality in kiwi if they are monitored from hatching or within 50 days of age.

Habitat Selection

- Sub-adult kiwi increasingly selected roost sites in holes as elevation increased. Below 600m in elevation kiwi selected roost sites in holes 19% of the time and above 600m in elevation this increased to 64%.

- Kiwi were found in surface roosts on 60% of all observations, and the use of surface roosts decreased with age-class (surface roost use: chicks, 91%; sub-adults, 69%; and adults, 34%).

- Female kiwi selected surface roosts more often than males regardless of age-class.

- Kiwi selected for dead fern fronds and debris (30% of surface roost sites) over other types of ground-cover when using surface roosts. There was a decreasing use of dead fern fronds and debris for surface roosts, over other types of ground-cover as age increases (chick age-class, 39%; sub-adults, 26%; adults, 14%).

- Sub-adult kiwi select for sub-alpine scrub over broadleaf forest.

Mortality

- All adult and sub-adult kiwi were found dead on the surface and not in holes, whereas 18% dead chicks were found in holes.

- ONE kiwi chicks had a 10% higher mortality rate than wild-reared kiwi.

- Almost a quarter of kiwi deaths (24%) and 20% of chick deaths were caused by the monitoring techniques at Moehau Kiwi Sanctuary. Alternative monitoring methods should be developed.

- Chicks had a higher mortality rate during summer than in other seasons.

6.6 Recommendations for further study

Opportunities for future research questions have arisen from this Thesis, and of particular interest is roost-site selection in sub-adult kiwi. It has been demonstrated that roost-site selection changes with elevation. It would be interesting to see whether roost-site selection is dependent on temperature or rainfall, by observing roost-site preferences of kiwi populations throughout their range on North and South Island, and whether preferences change depending on elevation and latitude. Current studies have focused almost entirely on North Island Brown Kiwi, with no published papers on roost-site selection for kiwi species found on offshore islands or on South Island.

Whether kiwi select for different roost site types depending on temporal changes in on forest condition and structure should also be a priority for future investigation.

Studies have observed that kiwi have preferences in habitat types and display distinct dispersal behaviour depending on either the age-class or gender. However, few studies have focused on differences between genders in different age-classes. This would be worthy of further investigation.

A number of studies on North Island Brown Kiwi populations have established that roost-site preferences change depending on the age-class and are similar between geographically isolated and genetically distinct populations. It is suggested that North Island Brown Kiwi roosting behaviour is similar throughout their range, and that there may be a genetic component to the variation between age-classes. Further comparative studies are needed to determine roosting preferences of North Island kiwi for different forest habitat types.

Determining dispersal distances and rates at different times of the year (months or seasons) would provide information on population dynamics and intrasexual competition influences on natal dispersal, and it would be desirable to do further comprehensive

dispersal studies on mainland NI Brown Kiwi populations that are not obstructed by the sea or other physical barriers as is the case at Moehau.

It would be worth comparing dispersal distances and rates among all kiwi species and isolated populations. Does the size of kiwi determine distances and rates of dispersal, and therefore what are the dispersal distances and rates in our smallest kiwi species, the Little Spotted Kiwi, and can this accurately be determined when all Little Spotted Kiwi populations are confined to offshore islands or mainland enclosures?

Due to the potential benefits of artificial burrows in reducing mortality, and the selection of holes for roosts by sub-adult and adult male kiwi, there should be further investigation into whether the use of artificial burrows can increase survivorship in kiwi.

The influence or impacts on genetic health on kiwi populations of ONE kiwi released into the wild is certainly of critical importance to the long-term conservation of endangered species, and worthy of consideration. Why is it that they have greatest mortality and lowest dispersal rates and distances? Are there differences between those kiwi that are captive-reared from eggs and those that are captive-reared only as chicks?

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