Reintroducing hihi (*Notiomystis cincta*) to the New Zealand mainland.

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ABSTRACT

This thesis investigated the potential for establishing a self-sustaining population of an endangered forest bird, the hihi (*Notiomystis cincta*) on the New Zealand mainland, and the factors that may influence this. Previous reintroduction attempts, mostly to offshore islands, have met with limited success, or been dependent on ongoing management. However, future conservation measures for hihi aim to reintroduce populations to the mature forest found on the mainland that hihi may be best adapted to. Such reintroductions come with new challenges for hihi conservation.

The first reintroduction of hihi to this environment occurred with two releases of hihi from Tiritiri Matangi Island to “Ark in the Park”, a predator-controlled site in Auckland’s Waitakere Ranges, in February and June 2007. This study reports on the survival and dispersal of hihi following these releases, using radio transmitters for post-release monitoring, and also gives information on the vulnerability of hihi to predators, and foraging behaviour at this site.

In terms of survivorship, birds released in February had higher apparent survival than those released in June, but this may have been due to higher dispersal in June. Birds released under a “delayed-release” strategy had lower long-term survival than those released immediately. There was some evidence that transmitters may have had an impact on dispersal and behaviour, but there was no evidence that transmitters reduced survival.

Individuals in better condition were more likely to disperse further in the first week post-release, but it was not possible to examine the relationship between condition and survival. Clutch size and hatching date were the two most influential factors found to affect individual condition in juvenile hihi from Tiritiri Matangi Island. It may be possible to use this information when selecting individuals for future translocations, but the impact on the source population should first be investigated, as well as the relationship between condition and survival.

The failure of previous hihi reintroductions has in part been attributed to a lack of diversity of natural food in regenerating forest, and all successfully reintroduced populations to date rely on supplementary food. However, little is known about how the diet of hihi changes at different life stages, between the sexes, by season and in different habitats. In this study, such information was provided for the first time for hihi using stable isotope analysis. I found evidence for dietary shifts across different life stages (nestling, fledgling, juvenile and adult), between the sexes, and in different habitats (regenerating forest vs mature forest), and I showed that diet may be one of the proximate factors influencing individual condition.

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1.1.1– Island ecosystems

Isolated island ecosystems are generally considered to be more vulnerable than larger continental regions (MacArthur and Wilson, 1967), with their often unique flora and fauna being poorly adapted to the changes that come with human occupation, such as the introduction of exotic species and diseases (IUCN, 2000). New Zealand provides one of the clearest examples of this. Once forming part of the Gondwana land mass, New Zealand became isolated approximately 80 million years ago, and the terrestrial fauna developed in the absence of mammals, with the exception of three species of bat (Worthy and Holdaway, 2002).

New Zealand's ecosystems are at present in a state of change, due primarily to the arrival of humans approximately 800 years ago (Wilmshurst *et al*. 2008). Early Polynesian settlers brought mammals such as the kiore/Pacific rat (*Rattus exulans*) and the kuri/Polynesian dog (*Canis familiaris*), and hunted the native wildlife for food. These early colonisers also reduced forest cover from 85 to 53% of the land area (McGlone, 1989; Ministry for the Environment, 1997; Worthy and Holdaway, 2002). The colonisation by Europeans in the 1800s brought further changes which would have irreversible effects – the introduction of a number of mammals, including the ship rat (*Rattus rattus)*, Norway rat (*Rattus norvegicus*), three species of mustelids (*Mustela furo, M. nivalis and M. erminea*.), cats (*Felis catus*) and the possum (*Trichosurus vulpecula*), all of which are now known to prey upon native fauna. Many European bird species were introduced, and these would have been accompanied by new pathogens and parasites that native species may have had little resistance to, although this has not been proven. Habitat clearance and fragmentation was accelerated, with native forest cover reduced to 23% of the land area within 100 years (Ministry for the Environment, 1997). In combination with hunting by museum collectors, these factors caused the extinction of species such as the huia (*Heteralocha acutirostris*) and piopio (*Turnagra capensis*); led to species such as the saddleback (*Philesturnus carunculatus*) and hihi/stitchbird (*Notiomystis cincta*) becoming restricted to offshore islands; and caused a major range reduction in others such as the kakapo (*Strigops habroptilus*), takahe (*Porphyrio mantelli*), and kokako (*Callaeas cinerea*). The ongoing effects of invasive species and habitat fragmentation continue to pose a threat to many native species (Worthy and Holdaway, 2002).

The focus for ecosystem restoration and endangered species management in New Zealand has traditionally centered on restoring offshore islands by mammal eradication and subsequent revegetation (Towns and Broome, 2005). This approach has allowed for the reestablishment of populations of threatened species at those managed island locations. Some of these programmes have met with success and widespread publicity, such as the recovery of the black robin

(*Petroica traversi*) in the Chatham Islands. However, conservation on offshore islands has some restrictions. Many of these islands are off-limits to the general public, reducing the opportunities for the majority of people to see the results of these conservation success stories. Islands that do not fit this trend (such as Tiritiri Matangi Island in Auckland's Hauraki Gulf) have illustrated the importance of involving people in conservation as an advocacy tool (Parker, 2008). Another important issue is that offshore islands are not always representative of the original or preferred habitat of a species, being limited in size and sometimes diversity, in comparison to the large tracts of mature forest found on the mainland. Islands may also have a different climate and soils to the mainland, and represent only a small fraction of the total New Zealand environment, and many of the islands that are most similar to mainland environments have been highly modified as they are often also suitable for farming (Meurk and Blaschke, 1990). These factors, either individually or in combination have limited the potential and success of some species reintroductions to islands (Hooson and Jamieson, 2004; Armstrong *et al.* 2007).

1.1.2 - Restoration on the New Zealand mainland

Conservation attempts on the mainland have increased over the past decade, both through the Department of Conservation's Mainland Island Programme (Saunders and Norton, 2001), and an increasing number of community-led initiatives. These programmes aim to restore a functioning ecosystem including all its components (birds, reptiles, invertebrates and plants), and achieving this with the participation of local communities and Iwi (McQueen *et al.* 2004; Bellingham *et al.* 2008). This has enabled the reintroduction of locally extirpated species such as the North Island robin (*Petroica australis*), saddleback, whitehead (*Mohoua albicilla*), and brown kiwi (*Apteryx mantelli*), as well as some reptile, invertebrate and plant species to areas where they had not previously been seen for sometimes more than 100 years (Armstrong, 2009). Successfully reintroducing a previously extirpated species to a restored ecosystem can demonstrate the restored integrity of the ecosystem (Lipsey and Child, 2007).

1.1.3 - Reintroductions as a conservation tool

A **reintroduction** is defined as "*the intentional movement of an organism into a part of its native range from which it has disappeared or become extirpated in historic times as a result of human activities or natural catastrophe*" (IUCN, 1987). This forms part of the process of **translocation** – "*the movement of living organisms from one area with free release in another*" (IUCN, 1987). Reintroductions have a long association with human history, frequently for hunting purposes, but have in recent decades become a common conservation tool in endangered species management (Griffith *et al*. 1989; Seddon *et al*. 2007; previous section). Such reintroductions have had a highly variable success rate, and often attract media attention as the public face of conservation. Reintroductions do not end with the release of the individuals – post-release monitoring is crucial to determine the fate of the individuals released and to assess the factors involved in determining the success or otherwise of the reintroduction attempt (Seddon *et al*. 2007).

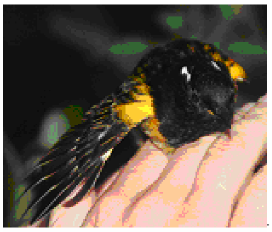
1.1.4 - Reintroductions to the New Zealand mainland – new challenges

One of the major problems that mainland restoration projects must deal with is how to deal with mammalian predators. There are generally two options: construct a predator-proof fence and eradicate the pests within, or maintain predator numbers to very low levels with intensive control. Both methods involve a long-term commitment in order to achieve success. The success of a reintroduction (defined as establishment and persistence of a population) of an extirpated species to an area where intensive predator control is undertaken will vary depending on the species. Some, such as the North Island saddleback, appear to have a low probability of establishment even when ship rat numbers are maintained to very low densities (1% tracking rates). In contrast, North Island robin populations may be able to grow if rat tracking rates are maintained below 20% (Armstrong *et al.* 2006).

The dispersal behaviour of the species being reintroduced can present another challenge for mainland reintroductions. Some forest birds such as the North Island robin are reluctant to cross significant gaps between forest patches (Richard, 2007). This behaviour will limit the opportunities for dispersal in a mainland island situation if the protected habitat is, for example, surrounded by a matrix of unsuitable habitat. Many New Zealand birds are flightless or have reduced flying abilities, and this reduces the possibilities for dispersal. However, where a protected area is adjacent to or sufficiently close to an unmanaged area of otherwise good habitat, dispersal can potentially undermine the success of the reintroduction attempt. Dispersing birds will have an increased risk of predation compared to when in the protected area, leading to a source-sink situation (Dias, 1996; Basse and McLennan, 2003). Reintroduced North Island robins at Wenderholm Regional Park have high productivity yet low recruitment, and this is thought to be due to high levels of juvenile dispersal out of the park to areas where little or no predator control is undertaken (Andrews, 2007). Neighbours of the Karori Wildlife Sanctuary situated in urban Wellington are thrilled at the sight of a saddleback or hihi in their back garden – and this has positive effects in enhancing visibility of and public support for the project – but there have been at least two hihi handed in to the sanctuary having been caught by domestic cats (Empson and Booth, 2007).

Dispersal can also be an issue in the immediate post-release phase. Little is known about the homing behaviour of most species, but there are examples in the literature of usually sedentary species covering considerable distances of “unsuitable” habitat to return to the source site (Clarke and Schedvin, 1997; Doncaster *et al.* 2001; Oppel and Beaven, 2002; Parker *et al.* 2004). The factors influencing individual dispersal in the post-release phase have been poorly studied following reintroductions. However, natural dispersal patterns of some species suggest that individual condition may be one contributing factor (Nilsson and Smith, 1985; Ferrer, 1992; Alonso *et al.* 1998; van Oort and Otter, 2005).

1.2 - Hihi conservation



1.2.1 – Hihi ecology

Hihi are an endangered forest passerine (30-40 g) endemic to New Zealand. They were once widespread throughout the North Island, but by the 1880s had become restricted to one population on Hauturu (Little Barrier Island, 3083 ha) in the Hauraki Gulf (Taylor *et al.* 2005; Figure 1.1). It is thought they became extinct on the mainland due to a combination of factors including predation by introduced mammalian predators, widespread habitat clearance at this time, and perhaps disease caused by new pathogens (Taylor *et al.* 2005). Hihi are now classified as vulnerable by the IUCN Red List of Threatened Species (IUCN, 2009) and nationally endangered on the New Zealand Department of Conservation's threatened species classification listing (Department of Conservation, 2002).

Hihi were once classified in the Meliphagidae family (honeyeaters), along with New Zealand's endemic tui (*Prosthemadera novaeseelandiae*) and bellbird (*Anthornis melanura*). However, recent molecular evidence has placed hihi in their own unique family, the Notiomystidae, of which they are the sole representative (Driskell, 2001; Ewen *et al.* 2006; Driskell *et al.* 2007). Like the honeyeaters, hihi feed on a combination of nectar, fruit and invertebrates. They have an unusual breeding system in that they are most often socially monogamous, but can form polygynous, polyandrous and polygynandrous breeding units, and have high levels of extra-pair paternity (Castro *et al.* 1996).

1.2.2 – Hihi reintroduction attempts

Conservation attempts for hihi began in the 1980s, with reintroductions to Cuvier (195 ha), Hen (500 ha) and Kapiti Islands (1966 ha) (Figure 1.1) (Angehr, 1984; Lovegrove, 1985). No population survived for longer than five years despite initially breeding successfully (Lovegrove, 1985; Castro *et al.* 1994). The first hihi reintroduction that resulted in a second permanent population occurred with the reintroduction of 48 and 47 birds, in 1991 and 1992 respectively, from Hauturu to Kapiti Island (Castro *et al.* 1994; Castro, 1995). This establishment appears to be due in part to the provision of supplementary food (sugar water), as the population was declining until supplementary feeding was introduced in 2000 (Taylor *et al.* 2005).

Figure 1.1. Map showing past and present hihi populations, including Hauturu (natural population), Kapiti (reintroduced successfully 1991), Mokoia Island (reintroduced 1994, removed 2002), Tiritiri Matangi Island (reintroduced 1995), Karori Sanctuary (reintroduced 2005), and Ark in the Park (reintroduction proposed 2007).

In 1994, 40 hihi were released on Mokoia Island (135 ha, Figure 1.1), and provided with supplementary food (Armstrong *et al.* 2002). This population fluctuated for the first four years but overall had a low survival rate and did not increase, consistent with what had occurred with populations on the earlier islands (Armstrong and Perrott, 2000). Research showed that the Mokoia population did benefit from supplementary feeding, with reproductive productivity being increased, but with no effect on adult survival (Armstrong *et al.* 2002; Castro *et al.* 2003; Armstrong *et al.* 2007). Survival may have been ultimately jeopardised by the high prevalence of the opportunistic pathogen *Aspergillus fumigatus* (aspergillosis), which led to high mortality of hihi on Mokoia Island and may have been the key limiting factor for the population (Alley *et al.* 1999; Perrott, 2001; Armstrong *et al.* 2002). This population may have been additionally limited by predation by the native owl, the morepork (*Ninox novaezelandiae*; Low, in press). The remaining hihi on Mokoia Island were transferred to Kapiti Island in 2002 (Taylor *et al.* 2005).

Tiritiri Matangi Island (220 ha, Figure 1.1), a Scientific Reserve covered in regenerating and replanted vegetation represents the most successful of the island reintroductions of hihi to date. Intensive management is still carried out to support this population, specifically supplementary feeding and nest box provision (Taylor *et al.* 2005). In 1995, 38 hihi were introduced to Tiritiri Matangi from Hauturu, but only 16 remained after the first month. A second release of 13 birds occurred in 1996, and again most females disappeared (Ewen, 1996; Armstrong *et al.* 2002). Despite these initial setbacks, the population has since shown a steady increase, at a rate sufficient to allow harvesting for reintroductions elsewhere (D. Armstrong, unpubl. data). The increase in population has depended on intense management of the population, including supplementary feeding (Armstrong and Ewen, 2001) and the provision of nesting boxes.

In 2005, the first reintroduction of hihi to the mainland took place, with the release of 63 birds at Karori Wildlife Sanctuary (250 ha, Figure 1.1). This site is composed primarily of regenerating forest, and is enclosed by a predator-proof fence. This reintroduction involved two releases, the first of 33 birds in February, and the second of 30 birds in May. Since reintroduction the population has been provided with supplementary food (Wombaroo™ and sugar water in alternate years) and nest boxes. This population had low initial mortality, with 90% of the birds surviving the first six weeks (Empson and Booth, 2007).

Despite these successes, no self-sustaining population (defined as persisting in the absence of ongoing human management) of hihi has yet been established. The failure of early reintroduction attempts has been attributed to the poor suitability of the habitat for hihi because early attempts were to islands with regenerating forest habitat. In particular, the low floral diversity on these islands may have resulted in "crunch" periods of food supply (Lovegrove, 1985; Castro *et al.* 1994). Since Mokoia Island, it has also been thought possible that disease such as aspergillosis (associated with disturbed habitats) may also have been a factor. The concerns over food supply were addressed subsequently with the introduction of supplementary feeding, but it remains unclear why and at what life stages it is most vital.

1.2.3 - Establishing a self sustaining hihi population

The success of a reintroduction does not rely solely on the establishment of the founder population, but also on its long-term chances of persistence (Armstrong and Seddon, 2008). It is necessary to eliminate the factor(s) that caused the extirpation of the population initially, but these may not always be clear. Predicting the habitat requirements for a population to become self-sustaining involves considering all aspects of the environment – food availability, patch size and isolation, presence of nest sites, roosting sites and even song perches, plant diversity, microclimate, levels of disturbance (past and present), disease, and predators (native and introduced) can all be factors influencing the suitability of habitat.

As such, future reintroductions of hihi needed to take into account the factors that may have prevented prior populations from becoming self-sustaining. The primary issues were identified as forest complexity (Makan, 2006), and prior levels of disturbance (increasing the occurrence of aspergillosis; Perrott, 2001). This meant looking to the mature forest habitat found on the mainland.

Little is known about the vulnerability of hihi to mammalian predators, although it is suspected that ship rats played an important role in their disappearance from the mainland. Mustelids are unlikely to have played a role in the extinction of hihi on the mainland because their release and subsequent expansion in the North Island occurred at the time hihi were already near extinction on the mainland. However mustelids are now widespread (King, 2005) and would represent a threat to hihi.

Hihi coexisted with kiore and feral cats on Hauturu, although there is evidence to suggest the hihi population increased following the removal of cats in 1981 (Lovegrove, 1985). On Kapiti, Norway rats and kiore were present and hihi numbers initially increased following their removal (Empson and Miskelly, 1999). Hihi are cavity-nesters, and this is likely to leave them susceptible to predation by ship rats and stoats (*Mustela erminea*) in particular, as is the case with other endangered New Zealand species that nest in cavities (O'Donnell, 1996; Taylor *et al.* 2005). Hihi also roost in cavities and epiphytes, another habit that may leave them vulnerable to ship rat predation outside of the breeding season.

Hence it was necessary to locate a site that met the habitat criteria, including a consistent and effective predator control programme. The Hihi Recovery Group identified the "Ark in the Park" site (1300 ha, see Chapter 2 for description) in Auckland's Waitakere Ranges as suitable, and a reintroduction proposal was put forward and accepted. This represented the first attempt to reintroduce hihi to mature forest habitat on the New Zealand mainland in the presence of mammalian predators (albeit in low numbers). Tiritiri Matangi Island was selected as the source population.

1.3 - Thesis outline

Chapter 2 covers the reintroduction of hihi to Ark in the Park in 2007. This study was designed to answer three key questions: 1) what is the translocation design that maximises post-release survival of hihi in a mainland environment? 2) what is the impact (if any) of carrying a transmitter on survival and behaviour? and 3) to what degree does dispersal occur in the post-release phase? In addition this chapter presents information on the vulnerability of hihi to predators at this site, and foraging behaviour.

Chapter 3 examines the influence of individual condition on the post-release dispersal behaviour of juvenile hihi in the immediate period following reintroduction. Ark in the Park is located within 13,000 ha of forest in the Waitakere Ranges, hence dispersal should not be limited and can potentially occur over a large area. This chapter also looks at the potential influence of carrying a transmitter on dispersal behaviour in the post-release phase.

Chapter 4 examines the social and environmental factors that may have led to variation in individual condition in juveniles during early growth in the source population, Tiritiri Matangi Island. Individual variation in condition may be linked to post-release survival and behaviour, and any factors that influence condition may be a guide to selecting individuals for future reintroduction attempts.

Chapter 5 examines the diet of hihi at both the source site, Tiritiri Matangi Island, and at the new habitat at Ark in the Park, and looks at shifts in diet by life stage, sex and season, using stable isotope analysis. The relationship between diet and condition is also examined.

Chapter 6 summarises the results from the previous four chapters, and discusses the potential for a self-sustaining hihi population on the New Zealand mainland.

All work was carried out with approval from the Massey University Animal Ethics Committee (07/11), with a High Impact, Research and Collection Permit from the Department of Conservation (National Permit Number AK-20621-FAU) and a permit from the Auckland Regional Council for work carried out in the Waitakere Ranges Regional Park.

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2

Reintroduction of hihi (*Notiomystis cincta*) to a predator-controlled mainland site.

Ark in the Park. Photo by author.

2.1 - INTRODUCTION

2.1.1 - Reintroductions and conservation

Recent decades have seen considerable declines in, and increasing threats to, the world's biodiversity, with current extinction rates 100 to 1000 times higher than past rates (Primack, 2004). This is due almost exclusively to human activities, such as habitat destruction, fragmentation and degradation, pollution, climate change, overexploitation, introduction of exotic species, and spread of disease (Primack, 2004). Some species are more vulnerable to extinction than others – such as those with specialised habitat requirements, with limited geographical range, that have evolved in geographic isolation, and/or are characteristically found in stable environments. In general, island species are more vulnerable to extinction than those found on the mainland (Primack, 2004).

An area where an extirpation of a species from its natural range has occurred is a good candidate for a species reintroduction, if the original cause of the extirpation has been eliminated or controlled, and no new threats have since emerged (Griffith *et al.* 1989; see Chapter 1). A successful reintroduction is one in which a self-sustaining population becomes established, the definition of which will vary from species to species (Griffith *et al.* 1989). It can mean in the absence of human management, or population persistence without further releases. Factors that contribute to the success of reintroductions can include habitat quality, releasing species into the core of their historical range (Griffith *et al.* 1989; Wolf *et al.* 1998), and the number of individuals released (Griffith *et al.* 1989; but see Wolf *et al.* 1998). Some reintroduction projects have met with limited long-term success, and the importance of designing such projects to incorporate a more experimental or adaptive management approach has been emphasised (Armstrong *et al.* 1994; Sarrazin and Barbault, 1996; Seddon *et al.* 2007), to enable the factors leading to success or failure of such projects to be more easily determined.

Reintroductions are frequently a component of restoration projects, which have a wider goal of "*assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed*" (SER, 2004). This goal is much broader than the single-species approach that reintroductions have. The role of the reintroduced species should be considered as a functioning component of the greater ecosystem –

taking into account both positive and negative effects on processes within the environment, as well as its interaction with other species (Lipsey and Child, 2007).

2.1.2 - Hihi reintroduction history

Hihi, or stitchbird (*Notiomystis cincta*) are an endangered New Zealand forest bird that have benefited from reintroductions (see Chapter 1). However, no reintroduced hihi population to date has become self-sustaining without the aid of human management. The Hihi Recovery Plan produced by New Zealand's Department of Conservation (Taylor *et al*. 2005) lists as one of its goals for 2004-09 to "identify sites favourable to the establishment of self-sustaining hihi populations and reintroduce hihi to the most favourable of these". The recovery plan defines self-sustaining as a population which does not require supplementary food or the intensive management of nest boxes to remain viable (Taylor *et al.* 2005). Research to date has suggested that the habitat at previous reintroduction sites may not have been suitable for hihi, being primarily island ecosystems that had been highly modified prior to restoration, and that mature forest may be the habitat type hihi are best adapted to (Chapter 1).

Sufficient areas of mature forest are primarily found on the New Zealand mainland. Mature forest is considered more likely to contain more complex and diverse habitat with a year-round supply of natural food, and more plentiful options for natural nest cavities, and hence should be preferable for future hihi reintroductions. A site in Auckland's Waitakere Ranges, "Ark in the Park", is currently the subject of a restoration programme, and was identified as suitable, due to its mature forest habitat and low densities of mammalian predators. A reintroduction of hihi to Ark in the Park was proposed for 2007 (Jack and Sumich, 2005). The source population was identified as Tiritiri Matangi Island, which has previously been used as a source for other hihi reintroductions (Taylor *et al.* 2005; Empson and Booth, 2007).

The primary goal for this reintroduction was to establish a population that could persist without reliance on supplementary food and artificial nest boxes. The reintroduction of hihi would also contribute towards the vision for the Ark in the Park project: to "*enhance the biodiversity and ecosystem function in the Ark area…*" (Bellingham *et al.* 2008). Hihi, at the bottom of the nectar-feeding hierarchy in New Zealand (Rasch and Craig, 1988), are unlikely to have a negative impact on the ecosystem, and as pollinators are more likely to enhance the ecological viability of the Ark in the Park project. For example, they are thought to be the primary pollinator of *Alseuosmia macrophylla* (Merrett *et al.* 2007), which occurs in the Waitakere Ranges.

2.1.3 – Translocation design

A number of factors can influence the success of reintroductions. For example, the success of a reintroduction is dependent in part on an appropriate translocation design for the species. A variety of methods can be utilised to enhance the survival of individuals in the post-translocation stage, and the success of these methods appears to vary amongst species (Bright and Morris, 1994; Letty *et al.* 2000; Franzreb, 2004; Letty *et al.* 2007). For example, different strategies can be used for releasing animals. Individuals can be released immediately with no assistance such as supplementary food provided (termed “hard” or “immediate” release), or can be held in aviaries or other enclosures at the site prior to release (“delayed” release), and provided with supplementary food and/or other resources (all forms of “soft” release) (Scott and Carpenter, 1987; Castro *et al.* 1994). Individuals can be released at a site where conspecifics are present, or released with other individuals they are familiar with (Castro *et al.* 1994).

There has been some variation in the post-release survival of hihi following translocations. The mortality of hihi in the six weeks post-release on Kapiti Island in 1991 was 37%, while it was 55% and 69% on Tiritiri Matangi for the 1995 and 1996 releases respectively. In contrast, on Mokoia Island post-release mortality (7% in the first six weeks) was found to be no higher than average mortality in the long-term (Armstrong *et al.* 1999). This difference in post-release mortality between Tiritiri Matangi, Kapiti and Mokoia could be explained by a variety of factors. Some of the techniques employed during and immediately following reintroduction and characteristics of the individual islands may have affected the survival of hihi. Post-release harassment by bellbird (*Anthornis melanura*) was noted on both Tiritiri Matangi (Wilson, undated) and Kapiti (I. Castro, pers. comm.), whereas bellbirds are not present on Mokoia. Bad weather may also have been a factor in the releases to Tiritiri Matangi (Armstrong *et al.* 1999).

Some hihi translocations have been carried out in the context of an experiment aiming to address management questions identified by the Hihi Recovery Group and to improve the chances of a successful reintroduction. The translocations of hihi to Kapiti Island in 1991 and 1992 presented an opportunity for the comparison of a variety of release strategies. For the 1991 translocation hihi that were kept in an aviary for two weeks on Kapiti prior to release had a lower survival rate (46% survived to first four weeks) than birds which were released immediately (75% survived to first four weeks) (Castro *et al.* 1994). The same study showed that there was no difference between birds released as pairs or in groups. The release in 1992 showed a trend for birds to survive better when released in the absence of conspecifics, and hihi released in areas free of conspecifics quickly moved to areas with resident birds (Castro *et al.* 1994; Castro, 1995). Armstrong *et al.* (1999) found that the site of release on Mokoia Island had no major effect on eventual distribution.

In contrast with the Kapiti releases there were no obvious differences between immediate and delayed released hihi at Karori in 2005 for survival to six weeks (Empson and Booth, 2007). For the first Karori release, immediate-release birds had 100% survival to six weeks, and delayed-release 93%, and for the second release immediate-release birds had 80% survival and delayed-release 87%. However looking at the longer-term survival percentages in the 12 months post-release, it appears that immediate-release birds had slightly higher long-term survival (Empson and Booth, 2007).

Post-release monitoring is an essential part of reintroductions, because it provides the means to determine the factors influencing the fate of the population after release, and helps address potential requirements for further management. In the case of the Ark in the Park hihi reintroductions, the use of radio transmitters was considered essential to determine the fate of individual birds, as the reintroduction site is part of a large area of continuous forest, the Waitakere Ranges (approximately 13,000 ha, Figure 2.1). Radio transmitters are a commonly used tool for post-translocation monitoring, and enable researchers to locate individual animals. It is, however, important that the results obtained are accurate and representative of the population. Radio transmitters may affect flight performance (Obrecht *et al.* 1998), can restrict movement and potentially increasing the probability of predation or impairment of breeding (Dilks *et al.* 1998), or can affect daily energy expenditure (Godfrey and Bryant, 2003). Research investigating the effects of radio transmitters on behaviour and survival has produced different results in different species. Most studies find no effect (Neudorf and Pitcher, 1997; Powell *et al.* 1998; Gursky, 1998; Kurta and Murray, 2002); however, some have shown that there are some differences in the behaviour of birds with transmitters compared to conspecifics without them (Wanless *et al.* 1988; Ward and Flint, 1995). Radio transmitters have been successfully used with hihi in the past, with no apparent effect on survival (Castro *et al.* 1994; Armstrong *et al.* 1999). In contrast Barr (2002) found that transmitters may have reduced hihi survival following translocation from Mokoia to Kapiti, although the sample size was too small to draw firm conclusions (nine birds fitted with transmitters from a total of 12).

2.1.4 - This release

This release was different from previous hihi reintroductions in that it was to a mainland site where predators were still present, albeit in small and controlled numbers. This study was designed to address three main questions and obtain information about important ecological aspects of hihi behaviour which would influence their survival in a mainland environment:

- What is the translocation design that maximises post-release survival of hihi at a mainland site?
- Do transmitters influence the survival and/or behaviour of hihi at Ark in the Park?
- To what degree will dispersal occur in the post-release phase at a mainland site?

In addition it was intended to provide information on the vulnerability of hihi to mammalian predators, and to provide information on the foraging behaviour of hihi in mature forest habitat.

2.2 - METHODS

2.2.1 - Study sites

- *2.2.1.1 – Source population: Tiritiri Matangi Island*

Tiritiri Matangi Island (220 ha) is a Scientific Reserve managed by the Department of Conservation, and is located in Auckland’s Hauraki Gulf (Figure 2.1). It has been the subject of a restoration programme since the 1970s involving extensive replanting and reintroduction of endangered wildlife (Rimmer, 2004). It is now a valuable tool for conservation advocacy, being open to the public and close to the Auckland mainland. Hihi were translocated to Tiritiri Matangi from Hauturu in 1995, and the population has since expanded. The hihi population is the subject of intensive management - supplementary food (sugar water) is provided year-round, and artificial nest boxes are used for breeding due to the lack of natural cavities in the regenerating forest (Taylor *et al*. 2005). The population is also monitored during the breeding season, with all chicks banded while in the nest. The hihi population on Tiritiri Matangi Island can be confidently used as a source for reintroductions, as up to 60 juveniles can be taken annually without causing a decline in the population (D. Armstrong, Massey University, unpubl. data).

Figure 2.1. Map showing Auckland region, with the location of Tiritiri Matangi Island and Ark in the Park. Red circle indicates Waitakere Ranges. Source: Google Earth.

- *2.2.1.2 – Release site - Ark in the Park*

Ark in the Park (1300 ha) is an unfenced mainland restoration programme situated within Auckland’s Waitakere Ranges (Figures 2.1 and 2.2). Restoration began in

2003 and the project is managed jointly by the Waitakere branch of the Royal Forest and Bird Protection Society (New Zealand's largest conservation NGO) and the Auckland Regional Council. The vegetation of Ark in the Park is composed of a combination of untouched kauri (*Agathis australis*) forest, and forest which has been regenerating for 60-100 years following logging and thinning in the 19th century (Esler, 2006). Intensive predator control using brodifacoum bait stations targets species such as ship rats (*Rattus rattus*) and possums (*Trichosurus vulpecula*), while traps target mustelids (*Mustela* spp.). The maintenance of pest species to extremely low levels has allowed for the reintroduction of whitehead (*Mohoua albicilla*) and the North Island robin (*Petroica australis*) (Bellingham *et al*. 2008).

Figure 2.2. Aerial map of the Waitakere Ranges (darker forested area), Auckland, New Zealand. Ark in the Park is the area encircled and release site represented by dot. Sourced from Orthophoto, Q11 Waitakere (2001/02), Crown Copyright Reserved.

2.2.2 - Study species

See Chapter 1 for details of hihi ecology and conservation status.

2.2.3 - Translocation design

See Richardson and Jack, 2008, for a more detailed report on the methods used in this translocation.

Two translocations, of 30 birds each, were planned initially for February and April 2007. However, the second translocation did not occur until June 2007 (see *2.3.3.3*). Each translocation was intended to comprise five adult males and 25 juveniles of an approximately equal sex ratio. Half were to be released immediately, and the other half kept in captivity on-site for 4-5 days.

Hihi were captured in February and June 2007 on Tiritiri Matangi using feeder stations and mist nets. Once captured the following was recorded:

1. Band combination/number,
2. Age (adult or juvenile)
3. Sex where possible, using colouration of male plumage to sex juveniles
4. Weight (g) (using 100 g pesola scales)
5. Tarsus length (mm),
6. Head to bill length (mm),
7. Wing length (mm),
8. Tail length (mm),

9. Body condition scores - these were assessed on a scale of 1-5, where 1=very poor condition and 5=very good condition, by feeling the amount of muscle around the keel (Taylor and Castro, 2001).

All birds were checked for presence or absence of sub-lingual oral fistulas (Low *et al*. 2007), ectoparasites and any other abnormalities. Faecal samples, a cloacal swab (to test for *Coccidia*, *Salmonella*, *Yersinia*, and *Campylobacter*), and a blood sample (to measure total plasma protein) were also collected from each bird as standard operating procedures for DoC approved translocations.

All hihi were then kept in temporary aviaries on Tiritiri Matangi Island while the disease screening results were awaited. This meant individuals were in captivity for 12-14 days in February (34 birds) and 9-12 days in June (36 birds). Hihi were fed an artificial diet similar to that given to the captive population at Mt Bruce and that used for the Karori birds (Empson and Booth, 2007). The behaviour of the birds while in the aviary was observed during feeding times, primarily to look for aggression between individuals or signs of stress.

Individuals were re-captured from the quarantine aviary on the day of release, and transmitters were attached to 12 birds for each release. All birds were re-weighed and body condition scores re-taken. Individuals were selected for release based upon the results of disease screening (advice was provided by Richard Jakob-Hoff, Veterinarian, Auckland Zoo) and weight changes during the quarantine period. Females weighing less than 27 g were released back on Tiritiri Matangi. Thirty hihi were released at Ark in the Park in February (5 adult males, 12 juvenile females, 13 juvenile males) and 29 in June (4 adult males, 12 juvenile females, 13 juvenile males).

Birds to carry transmitters (made by Holohil Systems Ltd, Canada) were selected based on sex and age, to ensure a representative number of each group were chosen to carry a transmitter. Transmitters were attached following the methods outlined in the Department of Conservation Hihi Standard Operating Procedure manual (Taylor and Castro, 2001) (Figure 2.3), with the addition of two thin strips of “Tesa” tape attached across the transmitter and to the skin of the bird either side. Following transmitter attachment, the bird was offered a drink of sugar water, and then placed inside the transfer boxes.

Figure 2.3. Female hihi following attachment of transmitter in February 2007. Photo: Melanie Duplain.

The weight of the February transmitters was 1.26 g, with an expected battery life of 6-8 weeks. In June, two different weights were used – 0.75 g, with an expected battery life of 4 weeks, and 0.9 g with an expected battery life of 6 weeks. Lighter transmitters were used in June due to concerns that the February transmitters were too close to the recommended 5% maximum of body weight suggested for birds (Kenward, 1987; White and Garrott, 1990), and it was thought this may have been affecting the behaviour of the February hihi (see *2.3.3.3*).

Six double-ended transfer boxes were used, providing 12 compartments which had been filled with pohuehue (*Muehlenbeckia complexa*) and flowering manuka (*Leptospermum scoparium*) branches, and which already had perches inside. A tin of honey/jam water, a piece of apple, and some Wombaroo™ honeyeater and lorikeet mix were also placed inside and attached to the base of the transfer box. Birds were transferred off the island by ferry, and then to Ark in the Park by van.

2.2.4 - Post-release monitoring

Set tracks in the Ark in the Park area (Figure 2.4) were walked at least every second day to ensure full coverage of the park area for the life of the transmitters. These included the Auckland City Walk, Anderson, West Tunnel Mouth, Tramline, Dam Road, Cascade, Fenceline, Robinson, Upper Kauri, Lower Kauri and Long Road tracks. In addition, the area from Muriwai, Goldie's Bush and Waitakere township in the north, Lake Wainamu and Anawhata in the west, Anawhata Road to the south and Scenic Drive to the east (Figure 2.4) were covered with the telemetry gear. Two sets of telemetry gear were available simultaneously, and assistance was provided by Ark in the Park contractors and volunteers. Most days it was possible to have two teams working and covering different areas of either Ark in the Park or the surrounding matrix.

Where a transmitter signal was picked up, the location from where the signal was obtained was noted using a GPS, and the direction of the signal noted using a compass, to estimate the location of the individual bird. Where possible, the signal was picked up again from another location, to enable the position of the bird to be determined more accurately by triangulation. Each hihi that remained in the park and carried a transmitter was observed directly at least once, to watch its behaviour and to identify any other hihi close by. All foraging observations were recorded. It was possible to identify from the sound of the signal if the bird was moving or not. Non-moving signals were used to retrieve birds that had died or transmitters that had fallen off.

A flyover was carried out on 27 March 2007 in an attempt to locate transmittered birds that had left the park area after the first release, before the battery of the transmitters was due to fail. This was not repeated after the second release.

Additional monitoring included searching each of the blocks identified for baitlines (laid out on a 50 x 50 m grid) in Ark in the Park (*Appendix A*) at least fortnightly, for 12 weeks after the first release, and eight weeks after the second release. This was done by following a different bait line each week, listening for hihi and attempting to attract them using playbacks of territorial calls and “stitch” vocalisations using a Philips Shoqbox MP3 player.

Seven supplementary feeding stations were set up prior to release (*Appendix B*), all within 500 m of the release site. Each feeder was monitored to identify the hihi using them by recording the band combinations of the birds visiting them. From

February-May 2007 these were watched on an ad-hoc basis, with each feeder being watched at least once a week, for 40 minutes at a time. In mid-May 2007 a regular roster of feeder monitoring commenced, with each feeder being watched for half an hour, three times a week initially, and twice weekly from August 2007. One of these feeders was never observed to be used by hihi (Feeder 1), and was moved to a new site in May 2007. Feeder usage was assessed by dividing the number of minutes all feeders were watched per month by the total number of recorded visits to all feeders.

Additional opportunistic observations were made by the Ark volunteers, who spend more than 300 hours per month at the site, as well as Auckland Regional Council staff and the general public.

2.2.5 - Recapture of Ark in the Park hihi

An attempt was made to recapture a number of the translocated hihi in the first week of September 2007 as part of the work carried out in Chapters 3-5. Seven mistnets were set up (at each feeder station), and birds caught were weighed, tarsus measurements taken, and body condition scores taken. In addition, a blood sample was taken and the left fifth rectrix feather (counted from the outside in) was plucked.

Figure 2.4. Map of Ark in the Park and northern part of Waitakere Ranges.

2.2.6 - Subsequent monitoring and third translocation

The post-release monitoring for this study ended in September 2007. Two contractors and volunteers carried out the breeding season monitoring from October 2007 through to February 2008. A third translocation occurred in May 2008 of a further 51 birds, with approval of the Hihi Recovery Group. Although discussed briefly later in this chapter, the breeding season and third translocation did not form a part of this study.

2.2.7 - Data analysis

Data for post-release survival were analysed using Program MARK (White and Burnham, 1999), by means of the "multi-strata with live recaptures only" model. This allowed for the variability in detectability (for transmittered vs non-transmittered birds) to be accounted for by having two states – T, where a bird is carrying a working transmitter, and N, where a bird is not carrying a working transmitter, with 0=not sighted. Otherwise the resighting probability was assumed to be constant. Hence, the model is analysing "apparent survival", taking into account the effect of the transmitter on detection. However, higher apparent survival may simply be a reflection of reduced dispersal, and this is not taken into account by the model. In addition, a transmittered bird (T) would over time become a non-transmittered bird (N), as the transmitter either falls off or the battery fails. The probability of N -> T was fixed at 0, as a non-transmittered bird will always remain so.

Data were analysed for the effect of release date (February or June), release method (immediate or delayed), carrying a transmitter, and sex on survival. This was looked at for a short-term period for both releases (first six weeks post-release) and a long-term period (from release to September 2007). Recapture periods were defined as a fortnight. The juvenile female JM-NJ was excluded from the model after her death as this mortality was considered an unusual event (see *2.3.5*). A goodness of fit test was run on the global model (median c-hat) to test for overdispersion. Models were run in a stepwise process by removing one factor at a time, first the effect of sex, then season of release (seas), the short- and long-term effects of carrying a transmitter (tx x short and tx x long), and the short- and long-term effects of release method (del x short and del x long).

2.3 - RESULTS

2.3.1 - Transfer and quarantine period

2.3.1.1 - *Disease screening results*

All samples from both capture periods were negative for *Salmonella*, *Yersinia*, avian malaria and coccidia. Fourteen of the 33 samples tested positive for *Campylobacter jejuni* in February, but the veterinarians considered that it was likely that this parasite was present on the mainland and therefore not of concern, and this testing was not carried out in June.

Three birds were held back from translocation in February due to concerns over low weight or disease screening results (one had a low red blood cell count, another had a low white blood cell count and presented reactive lymphocytes, and one female weighed 29 g). However, a further three that had returned concerning disease screening results (YM-G, high white blood cell count; OM-NR, low white blood cell count and reactive lymphocytes; G-JM, anaemia) were released as there were insufficient "spare" birds to hold all back and still release a total of 30. None of these three birds were subsequently resighted following release. An attempt was made to capture a greater number of birds in the second transfer to ensure greater flexibility in the selection of apparently healthy individuals. However it was only necessary to hold back one female from translocation in June, with disease screening showing the presence of monocytes, a type of white blood cell associated with invasions of bacteria or other foreign objects (Hale and Margham, 1988). No other birds in June returned any results of concern.

2.3.1.2 - Condition in captivity

The majority of birds gained weight while in the aviary in February (27 out of 34 gaining weight, four maintaining), with only three losing weight (1-1.5 g) (Figure 2.5a). Weights at the time of release ranged from between 32 to 38.5 g for adult males, 32 to 40.5 g for juvenile males, and 27.5 to 34.5 g for juvenile females (Figure 2.5c). Body condition in general increased during the captive period. For adult males, the most frequent body condition score was 2-3, and for both juvenile males and females it was 3-4 (Figure 2.5e).

In contrast to February, the majority of birds (36) in June lost weight while in the aviary (losing between 0.5 and 5 g) (Figure 2.5b). Twelve juvenile females, nine juvenile males and three adult males lost weight, while one adult male and one juvenile male maintained weight. Only three juvenile females, four juvenile males and one adult male gained weight while in the aviary. At the time of release, adult males weighed between 35 and 43 g, juvenile males 33 to 39 g, and juvenile females 26.5 to 31.5 g (Figure 2.5d). Juvenile females weighing less than 27 g were held back from translocation in June. Body condition scores appeared to be slightly higher in June compared to February – for adult males the most frequent score was 4 or higher, and for juvenile males and females it was 3-4 (Figure 2.5f). This may be due to observer bias, as the personnel involved differed between the two translocations. I also observed that considerably less food was taken by hihi in the aviaries in June, although this was not quantified.

In June, a small amount of aggression in the aviary on Tiritiri Matangi was noted, primarily with males displacing females from food sources.

2.3.1.3 - Transfer

February release: The first release occurred at Ark in the Park on 23 February 2007, at 1615 hours. A total of 14 birds was released (six juvenile females, six juvenile males and two adult males), and the remaining 16 (six juvenile females, seven juvenile males and three adult males) were placed inside an on-site aviary until 27 February, when they were released at 1530 hours (Table 2.1).

June release: The second release occurred on 16 June 2007, with 16 birds (eight juvenile females, seven juvenile males and one adult male) being released at 1600 hours. The remaining 13 (five juvenile females, five juvenile males and three adult males) were placed in the on-site aviary, but due to concerns over aggression were released earlier than planned, at 1200 hours on 18 June (Table 2.2). A dead adult male was subsequently discovered inside the aviary (see *2.3.5)*.

Table 2.1. Number of birds for each release method, and number of birds carrying transmitter, by sex and age in February 2007 release.

	Immediate-release	**Delayed-release**	**Carried 1.26 g transmitter**	**No transmitter**	**Total**
Adult males	2	3	2	3	5
Juvenile males	6	7	6	7	13
Juvenile females	6	6	4	8	12
Total	14	16	12	18	30

Table 2.2. Number of birds for each release method and transmitter weight, by sex and age in June 2007 release.

	Immediate-release	**Delayed-release**	**Carried 0.75 g transmitter**	**Carried 0.9 g transmitter**	**No transmitter**	**Total**
Adult males	1	2	0	1	2	3
Juvenile males	8	5	2	4	7	13
Juvenile females	7	5	4	1	7	12
Total	16	12	6	6	16	28

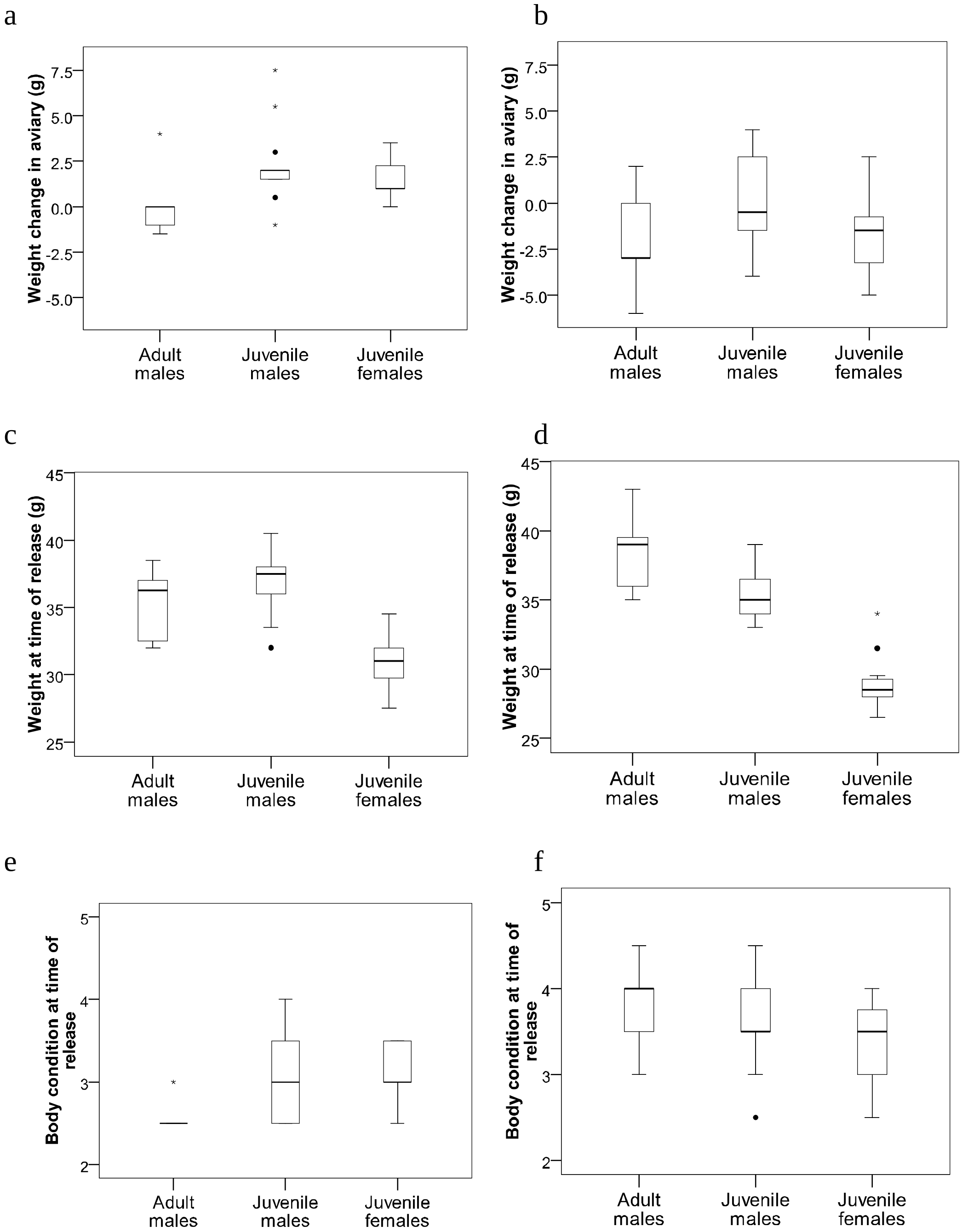


Figure 2.5. Condition of hihi at time of release. a) Weight change in captivity in February, b) weight change in captivity in June, c) weight at time of release in February, d) weight at time of release in June, e) body condition scores at time of release in February, f) body condition scores at time of release in June. Boxes represent minimum, first quartile, median, third quartile and maximum.

2.3.2 - Post-release monitoring

2.3.2.1 - Radio telemetry

By the end of the first week following the first release, it was clear that interference (possibly from the radar dome on Scenic Drive), in particular in the area east of Scenic Drive (Figure 2.6) was going to severely compromise the effectiveness of the transmitters. Large areas of good habitat within 2 km of the release site were therefore ineffective for telemetry. A total of four transmittered birds could not be located (two in February and two in June), and it is likely that at least some of these were in this area.

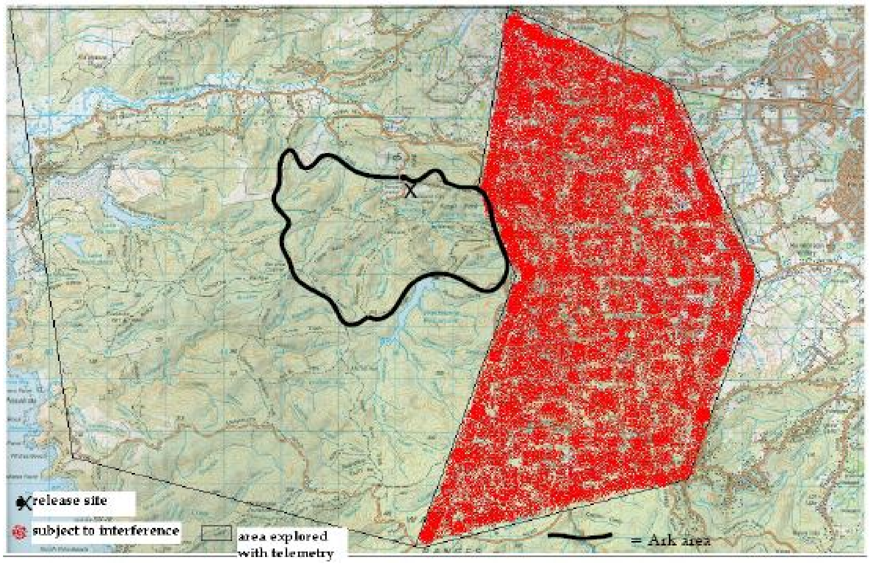


Figure 2.6. Map showing area covered with radio telemetry gear, and area subject to interference (see *2.3.2*).

In February, transmitters were attached to two adult males, six juvenile males and four juvenile females (Table 2.1). All known transmitters failed due to falling from the bird rather than battery failure. Four transmitters fell during the second week, two during the third, one during the fifth and one during the seventh (that of an adult male). It is possible that these transmitters came off earlier than expected as a result of the juveniles growing into their adult plumage at the time the transmitters were attached. Two remained unaccounted for – most likely due to the bird leaving the park area, and perhaps being in the area where interference was an issue. Another was known to have left the park area but was not seen again, and another died after five weeks with the transmitter still attached.

In June, two types of transmitters were used. The 0.75 g type was attached to two juvenile males and four juvenile females (Table 2.2). Of these, one failed after one week (but remained attached until removal in September). Two worked until the sixth week when the battery expired (one was still attached in September, but the other bird was not seen again). One was still working when the bird died in the third week, and another was known to have left the park and was in the area rendered ineffective by the interference. The remaining transmitter was never located, most likely due to the bird leaving the park area.

The 0.9 g type was attached to one adult male, four juvenile males, and one juvenile female (Table 2.2). One fell from the bird after two weeks, and one was attached to the bird when it died the day after release. Two worked until the battery failed in the eighth week (one removed in September; the other had fallen off by November), and one was never located. The remaining bird was seen in the two days after release but then disappeared and the signal was not picked up again.

2.3.3 – Survival

The goodness of fit test gave a c value of 1.04 (SE=0.13) for the global model (5 degrees of freedom). The model that gave the best fit was that which took into account the effect of the transmitters in June, the long-term effect of release strategy, season of release, and time (Table 2.3).

- *2.3.3.1 - Immediate vs delayed release*

The models gave limited support for any short-term (i.e. within the first six weeks after release) effect of release strategy on survival. However, there was strong support for an effect of release method on long-term survival, with immediate-release birds having a much higher long-term survival probability (0.98, 95% CI 0.898-0.996) than delayed-release birds (0.80, 95% CI 0.626-0.907) for each two-week time period (Figure 2.7), although the confidence intervals just overlap.

- *2.3.3.2 - February vs June release*

The model with the most support suggests that survival differed between February and June, with survival to six weeks appearing to be higher in February. This can be explained by the different effect of carrying a transmitter in June, with transmittered birds having much higher apparent survival than non-transmittered birds in June – in February there was no apparent effect of transmitter (Figure 2.7).

- *2.3.3.3 - Effect of transmitters on survival and behaviour*

None of the models gave any support to there being any long-term effect of carrying a transmitter on survival. However in June there was an apparent short-term effect on survival, with the probability of a transmittered bird surviving the first two weeks being 0.58 (95% CI 0.33-0.79), but only 0.23 (95% CI 0.09-0.46) for a non-transmittered bird (Figure 2.7).

In February, 33% (n=4) of birds carrying transmitters were regularly sighted at the feeders, as compared to only 6% (n=1) without a transmitter. There was no evidence that the burden of carrying a transmitter affected survival – the one transmittered bird that died (SM-OG) had gained both weight and body condition since the release date (see *2.3.5*). Due to these concerns that the February transmitters were adversely influencing behaviour by reducing movement and/or increasing dependency on feeders, lighter transmitters were ordered for the second release. As these could not arrive in the country before June, this led to the postponement of the second release date.

In the first week post-release in June, 8% (n=1) of birds were sighted using feeders, as compared to 19% (n=3) of non-transmittered birds.

- *2.3.3.4 - Long term population estimates*

The long-term probabilities of survival were considerably higher for the immediate-release birds than for those that were delayed-release. There was no effect of carrying a transmitter on long-term probability of survival. The annual survival probability for immediate-release birds was 0.60 (95% CI, 0.06-0.91), and 0.003 (95% CI, $5.03E^{-06}$- 0.08) for delayed-release birds.

2.3.4 - Dispersal

Dispersal was high in the immediate post-release period, with 8 of the 24 (33%) transmittered birds thought to have left the park area within the first week post-release (three were known to, five suspected to as not located in park area by the end of the first week). None of these are known to have returned to the park, and one mortality was confirmed outside of the park area (see *2.3.5*). Looking at the maps showing the known dispersal of all birds (including those that did not carry transmitters) (Figure 2.10), there was a trend for female hihi to move further than males. However, looking only at transmittered birds (Figure 2.9), juvenile females show a trend towards staying in the core protected area more than juvenile males, with adult males being most likely to disperse out of the park.

A higher proportion of transmittered birds left the park area in June (5 of 12, 42%) than in February (3 of 12, 25%). A higher percentage of delayed-release birds dispersed out of the park (5 of 13, 38%) than those that were immediate-released (3 of 11, 27%) (Figure 2.8) (although the confidence intervals are large).

The furthest confirmed sighting of a hihi from the release site was of a female approximately 7 km away in May 2007, off the Kuataika track near Anawhata. An unconfirmed sighting of a male on West Coast Road in winter 2007 is more than 8 km from the release site (Figure 2.11).

Table 2.3. Candidate models generated by Program MARK for hihi survival at Ark in the Park, February-September 2007. Global model in bold. The various models consider the effects of carrying a transmitter (tx), release date (feb, june), delayed-release (del), time, and short-term and long-term effects (short, long).

Model	**AICc**	**Delta AICc**	**AICc Weight**	**Model Likelihood**	**No. Parameters**	**Deviance**
{S(tx*june+del*long+seas+time)}	419.65	0	0.46	1	13	303.9492
{S(tx*june+del*long+del*feb+seas+time)}	421.73	2.08	0.16	0.3529	14	303.6727
{S(tx*june+del*long+del*june+seas+time)}	422.00	2.35	0.14	0.3085	14	303.9416
{S(del*long+seas+time)}	422.63	2.98	0.10	0.2249	12	309.2642
{S(tx*june+del*seas+seas+time)}	424.11	4.46	0.049	0.1073	15	303.6652
{S(tx*june+del*long+time)}	425.06	5.41	0.03	0.0669	12	311.6886
{S(tx*long+tx*june+del*seas+seas+time)}	426.16	6.51	0.02	0.0386	16	303.293
{S(tx*seas+del*sea+seas+time)}	427.92	8.27	0.007	0.016	17	302.6075
{S(tx short+tx*long+del*seas+seas+time+sex	428.85	9.20	0.005	0.01	17	303.535
{S(tx*short+del*seas+seas+time+sex)}	428.92	9.28	0.004	0.0097	18	301.1296
{S(tx*long+del*seas+seas+time)}	428.97	9.32	0.0043	0.0094	15	308.5246
{S(tx*seas+del*seas+time)}	429.95	10.3	0.00267	0.0058	16	307.0797
{S(tx*seas+seas+time)}	430.18	10.53	0.00238	0.0052	14	312.1181
{S(tx*seas+del*seas+seas+time+sex)}	430.28	10.63	0.00226	0.0049	18	302.4836
{S(tx*june+del*short+seas+time)}	430.51	10.86	0.00201	0.0044	14	312.4516
{S(tx*long+tx*feb+del*seas+seas+time)}	430.7	11.05	0.00183	0.004	16	307.8307
{S(tx*long+del*seas+seas+time+sex)}	431.29	11.64	0.00136	0.003	16	308.4263
{S(tx*sex+tx*seas+del*seas+seas+time+sex)}	**431.38**	**11.73**	**0.0013**	**0.0028**	**19**	**301.0733**
{S(tx*seas+seas+time+sex)}	432.56	12.91	0.00072	0.0016	15	312.114

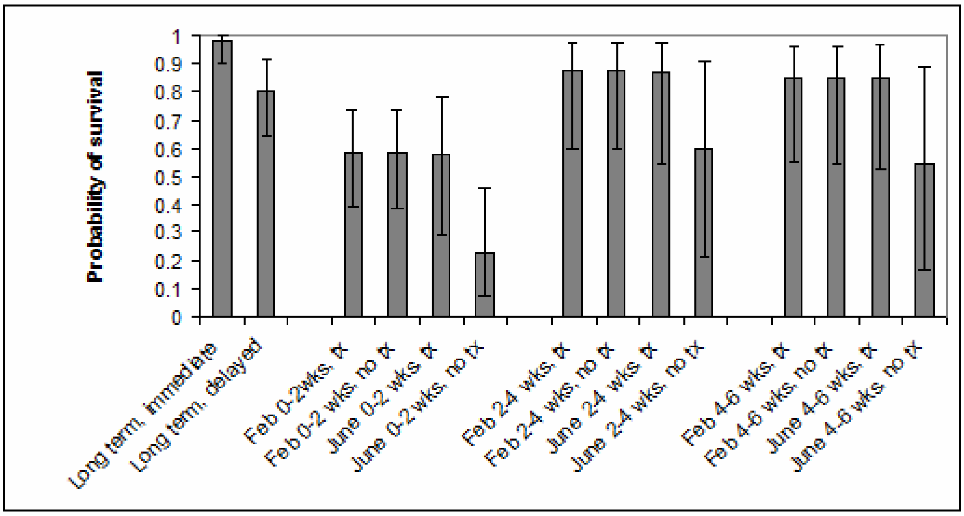


Figure 2.7. Survival probabilities (from best model, {S(tx*june+del*long+seas+time) for each time period for hihi at Ark in the Park, with 95% confidence intervals.

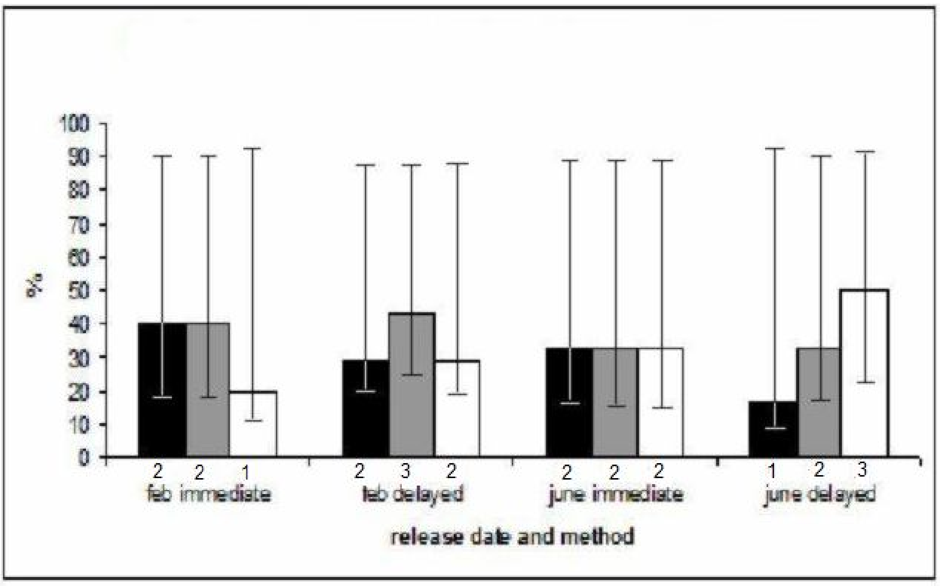


Figure 2.8. Dispersal of transmittered hihi at Ark in the Park by release date and method, with 95% confidence intervals. Black – stayed in core Ark in the Park area where feeders located, grey – left core but stayed within Ark boundary, white – left Ark boundary. Sample size below each bar.

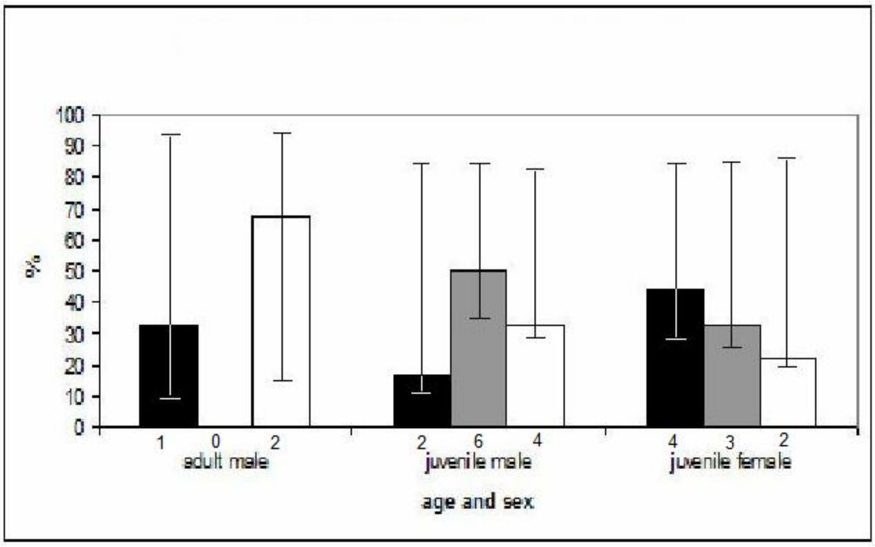
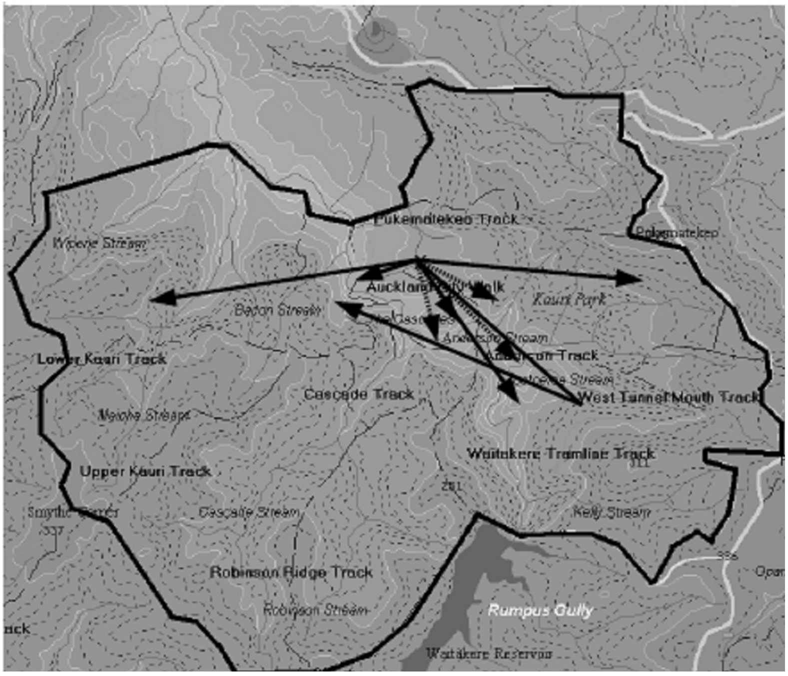
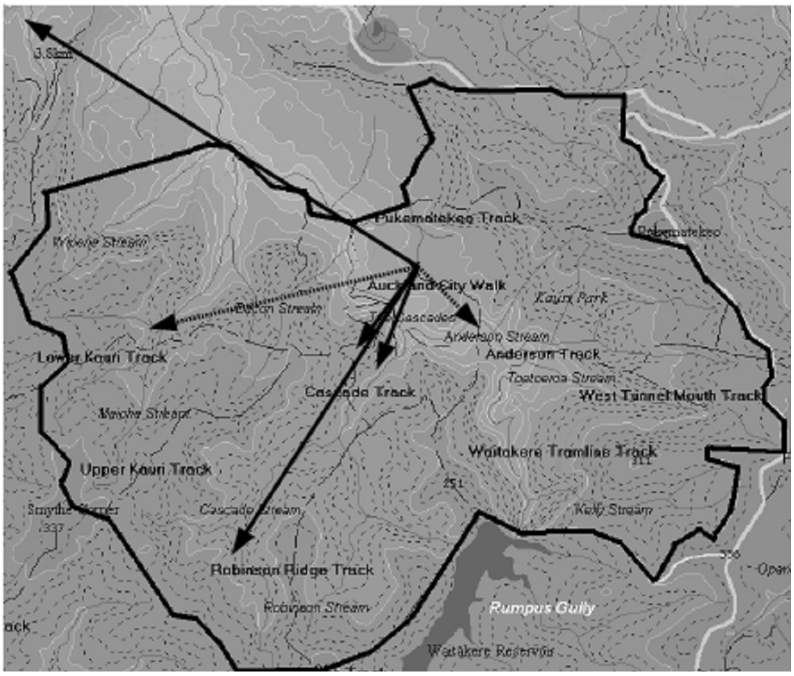


Figure 2.9. Dispersal of transmittered hihi at Ark in the Park by sex and age, with 95% confidence intervals. Black – stayed in core Ark in the Park area where feeders located, grey – left core but stayed within Ark boundary, white – left Ark boundary.

Figure 2.10. Dispersal maps of hihi at Ark in the Park, February and June 2007. Each solid arrow represents a bird that carried a transmitter, and each dashed arrow represents a bird that did not carry a transmitter. Arrows represent the furthest distance detected for each individual from release day to September 2007. X marks the release site, and the solid black line shows the Ark in the Park area. Three adult males were released in June (one with a transmitter, two without), but none were located, so no map is presented here.

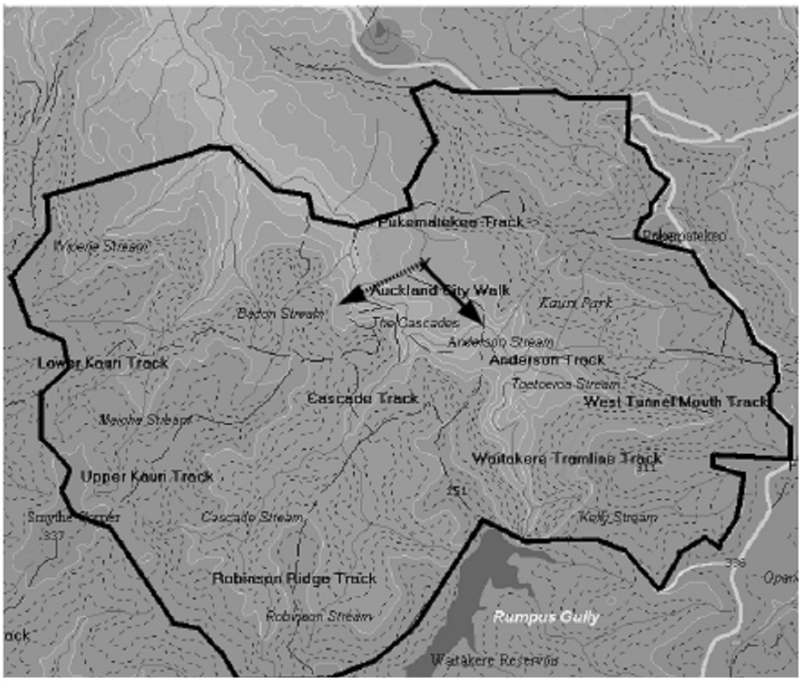


Dispersal of juvenile males released in February. Six carried transmitters (one not located) and seven did not (three not located).

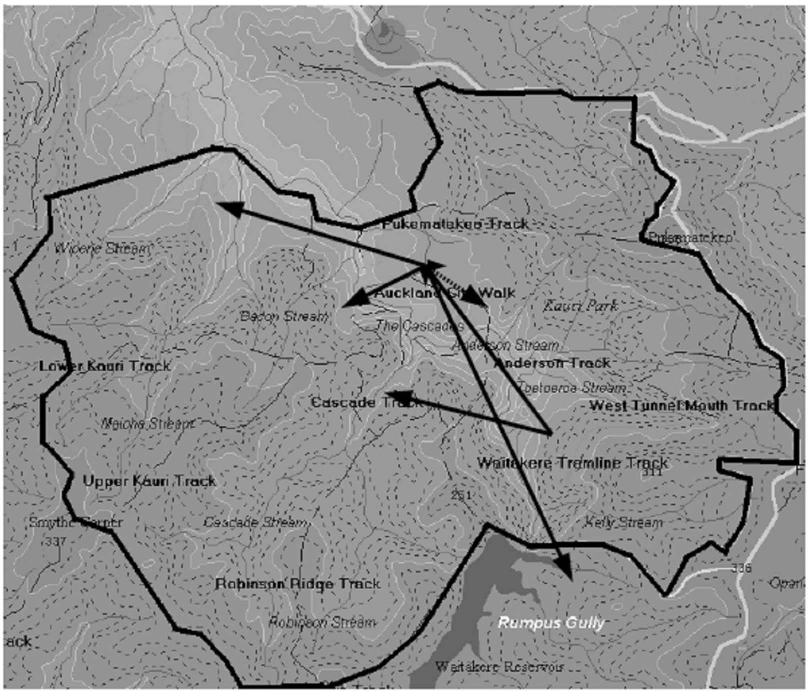


Dispersal of juvenile females released in February. Four carried transmitters (all located) and eight did not (six not located).

Figure 2.10 continued.

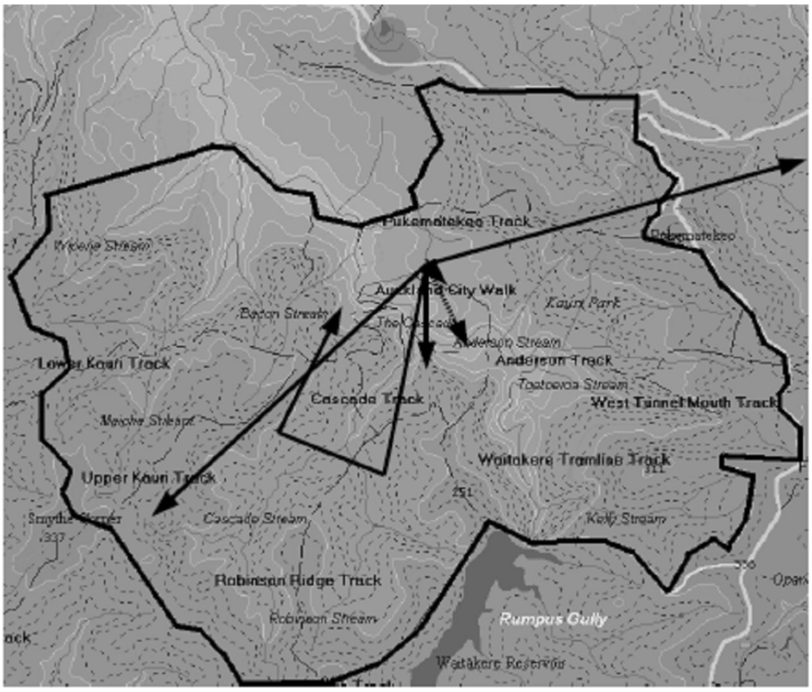


Dispersal of adult males released in February. Two carried transmitters (one not located) and three did not (two not located).



Dispersal of juvenile males released in June. Six carried transmitters (two not located) and seven did not (four not located).

Figure 2.10 continued.



Dispersal of juvenile females released in June. Five carried transmitters (all located) and seven did not (six not located

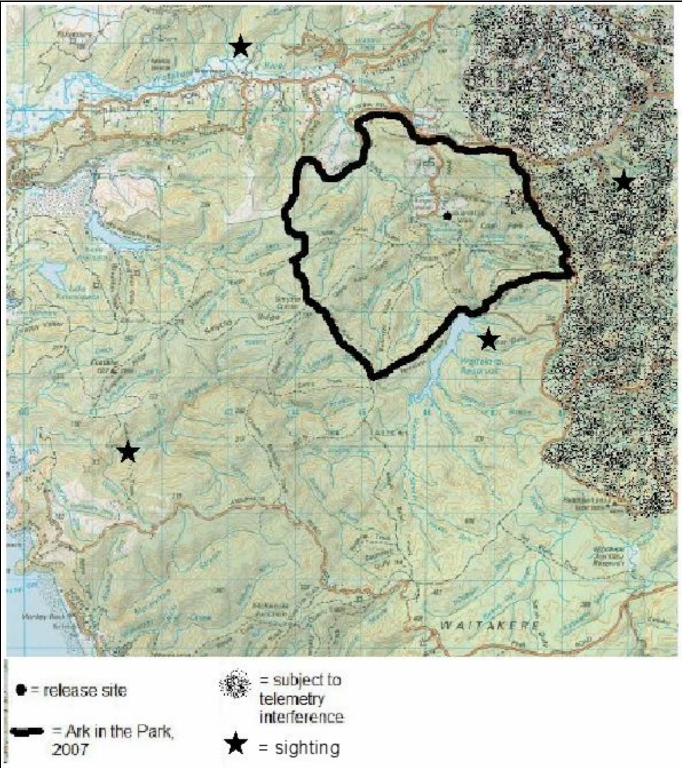


Figure 2.11. Dispersal of hihi outside Ark in the Park to September 2007.

2.3.5 - Causes of mortality

Five of the 59 birds brought over from Tiritiri Matangi Island were confirmed to have died.

SM-OG. Juvenile male, released February.

The body of this bird was located near the entrance to the Auckland City Walk on the morning of 30 March 2007, using the non-moving telemetry signal. He had been sighted on 28 March, and it is likely that death occurred on 29 March, a day of heavy rain and strong winds. When the body was found, wasps (*Vespula germanica*) were attacking the carcass and had eaten 2 mm cube of pectoral muscle. The pathology report (*Appendix C*) showed that the body was otherwise in good condition and in the five weeks since release this bird had gained 4 g (from 33.5 to 37 g), and the body condition score had increased from 2.5 to 4. Although this bird had previously been suspected to have aspergillosis (based on abnormalities in vocalisations), no sign was found during autopsy, and the pathology report suggests that wasp attack may have been the cause of death although it is not conclusive.

M-WO. Adult male, released June.

This bird died in the on-site aviary prior to being released in June (body found 18 June 2007). It had been observed that there was some aggression in this aviary in June (although that observed was of males displacing females). The pathology report attributes death to head trauma (*Appendix D*).

BY-M. Juvenile male, released June.

This male left the Ark in the Park area the day after release, and was still alive at approximately 1600 hours on 17 June, located near the reservoir on the south side of Dam Road. His transmitter signal was still the following morning, so it is likely he died overnight. The body was retrieved from epiphytes roughly 10 m up a rewarewa (*Knightia excelsa*) tree. The bones showed signs of rodent chew marks (I. Castro and M. Potter, Massey University, pers. comm.), but it was unclear if death resulted from predation, or the body was scavenged by rodents after death from another cause. This male had lost 4 g during the quarantine period on Tiritiri Matangi Island.

M-SS. Juvenile female, released June.

This female died on 30 June 2007, two weeks after being released. The body was located via the transmitter signal in epiphytes approximately 15 m up a large (25-30 m) rimu (*Dacrydium cupressinum*) (Figure 2.12) in the southern part of Ark in the Park (R block). The autopsy showed that the bones had signs of rodent chew marks (*Appendix E*), however it could not be determined if predation was the cause of death, or if the body had been scavenged and death was due to another cause. This female had lost 3.5 g during the quarantine period on Tiritiri Matangi Island.

JM-NJ. Juvenile female, released February.

The body of this female was found in a stoat trap (DoC 200 type, C7 at the intersection of Cascade and Upper Kauri tracks) on 9 July 2007 in the course of routine trap inspections by Ark in the Park personnel. The trap had been checked

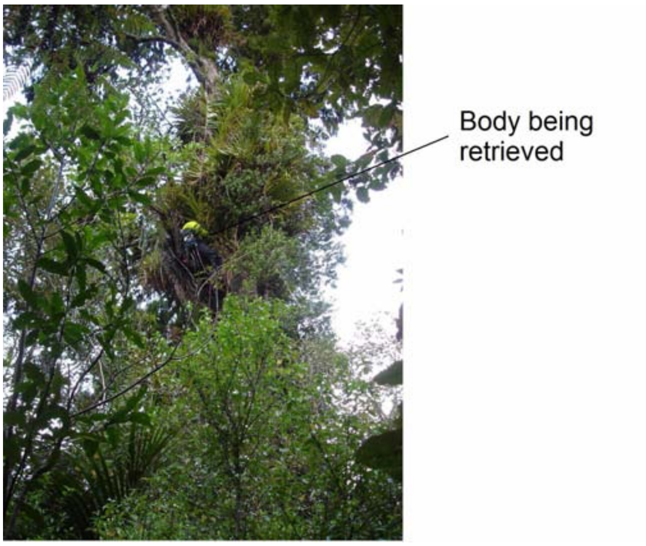


Figure 2.12. Retrieval of the body of M-SS, juvenile female, from epiphytes in rimu.

and found empty two weeks prior and the body appeared to be about one to two weeks decomposed, hence a post-mortem was not possible. These traps are kept in wooden boxes which superficially resemble the nest boxes in which hihi breed on Tiritiri Matangi Island. However all nesting attempts at Ark in the Park have been in natural cavities (despite wooden boxes being available), and to date no further instances of hihi being caught in stoat traps have occurred.

2.3.6 - Foraging observations

Hihi were sighted foraging on a number of flowering and fruiting species at Ark in the Park, including two species that represent a new feeding record for hihi based on the list presented in Perrott and Armstrong (2000) (Tables 2.4 and 2.5). In addition, hihi were observed feeding on the nectar from hebe (*Hebe* spp.) and kakabeak (*Clianthus pucineus*) flowers planted at the ranger's station at the Cascades Kauri Park (close to the release site) during winter 2007, and on the nectar of pohutukawa (*Metrosideros excelsa*) trees on the golf course also close to the release site. In spring 2007, hihi were observed feeding on kiekie (*Freycinetia banksii*).

Table 2.4. Plant species foraged on by hihi in autumn 2007 (late February to May) at Ark in the Park

Flowers	**Fruit**
Puriri *(Vitex lucens)* Pate *(Schefflera digitata)* Lacebark *(Hoheria populnea)* Rata vine *(Metrosideros fulgens)* Nikau *(Rhopalostylis sapida)* Small white rata vine *(Metrosideros perforata)*	Kahikatea *(Dacrycarpus dacrydioides)*** Pate *(Schefflera digitata)* Karamu *(Coprosma robusta)* Mamangi/tree coprosma *(Coprosma arborea)* Shiny karamu *(Coprosma lucida)* Hangehange *(Geniostoma rupestre)* Mapou *(Myrsine australis)* Kawakawa *(Macropiper excelsum)* *Melicytus macrophyllus* ** Mahoe *(Melicytus ramiflorus)* Putaputaweta *(Carpodetus serratus)* Mingimingi *(Cyathodes juniperina)* Lancewood *(Pseudopanax crassifolius)* Hinau *(Elaeocarpus dentatus)* Tutu *(Coriaria arborea)*

*** indicates a new feeding record for hihi, based on list presented in Perrott and Armstrong, 2000*

Table 2.5. Plant species foraged on by hihi in winter 2007 (June to August) at Ark in the Park.

Flowers	**Fruit**
Kohekohe *(Dysoxylum spectabile)* Pohutukawa *(Metrosideros excelsa)* Five finger *(Pseudopanax arboreus)* Tree fuchsia *(Fuchsia excorticata)* Rata vine *(Metrosideros fulgens)* Toropapa *(Alseuosmia macrophylla)*	Mamangi/tree coprosma *(Coprosma arborea)* Karamu *(Coprosma robusta)* Shiny karamu *(Coprosma lucida)* Pate *(Schefflera digitata)* Lancewood *(Pseudopanax crassifolius)*

*** indicates a new feeding record for hihi, based on list presented in Perrott and Armstrong, 2000*

2.3.7 - Feeder usage

Overall usage of the seven supplementary feeding stations appeared to be minimal in comparison with feeder use at other sites, with some individuals at Ark in the Park using them more frequently than others. There seemed to be an increase in visitations in June after the second release – with not only visits from the newly released June birds but also by some of the February birds (Figure 2.13). This coincided with a reduction in available natural food, with little fruiting and only rata vine flowering (pers. obs.).

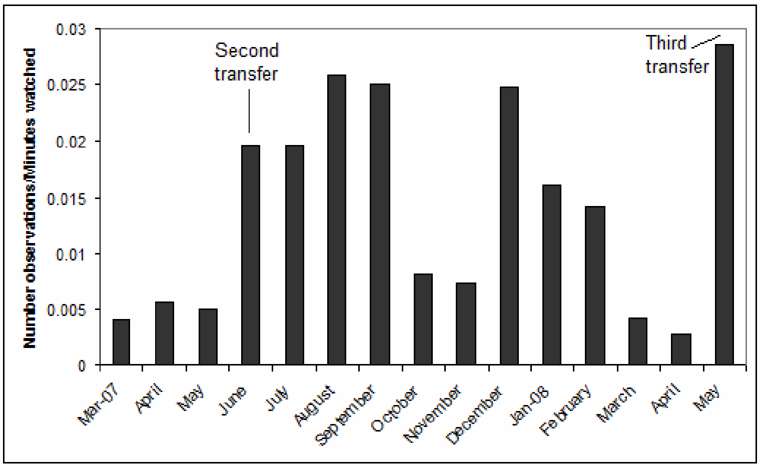


Figure 2.13. Use of supplementary feeder stations by hihi at Ark in the Park, March 2007-May 2008.

2.3.8 - Recapture in September

Six hihi (Table 2.6) were recaptured in September 2007 as part of the research for Chapters 3-5. At this time, 11 were known to be alive (five juvenile males – two from February, two from June; four juvenile females – one from February, three from June; and two adult males – both from February). However it was only possible to capture those that were making use of the feeders and remained in the core area.

Overall, the birds captured were in good condition, with all except one gaining weight since release (Table 2.6). The exception, JM-NY (lost 1 g), had been a rare visitor at feeders until August 2007 when he was sighted a number of times. All had gained or maintained body condition scores except the juvenile female BS-M.

Table 2.6. Weight and body condition scores of hihi recaptured in September 2007. WtPR= Weight prior to release, WtR= weight at recapture, BCPR= body condition score prior to release, BCSR= body condition score at recapture.M= male, F= female, A= adult, J= juvenile.

Hihi	**Released (2007)**	**Age & sex**	**WtPR (g)**	**WtR (g)**	**BCPR**	**BCR**	**Comments**
YN-BM	February	AM	37	38	3	3	Four tail feathers remaining, broken primary.
JM-NY	February	JM	38	37	3	3	Missing two tail feathers.
M-NG	February	AM	36.5	37	2-3	4	
YY-JM	February	JM	32	34	2-3	3	
JM-OR	June	JM	34.5	37	3.5	4.5	Transmitter removed.
BS-M	June	JF	28.5	29	4	2	Injured leg. Transmitter removed.

This female had injured her leg shortly after release in June, and had been dependent on feeders since. She was not seen again after November 2007. Two of the June-release birds were still carrying transmitters, and these were removed.

YN-BM was missing a number of tail feathers, and the first wing primary was broken, perhaps indicating a close encounter with a predator. JM-NY was also missing two tail feathers.

2.3.9 - Update on population: 2007/08 breeding season and third release in May 2008

Eight birds were sighted during the 2007/08 breeding season (one adult male, four juvenile males and three juvenile females), with three known breeding pairs producing a minimum of two successful clutches, and one that failed late in the season (Warneford and Gietl, 2008). By May 2008 only two of the 2007 birds were being regularly sighted (both males that had been immediate-released in

February). A further 51 hihi were released into the Ark in the Park from Tiritiri Matangi Island on 22 May 2008 – all were released immediately after being kept in quarantine on Tiritiri Matangi Island.

During the 2008/09 breeding season two of the original 2007 birds were seen (the same two males), a female produced in the 2007/08 season was identified breeding, as were 11 males and five females that had been released in May 2008. One of these males is known to alternate between the Ark in the Park area (where he breeds and uses the feeders), and a site outside of the park approximately 2.5 km away where predator control is undertaken.

2.4 - DISCUSSION

– 2.4.1 - Translocation design

2.4.1.1 - Quarantine period and captivity

There was a difference in weight changes between the two releases, with almost all birds maintaining weight in February, while in June the majority lost weight. Hihi are documented to lose weight during the winter period (Low, 2006), and it may be that the weight loss during the June quarantine period is related to metabolic changes occurring at this time of year in preparation for the breeding season. Significant weight loss can also be attributed to stress in captivity and/or starvation. Although hihi had *ad libitum* food in the aviary individuals may have not been able to access food equally. Weight loss during the quarantine period may have affected survival after release. For example, the two birds that died in the post-release period following the June release had lost the greatest amount of weight of the transmittered birds during the quarantine period (3.5 g and 4 g). This may have been a direct cause of death, or it is also possible that the loss of condition may have made the birds more susceptible to predation (Teixeira *et al.* 2007). More aggression was noted in the aviaries in June than in February – primarily from males. Juvenile male hihi moult into adult plumage three months after fledging and therefore the June birds would have been at the end of the moulting to adult period (I. Castro, pers. comm.). In passerines, moulting to male plumage is correlated to high testosterone levels which in turn are associated with aggression (Peters *et al.* 2000). Therefore it is likely that June is not an ideal time for translocating juvenile hihi, due to an increase in potential complications such as weight loss and increased levels of stress. It may also be preferable not to translocate individuals that have lost more than 2-3 g during the quarantine period.

Individuals that had concerning results from the February disease screening were still released as there would not otherwise have been a sufficient number of birds to release. It would have been preferable that these birds not be released, as none of these were sighted again. It should be ensured for future translocations that a higher number of birds be caught and screened than are needed for the release.

2.4.1.2 - Timing of release

Considerably more natural food was available in February than June, when little was fruiting and flowering. Invertebrates in general are also likely to be less abundant during winter (Moeed and Meads, 1992), although this was not quantified in this study. This may be a cause of the lower survival of the June birds. Competition from the existing birds and higher dispersal may also be explanations. These factors, combined with the observed high levels of aggression in captivity in June, suggest that it would be best for future hihi translocations to similar habitat to be carried out between February and May, with only one release.

2.4.1.3 - Immediate vs delayed release

There appeared to be no difference in short-term survival for the immediate- and delayed-released birds. However, the long-term survival (to 3-7 months) for delayed-release appears to be considerably lower, although confidence intervals are large. Delayed-release hihi from the Kapiti Island translocation (Castro *et al.* 1994) also had lower survival than those released immediately. This was apparent in the first four weeks, although was not investigated over a longer time frame. The Karori release was not modelled in a similar way to this study, but the survival percentages plotted over time do show that delayed-release birds had slightly lower long-term survival than the immediate-release birds. The long-term effects of delayed-release are not generally looked for in reintroduction studies, and it is frequently recommended that this strategy be used, even while acknowledging the role of stress in translocations (Wanless *et al.* 2002; Teixeira *et al.* 2007). In this study (as well as the Karori translocation) it should be kept in mind that there was a captive period for all birds prior to release, due to disease-screening requirements, and so the difference between the two groups is simply that the captive period was longer for delayed-release birds, in addition to the transfer to a new aviary with a different group of birds.

The long-term impacts of stress caused by translocations and in particular the captivity period are poorly understood (Teixeira *et al.* 2007; Dickens *et al.* 2009). The stress response of an individual can be quantified by measuring glucocorticoid levels, and most studies have shown that these become elevated in the initial stages of captivity, but then decline over time (Teixeira *et al.* 2007; Franceschini *et al.* 2008; Rothschild *et al.* 2008). This type of short-term response is seen as acute stress and can have a beneficial effect (Cabezas *et al.* 2007), but an individual that experiences a series of acute stressors can become chronically stressed (Dickens *et al.* 2009). Chronic stress can cause immune system suppression, and may be a cause of translocation failure in some cases. Dickens *et al.* (2009) found there to be an additive effect of the stressors involved in translocation (handling, the captive period, and introduction to a novel environment) in an experiment carried out with chukar partridges (*Alectoris chukar*). Significantly, these changes persisted beyond exposure to these stressors, with even a single capture event being sufficient to cause a long-term decrease in endocrine responsiveness. It is possible that the extra level of stress caused by transferring birds from one aviary to another and then keeping them in captivity for an extra time period was sufficient to increase the probabilities of some individuals becoming chronically stressed. It is likely that these responses will differ between species, with different attributes of translocations being stressors for some species but not others. In the case of hihi, it seems clear that delayed-release has no benefit, and likely has a considerable adverse impact, and it should not be used for future translocations. In addition, this result would seem to emphasise the possibility that captivity for hihi does constitute a stressor, and future translocations should aim to keep the quarantine period to a minimum to enhance post-release survival, should captivity be considered necessary.

The annual probability of survival for delayed-release birds was close to 0, and this is supported by observations, with 4 of the 5 hihi that survived to breed being immediate-releases. The poor long-term survival of delayed-release hihi is likely one of the major factors causing the decline of the 2007 population.

Recommendations for future hihi translocations

- Translocations should ideally be carried out between February and May.
- Delayed release strategies should not be used in hihi translocations.
- Captivity periods should be kept to the necessary minimum.
- One release rather than multiple releases (assuming there is adequate infrastructure at the source site to keep a higher number of birds in captivity for the quarantine period).
- Catch a higher number of birds than required for the translocation to allow flexibility in selecting individuals for translocation.
- Avoid translocating individuals that have lost more than 2-3 g during the quarantine period.

– 2.4.2 - Impact of transmitters on survival and dispersal

I found no negative effect of transmitters on bird survival, and in fact found a positive effect on survival in June. This may be explained by the higher detection probability for transmittered (as compared to non-transmittered) birds in June, when dispersal appeared to be higher. The dispersal figures (Figures 2.8-2.10) suggest that there may be a relationship between ability to carry a transmitter and sex/age, and this may be related to the weight of the bird.

Recommendation

Although I found no effect of the transmitters on survival, transmitters may have some impact on hihi and I recommend to be on the conservative side and that when using transmitters in hihi the 0.75 g and 0.9 g transmitters be used, rather than the 1.26 g transmitters.

– 2.4.3 - Dispersal and impact on establishment of a self-sustaining population

Dispersal appeared to be higher following the June release than in February. Sample sizes were small, however, and these results should be treated with caution. Higher dispersal in June may have been due to competition from the existing birds. This is supported by observations of newcomers being met with aggression from the February hihi (pers. obs.). There was also considerably less natural food available in June than in February (pers. obs.), and this may have led to the birds travelling further in June to find food, despite the availability of supplementary food. Sightings of hihi at the ranger's station and on the golf course only occurred during the winter months, and this increase in range and willingness to cross open areas may be explained by increased searching for food. Tui are also known to increase their movements in search of food at this time of year (Bergquist, 1989). Castro *et al.* (1994) also reported higher dispersal and high levels of aggression between individuals after the second release on Kapiti

Island despite both releases taking place at the same time of the year. These results suggest that either competition or some other form of social constraint may have been responsible for the dispersal pattern.

Looking at the dispersal maps for all birds, it appears that females moved further than males. However, looking only at transmittered birds it appears that juvenile females were more likely to stay in the core protected area than juvenile males, with adult males dispersing the furthest. It is worth keeping in mind that the results from the transmittered birds may not be representative of all birds, although the intention was that they should be (see Chapter 3). The sample size is small, and confidence intervals large. The dispersal results for transmitterised birds, with males dispersing further may suggest that adult males being larger are more able to cope with the additional burden of a transmitter, than the smaller juvenile females. As such, the overall percentage of birds dispersing out of the park may have been much higher than suggested by the results from the transmittered birds. As it is, the results from the transmittered birds suggest that 33% of the birds left the park area (assuming that where a signal was never obtained, the bird had left the park) in the immediate post-release period (i.e. within the first few days).

Dispersal of birds into less accessible and less well monitored areas may also account for the apparent ongoing decline of the hihi population in 2007. From the transmittered birds and other sightings it is known that hihi did disperse throughout the park area, most frequently as single individuals. Although no sightings have been reported by volunteers or contractors from these areas subsequent to the intensive monitoring period that ended in September 2007, this may simply be a reflection of the difficulty of detecting a small number of birds in a large area. Breeding season monitoring has been restricted to the core area (less than 25% of the total Ark area). Two birds were resighted at feeders in winter 2007 (both juvenile males) after a lengthy absence, suggesting they had been spending the majority of their time further out in the park (or perhaps outside it). Neither have been sighted again. M-YB (juvenile male) dispersed to T block after being released in June, and remained consistently at the same site until the breeding season, when he returned to the core and paired up with a resident female (Warneford and Gietl, 2008). This may suggest that there were no available breeding partners for this male at his original site, necessitating a return to the core area. SM-YR (juvenile female) spent the first two to three weeks post-release in R and F blocks in close proximity to another female, M-SS, but returned to remain near Feeder 7 following the death of M-SS. This evidence, combined with no sightings subsequent despite searching in the 2008/09 season, and the behaviour of the birds released in May 2008, suggests that if there are individuals remaining undetected outside the core area, it is likely to be only in very low numbers.

– 2.4.4 - Predation and impact on the establishment of a self-sustaining population

The population from the first two transfers (in 2007) has shown an ongoing decline, with only two original birds (both males) and one female produced in the first breeding season known to be remaining by the 2008/09 breeding season.

Without the third release in May 2008, the Ark in the Park hihi population would most likely have died out. There are many possible reasons for this, including the effect of the release strategy, but ongoing predation by ship rats, cats or stoats may also have contributed to the decline, despite intensive pest control within Ark in the Park boundaries. It may also be possible that the delayed-release birds may have been more susceptible to predation due to the impacts of chronic stress (Teixeira *et al*. 2007). There were two known mortalities in June/July 2007 where transmittered birds were either predated or scavenged by a rodent. Whether or not a predator was responsible for these deaths, it is still an indication that there are at least sufficient rat numbers in the park to quickly locate a dead bird. Rat monitoring at Ark in the Park is undertaken three times a year. Tracking rates were higher than usual in April 2007 (10%), the majority of which were catches along the north-western border of the park, but returned to the more usual low levels of 0% and 4% in September and December 2007 respectively (M. Colgan, Ark in the Park, pers. comm.). Both hihi mortalities with rodent chew marks were found in epiphytes 10-15 m high, while the two mortalities found at ground level were untouched by scavengers (although they were also retrieved more promptly). Monitoring and control of ship rats at Ark in the Park – as at all areas where rat control occurs in New Zealand – is carried out at ground level, yet research shows that ship rats will often spend a large proportion of their time in the canopy, especially in mature habitat such as that found in the Waitakere Ranges. Research to date suggests that the degree of arboreality varies according to season, habitat and food availability (Best, 1969; Dowding and Murphy, 1994; Hooker and Innes, 1995; Pryde *et al*. 2005; Latham, 2006; Whisson *et al*. 2007), but still little is known about how this varies between individuals, and what impact this might have on the effectiveness of ground control operations and the accuracy of monitoring techniques.

It was noted on two of the six birds recaptured in September (Table 2.6) that tail feathers were missing, and in one a primary feather was also broken. These can both be indications of an encounter with a predator (avian or mammalian). Birds that have been translocated from offshore islands that are predator-free can often be behaviourally naïve and have poor predator-avoidance strategies (Moore *et al*. 2008), further increasing their susceptibility to predation post-release (McLean *et al*. 1999; Blumstein, 2002).

Feral cats (*Felis catus*) are known to be present through the Ark in the Park area (Bellingham *et al*. 2008), and this may be or become a contributing threat to the establishment of a hihi population. Hihi coexisted with cats on Hauturu (Veitch, 2001), but there is evidence to suggest the population increased following their removal in 1981 (Lovegrove, 1985). Stoats appear to be maintained at low levels in the park, but are also likely predators of hihi. One or a combination of these predators may be responsible for at least some of the decline in the hihi population. It may also be of note that a sharp decline in the North Island robin population at Ark in the Park occurred between the 2007/08 and 2008/09 breeding seasons that may be attributable to a concurrent increase in feral cat numbers. Aside from introduced mammals, there is also the native morepork (*Ninox novaeseelandiae*), which are known to be present in high numbers at Ark in the Park (Fraser and Hauber, 2008). Morepork are known predators of hihi and have been suggested as population regulators at other translocation sites (Low, in press).

– 2.4.5 – Foraging observations of hihi at Ark in the Park and feeder usage

Natural food – nectar, fruit and invertebrates – was readily utilised by hihi at Ark in the Park from day one. Kahikatea fruit was seen being taken on the first day of release. This is significant because kahikatea is not present at the source site (Tiritiri Matangi Island). In addition, hihi were observed feeding on two plant species not previously documented in hihi diet (Tables 2.4 and 2.5), illustrating their ready adjustment to the new habitat. Those birds that were recaptured in September 2007 were all found to have gained weight since release (Table 2.6), with one exception (plus an injured female which had gained weight but lost body condition), suggesting that the birds were overall in good condition and obtaining sufficient energy from the food supply. It should be noted that these recaptures were biased towards individuals that were using feeders, as these were the only birds it was possible to capture, and these birds may be those most in need of supplementary food, and therefore in poorer condition.

Feeder usage appears to vary substantially between individuals, with some using them frequently and others rarely or not at all. The two males that were known to survive the first year were both regular feeder users. Peaks in feeder usage occurred over winter 2007 and during the 2007/08 breeding season (Figure 2.13). The observation that less natural food was present over winter may explain the peak at this time of year. During the breeding season, two of the pairs were regular feeder users, and the third was not (Warneford and Gietl, 2008). The pair that did not use the feeders successfully fledged young (Warneford and Gietl, 2008). It is possible that the birds that do use feeders only do so because they became habituated to using them on Tiritiri Matangi Island, where there are gaps in natural food availability and feeder usage is widespread. No young hihi that have fledged at Ark in the Park have yet been seen using feeders (A. Warneford, Ark hihi contractor, pers. comm.).

Recommendation

As it has been observed that there is some variation in the natural food supply for hihi in the Waitakere Ranges, combined with the increase in feeder usage during the breeding season, it is recommended that the precautionary approach be adopted and the feeders be maintained at the present level while the future of the Ark hihi population remains uncertain.

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3

Influence of individual condition on the post-release dispersal of a reintroduced hihi (*Notiomystis cincta*) population.

Male hihi at Ark in the Park. Photo: Eric Wilson

3.1 - INTRODUCTION

3.1.1 - The role of dispersal in the establishment of reintroduced populations

Reintroduction, the attempt to return a species to a part of its historical range where it has been extirpated, has become an increasingly common tool in the conservation of endangered species (Armstrong and Seddon, 2007). A range of factors can influence the success of such projects, such as the survival and dispersal of individuals in the post-release phase. Frequently reintroductions occur to an area that differs from the surrounding landscape in some way; the habitat may be considered to be higher quality, or managed to lessen the impact of invasive species. Where this is the case, dispersal of the reintroduced individuals out of the "protected" area may reduce the number of individuals founding the population, compromising the chances of a successful reintroduction.

Dispersal is an important biological process, described as operating at "multiple temporal and spatial scales, with implications at multiple scales of organisation: for the survival, growth and reproduction of individuals; for the composition, structure and dynamics of populations and communities; and for the persistence, evolution and geographical distribution of species" (Nathan, 2001). Dispersal is typically divided into two categories: natal dispersal, the movement between the natal area and the area where breeding first takes place; and breeding dispersal, the movement between two successive breeding areas (Clobert *et al.* 2001).

The behaviour of reintroduced individuals in the post-release phase can differ from usual dispersal activity. Species that are generally considered sedentary have been recorded to travel large distances, and cover "unsuitable" habitat to return to the source site (Clarke and Schedvin, 1997; Doncaster *et al.* 2001; Oppel and Beaven, 2002; Parker *et al.* 2004). Post-release dispersal can be directional, with individuals returning, or attempting to return, to the source site, or random (Moehrenschlager and Macdonald, 2003; Wakeling, 2003). Some studies of avian reintroductions have shown that dispersal occurs in the first two weeks following release, after which individuals are more likely to settle and form a home range (Tweed *et al.* 2003; Sullivan, 2006).

The factors influencing post-release dispersal in reintroduced populations have been poorly studied. However there has been considerably more work done on the factors influencing natural dispersal patterns. Many studies have found a relationship between the timing and nature of natal dispersal, and the condition of the individual. Higher quality juveniles (as defined by body size, maternal feeding rates or nutritional condition) have been shown to disperse earlier, or to higher quality habitat, in some studies (Nilsson and Smith, 1985; Ferrer, 1992; Alonso *et al.* 1998; van Oort and Otter, 2005; but see Pasinelli *et al.* 2004; Winkler *et al.* 2005; Eikenaar *et al.* 2008). Belthoff and Dufty (1998) showed that locomotor activity increases during the dispersal period in juvenile screech-owls (*Otus* spp.), and that this coincides with an increase in the hormone corticosterone. They found that if an individual is also in good body condition at this time, dispersal will occur. Similar studies suggest that there may be a threshold of condition for dispersal in some species, perhaps body mass, body fat or some related variable (Nunes and Holekamp, 1996; Alonso *et al.* 1998; Barbraud *et al.* 2003). Dispersal is known to be energetically expensive and may carry a higher risk of mortality than non-dispersal (Gaines and McClenaghan, 1980; Ruxton *et al.* 1997; Bonnet *et al.* 1999). Good body condition would enable an individual to cover a greater distance without increasing its probability of mortality.

In terms of reintroductions, and considering what we know about natal dispersal, individuals in better condition at the time of reintroduction may tend to disperse further. This chapter examines the post-release dispersal of a reintroduced population of hihi/stitchbird (*Notiomystis cincta*), an endangered New Zealand forest bird, and the relationship with individual condition measured using a variety of methods.

3.1.2 - Use of radio transmitters in studies of dispersal and behaviour

Dispersal distances in this study were determined using radio telemetry. Radio transmitters are a commonly used tool in studies of dispersal, but it is important to ensure that transmittered individuals are behaving in a manner similar to non-transmittered individuals (Withey *et al.* 2001). Transmitters have been used previously with hihi with no apparent effect on survival (Castro *et al.* 1994; Armstrong *et al.* 1999; but see Barr, 2002). However, it is essential to know whether the transmittered individuals are representative of the study population not only in terms of survival, but also in their behaviour. Many studies find no effect of carrying a transmitter (see Chapter 2), but there are examples in the literature citing effects of carrying a transmitter on flight performance and activity levels (Aldridge and Brigham, 1988; Mikesic and Drickamer, 1992). Withey *et al.* (2001) recommend that researchers using radio telemetry should not assume that carrying a transmitter has no effect on an animal's behaviour. The results of this study (Chapter 2) suggested that transmitters had no effect of reducing survival, but may have had an effect on behaviour.

3.1.3 - Assessing individual condition

Individual condition has been defined to indicate the ability of an individual to cope with present and future physiological stress, and therefore the ability to enhance fitness (Carrascal *et al.* 1998). Assessing the condition of an individual can be complex, as the more traditional means of using body mass or body condition scores may not always accurately reflect condition. For example, body condition scores may be higher for socially subordinate birds as they are less able to quickly access a guaranteed food source, and so are more in need of a large fat store (Pravosudov *et al.* 1999; but see Lundborg and Brodin, 2002). Ptilochronology is a means of assessing nutritional condition of the individual while the feather is being grown (in the case of juveniles, as a nestling and fledgling) by measuring the width of daily growth bars on the feather (Figure 3.1) (Grubb, 1989; 2006). Early nutrition is thought to be one of the factors contributing to condition in juveniles, and individuals with poor natal nutrition have been found to have lower phenotypic quality as adults (Ohlsson *et al.* 2002; Blount *et al.* 2003; Buchanan *et al.* 2003). Ptilochronology has been directly related to nutritional condition in studies where food sources have been controlled (Grubb, 1991; Jenkins *et al.* 2001).

Figure 3.1. Red-cockaded woodpecker (*Picoides borealis*) feathers with daily growth bars visible. © Richard N. Conner (Grubb, 2006).

The presence of fault bars on feathers can also indicate that some form of stress occurred during this period of the feather's growth. Fault bars are feather abnormalities that look like narrow and translucent bands arranged approximately perpendicular to the feather rachis (Figure 3.2). They are produced by some barbules being slimmer or completely absent as a result of a variable time lag on the deposition of keratin during growth (Sarasola and Jovani, 2006), and can be caused by stressors such as malnutrition or handling (Riddle, 1908; King and Murphy, 1984). Fault bars can be induced by glucocorticoids (Bortolotti *et al.* 2002), and there may also be some genetic variability in the propensity for their occurrence (Jovani and Blas, 2004). They may be an indicator of the susceptibility of an individual to stress and probability of survival, and as such can be a good measure of individual fitness (Bortolotti *et al*. 2002).

Figure 3.2. Multiple fault bars on the tail feathers of a juvenile female hihi from this study. Photo: Melanie Duplain.

In the case of this reintroduced hihi population, all individuals were kept in captivity while disease screening was carried out prior to release. In this chapter, the response of the individual to this captive period was also used as an assessment of the condition of the individual at the time of release, by looking at the weight change during this period. Some individuals are better able to cope with the stressors associated with captivity than others, and this may be reflected in post-release dispersal behaviour. The stress response may also be associated with body condition (Welch, 1996). The captivity period associated with translocations can cause an increase in the stress response (as assessed by measuring glucocorticoid levels), and elevated glucocorticoids can trigger a behavioural response such as an increase in locomotive activity, and hence increased dispersal (Cabezas *et al*. 2007; Dickens *et al*. 2009).

This study addresses the following questions:

- *What was the relationship between the individual condition variables?*
- *Did the condition of individuals prior to release influence dispersal distance in the post-release phase?*
- *Were transmittered birds representative in terms of individual condition? If so, then:*
- *Did carrying a transmitter influence dispersal behaviour in the post-release phase?*

3.2 - METHODS

3.2.1 - Study species:

See Chapter 1 for details of hihi ecology and conservation efforts, and Chapter 2 for details of the reintroduction of hihi from Tiritiri Matangi Island to Ark in the Park in 2007.

3.2.2 - Study sites:

- *3.2.2.1* - *Tiritiri Matangi Island – see Chapter 2.*
- *3.2.2.2* - *Ark in the Park – see Chapter 2.*

3.2.3 - Indicators of individual condition

All juveniles were captured on Tiritiri Matangi Island for translocation to Ark in the Park in February and June 2007. At the time of capture, the following measurements were taken: weight, tarsus and body condition scores (see Chapter 2). Measurements (weight and tarsus) of all nestling hihi on Tiritiri Matangi Island are taken at 21 days when banding occurs.

The fifth rectrix was plucked from each bird, and then stored in individual envelopes. The growth bars on each of these feathers were measured at a later date using the methods outlined by Grubb (2006). I also counted the total number of fault bars on each feather, weighed it and measured its length.

At the end of the captive period (9-14 days) all birds were reweighed and 12 individuals in each translocation were attached with radio transmitters (see *2.2.3* for further detail).

The condition variables used were:

- **Weight:tarsus at 21 days**
- **Weight:tarsus at time of capture**
- **Body condition scores at time of capture**
- **Weight change during captive period**

- **Feather weight/feather length**
- **Average growth bar width**
- **Total number of fault bars.**

3.2.4 - Post-release monitoring

See *2.2.4* for details of post-release monitoring.

3.2.5 - Data analysis

- *Relationship between individual condition variables*

All individual condition variables were tested for normality, using Kolmogorov-Smirnov tests for continuous variables, and Chi-square tests for discrete variables. A Spearman-rank correlation was performed to examine the relationship between individual condition variables.

- *Did the condition of individuals prior to release influence dispersal distance in the post-release phase?*

Data for dispersal in the first week post-release were analysed for the 21 juvenile hihi that carried transmitters (the remaining three birds carrying transmitters were adult males and were excluded due to the difficulty of comparing condition of adults with juveniles). Of these, 12 were male and nine female. One male (BY-M) died in the second day post-release, and was excluded from the analysis. There were two sets of siblings within the remaining 20 birds, and for these individuals values were averaged to eliminate any possible nest effect. Individuals that did not carry transmitters were not used for this analysis as it was not possible to determine dispersal distance for those that left the monitored area.

The degree of dispersal was divided into three categories: 1=dispersed <1 km from release site (n=5), 2=dispersed 1-2 km (n=8), and 3=dispersed >2 km (n=6) (see Figure 3.3). The relationship between dispersal of transmittered birds and each individual condition variable was examined using Kruskal-Wallis tests. An attempt was made to include sex and release date (February or June) as covariates, but due to the small sample size it was not possible to run these tests with covariates.

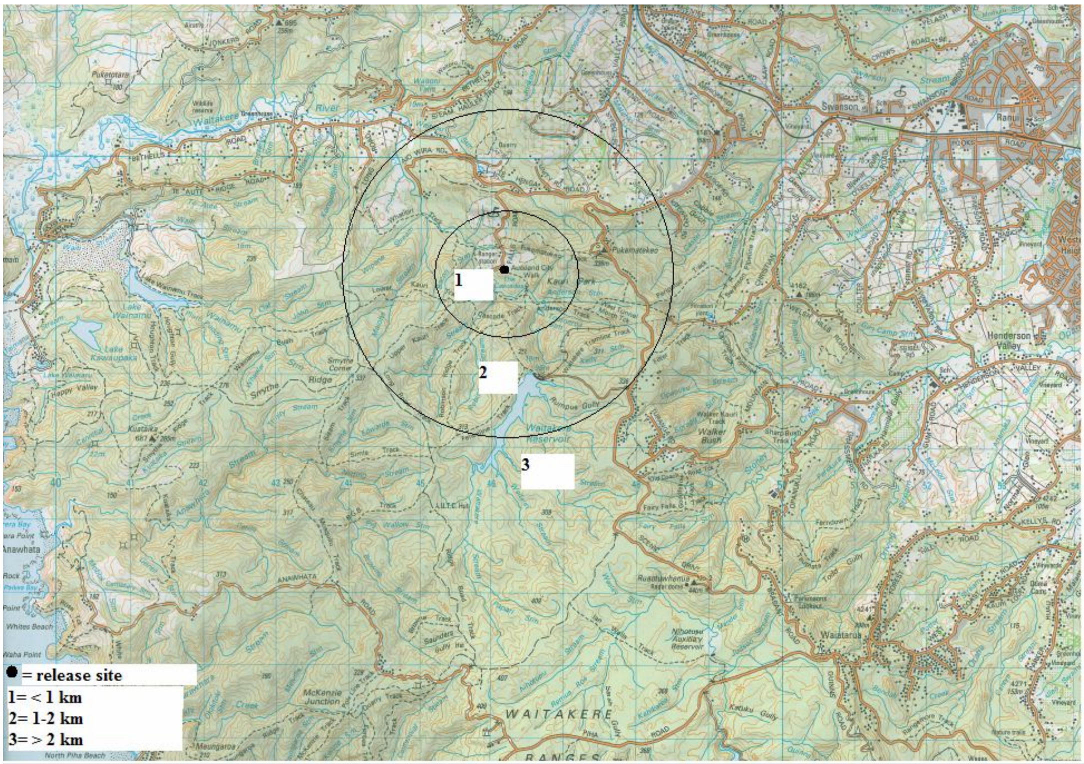

Figure 3.3. Map showing release site at Ark in the Park and three dispersal categories. 1=dispersed < 1 km from release site, 2=dispersed between 1 and 2 km from release site, and 3=dispersed > 2 km from release site.

- *Were transmittered birds representative in terms of individual condition?*

During the translocation process, an attempt was made to attach transmitters to a representative sample of birds, with the appropriate ratio of males:females and adults:juveniles selected. At the same time, it was important to ensure that the individuals selected were in sufficient condition to carry a transmitter, and in particular females of low weight were not selected to carry transmitters (and also not used for translocation, where possible). Therefore, it was important to ensure that transmittered birds were representative of all birds in terms of the individual condition variables before any comparisons could be made between the behaviour of transmittered and non-transmittered birds. This was done by comparing the individual condition variables for the two groups using independent T-tests and Mann-Whitney U tests.

- *Did carrying a transmitter impact dispersal behaviour in the post-release phase?*

If there was no significant difference between the individual condition variables for birds that did or did not carry transmitters, it should be expected that there be no difference between these two groups in dispersal behaviour. For the birds that dispersed >1 km, data were limited due to the difficulties of locating birds without transmitters with high dispersal.

However, for the group with dispersal <1 km, the data from sightings alone could be considered more reliable, with a high chance of resighting individuals that stayed within this area. Hence, if transmittered birds are considered representative, it should be expected that there be no difference in condition variables between transmittered and non-transmittered birds with dispersal <1 km. This was tested for each individual condition variable using Mann-Whitney U tests.

3.3 - RESULTS

3.3.1 - Relationship between variables of condition

There were some correlations between the variables used to assess condition (Table 3.5). Weight:tarsus of the birds at 21 days was positively correlated with feather weight/feather length (Spearman-rank, $p=4.35E^{-05}$) and negatively correlated with the total number of fault bars on the fifth rectrix (Spearman-rank, p=0.02; Figure 3.4a). Weight:tarsus at the time of capture was also positively correlated with feather weight/feather length (Spearman-rank, p=0.03), and also the body condition score at the time of capture (Spearman-rank, p=0.03). Average growth bar width was not correlated with any of the measures of weight, but showed an almost significant (Spearman-rank, p=0.06) negative correlation with the total number of fault bars (Figure 3.4b). Fault bars were also negatively correlated with feather weight/feather length (Spearman-rank, p=0.02).

3.3.2 - Did the condition of individuals prior to release influence dispersal distance in the post-release phase?

The relationship between dispersal distance and individual condition was not significant for birds with transmitters (Table 3.1). However, looking at the graphed means, it appears that there was a trend for birds with wider growth bars and fewer fault bars on the fifth retrix to disperse further (Figure 3.5d and f respectively). Birds that lost weight in captivity all had high (>2 km) dispersal (Figure 3.5b).

Table 3.1. Results of Kruskal-Wallis test for relationship between each individual condition variable and dispersal distance for birds carrying transmitters.

Individual condition variable	H	df	P
Weight:tarsus at capture	0.80	2	0.67
Weight change in aviary	2.0	2	0.37
Body condition scores	1.32	2	0.52
Feather weight/feather length	0.15	2	0.93
Average growth bar width	3.83	2	0.15
Total number fault bars	2.41	2	0.30

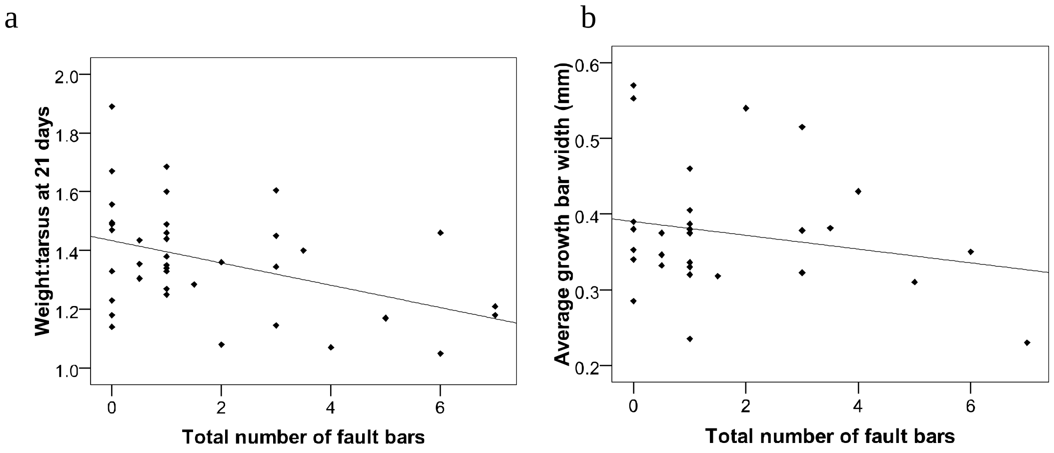

Figure 3.4. a) Relationship between growth bar width and total number of fault bars, b) relationship between total number of fault bars and weight:tarsus at 21 days.

3.3.3 – Were transmittered birds representative in terms of individual condition?

There were no significant differences between transmittered and non-transmittered birds for any of the individual condition variables (Tables 3.2 and 3.3). Therefore the transmittered birds could be considered representative in terms of initial condition, enabling a comparison to be made for dispersal behaviour (*3.3.4*).

Table 3.2. Results of independent t-test examining difference in normally distributed individual condition variables between all transmittered and non-transmittered birds.

Individual condition variable	t	df	sig (2-tailed)
Weight:tarsus at 21 days	0.58	55	0.57
Weight:tarsus at capture	1.30	53	0.20
Weight change during captive period	-0.46	52	0.65
Body condition scores	1.89	54	0.07
Feather weight/feather length	1.22	54	0.23
Average growth bar width	-0.05	41	0.96

Table 3.3. Results of Mann-Whitney U test examining difference in individual condition variables (with non-parametric distribution) between all transmittered and non-transmittered birds.

Individual condition variable	Z	P
Total number of fault bars	-0.62	0.54

3.3.4 - Did carrying a transmitter impact dispersal behaviour in the post-release phase?

Transmittered birds that dispersed <1 km had significantly higher body condition scores (p=0.02, Figure 3.6c) and significantly narrower growth bars (p=0.03, Figure 3.6d) when compared to non-transmittered birds with dispersal <1 km. For all other variables, there was no significant difference, although for total number of fault bars it appeared that the transmittered birds showed a trend to have a higher number of fault bars (p=0.13) than non-transmittered birds (Table 3.4).

Table 3.4. Results of Mann-Whitney U tests for differences between transmittered and non-transmittered individuals with dispersal <1 km.

Individual condition variable	**Z**	**P**
Weight:tarsus at capture	-1	0.32
Weight change during captive period	-0.27	0.79
Body condition scores	-2.27	**0.02**
Feather weight/feather length	-1.4	0.16
Average growth bar width	-2.13	**0.03**
Total number of fault bars	1.52	0.13

Table 3.5. Results of Spearman Rank Correlation for indicators of individual condition. Numbers in bold are significant (p<0.05).

	Weight: tarsus at capture	**Body condition score**	**Feather length (mm)**	**Feather weight (g)**	**Feather weight/feather length**	**Average growth bar width**	**Total fault bars**
Weight:tarsus at 21 days							
Correlation coefficient	0.15	-0.05	0.51	0.67	0.66	-0.17	-0.39
valid cases	29	29	29	29	29	23	29
one-sided significance	0.22	0.40	**0.002**	**2.96E-05**	**4.35E-05**	0.22	**0.018**
Weight:tarsus at capture							
Correlation coefficient		0.36	0.37	0.40	0.36	0.20	-0.23
valid cases		29	29	29	29	23	29
one-sided significance		**0.03**	**0.02**	**0.02**	**0.03**	0.19	0.12
Body condition scores							
Correlation coefficient			0.07	0.04	-0.05	-0.1	-0.11
valid cases			29	29	29	23	29
one-sided significance			0.36	0.41	0.39	0.33	0.29
Feather length (mm)							
Correlation coefficient				0.88	0.66	0.03	-0.39
valid cases				29	29	23	29
one-sided significance				**1.76E-10**	**4.64E-05**	0.45	**0.018**
Feather weight (g)							
Correlation coefficient					0.92	-0.08	-0.39
valid cases					29	23	29
one-sided significance					**4.13E-13**	0.36	**0.018**
Feather weight/feather length							
Correlation coefficient						-0.02	-0.37
valid cases						23	29
one-sided significance						0.46	**0.02**
Average growth bar width							
Correlation coefficient							-0.33
valid cases							23
one-sided significance							0.06

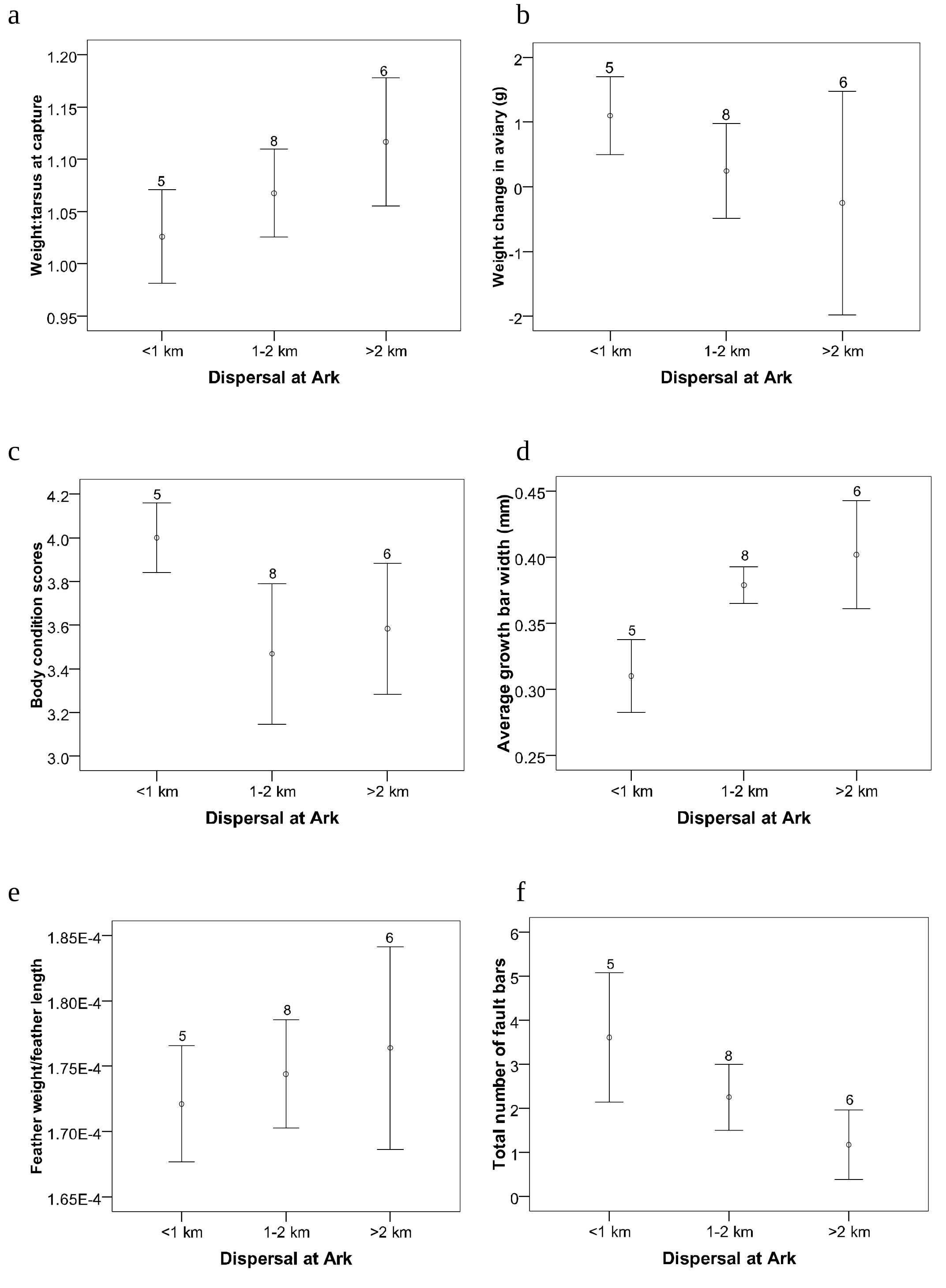

Figure 3.5. Means and standard error bars for relationship between individual condition variables and dispersal. a) Weight:tarsus at capture, b) weight change in captivity, c) body condition scores, d) average growth bar width, e) feather weight/feather length, f) total number of fault bars. Sample size (n) above bar for each group.

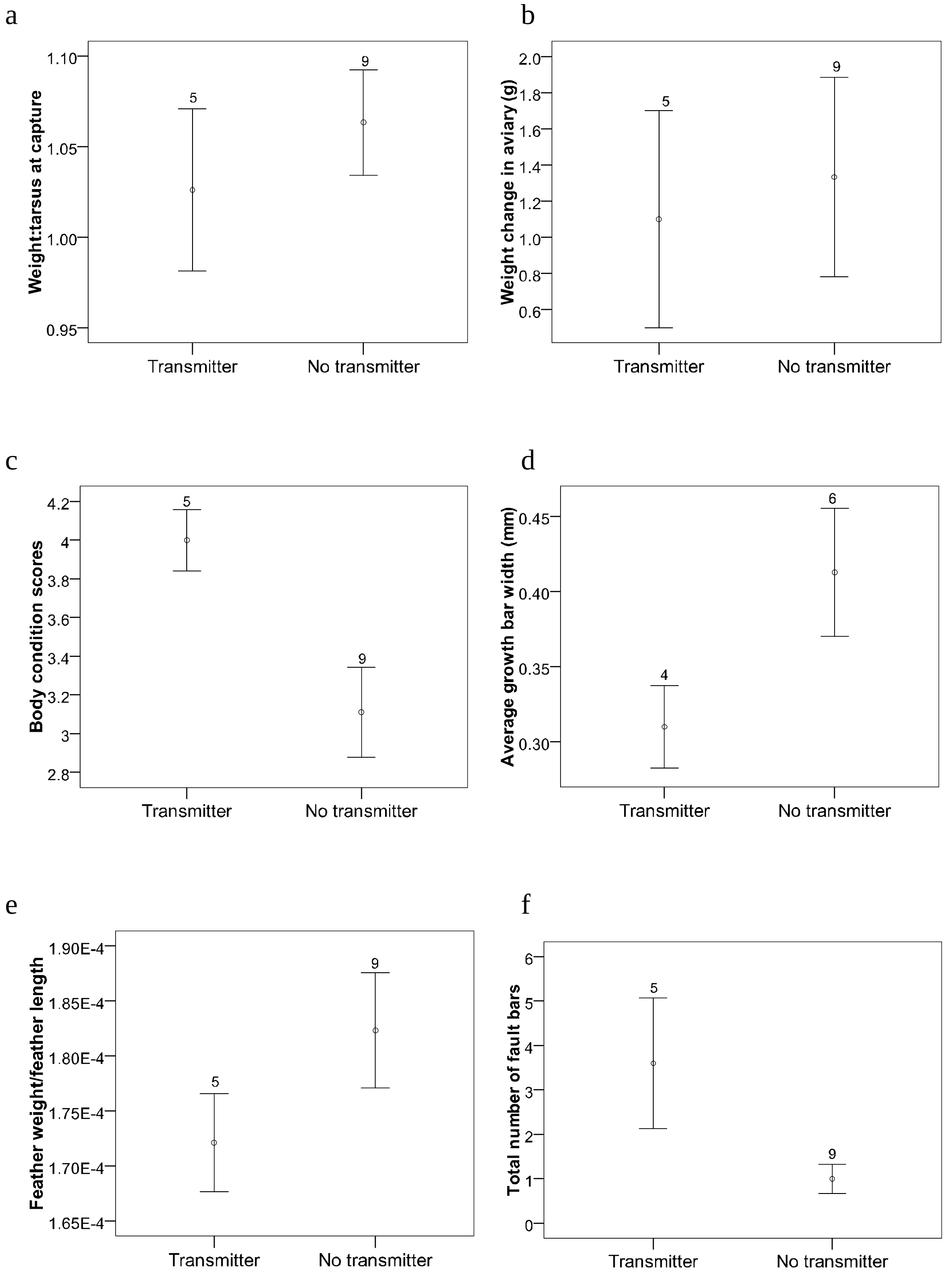

Figure 3.6. Means and standard error bars for comparison of initial condition variables for birds that dispersed <1 km. Sample size (n) above bar for each group.

3.4 - DISCUSSION

3.4.1 – What was the relationship between the individual condition variables?

The correlations between weight:tarsus at 21 days, feather weight/feather length and the total number of fault bars make intuitive sense as this is the time period at which the feather is being grown. Limitations in the food supply at this stage of growth would likely result in a smaller nestling, and may cause stress leading to the formation of fault bars on tail feathers. It would appear that some impacts during early growth can be partially compensated for by the time of fledging, as can occur in other species (Metcalfe and Monaghan, 2001; Ali and Wootton, 2005; Johnsson and Bohlin, 2006), as weight:tarsus at time of capture (either in February or June) shows only a correlation with feather weight/feather length.

The lack of correlation between average growth bar width and all other factors is interesting (although there was a near significant correlation with total number of fault bars). This emphasises the point made by some authors (Pravosudov *et al.* 1999; Grubb, 2006) that weight or body condition scores may not be an accurate means of assessing condition. Average growth bar width was nearly correlated with the total number of fault bars, which in turn showed a relationship with feather weight/feather length and weight:tarsus at 21 days, indicating a potential relationship between these factors. It may be possible that fault bars tend to be produced earlier in growth (i.e. closer to 21 days), whereas the average growth bar width represents the condition of the individual during the full period of feather growth.

3.4.2 - Did the condition of individuals prior to release influence dispersal distance in the post-release phase?

I found no significant relationship between any of the variables of condition and dispersal distance, but there was a general trend for “better” birds to disperse further – those that were heavier, had wider growth bars and less fault bars tended to be those that dispersed more than one kilometre from the release site. In addition birds that lost weight all had higher (>2 km) dispersal. This may be a reflection that these birds were in better condition at the time of capture and could therefore afford to lose more weight. It is difficult to know how much can be read into these results with a small sample size, but they do give weak support to the hypothesis that individuals in better physiological condition would be able to disperse further. The results presented in Chapter 2 suggest that in this study there were other factors that may also have impacted on dispersal – release method and timing of release in particular. There is evidence to suggest the different release methods had differing levels of stress, perhaps causing an increased dispersal response from the more stressed individuals. The timing of release may have had an effect on dispersal, with the birds from the second release perhaps being affected by the existing population, or the lesser amount of natural food available at this time.

If the hypothesis that individuals in better condition do disperse further in the post-release phase of reintroductions is correct, this is something that could compromise the success of these projects. Individuals in better condition are also likely to have higher long-term survival probabilities, and so it may mean that founder populations are based upon birds with lower chances of long-term survival.

However, there is potential for further research to provide additional insight into the factors influencing post-release dispersal. If post-release dispersal is partially a response to stress, the higher dispersal of "better" birds may be a result of their being physiologically able to disperse further as part of the stress response. Reducing the stress on individuals during translocations may have an effect of reducing dispersal in the post-release phase.

3.4.3 - Did carrying a transmitter impact dispersal behaviour in the post-release phase?

There was some evidence that transmitters impacted dispersal behaviour. The whole dataset shows that transmittered birds were representative of all birds in all individual condition variables, yet for those that dispersed less than one kilometre, there was a clear difference between the two groups that was significant for two variables. The results indicate that the transmittered birds that had limited dispersal tended to be those with narrower growth bars, smaller feathers, and a higher number of fault bars (the latter two not significant). Interestingly, they also had significantly higher body condition scores. This may emphasise that using body condition scores may not be a useful indicator of condition in hihi, although further research would be useful, looking at the long-term survival and reproductive success of individuals and relating it to the various indices of condition.

These results should be interpreted with caution. The data for individuals that did not carry transmitters is likely to be biased towards those that survived long enough to be sighted, and these birds may well have been those in better condition. This factor alone may explain the difference between the two groups.

However, it may also be possible that the combination of being in poorer condition and having the burden of carrying a transmitter had an additional effect of decreasing dispersal. While 5% of body weight is the most cited recommendation as a maximum for transmitter weight, Withey *et al.* (2001) recommend that, for birds, transmitters should not exceed 3% of total body mass. For a 30 g bird, this would suggest 0.9 g as the maximum weight, and would mean that the transmitters used in February (1.26 g) exceeded this recommendation for some individuals. The results of this study, suggesting that transmitters limited dispersal in some birds, support observations that were made in the first few weeks after the February release, in which a larger number of birds carrying transmitters were sighted by chance (i.e. not by radio telemetry) close to the release site than those that did not carry transmitters (see *2.3.3.3*). This observation led to concern that the February transmitters were too heavy, and lighter transmitters were used in June. No differences in behaviour were observed in June between birds that did or did not carry a transmitter.

3.4.4 - Conclusions

These results emphasise the difficulties in studying dispersal in animals capable of moving long distances, and the importance of ensuring behaviour is accurately represented by transmittered individuals in such studies. Caution should be taken in interpreting the results of this study, with the small sample size and the difficulty in obtaining good data from non-transmittered individuals. However, the results do suggest the potential for further research into the factors influencing post-release dispersal. Understanding these factors may enable translocation managers to design future transfers in a way that minimises post-release dispersal and enhances the chances of reintroduced individuals establishing a healthy, self-sustaining population.

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4

Factors influencing the condition of juvenile hihi (*Notiomystis cincta*) in a managed population.

Female hihi at sugar water feeder. Photo: Isabel Castro.

4.1 - INTRODUCTION

The condition of an individual during the early stages of development can have an important influence on the probability of survival to adulthood in avian species. However, defining what precisely is meant by condition can be problematic. Individuals in "better" condition are those that have an increased probability of survival to breeding age, and are considered to be more "fit". Stearns (1976) refers to fitness as "something everyone understands but no one can define precisely". However, he goes on to define a fit individual as one that is better represented in future generations than its relatively unfit competitors.

Condition is often measured by physical properties such as body mass or the amount of fat stored on the individual, and such measures have been associated with the probability of survival in birds, in particular at the nestling stage (Hochachka and Smith, 1991; Magrath, 1991; Nilsson and Gardmark, 2001). It can therefore be concluded that nestling condition is an important factor influencing the potential lifetime fitness of an individual.

Nestling birds differ in their net intake of energy and nutrients, and this can lead to variation in the condition of nestlings (Hochachka and Smith, 1991). Early nutrition is thought to be one of the factors affecting condition in juveniles, and individuals with poor natal nutrition have been found to have lower phenotypic quality as adults (Ohlsson *et al.* 2002; Blount *et al.* 2003; Buchanan *et al.* 2003). Natal nutrition is affected by the quality and quantity of food that is provided to the developing chicks by the provisioning parents. This can be influenced by a number of factors.

Natal condition and nutrition can be influenced by the quality of the parents provisioning the chicks with food. Parental quality can in part be related to age. The typical pattern is for reproductive success of an adult bird to increase with age, and then decrease at the end of the individual's life (senescence) (Forslund and Part, 1995). In passerines, the most dramatic change occurs between the first and second year (Curio, 1983; Sendecka *et al.* 2007), with second year birds typically having much higher reproductive success than those in their first year. Four main explanations for this change have been put forward (Forslund and Part, 1995): 1) the progressive appearance or disappearance of phenotypes, with selection acting to enhance female quality for successive cohorts, 2) delayed breeding by some birds enabling them to gain resources and therefore have higher reproductive success when they do start breeding, 3) age-related improvement in competence, with birds gaining experience or perhaps becoming more dominant with time, and 4) optimisation of reproductive effort, with an enhancement of effort as birds become older due to the associated decrease in life expectancy and therefore residual reproductive value.

The number of siblings in the nest is another factor influencing condition of the individual. This can be due to variation in the parents' ability to provision increasing numbers of chicks, and also differing competitive abilities between siblings (Nilsson and Gardmark, 2001). Many studies have shown that nestling condition (usually measured using body mass) declines with increasing clutch size (De Steven, 1980; Murphy, 1983; Hochachka and Smith, 1991). However, where a population is supplementary fed the constraints on food supply have been shown to be removed in some studies (Hochachka and Smith, 1991), reducing the impact of clutch size on nestling condition, and increasing overall nestling survival.

Lack (1947) hypothesised that clutch size has evolved to match the maximum number of young that the parents can feed on average. However, the evidence does not always support this, with other models predicting that the most common clutch size will be less than what is most productive (Stearns, 1976; De Steven, 1980; Murphy, 1983). This may be because larger broods increase stress and decrease survival of the parents (De Steven, 1980; White *et al*. 1991). Tinbergen and Daan (1990) showed that great tits (*Parus major*) will most often produce the number of eggs that maximises their individual lifetime fitness, rather than what results in the greatest reproductive value for that season.

Environmental factors can also affect nestling condition. For example, chick condition and survival improves with increased food quality and quantity (Hochachka and Smith, 1991; Sanchez *et al*. 2007). Nutrition can be affected by habitat quality (such as diversity of the vegetation), or the provision of supplementary food, and can also vary seasonally with natural variations in prey populations or flowering/fruiting patterns and climate.

Nestling survival often shows a decrease as the breeding season progresses. In many studies it is not clear why this is so, but changes in food supply or intolerance of temperature changes may be contributing factors (Perrins, 1965; Price *et al*. 1988; Norris, 1993; Wiggins *et al*. 1994). For instance Murphy (1983) found that sudden changes in temperature and precipitation were a major influence on the ability of parents to feed young. Low and Part (2009) showed a strong link between nestling survival and increased temperatures. Pathogens and parasites such as nest mites have also been found to influence the survival of nestlings in some species (Gwinner and Berger, 2005; Ewen *et al*. in prep.), and these may also be related to temperature changes.

This chapter will examine some of the social and environmental factors influencing nestling condition in a managed population of an endangered species, the hihi or stitchbird (*Notiomystis cincta*), using a variety of measures of condition (see Chapter 3 for description and reasoning behind measures used). This hihi population is frequently used as a source site for reintroductions, and the condition of individuals selected for reintroduction appears to have an impact on the behaviour of individuals after release (Chapter 3), and may also have an impact on the probability of survival, although this is only speculative. Hence, the condition of reintroduced individuals is one factor which can influence the success or otherwise of the reintroduction attempt. An understanding of the factors influencing condition at the source site may be of benefit when selecting individuals for future reintroductions.

The following hypotheses are made:

- Condition of nestlings will increase with increasing age of the female parent.
- Condition of nestlings will decrease with an increase in number of siblings.
- Condition of nestlings will be higher earlier in the season than later in the season.
- Condition of nestlings will vary between forest patches, due to the variation in forest complexity on Tiritiri Matangi Island.

4.2 - METHODS

4.2.1 - Study species:

See Chapter 1 for detail on hihi ecology and conservation.

4.2.2 - Study site: *Tiritiri Matangi Island.*

See Chapter 2.

4.2.3 - Indicators of condition:

Indicators of condition were obtained from 56 juveniles (28 females, 28 males) captured as part of a translocation carried out in February and June 2007. See Chapters 2 and 3 for further detail of the methodologies used for obtaining condition data. Table 4.1 presents a list of the condition variables used for the analysis, and the social and environmental factors that may have contributed to variation in condition.

Data on the age of the mother were obtained from the Tiritiri Matangi Island hihi database, collected by the Department of Conservation in conjunction with other researchers. Information was also obtained on the number of chicks that were present in each nest at 21 days after hatching (when banding occurred), the date of hatching, and the forest patch where each individual was hatched. A total of 13 forest patches were represented by the data, of a possible 17 (Figure 4.1). There is variation in the type of habitat represented by the different forest patches, with some comprising mostly original forest and others mostly regenerating or replanted. Weight:tarsus measurements were available for each bird at 21 days of age, and for some at 12 days (n=21).

4.2.4 - Data analysis:

Data were analysed for all juveniles on Tiritiri Matangi that were captured as part of the translocation (n=56). Condition values were averaged where individuals from the same clutch were taken (n=17), and therefore the sample size used for the analyses was 39 individual measurements.

Table 4.1. Variables of individual condition used in analysis, and the potential influencing factors examined.

Variables of individual condition
Weight:tarsus at 12 and 21 days, and at time of capture for translocation (February or June 2007)
Weight change during captive period for translocation
Body condition scores at time of capture for translocation (February or June 2007)
Tail feather weight/feather length
Average growth bar width
Total number of fault bars on tail feather

Potential influencing factors
Age of mother
Clutch size (number chicks in the nest at 21 days)
Time of fledging (early or late)
Forest patch hatched in

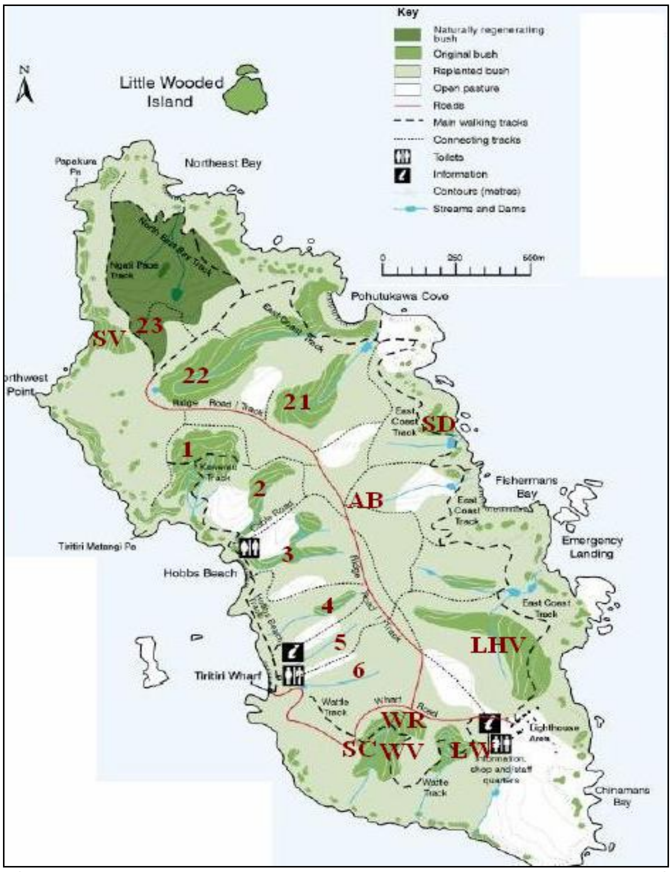

Figure 4.1. Map of Tiritiri Matangi Island, showing vegetation structure and forest patches. Red numbers and letters indicate the names of individual forest patches. Map sourced from Tiritiri Matangi Island visitor map (http://www.tiritirimatangi.org.nz/images/Map/TiriMapAndTrackInfo.pdf).

All variables were tested for normality (*Appendix F*), using the Kolmogorov-Smirnov test for continuous variables and Chi-square tests for discrete variables. The effect of age of mother was tested for using a Kruskal-Wallis test, as the sample size was small. The effect of clutch size was tested for using an ANOVA for all variables except weight:tarsus at 12 days (sample size too small) and total number of fault bars (non-parametric data), where Kruskal-Wallis tests were used instead. The effect of time of season was tested for using a Mann-Whitney U test, and the effect of forest patch was examined using ANOVAs for all variables except average growth bar width (sample size too small) and total fault bars (non-parametric data), where Kruskal-Wallis tests were used.

4.3 - RESULTS

4.3.1 - Effect of age of mother

There was no significant effect of age of mother on any of the variables of condition (Table 4.2), and older females did not appear to have more chicks in the nest at 21 days (Figure 4.2).

Table 4.2. Results of Kruskal-Wallis tests for effect of age of mother on individual condition, df=degrees of freedom.

Individual condition variable	H	df	P
Weight:tarsus at 12 days	6.16	4	0.19
Weight:tarsus at 21 days	5.26	6	0.51
Weight:tarsus at capture	2.66	6	0.85
Weight change during captive period	9.15	6	0.17
Body condition scores	6.34	6	0.39
Feather weight/feather length	6.46	6	0.37
Average growth bar width	5.82	6	0.44
Total number of fault bars	6.15	6	0.41

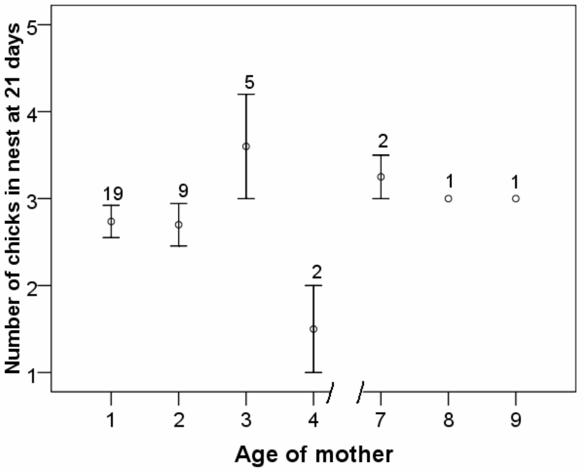

Figure 4.2. Means and standard error bars for relationship between age of mother and number of chicks in the nest at 21 days. Sample size (n) above bar for each group.

4.3.2 - Effect of clutch size

There was a significant effect of clutch size on the variable feather weight/feather length (p=0.05, Table 4.3) – individuals from single bird clutches have significantly heavier and longer feathers than those from multi-bird clutches (Figure 4.3a). There was also a trend for individuals from single bird clutches to have wider growth bars (Figure 4.3b), and for the total number of fault bars produced on an individual feather to increase as the number of siblings in the nest increased (Figure 4.3c), although these differences were not significant (Table 4.3, 4.4).

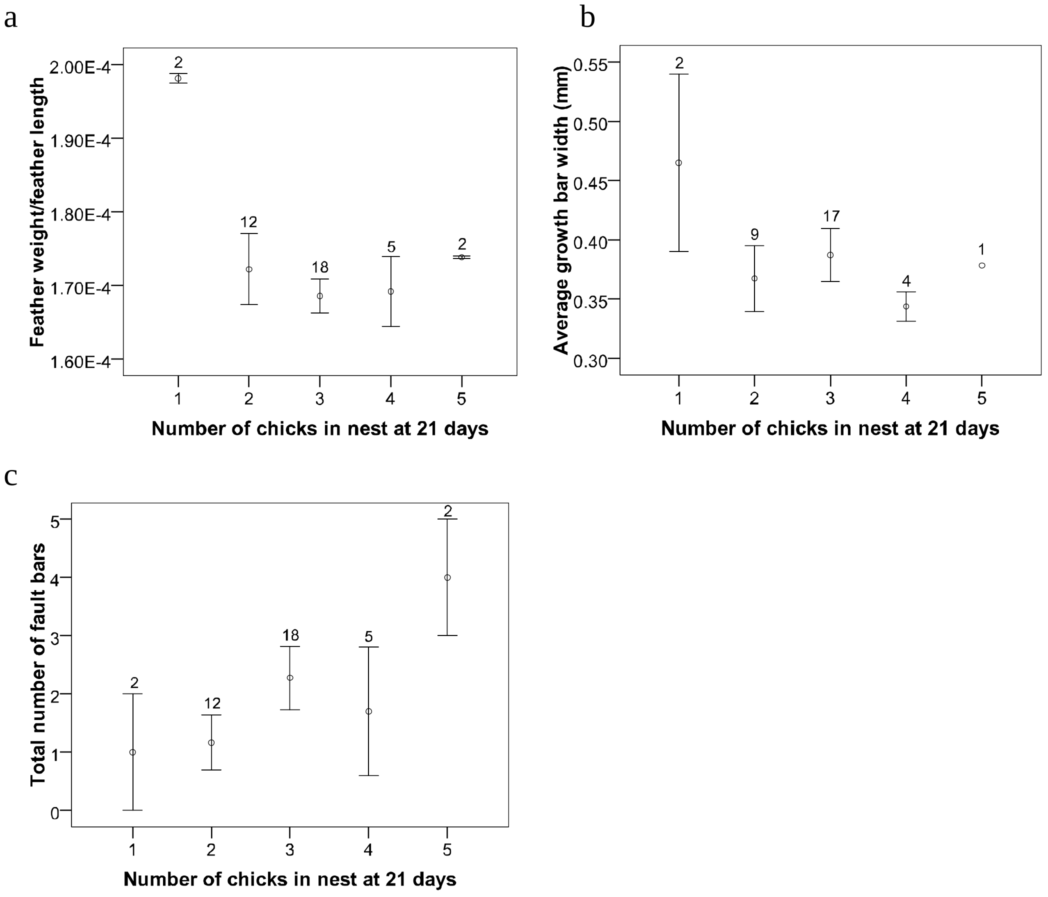

Figure 4.3. Means and standard error bars for effect of clutch size on a) feather weight/feather length, b) average growth bar width and c) total number of fault bars. Sample size (n) above bar for each group.

Table 4.3. Results of ANOVAs for effect of clutch size on normally distributed individual condition variables.

Individual condition variable	F	P
Weight:tarsus at 21 days	0.78	0.55
Weight:tarsus at capture	0.84	0.51
Weight change during captive period	1.98	0.12
Feather weight/feather length	2.69	**0.048**
Average growth bar width	0.64	0.64
Body condition scores	0.36	0.84

Table 4.4. Results of Kruskal Wallis tests for effect of clutch size on non-parametric individual condition variables, df=degrees of freedom.

Individual condition variable	H	df	P
Weight:tarsus at 12 days	1.57	2	0.46
Total number of fault bars	3.98	4	0.41

Table 4.5. Results of Mann-Whitney U tests for effect of time of season on individual condition.

Individual condition variable	Z	P
Number of chicks fledged	-1.95	**0.05**
Weight:tarsus at 12 days	-2.11	**0.03**
Weight:tarsus at 21 days	-1.48	0.14
Weight:tarsus at capture	0.64	0.52
Weight change during captive period	-1.63	0.1
Body condition scores	1.5	0.14
Feather weight/feather length	-1.34	0.18
Average growth bar width	0.88	0.38
Total number of fault bars	-0.82	0.41

Table 4.6. Results of ANOVA for effect of forest patch on normally distributed individual condition variables.

Individual condition variable	F	P
Clutch size	1.24	0.31
Weight:tarsus at 21 days	1.28	0.29
Weight:tarsus at capture	2.2	**0.04**
Weight change during captive period	1.14	0.37
Body condition scores	0.97	0.5
Feather weight/feather length	1.6	0.15

Table 4.7. Results of Kruskal-Wallis for effect of forest patch on non-parametric individual condition variables, df=degrees of freedom.

Individual condition variable	H	df	P
Weight:tarsus at 12 days	10.68	9	0.3
Total number of fault bars	10.45	12	0.58
Average growth bar width	5.94	10	0.82

4.3.3 - Effect of time of season

There were significantly more chicks present per nest at 21 days post-hatching for nests in November or December than in January or February (Table 4.5, Figure 4.4a), with early nests having on average 2.96 chicks and late nests 2.4 chicks. Early chicks were also significantly heavier at 12 days (Table 4.5, Figure 4.4b), but this difference was no longer present by 21 days of age.

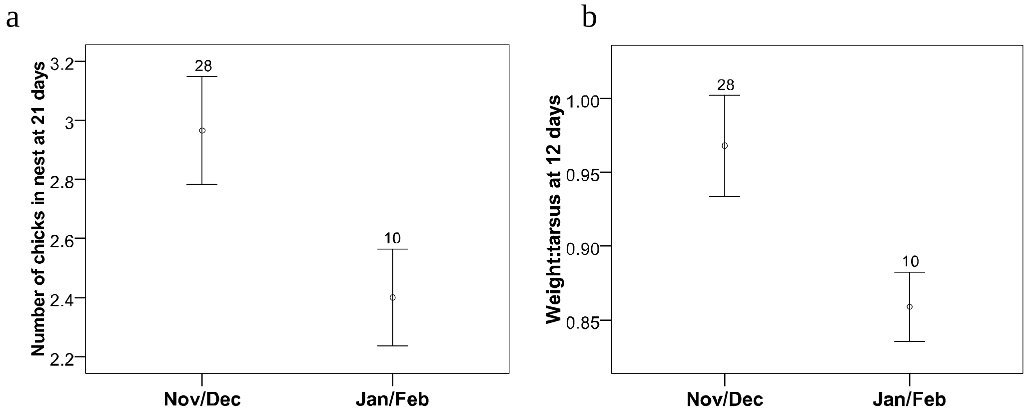

Figure 4.4. Means and standard error bars for effect of time of season on a) number of chicks in each nest at 21 days, and b) weight:tarsus at 12 days. Sample size (n) above bar for each group.

4.3.4 - Effect of forest patch

There were no significant differences between the different forest patches for any variables except that of weight:tarsus at capture (Tables 4.6, 4.7, Figure 4.5). Chicks from forest patches 2, 3, LHV and SC had the highest mean weight:tarsus ratios, while chicks from forest patches 4, 5 and LW had the lowest.

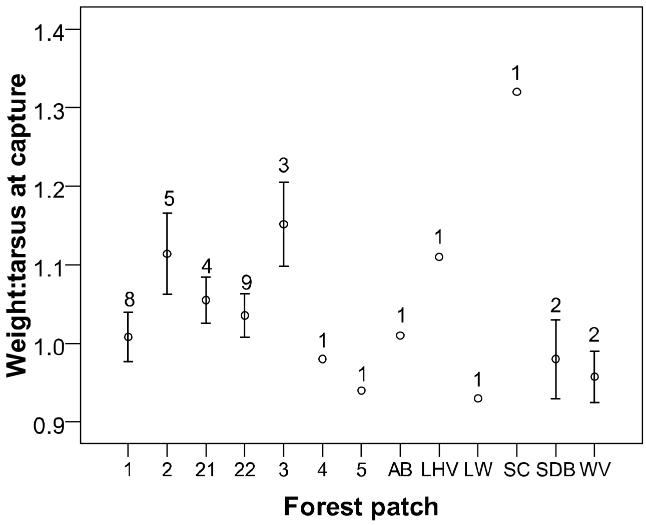

Figure 4.5. Means and standard error bars for effect of forest patch on weight:tarsus at time of capture. Sample size (n) above bar for each group.

4.4 - DISCUSSION

4.4.1 - Age of mother

My results suggested that the age of the mother had little or no effect on nestling condition or clutch size. Previous studies of hihi populations have shown that older females lay significantly more eggs (Castro *et al.* 2003), or that there is a quadratic relationship between female age and the number of eggs laid, as well as number of chicks hatched, fledged and recruited to the breeding population (Low *et al.* 2007). In this study, the number of eggs laid by each breeding female was not looked at, but if older females laid more eggs, it was not reflected with more chicks in the nest at 21 days. Low *et al.* (2007) suggested that the apparent effect of female age could be explained by the later establishment of territories by first-year breeders. The majority of older females would have a territory already established at the beginning of the breeding season, enabling breeding to start earlier, and therefore increasing the number of clutches that could be laid over the breeding season (Low *et al*. 2007). This may account for the greater number of young produced by older females, rather than an increase in their ability to provision young due to increasing experience. Conversely, there was no apparent decrease in nestling condition due to senescence of the female parent. This result lends little support to the hypothesis that age-related improvements in reproductive success occur due to improvements in competence – if this was the case it would be expected that older females would be producing nestlings with higher nutritional condition. However, the sample size is small and for only one season and it is recommended that further research with a larger sample size and over consecutive seasons be carried out before any conclusive statements can be made.

4.4.2 - Clutch size

I found that clutch size had an influence on nestling condition, in agreement with the results of other studies (De Steven, 1980; Murphy, 1983; Hochachka and Smith, 1991). The provision of supplementary food to this population did not appear to be sufficient to remove this effect. Low and Part (2009) also found that clutch size was one factor impacting the probability of a nestling surviving to fledge in a study of survival patterns in hihi on Tiritiri Matangi Island, with chicks in large clutches being more likely to survive than those from small clutches. I found that nestlings in larger clutches tended to have more fault bars, suggesting an effect of some type of stress – possibly malnutrition as the provisioning parents failed to provide adequate food for all nestlings at some period of the nestling’s growth. This suggests that hihi parents on Tiritiri Matangi Island may be more reliant on natural food for providing nestlings with adequate nutrition than supplementary food, and that this may be a limiting factor. Invertebrates form an important part of nestling diet in other nectar-feeding species (Maher, 1996; Oliver, 1998). The decreased nutritional condition of nestlings from larger clutches may relate to the decreased ability of parents to provide all nestlings with the same number of invertebrates, or may indicate that invertebrate availability is a limiting factor on Tiritiri Matangi Island.

Although there was an effect of clutch size on feather weight/feather length, average growth bar width and number of fault bars, there was no effect on the other variables that relate to body weight and body condition scores. This may support the suggestion by some (Grubb, 2006) that body weight may not be the best way to assess nutritional condition. It may also be possible that body weight is affected by higher intake of specific types of food, whereas nutritional condition may be affected by a different nutritional ratio.

4.4.3 - Time of season

Earlier nests were more successful in that they had a larger number of chicks in the nest at 21 days, although this study did not look at subsequent fledging success and recruitment to the breeding population. The higher success of earlier nests may be a consequence of the significantly heavier weight of nestlings at 12 days of age for earlier nests – heavier nestlings at this age may have a better chance of surviving to fledge (Low and Part, 2009). Low and Part (2009) found that hihi nestling survival on Tiritiri Matangi decreased over the season, but that this was confounded by a parallel increase in temperatures, which was also shown to influence survival. This decline over the season may be related to changes in natural food availability throughout the season (which may also relate to temperature changes), but this has not been quantified during any study of hihi survival and/or condition on Tiritiri Matangi Island. It may also reflect a difference in parental investment between first and second clutches.

Norris (1993) suggested that there are two possible reasons for declines in survival over the breeding season: differences in parental quality, with "better" birds more likely to breed earlier, or differences in the environment. He found more support for the latter (Norris 1993; see also Wiggins *et al.* 1994). If resources are less available later in the season, females may lay smaller clutches later in the season to increase the chances of raising at least some young to fledging (Perrins, 1965). Research into the changes in natural food availability (in particular invertebrates) over the breeding season on Tiritiri Matangi Island may provide further explanation.

4.4.4 - Forest patch

There was a significant effect of forest patch on the weight:tarsus ratio at the time of capture, but not on the other variables of condition. This result is curious as any effect of the forest patch a bird was born in would be expected to be seen during the stages of early growth, rather than after the bird had dispersed from this patch (as most juveniles were captured in a different patch from that which they had been hatched in, pers. obs.). The sample sizes for each forest patch are probably too small to say anything meaningful from this result, although the forest patches with lighter birds do tend to be those with less mature and more obviously planted vegetation structure (bush 4, 5, SDB, WV, and LW). Supplementary food is widely available throughout most of the island (although bush 4, 5, and SDB are some of those furthest from feeders). Possibly juveniles from these patches need to disperse further to be closer to feeders (or to join crèches of other juveniles), and this may have an adverse impact on condition at this life stage.

4.4.5 - Interpretation and application of results

My results generally support the findings of Low and Part (2009), showing that clutch size and hatching date are factors influencing nestling condition (and in turn, possibly affecting survival and potential lifetime fitness). It is worth keeping in mind that this data set only looked at individuals that had survived long enough to be captured for translocation (although they may not have gone on to be recruited into the breeding population), lending a bias to these results in favour of birds with higher chances of survival (and therefore possibly in better condition).

Further research into changes in food availability over the breeding season would be worthwhile to determine the factors enhancing condition and productivity in the first half of the season. Other factors may also play a role and future research should take these into consideration, in particular the impact of nest mites, which are a known problem for nestling hihi in artificial nest boxes (Taylor *et al.* 2005), and nest box microclimate.

The results of this study do not provide any clear guide in selecting individuals for reintroductions, although birds from smaller clutches which hatched earlier in the season would be preferable, and may have higher potential lifetime fitness. The impact that this would have on the source population should also be considered. Taking birds from smaller clutches would have more impact on reducing genetic diversity of the source population as it would reduce the number of remaining siblings that could survive to be recruited to the breeding population. Likewise, targeting birds from earlier in the season may lead to overall reduced survival and recruitment of juveniles for that season, even when taking into account the reduction in competition for resources caused by the removal of a large number of juveniles. On the other hand, it may be that removing birds hatched earlier in the season has a consequence of reducing competition and increasing the chances of survival for those hatched later that are left behind.

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5

Hihi diet in differing habitats, and the relationship with individual condition.

Hihi on kiekie (*Freycinettia banksii*) in the Waitakere Ranges. Photo: Eric Wilson

5.1 - INTRODUCTION

5.1.1 – Avian diet

The diet of birds varies between the different life stages - from the early nestling stage, to post-fledging, and then to adulthood (Marchetti and Price, 1989; Lindstrom, 1999). It is known that the diet of individuals during the earliest developmental stages can have lasting effects to adulthood, and it is usually found that the earlier an individual's development is disturbed by a deficient diet, the stronger the effect (Lindstrom, 1999). A reduction in the quality or quantity of food received by nestlings can influence size, metabolism, immune function, song complexity and sexual attractiveness as adults, and ultimately survival (Watanuki, 1992; Saino *et al*. 1997; Birkhead *et al*. 1999; Lindstrom, 1999; Wilkin *et al*. 2009).

It is often the quality of the diet that is the most important factor. In experimental studies, growth rates and immune function are known to be influenced by changes in protein levels (Saino *et al*. 1997; Birkhead *et al*. 1999) or the presence of amino acids (Serafin, 1982; Fancher and Jensen, 1989) in nestling diet. Invertebrates often provide an important protein source in nestling diet - even in species in which it is not an important component of adult diet (Young, 1971; Oliver, 1998). The appropriate balance of invertebrates in the diet has been linked to body condition (Johnston, 1993; Borg and Toft, 2000; Donald *et al*. 2001; Wilkin *et al*. 2009). Johnston (1993) demonstrated that the relationship between food quality and body condition may not always be straightforward. Johnston found that house martin (*Delichon urbica*) nestlings on a high-fat diet were of larger body weight (perhaps due to accumulation of larger fat reserves), but had overall slower growth than nestlings on a low-fat diet.

The diet of juveniles in the post-fledging stage generally undergoes another shift, with selection for juveniles to reach adult form as quickly as possible (Marchetti and Price, 1989). After fledging, birds will go through a period of decreasing dependence on parents for food, and even when totally independent the diet and foraging techniques of juveniles commonly differ from adults in the same area. Marchetti and Price (1989) suggest that this is primarily due to morphological and learning constraints in juveniles, which disappear with physical maturation and learning by experience, and that decreased foraging efficiency is one of the likely causes of higher mortality in juveniles.

The quality of food presented to nestlings can be influenced by food availability, and this can often be linked to habitat. Habitat quality can be difficult to define and it is sometimes assumed that, in species considered mature forest specialists, older forest will contain a wider selection of potential food items, although this is not always the case (Hanula and Engstrom, 2000). Invertebrate communities may be influenced by plant species diversity and composition, and the structural features of forests, and this may in turn influence nestling diet and survival (Mizutani and Hijii, 2002).

5.1.2 – This study

This study examines the diet at various life stages of a supplementary-fed population of the endangered New Zealand forest bird, the hihi or stitchbird (*Notiomystis cincta*), and the relationship between diet and condition. Hihi (once thought to belong to the honeyeater family, see Chapter 1) feed on a combination of nectar, fruit and invertebrates, the proportions of each in the diet changing according to season and location (Gravatt, 1969; Rasch, 1985; Lovegrove, 1985; Castro *et al*. 1994; Wilson, 1997; Perrott, 1997), and possibly sex and life stage (Wilson, undated). Hihi nestlings are thought to be fed by the parents on insects <3 mm in the first 8-10 days in the nest, and then a combination of nectar, fruit and larger insects (Lovegrove, 1985; I. Castro, pers. comm.). Little is known about the diet of juvenile hihi once they have fledged, with the only published study showing that juveniles included fewer invertebrates in the diet than adults at the same time, based on observational data (Wilson, undated). However, this study had a small sample size, and may not have been representative. In other nectar feeders, invertebrates comprise a significant part of nestling and fledgling diet, despite being of limited importance in the diet of adult birds (Young, 1971; Oliver, 1998). Differences between males and females may also occur, with Wilson (undated) finding females feeding on a higher proportion of invertebrates than males in autumn.

The diet of adult hihi has been the subject of many studies, both in naturally occurring populations, and recently translocated populations that are provided with supplementary food. Two translocated populations provide evidence of the importance of supplementary food for hihi (Armstrong and Ewen, 2001; Castro *et al*. 2003). However, it is unclear why hihi are unable to find sufficient food in these areas. Armstrong and Ewen (2001) looked at nectar gaps and their findings on Tiritiri Matangi Island supported the hypothesis that hihi are unable to find enough of particular food sources at given times of the year. Hence diet may be constrained by the botanical diversity of the site, and the stage of regeneration. The apparent dependence of hihi on supplementary food where habitat is regenerating, in combination with their use of tree cavities for breeding, suggests that hihi are a mature forest species (Taylor *et al*. 2005; Makan, 2006). Any advances in knowledge of hihi diet at all life stages, in different habitats, and the relationship to condition may be of benefit to conservation of the species.

In this chapter I present the results of a study using stable isotope analysis from hihi blood and feathers to provide information about hihi diet at an established translocated island population, and at a newly translocated mainland site. These sites have different habitats (see Chapter 2), with the island comprising a mix of regenerating and recently planted forest habitat, and the mainland site a mix of original mature kauri (*Agathis australis*) and regenerating podocarp/broadleaf forest.

5.1.3 – Studying diet using stable isotope analysis

Stable isotope analysis provides a more accurate means of assessing diet than observations alone. Isotopes are different forms of the same chemical element varying in the number of neutrons and therefore having a different atomic mass. Many of these forms do not decay with time, and are referred to as "stable". As they are present in all life forms, an animal's tissues will reflect the isotopic ratio of its food (measured using a mass spectrometer), which in turn reflect the isotopic ratios of local water and soil, and the trophic level of ingested food. Hence, isotope analysis of tissue samples can provide information on the dietary composition of an individual animal over specific time periods (Fry and Sherr, 1984; Michener and Lajtha, 2007). Analysis can be particularly useful in species where two isotopically distinct dietary sources are available (Hobson and Clark, 1992; Angerbjorn *et al.* 1994), providing quantitative information on the relative contributions of each. In the case of hihi, carbon and nitrogen isotope analysis should be able to provide information on the proportions of carbohydrate (i.e. nectar, fruit and sugar water) and protein (i.e. invertebrates) in the diet.

Tissues with rapid isotopic turnover (e.g. blood samples) will reflect the recent diet of the individual, whereas tissues with slow turnover (e.g. feathers) will reflect longer-term dietary averages. A blood sample represents the diet of the individual over a few days prior to sampling. The isotopic composition of feathers records the diet while the feather is growing, as feathers become essentially inert structures after growth with no further isotopic exchange occurring (Hobson and Clark, 1992).

5.2 - METHODS

5.2.1 - Study species

See Chapter 1 for detail of hihi ecology and conservation.

5.2.2 - Study sites

5.2.2.1 - Tiritiri Matangi Island – See Chapter 2.

5.2.2.2 - Ark in the Park, Waitakere Ranges – See Chapter 2.

5.2.3 - Stable isotope analysis

5.2.3.1 - Blood and feather sampling

A blood sample was taken from juveniles and adult males caught during the process of translocation from Tiritiri Matangi Island to Ark in the Park in February and June 2007 (see Chapter 2 for further detail). Adult females were not captured as part of the translocation, so it was not possible to obtain samples from this demographic group. Approximately 75 µL was taken from each bird. Feather samples were taken at the same time, with the fifth rectrix plucked from each bird captured.

Ark in the Park samples were obtained in September 2007. Six birds that had been released in February or June 2007 were captured using mistnets set up at the supplementary feeder stations (see Chapter 2). The fifth rectrix was replucked from all except one bird, because two tail feathers were missing, including the regrown fifth rectrix. Again, a blood sample of 75 µL was also taken from each bird. In addition, the fifth rectrix was replucked from a juvenile male that died in late March 2007 (see Chapter 2), at which time it was approximately three-quarters regrown.

All blood samples were stored in eppendorfs and frozen until they were prepared for analysis. Feathers were used for the work described in Chapters 3 and 4 (handled using gloves) before being sent for isotope analysis. Feathers were kept in individual envelopes.

5.2.3.2 - Blood sample preparation for isotope analysis

Blood samples were removed from the freezer and placed in ovens at 60°C overnight. The dried sample was centrifuged, then removed and ground to a fine powder using a mortar and pestle. This powder was then transferred to a clean eppendorf.

5.2.3.3 - Food source sampling

Potential food sources for Tiritiri Matangi Island were collected in February and June 2007. Samples of flowers and fruit in season at the time of collection were obtained (Table 5.1). As this study commenced in February 2007 it was not possible to obtain the full range of potential food sources for the period covered by the isotope data (early 2006 to June 2007) - for example the period when chicks were in the nest for the 2006/07 breeding season. In particular flowering species not collected that are a major component of hihi diet on Tiritiri Matangi Island are pohutukawa (*Metrosideros excelsa*) and kowhai (*Sophora microphylla*). Invertebrates considered likely to be taken by hihi were obtained by searching foliage and bark of vegetation in hihi territories, primarily small flies. Five samples of the raw sugar that is used to make the supplementary food were analysed for ^{13}C only, and the mean value used.

Food samples were obtained from Ark in the Park during late March/early April and August 2007 (Table 5.1).

5.2.3.4 - Food sample preparation

All samples were kept frozen until prepared for analysis. Flower and fruit samples were then oven dried overnight at 60°C, and ground to a fine powder in the same manner as the blood samples. Invertebrate samples were also oven dried overnight, and then sent for lipid extraction prior to analysis.

Table 5.1. Potential plant food sources sampled from Tiritiri Matangi Island and Ark in the Park (Waitakere Ranges) in 2007.

Site/Period	Flowers	Fruit
Tiritiri Matangi Island, February 2007	*Hebe* spp., puriri (*Vitex lucens*), mahoe (*Melicytus ramiflorus*), manuka (*Leptospermum scoparium*).	Mapou (*Myrsine australis*), fivefinger (*Pseudopanax arboreus*), *Coprosma robusta,* cabbage tree (*Cordyline australis*), mahoe, puriri, wharangi (*Melicope ternata*), hangehange (*Geniostoma rupestre*).
Tiritiri Matangi Island, June 2007	Manuka, kohekohe (*Dysoxylum spectabile*), puriri, wattle (*Albizia lophantha*), *Rhabdothamnus solandri*.	Mahoe, fivefinger.
Ark in the Park, April 2007	Lacebark (*Hoheria populnea*), rata vine (*Metrosideros fulgens*).	Kahikatea (*Dacrycarpus dacrydioides*), hangehange, *Coprosma robusta*, mingimingi (*Cyathodes juniperina*), pate (*Schefflera digitata*), putawetaweta (*Carpodetus serratus*), mapou, *Melicytus macrophyllus.*
Ark in the Park, August 2007	Tree fuchsia (*Fuchsia excorticata*), toropapa (*Alseuosmia macrophylla*).	*Coprosma arborea*.

5.2.3.5 - Analysis of samples

All samples were sent to the National Institute of Water and Atmospheric Research (NIWA) Ltd in Wellington for stable isotope analysis.

Carbon and nitrogen isotope ratios of all samples were reported as ratios in delta (δ) units as parts per thousand (‰), using the following equation:

$$\delta X = (R_{sample}/R_{standard} - 1) \times 1000$$

where R is the corresponding ratio $^{13}C/^{12}C$ (δC) or $^{15}N/^{14}N$ (δN). $R_{standard}$ is the Pee Dee Belemnite for ^{13}C and atmospheric N_2 for ^{15}N (Kelly, 2000; Bearhop *et al.* 2003; Evans Ogden *et al.* 2006).

5.2.4 – Individual condition variables

See Chapters 3 and 4 for detail on collection methods of the variables of individual condition used.

5.2.5 - Data analysis

Differences in $\delta^{13}C$ and $\delta^{15}N$ values between groups (Table 5.2) were tested for significance using either ANOVA (for normally distributed data) or Kruskal-Wallis tests, depending on the normality of the data. The difference between male and female $\delta^{13}C$ and $\delta^{15}N$ values were tested for significance using either the independent t-test (for normally distributed data) or Mann-Whitney U test.

The relationship between $\delta^{15}N$ or $\delta^{13}C$ and the variables of condition were analysed using either a Pearson Correlation or Spearman-Rank Correlation depending on the normality of the data. For nestlings, the individual condition variables used were: weight:tarsus at 21 days, feather weight/feather length, average growth bar width, total number of fault bars, age of mother, and early (November or December 2006) or late (January or February 2007) fledging date. For fledglings and winter juveniles, the same variables were used, except that weight:tarsus at 21 days was substituted with weight:tarsus at the time of capture (either February or June 2007 – i.e. at the time the blood sample was taken). For adult males, again weight:tarsus at time of capture was used, as well as the age of the male, feather weight/feather length, average growth bar width, and total number of fault bars. Feather variables (i.e. feather weight/feather length, average growth bar width, and total number of fault bars) represent the condition of the individual at the time the feather was being grown, which for juveniles was while the bird was in the nest, and for adult males post-moulting after the breeding season (Table 5.2). Juvenile hihi do not moult the tail feathers grown in the nest until the end of their first breeding season, and adult hihi moult tail feathers at the end of each breeding season.

Table 5.2. Samples obtained from hihi for stable isotope analysis in 2007 from Tiritiri Matangi Island and Ark in the Park (Waitakere Ranges), the time period this sample represents, and the number of samples obtained for each group.

Group	Time period represented	Sample used	Site	N
1	Nestling 2006/07	February and June juvenile feathers	Tiritiri Matangi	56
2	Post-fledgling 2006/07	February juvenile blood	Tiritiri Matangi	29
3	Winter juvenile 2007	June juvenile blood	Tiritiri Matangi	30
4	Adult male post-breeding season 2005/06	February adult male feather	Tiritiri Matangi	13
5	Adult male post-breeding season 2006/07	February adult male blood, June adult male feather	Tiritiri Matangi	38
6	Adult male winter 2007	June adult male blood	Tiritiri Matangi	25
7	Post-release February 2007	Feather plucked in September from birds released in February	Ark in the Park	5
8	Post-release June 2007	Feather plucked in September from birds released in June	Ark in the Park	2
9	September 2007	Blood sample from birds caught in September	Ark in the Park	6

5.3 - RESULTS

5.3.1 - Diet of hihi on Tiritiri Matangi Island

5.3.1.1 - Food sources

The results show that the sugar water has more depleted $\delta^{13}C$ values than all other potential food sources analysed. In February (Figure 5.1), invertebrates plotted much lower in $\delta^{15}N$ than either flowers or fruit, however the reverse was the case for the June sources (Figure 5.2). Flowers plotted similarly in both February and June, however fruit was considerably lower in $\delta^{15}N$ in June than in February. See *Appendix I* for a list of values for all the potential food sources collected.

5.3.1.2 - Juvenile diet

There was a significant difference in $\delta^{15}N$ ($p<0.01$) between nestlings and juveniles after they had left the nest (Figure 5.3, 5.4a; *Appendix G - Table 1*), and between $\delta^{13}C$ ($p<0.01$) for birds at the post-fledgling stage and at the nestling and winter juvenile stage (Figure 5.3, 5.4b; *Appendix G - Table 2*). There were no significant differences between the sexes at any stage except for winter juveniles in $\delta^{15}N$ (Figure 5.5; *Appendix G - Table 3*). Males had significantly lower $\delta^{15}N$ than females ($p=0.03$; mean $\delta^{15}N$ for males=7.78, SE 0.31, mean $\delta^{15}N$ for females=8.8, SE 0.31).

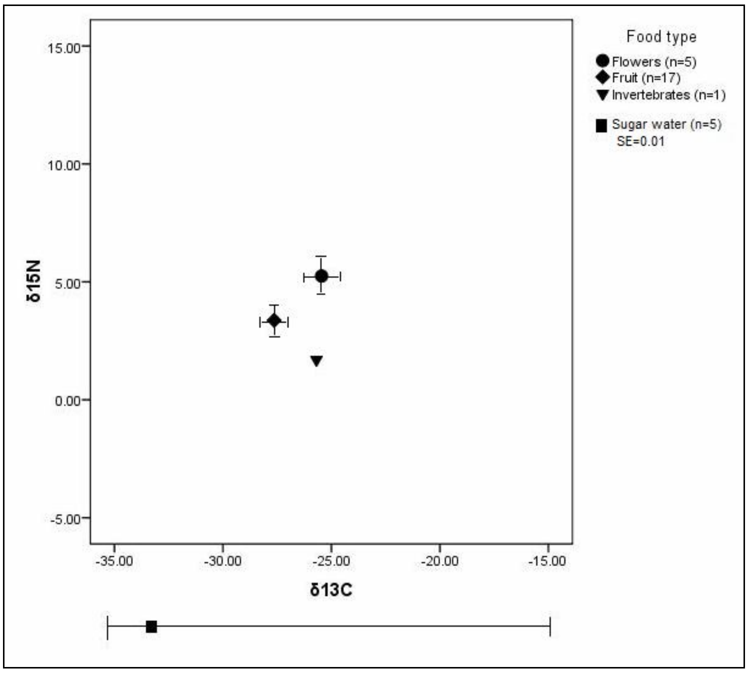

Figure 5.1. Means and standard error bars for isotopic values of potential food sources from Tiritiri Matangi Island, for samples obtained in February 2007. The bottom line represents value for δ^{13}C only for sugar water, as δ^{15}N was n/a for this food group.

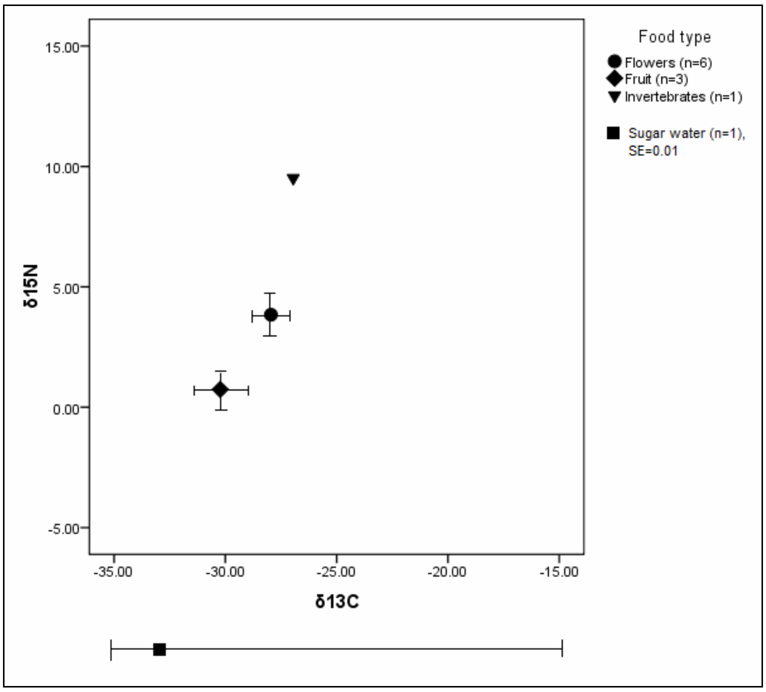

Figure 5.2. Means and standard error bars for isotopic values of potential food sources from Tiritiri Matangi Island, for samples obtained in June 2007. The bottom line represents value for δ^{13}C only for sugar water, as δ^{15}N was n/a for this food group.

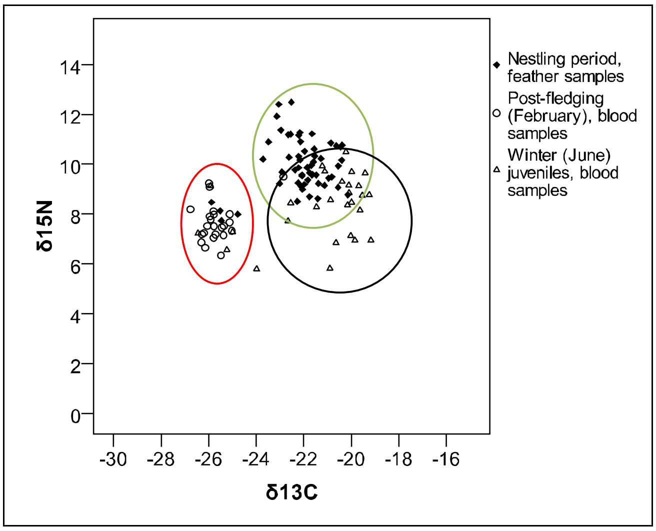

Figure 5.3. Isotopic values for hihi samples from Tiritiri Matangi Island as nestlings (green), post-fledgling period (red) and winter juveniles (black).

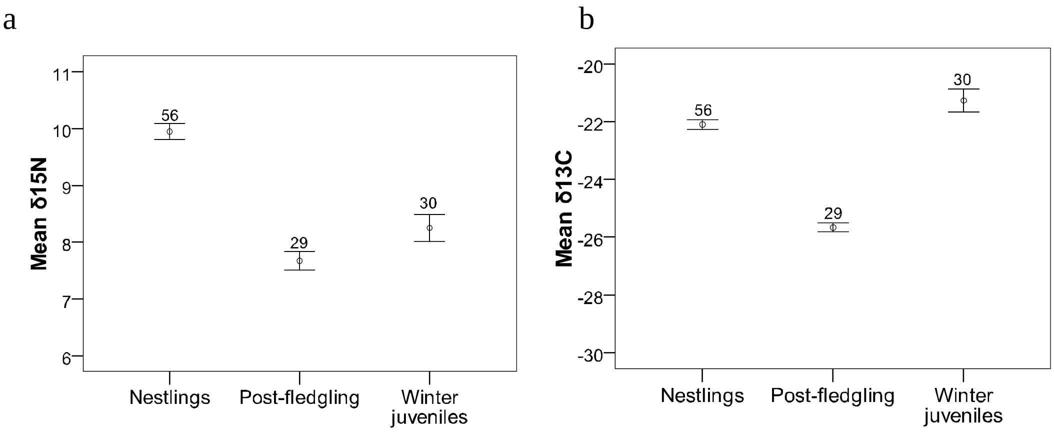

Figure 5.4. Means and standard error bars for differences between nestlings (feather samples), post-fledgling period (blood samples) and winter juveniles (blood samples) for a) δ^{15}N and b) δ^{13}C on Tiritiri Matangi Island. Sample size (n) above bar for each group.

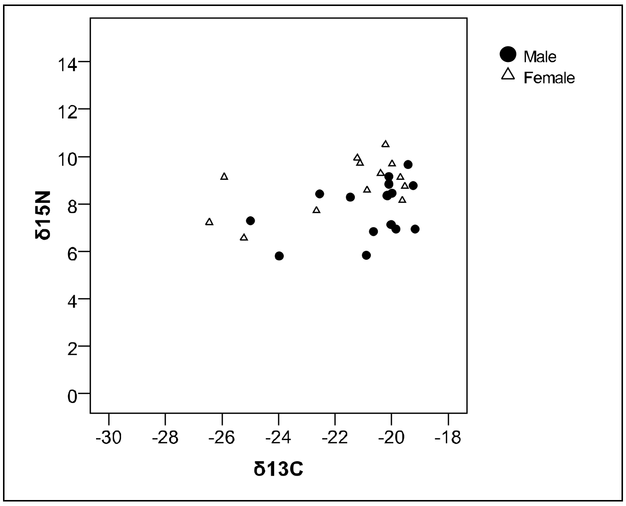

Figure 5.5. Difference in isotopic values for male and female hihi as winter juveniles (blood samples) on Tiritiri Matangi Island. 1=male, 2=female.

5.3.1.3 - Adult male diet

There were no significant differences in δ^{15}N values in adult male diet subsequent to the 2005/06 breeding season compared to subsequent to the 2006/07 season (Figure 5.6, 5.7a; *Appendix G - Table 4*). However, there was a significant difference between the δ^{13}C values for the two seasons, although it did not appear to be a large difference (Figure 5.6, 5.7b; *Appendix G - Table 5*). There was a significant difference in both δ^{15}N and δ^{13}C values between the post-breeding season results and those for adult males during winter 2007, indicating a shift towards a diet with lower δ^{15}N and higher δ^{13}C.

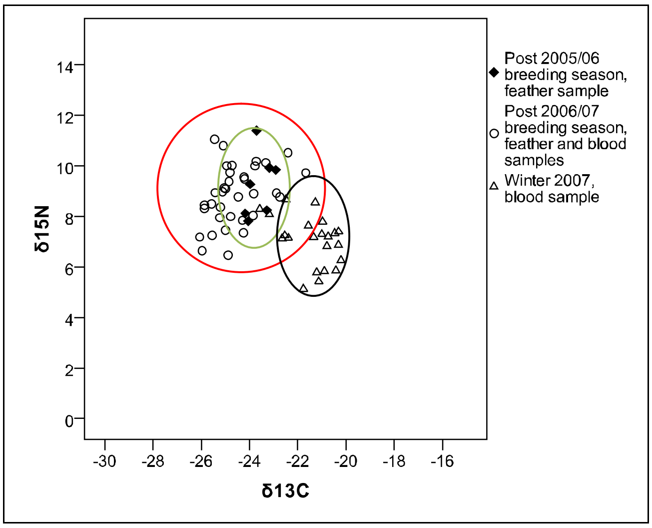

Figure 5.6. Isotopic values for adult male hihi samples from Tiritiri Matangi Island during post-2005/06 breeding season period (green), post-2006/07 breeding season period (red), and winter 2007 (black).

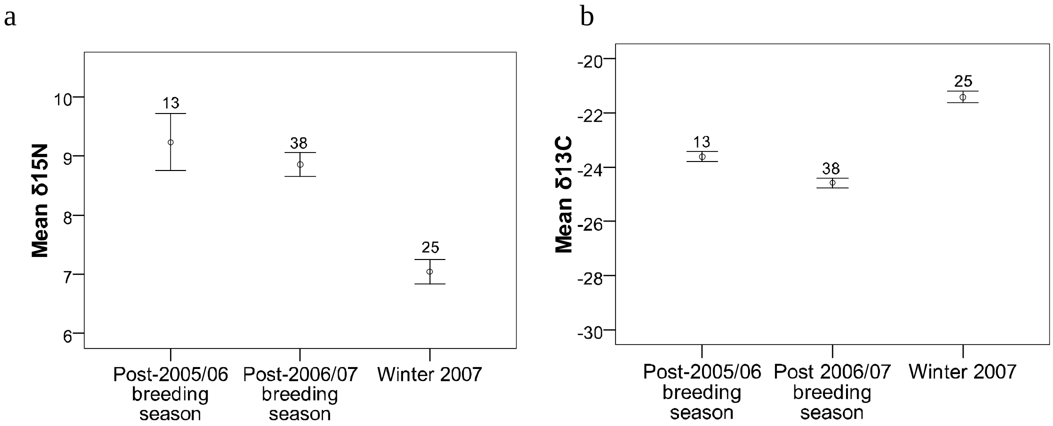

Figure 5.7. Means and standard error bars for differences between post-2005/06 breeding season (feather sample), post-2006/07 breeding season (feather and blood sample) and winter 2007 (blood sample) for a) δ^{15}N and b) δ^{13}C on Tiritiri Matangi Island. Sample size (n) above bar for each group.

5.3.2 - Diet and relationship to condition at each life stage on Tiritiri Matangi Island

See *Appendix H* for results of Pearson and Spearman-Rank Correlation for relationship between δ^{15}N and δ^{13}C and variables of condition.

5.3.2.1 - Nestling stage

There was a significant correlation between δ^{15}N values and weight:tarsus at 21 days ($p<0.01$) for hihi nestlings, with weight:tarsus increasing as δ^{15}N increases. There were also significant correlations between δ^{13}C values and weight:tarsus at 21 days ($p=0.02$), total number of fault bars ($p=0.004$), and almost significant correlations between feather weight/feather length ($p=0.053$) and average growth bar width ($p=0.095$) (Figure 5.8). Weight:tarsus, feather weight/feather length, and average growth bar width increased as the δ^{13}C value decreased, while the total number of fault bars decreased.

- *5.3.2.2 - Post-fledgling period*

There was a significant correlation between the time of fledging and δ^{15}N (p=0.002), with those birds fledging in the first half of the season having significantly lower δ^{15}N values than those fledged in the second half (Figure 5.9). There were significant correlations for δ^{13}C values and weight:tarsus (p=0.004) and feather weight/feather length (p=0.02) (Figure 5.10), showing the same pattern as for nestlings – an increase in weight:tarsus and feather weight/feather length as δ^{13}C decreased.

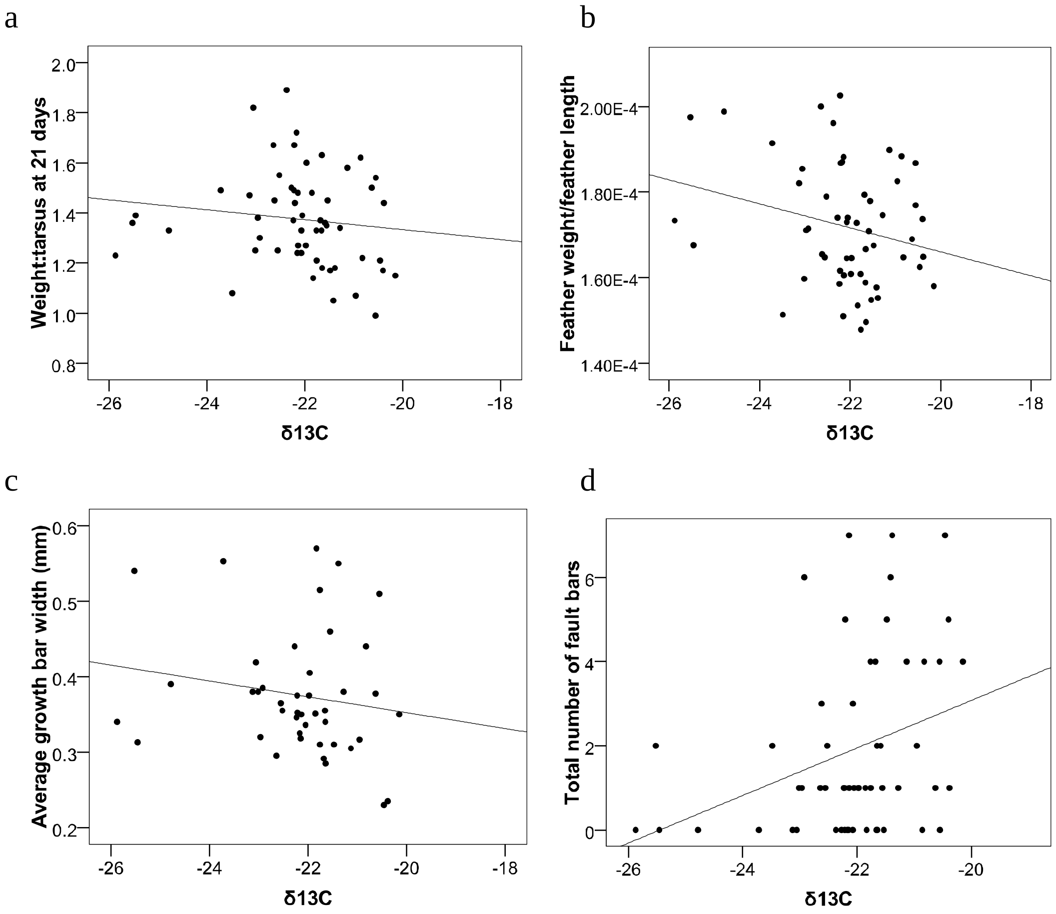

Figure 5.8. Scatterplots showing relationship between δ^{13}C in nestling diet (feather sample) on Tiritiri Matangi Island and a) weight:tarsus at 21 days, b) feather weight/feather length, c) average growth bar width and d) total number of fault bars.

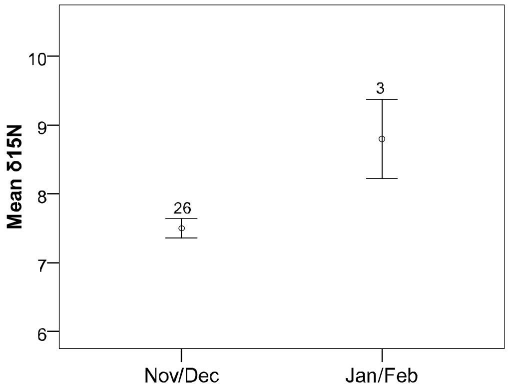

Figure 5.9. Means and standard error bars showing difference in $\delta^{15}N$ values in February diet (blood samples) on Tiritiri Matangi Island for juveniles fledged early in the season (1, November or December) and late (2, January or February), sample size (n) above bar.

- *5.3.2.3 - Juveniles in winter*

There was a significant correlation between $\delta^{15}N$ and weight:tarsus (p=0.003, Figure 5.11a) and average growth bar width (p=0.04, Figure 5.11b), with both decreasing as $\delta^{15}N$ increased. There was a significant correlation between $\delta^{13}C$ and feather weight/feather length (p=0.02, Figure 5.11c), with the same pattern as in other age groups – feather weight/feather length increased as $\delta^{13}C$ decreased.

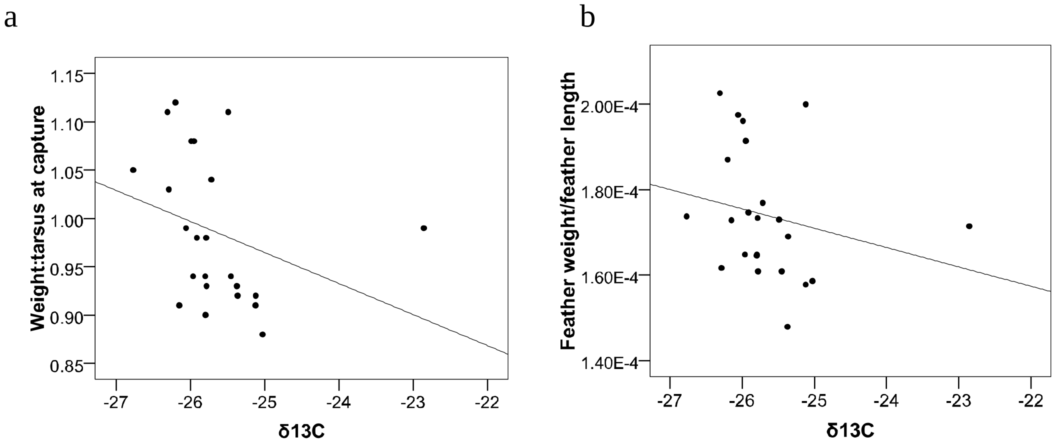

Figure 5.10. Scatterplots showing correlations between a) weight:tarsus at capture and $\delta^{13}C$ values for juveniles during the post-fledgling stage, and b) feather weight/feather length and $\delta^{13}C$ values during the post-fledgling stage.

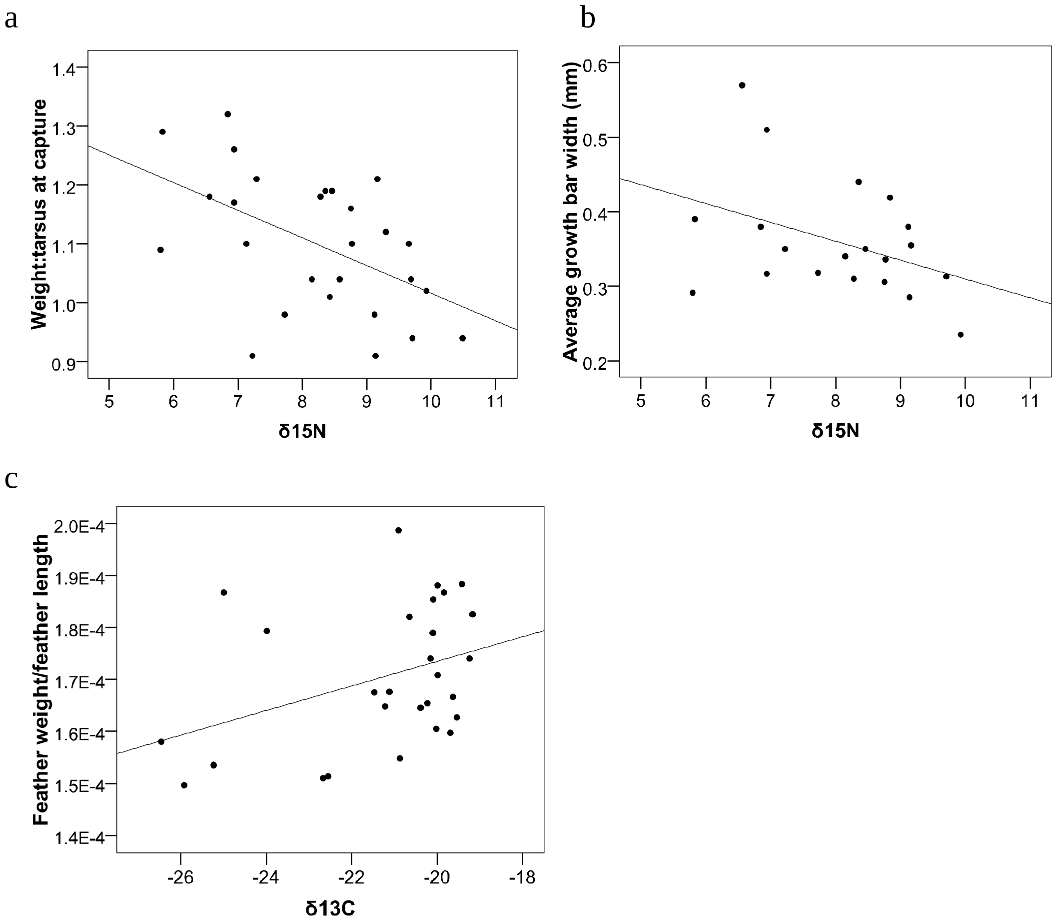

Figure 5.11. Scatterplots showing correlations between $\delta^{15}N$ in diet of juveniles in winter (blood sample) on Tiritiri Matangi Island and a) weight:tarsus at capture and b) average growth bar width, and c) between $\delta^{13}C$ in diet of juveniles over winter and feather weight/feather length.

- *5.3.2.4 - Adult males post-breeding season*

There were no significant correlations between either $\delta^{13}C$ or $\delta^{15}N$ and the variables of individual condition for adult males subsequent to the breeding seasons of 2005/06 and 2006/07 (*Appendix H*).

- *5.3.2.5 - Adult males in winter*

There were no significant correlations between either $\delta^{13}C$ or $\delta^{15}N$ and the variables of individual condition for adult males in winter 2007 (*Appendix H*).

5.3.3 - Diet of hihi at Ark in the Park

The food sources from Ark in the Park (Figure 5.12) plotted significantly differently than those from Tiritiri Matangi (Figure 5.1 and 5.2), with much lower δ^{15}N signals. Invertebrates plotted lower in δ^{15}N and δ^{13}C than the other food sources at Ark in the Park. There appeared to be a shift for both fruit and flowers to increase in δ^{15}N and decrease in δ^{13}C between April and August. See *Appendix J* for list of values for all potential food sources collected from Ark in the Park.

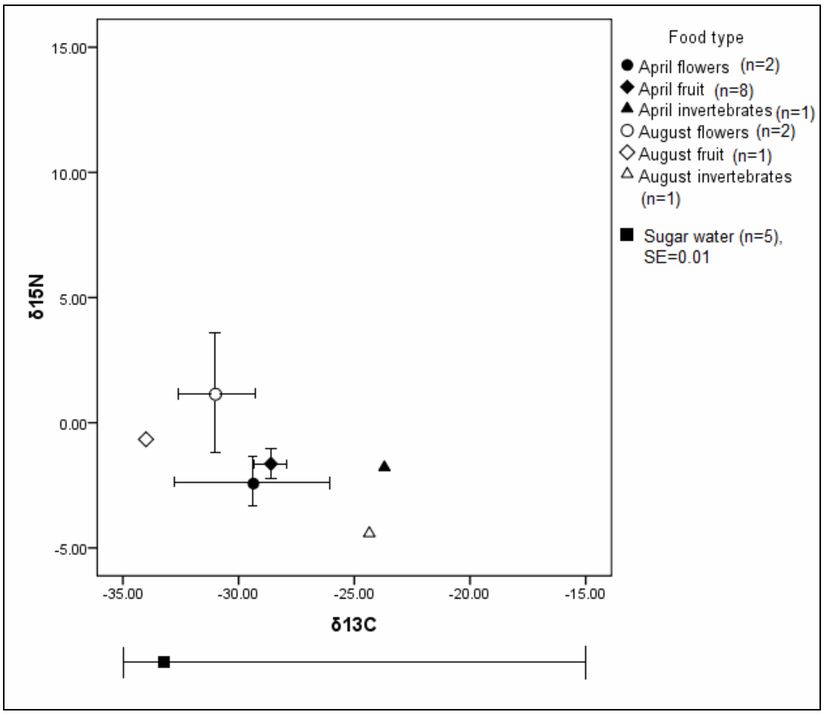

Figure 5.12. Means and standard error bars for isotopic values of potential food sources from Ark in the Park, sampled in April and August 2007. The bottom line represents value for δ^{13}C only for sugar water, as δ^{15}N was n/a for this food group.

There were no significant differences in δ^{13}C across the three sampling times for Ark in the Park (p=0.37) (Figure 5.13; *Appendix G - Table 6*). However, there was a small significant difference in δ^{15}N values (p=0.05) (*Appendix G - Table 7*), with the birds from June having higher values. The sample size for this group was very small (n=2).

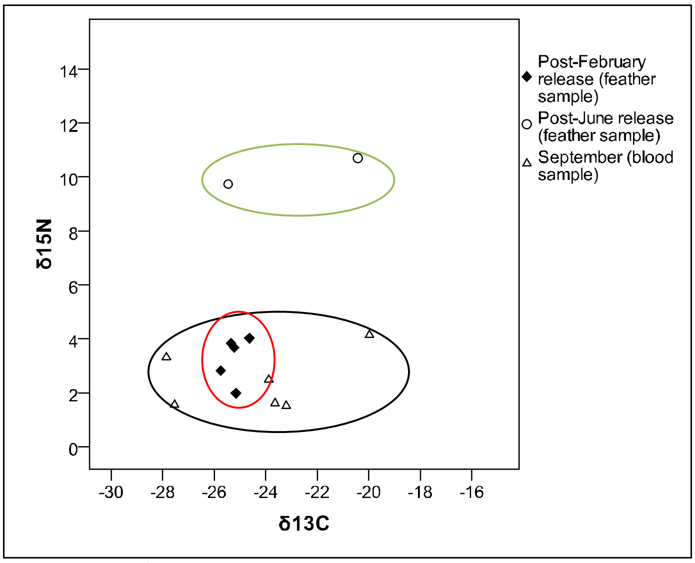

Figure 5.13. Isotopic values for hihi diet at Ark in the Park in the post-February release period (red), post-June release period (green), and September 2007 (black).

5.4 - DISCUSSION

5.4.1 - Diet on Tiritiri Matangi Island

Diet and life stages

The data show that the diet of hihi shifts across different life stages. Nestling diet was more enriched in δ^{15}N than the diet of juveniles during the post-fledging stage and their first winter. δ^{15}N is preferentially incorporated into the tissues of consumers, and so becomes systematically enriched at each trophic level (Kelly, 2000). This implies that nestlings were being fed food higher in the food chain as compared to the diet of independently foraging juveniles, supporting observations that nestlings are fed a large number of invertebrates by parents while in the nest.

February juveniles had significantly depleted δ^{13}C compared to nestlings or winter juveniles. This could be explained by higher dependence on supplementary feeders by juveniles at this stage, although this is not borne out by observations, as during February on Tiritiri Matangi Island feeders appeared to be more dominated by bellbirds (*Anthornis melanura*), and adult hihi are seen using them more frequently than juveniles (Low and Part, 2009; pers. obs.).

Juveniles were feeding differently from adult males in both February and June. In February, juvenile diet was more depleted in $\delta^{15}N$ and $\delta^{13}C$ compared to adult male diet. This suggests that adult males were feeding higher trophically than juveniles at this stage perhaps as a requirement to moult. Juveniles may have been using feeders more often at these times, although observations at feeders show that adults use the feeders more than juveniles at this time of year (pers. obs.). However, the difference in $\delta^{13}C$ may also be explained by variation in natural food consumed. Two of the most abundant fruiting species at the time, *Coprosma robusta* and mahoe (*Melicytus ramiflorus*) both had $\delta^{13}C$ values that were almost as depleted as sugar water (*Appendix I*). Juvenile hihi were frequently seen feeding on both of these species at this time (pers. obs.) and it would seem more probable that the higher $\delta^{13}C$ value can be explained by this rather than a greater use of supplementary food. Adult males, being both more experienced and more socially dominant, are probably able to feed on a wider variety of food at this time, including some less abundant species, and this could account for the difference in the isotopic values.

It is also interesting to note the difference in $\delta^{15}N$ in the February diet between early and later fledglings, although the sample size for the latter group was very small (n=3). This may reflect a change in the diet of fledglings with increasing levels of experience, or may relate to variation in social dominance by age, and hence variation in access to different food sources. More recently fledged birds had significantly higher $\delta^{15}N$. Again, based on the food source values obtained, this result was difficult to interpret. It could be due to more nectar or invertebrates in the diet of older birds – perhaps a consequence of increased foraging proficiency. Alternatively, older juveniles could have been using feeders more. As there was no difference between $\delta^{13}C$ values for early and late fledglings, this suggests the difference in $\delta^{15}N$ values was more likely to be due to variation in the proportions of natural food taken, rather than supplementary food. It could also be that more recently fledged birds have more enriched $\delta^{15}N$ values as they still have some of their enriched nestling signature incorporated in their tissues (S. Bury, NIWA, pers. comm.).

In winter, a difference between adult male diet and juvenile diet was still present. There was no significant difference between $\delta^{13}C$ values, suggesting that the gap in the variety of dietary sources obtained has closed, but there was still a significant difference between $\delta^{15}N$ values. However in contrast to February it appeared that juveniles were feeding at a higher trophic level than adult males. This implies that juveniles were either feeding on a higher proportion of invertebrates than adult males, or perhaps (given the probable reduced abundance of invertebrates in winter) there were differences in the amount of kohekohe (*Dysoxylum spectabile*) nectar taken. Kohekohe is one of the most prolific flowering species at this time of year and is heavily fed upon by hihi on Tiritiri Matangi Island.

Dietary differences between sexes at the nestling and juvenile stage

There were no differences between the sexes at either the nestling or immediate post-fledgling stage. However, by winter a significant difference between males and females was apparent, with females having a $\delta^{15}N$ value that was more enriched than males. Two possible explanations are that females were feeding on more invertebrates than males leading into the breeding season; or that males, being more dominant than females (Craig, 1985), had more access to flowering plants such as kohekohe at this time of year. This result supports the sex differences in hihi found by Angehr (1984) and Gravatt (1969), with females feeding on more invertebrates over a twelve month period. Dietary differences between the sexes can also occur in other species of birds and mammals, due to either differing requirements during the breeding season or morphological differences (Beier, 1987; Rose, 1994; Clarke *et al*. 1998).

Adult male diet

There was little change in the diet of adult males between the two seasons (the end of the 2005/06 and 2006/07 breeding seasons) suggesting that at least for these two years, food availability was similar. However there was a shift between the diet of adult males at this time of year (late summer/early autumn) and during winter. $\delta^{15}N$ values were significantly more depleted in winter, while $\delta^{13}C$ values were significantly enriched. This could suggest that supplementary feeders were used more in late summer/early autumn than in winter, or possibly that invertebrates did not form as large a part of the diet at this time of year.

5.4.2 - Diet and relationship to condition on Tiritiri Matangi Island

Carbon isotopic signatures appeared to be most strongly correlated with condition, with $\delta^{15}N$ also having some correlations at the nestling stage and over winter. It appears that condition increased as $\delta^{15}N$ increased and $\delta^{13}C$ decreased. From the food source values that were obtained, it is difficult to say what differences in diet could lead to these changes. If the food sources obtained in February accurately represent all potential food source isotope values, then it would seem that the increase in condition may be linked to an increase in nectar in the diet, but if the invertebrate samples from June are more representative, then increase in condition would be more likely attributed to more invertebrates in the diet. The lower $\delta^{13}C$ value could also be explained by an increase of sugar water in the diet.

The correlation of average growth bar width and $\delta^{15}N$ at the winter juvenile stage is difficult to explain, as these growth bars relate to the condition of the individual while in the nest. It is possible that there was some effect of early growth that caused some variation in foraging ability or dominance at a later stage. Experiments on zebra finches (*Taeniophygia guttata*) have shown that a high quality diet during the first six weeks of life results in adults which are significantly heavier than those raised with a low quality diet (Bech *et al.* 2005). Similar results were found by Ohlsson *et al.* (2002) in ring-necked pheasants (*Phasianus colchicus*). In their study, male pheasants fed a high quality diet during the first eight weeks post-hatching were not only larger but also had more colourful wattles when sexually mature. Larger birds have been found to be more dominant and achieve greater reproductive success in several species of birds

(Ankney and MacInnes, 1978; Boag and Grant, 1981; but see Davies *et al*. 1988). However, there has not been similar work carried out with hihi, and my result may be spurious, with the significance due to chance.

There appeared to be no relationship between adult male condition and diet based on the variables used. This may be partly because some of the condition variables – i.e. those obtained from feathers – did not correspond to the same time period as when the blood sample was taken (some of the adult males post-2006/07 breeding season and all adult males in winter 2007). Another explanation could be that there were factors influencing adult male condition other than diet. Condition at the end of the breeding season may be related to the amount of energy the individual has invested in reproduction – such as level of parental care, or the degree of extra-pair copulation effort a male has invested. The availability of supplementary food may also mask any effect on condition that may otherwise appear due to variations in dominance or social rank. It could also be possible that adult condition is linked to early developmental influences, as found in other studies (Ohlsson *et al*. 2002; Blount *et al*. 2003; Buchanan *et al*. 2003) that demonstrate a link between early growth and adult phenotypic quality, and this could be of interest for further research.

5.4.3 - Ark in the Park diet

It was not possible to compare the diet of hihi at Ark in the Park with Tiritiri Matangi Island as the samples for both represented diet at differing time periods.

However, the samples from Ark in the Park did span three different time periods, although the sample sizes were small (n=5, 2 and 6, from a total of 7 individuals). There was no significant difference in δ^{13}C values between the three groups, although there was some individual variation which may relate to feeder use. It should be noted that all birds sampled at Ark in the Park were caught while visiting feeders, hence there was probably a bias towards birds that incorporated a higher proportion of sugar water into the diet. This may have been because they were in poorer condition for some reason and unable to forage on sufficient natural food, because they had become more habituated to feeders on Tiritiri Matangi than other translocated individuals, or use may have been opportunistic as a feeder happened to be located in the area that became their territory.

There was a significant difference between δ^{15}N for the three groups, with the feather grown in birds subsequent to the June release having a much higher δ^{15}N value than the feather grown subsequent to the February release, or the blood sample taken in September. The sample size for the post-June release was two birds, one of which was a female who injured her leg one week after release and became a heavy feeder user thereafter. This individual was not seen again after mid-November 2007. Surprisingly, given the observed high dependency on sugar water, the δ^{13}C value for this bird in September was in fact much higher than any other individual. This may have been because the bird was in poor condition (see Chapter 2, Table 2.6), and may have begun metabolising its own tissues (Hobson *et al.* 1993; S. Bury, NIWA, pers. comm.), producing an enriched δ^{13}C value.

However, it may be that these two samples did represent a shift in diet between these time periods at Ark in the Park, as the availability of natural food in June/July was observed to be different than at other times of year (see Chapter 2). In February/March, there were a large number of plant species in heavy fruit, and this was likely the primary food source at this time. By June/July there was little that was either flowering or fruiting, with flowering rata vine (*Metrosideros fulgens*) being the only notable abundant source at this time. Invertebrates were probably less abundant at this time of year. By August/September a number of species were observed to be flowering prolifically, e.g. toropapa (*Alseuosmia macrophylla*) and tree fuchsia (*Fuchsia excorticata*). There was no indication from the δ^{15}N values of sampled food sources what may have been producing the enriched δ^{15}N values in the birds, as bird δ^{15}N values exceeded all of the sampled food source δ^{15}N values. Feeder usage was observed to increase at this time (Chapter 2), and this may explain the shift in δ^{15}N.

5.4.4 – Potential sources of error: Food sources and collection methodology

The difference between food sources at Tiritiri Matangi Island and Ark in the Park, with the Ark δ^{15}N and δ^{13}C signal considerably depleted, was probably due to the marine influence on Tiritiri Matangi Island (Hobson *et al*. 1994).

It was not possible to carry out source apportionment modelling of hihi diet due to low sample numbers of birds (at Ark in the Park), variability in bird isotopic signatures and likely missing food sources. For example, on Tiritiri Matangi

Island, some important hihi species flowering during the breeding season (October to March) were not collected due to the timing of the field work, such as pohutukawa and kowhai. The results from February differ from those in June, with invertebrates plotting much lower in $\delta^{15}N$ than would be expected. Invertebrates would be expected to plot higher trophically than fruit or nectar. This problem could be resolved by collecting a wider range of potential invertebrate sources, and analysing each species separately, rather than amalgamating the invertebrates prior to analysis. In addition, the full flower was sampled, whereas hihi only take nectar – it is not known if the isotopic value between the two would differ, and this needs to be assessed.

If it were possible to collect more robust food source data, prey polygon plots using the isotopic values of the food sources collected combined with isosource or bayesian modelling (Phillips and Gregg, 2001, 2003; Jackson *et al.* 2009) would reveal the likely percentage contributions of the different food sources to the diet of hihi at each life stage. However, it was still possible to make some statements about hihi diet on Tiritiri Matangi Island and at Ark in the Park.

In addition, the isotopic fractionation factor from diet to feather and from diet to blood is not known, but it is likely that there is a difference (Michener and Lajtha, 2007). A difference between the two may be a contributing factor to differences between groups where different tissues were sampled (e.g. between nestlings where feathers samples were used and February and June fledglings where blood samples were used).

5.4.5 - Conclusions

These results suggest that dietary shifts occur in the hihi population on Tiritiri Matangi Island across different life cycle stages, seasons, and sex. There also appeared to be shifts in diet of birds inhabiting more mature forest habitat at Ark in the Park. However, it was not possible to state with any confidence the nature of these changes, due to a lack of robust data on potential food sources.

There was a link between diet and individual condition of juvenile hihi, but not for adult males, at least for the individual condition variables used. In juveniles, diet appeared to be a major proximate factor influencing condition, but it was not clear from these results why this variation occurs. Variation in dietary input may be the mechanism underlying the differences in condition presented in Chapter 4.

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6

General Discussion

Female hihi. Photo: Isabel Castro

6.1 - Hihi translocation methodology

The results of this study provide some clear guidelines for future hihi translocations, as outlined in Chapter 2. The importance of minimising captivity periods was emphasised, while acknowledging the difficulty in finding the balance between this and keeping in place rigorous disease screening protocols. This study also supports previous evidence that so-called “soft” release strategies do not enhance post-release survival in hihi, and may in fact decrease it, and it is strongly recommended that this technique is not used again for future hihi translocations. There was no evidence to suggest any benefit to having two releases of a smaller number of birds, rather than one of a larger number, and there was evidence to suggest translocations of juvenile hihi should occur in late summer/early autumn rather than in early winter.

The role of transmitters in post-release monitoring was discussed in this study (Chapters 2 and 3). There was evidence suggesting that while carrying a transmitter did not affect the survival of individuals, there may have been some impact on behaviour, possibly limiting dispersal. Although this did not directly impact the success of the reintroduction, it is important to keep in mind that the behaviour of tagged birds may not be representative of the translocated birds as a whole. In addition, if the burden of a transmitter is sufficient to alter dispersal behaviour, there may be other less obvious impacts that would be preferable to avoid. The use of transmitters comes with both costs and benefits. Without transmitters, it would not have been possible to estimate the degree of post-release dispersal that occurred (and the distances/directions involved). However, if the transmitters themselves impacted dispersal behaviour, then the true level of dispersal that occurred in this translocation may have been underestimated. Decisions regarding the future use of transmitters on hihi should be made with care, and any improvements in technology reducing the weight of transmitters looked into.

6.2 - Future of hihi on the New Zealand mainland

The release of hihi at Ark in the Park has raised both positive and negative aspects regarding the future potential of self-sustaining hihi populations on the New Zealand mainland. It has shown that the mature habitat of the Waitakere Ranges appears in many respects to be suitable for hihi, with a wide range of natural food sources utilised, including some plant species not previously encountered at the source population. There has been no evidence that aspergillosis occurs in this habitat, which may be due to the low levels of historical disturbance in comparison to other sites such as Mokoia Island and Karori Sanctuary where aspergillosis has been or still is a problem (Alley *et al*. 1999; Empson and Booth, 2007).

The potential for a self-sustaining hihi population at Ark in the Park may be compromised by two factors: predation and dispersal. It is not yet known how much of a problem ongoing dispersal out of the protected area will be. Post-release dispersal was high (minimum 33%), but it is not known how many individuals move out of the protected area throughout the year, how far juveniles will disperse, and to what degree this will undermine the persistence of the population. In addition, the vulnerability of hihi to mammalian predators is still uncertain. There was some evidence that predation by ship rats occurred in two individuals in the post-release stage, but this could not be confirmed and may have been scavenging rather than predation. There has been no direct evidence of predation by introduced mammals during nesting to date, although one female disappeared during the incubation stage in the 2008/09 breeding season (Warneford and Gietl, 2008; Warneford, 2009). The role of avian predators and competitors – both native and introduced – may also be of significance. Moreporks are present in high numbers at Ark in the Park (Fraser and Hauber, 2008), and there are also significant numbers of introduced eastern rosellas (*Platycercus eximius*), sulphur-crested cockatoos (*Cacatua galerita*), starlings (*Sturnus vulgaris*) and Indian mynas (*Acridotheres tristis*), all of which are cavity-nesters. All except cockatoos have been observed causing disturbances at hihi nest sites (Warneford, 2009).

Hence, there is potential for a hihi population to establish at Ark in the Park, but it is probably dependent on the answers to the questions of predation and dispersal. The third top-up release had apparently higher initial survival, possibly due to the difference in translocation techniques (one sole immediate release in autumn). A subsequent top-up in 2010 is an option (Hihi Recovery Group Meeting, April 2009), and would maximise the genetic diversity of the founding population. It is important to decide where to draw the line in carrying out top-up translocations, as there is little point putting more birds in if the population is showing a continuous decline, and the causes are not reversible.

The problems encountered by the Ark in the Park hihi reintroduction are reflective of issues with mainland reintroductions in general. The vulnerability of many species to mammalian predators is often uncertain, and can in some cases be determined by a research-by-management approach such as that used with kokako (Basse *et al.* 2003). This approach has risks while population numbers remain small. Dispersal is also a challenge for species other than hihi, for example the North Island robin population at Wenderholm Regional Park where juveniles frequently disperse out of the protected area (Andrews, 2007). An understanding of the natural dispersal patterns in these species may enhance the prospects of overcoming this problem.

It may be that, for hihi, there is better potential on the mainland at a site where the protected area is not surrounded by contiguous unprotected habitat, and/or where predators have been eradicated. Such a reintroduction occurred in March 2009, to the Maungatautari Ecological Island in the Waikato, and this reintroduction may provide the best chance yet for a self-sustaining population of hihi other than that on Hauturu.

The outcome of the Ark in the Park reintroduction over the next few years will provide guidance to the Hihi Recovery Group regarding potential sites for future reintroductions. If the Ark site proves to be successful, this would open up a large range of other potential sites. If not, the list would be much shorter, as there are fewer mainland restoration projects where predators are eradicated and dispersal is limited. George Angehr, in 1985, raised the possibility of reintroducing hihi to the mainland, but suggested there would be little hope for this in the conservation climate of the time. He remained optimistic, however, stating that “perhaps some day the piercing call of the kotihe (hihi) will once again resound in its original haunts” (Angehr, 1985). With hihi reintroduced to three mainland sites to date, the future for this species is looking brighter than once thought possible.

6.3 - Post-release behaviour and influences

One important factor determining the success of a reintroduction attempt is the size of the founding population (Armstrong and Seddon, 2007). This can be affected by the behaviour of individuals in the post-release phase. This study

(Chapter 3) showed that the condition of an individual prior to release may influence how far an individual disperses, although this may have been due to the additional effect of carrying a transmitter. This finding has important implications, as it is the individuals with limited dispersal that will contribute to the founding population. A more detailed understanding of the factors influencing post-release dispersal could contribute to enhancing the success of reintroductions where post-release dispersal has the potential to undermine establishment.

6.4 - Condition of juvenile hihi

The results of Chapter 3 showed that the condition of individuals may be one of the influencing factors for post-release behaviour following reintroduction, and as such it could be of benefit to understand the causes of variation in condition in the source population, Tiritiri Matangi Island. This may also contribute to our knowledge of general hihi ecology. Chapters 4 and 5 looked at the role that social, environmental, and nutritional factors play in determining individual condition of juvenile hihi. The most significant factors appeared to be clutch size, hatching date, and diet (with diet possibly being the mechanism of variation in the former two). Before using these results, it is important to understand the relationship between individual condition and post-release survival. At present all that is implied is that juveniles from small clutches hatched early in the season are in better condition, and therefore may disperse further in the post-release stage, which is not desirable for most reintroductions.

6.5 - Hihi diet

Hihi food requirements have been frequently cited as one possible explanation for the failure of the early reintroductions, with suggestions that an inadequate diversity of natural food led to declines (Lovegrove, 1985; Castro, 1995). All successfully reintroduced populations are provided with supplementary food to varying degrees. Despite this there is a limited understanding of how hihi dietary requirements change through the different life stages, seasons, and between the sexes, and how differences in habitat may influence this. Chapter 5 attempted to address this issue for hihi on Tiritiri Matangi Island and at Ark in the Park, but was restricted by limitations in the methodology used. Despite this, it was possible to detect changes in diet across all life stages in both habitats, and between the sexes for juveniles in their first winter on Tiritiri Matangi Island. However, what dietary differences these represent could only be speculated on without further research.

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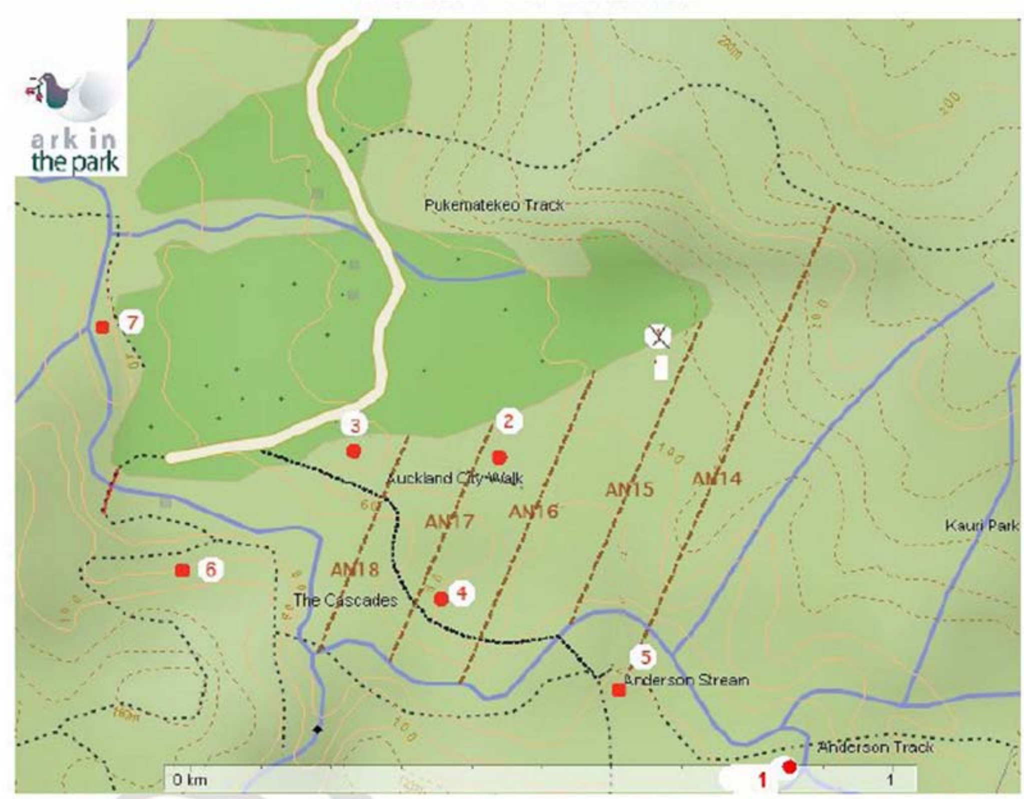
Appendix A. Map showing baitlines and blocks at Ark in the Park.

Appendix B. Supplementary feeder stations at Ark in the Park.



Note: Feeder 1 was originally located NE of Feeder 2, but was moved to a new location off the Anderson track in May 2007. Feeder 3 is also the location of the aviary where delayed-release birds were held, and is close to the site of release of the immediate-release birds.

Appendix C. Pathology report for SM-OG, died 30 March 2007.

Institute of Veterinary, Animal and Biomedical Sciences

PATHOLOGY REPORT

Submitter's Date 02/04/2007 Accession
40002

TO: Isabel Castro
Institute of Natural Resources
Massey University

Species: Avian-WL Hihi (Stitchbird)	Sex: Male	Age: Subadult	Breed:
ID: SM/OG	At Risk:	Affected:	Dead:
Owner: DoC, Waitakere Ranges		Prev. Accn.:	Type: Post Mortem

HISTORY
One of 30 hihi translocated from Tiritiri matangi to the Waitakere ranges 6 weels ago as part of " Ark in the Park". Found dead on Friday and couriered chilled over the weekend. Wasps were attacking the carcass and had eaten 2mm cube of pectoral muscle.

GROSS FINDINGS
Weight = 37.5gms . Body condition score 7/9 with good reserves of subcutaneous fat. Both lungs were slightly congested with small blotchy areas of haemorrhage in the cranial part of the right lung.

All the internal organs were pale particularly the liver. The ventral surface of the liver had a pale white streaky discoloration on its surface. The spleen was slightly elongated. The gizzard and proventriculus were empty. The intestines contained a moderately large amount of semi fluid contents. The feathers were missing from the head. An 8mm maggot was present in the left ear.

PROVISIONAL DIAGNOSIS
Wasp attack

File Nos.:

Students:

Date: Pathologist M R Alley

Copy

Appendix D. Pathology report for M-WO, died 18 June 2007.

Institute of Veterinary, Animal and Biomedical Sciences

PATHOLOGY REPORT

Submitter's Date 22/06/2007 Accession
40277

TO: Sandra Jack
Ark In The Park
PO Box 108055
Auckland

Species: Avian-WL (1) Sex: Male Age: 1.5 Yrs Breed:
Hihi (Stitchbird)

ID: Leg band L: White/Orange; At Risk: Affected: Dead:

Owner: DoC, Auckland Prev. Accn.: Type:
Post Mortem

HISTORY
Found on 18/6/07 in temporary aviary at Cascade Kauri Park, northern Waitakere ranges. Yesterday when I went to release the birds placed in the aviary at the park I found one dead adult male. He had managed to wedge himself in some of the foliage which had been placed in the aviary. 12 other birds were released that had been held for soft release

GROSS FINDINGS
Weight 43gm, Body condition score 7/9. Excellent subcutaneous and abdominal fat reserves were present. There was a recent haemorhage on the left caudodorsal aspect of the skull covering a 10mm area. No abrasions were seen on the skin. No other gross abnormalities were observed.

PROVISIONAL DIAGNOSIS
Trauma - head

File Nos.:

Students:

Date: Pathologist: A G Hill / M R Alley

Copy

Appendix E. Pathology report for M-SS, died 30 June 2007.

Institute of Veterinary, Animal and Biomedical Sciences

PATHOLOGY REPORT

Submitter's Date Sent: 09/07/2007 Accession No.:
40310

TO: Kate Richardson
Ark In The Park
96 Bethells Road, RD1
Waitakere
Auckland

Species: Avian-WL (1) Sex: Female Age: Juvenile Breed:
Hihi (Stitchbird)

ID: M/SS Metal band C79322 At Risk: Affected: 1 Dead:
1

Owner: Prev. Accn.: Type:
Post Mortem

HISTORY
Died 30 June/1 July 2007. Remains retrieved from epiphytes 10-15m up a large rimu on 7/7/07. Kept in fridge until morning of 9/7/07. Transmitter included, was found 10-15cm from the body. No signs of a predator were noted. This bird had lost 3-5 grams in the aviary prior to release

GROSS FINDINGS
There was very little soft tissue present on the carcass, and most of the skin was absent. The cranium was missing, as was the brain and eyes. There was no evidence of a submandibular oral fistula. There were no internal organis remaining, and the majority of the musculature had been removed. There were chew marks present on the keel. Most of the ribs were missing, as were both femurs. The synsacrum had no evidence of injury, and was disarticulated from the carcass. There were no palpable long bone fractures. The transmitter was separate from the carcass, and was attached to a small piece of skin. There were no abnormalities on the feet.

DIAGNOSIS
Rat predation/scavenging

COMMENTS
Unfortunately, we are unable to perform any histopathology as there is no remaining soft tissue on the carcass. The chew marks on the keel are consistent with those caused by a rat, but there is no way to tell whether these are caused by predation or as a result of scavenging after death.

File Nos.:

Students:

Date: Pathologist: K J Morgan

Copy to:

Appendix F. Results of Kolmogorov-Smirnov test and Chi-square test for normality of distribution of condition variables.

Table 1. Kolmogorov-Smirnov test for continuous variables

	N	**D**	**P**
Weight:tarsus at 12 days	21	0.15	0.75
Weight:tarsus at 21 days	39	0.08	0.95
Weight:tarsus at capture	39	0.1	0.83
Weight change in aviary	39	0.16	0.28
Feather weight/feather length	39	0.11	0.77
Average growth bar width	33	0.22	0.09

Table 2. Chi-square test for discrete variables, df=degrees of freedom.

	Classes	**Chi-square**	**df**	**P**
Body condition scores	6	1.66	3	0.65
Total fault bars	8	16.1	5	**0.007**

Appendix G. Results of statistical tests from Chapter 5.

Table 1. Results of ANOVA to test for differences between groups 1 (nestlings, feather sample), 2 (post-fledgling period, blood sample) and 3 (winter juveniles, blood sample), $\delta^{15}N$ on Tiritiri Matangi Island.

	F	**P**		
	47.70	$1.99458E^{-15}$		
	(Mean)	**2**	**3**	**1**
2	7.67	----	0.59	0.52
3	8.25	no	----	0.48
1	9.94	yes	yes	----

Table 2. Results of Kruskal Wallis test for differences between groups 1 (nestlings, feather sample), 2 (post-fledgling period, blood sample) and 3 (winter juveniles, blood sample), $\delta^{13}C$ on Tiritiri Matangi Island. df=degrees of freedom.

H	**df**	**P**
52.05	2	$4.99E^{-12}$

Table 3. Results of t-test ($\delta^{15}N$) and Mann-Whitney U test ($\delta^{13}C$) for difference in isotopic values between the sexes at each life stage.

	group	**p**
$\delta^{15}N$	1 – nestlings	0.15
	2 – post-fledgling	0.5
	3 – winter juveniles	**0.03**
$\delta^{13}C$	1 – nestlings	0.09
	2 – post-fledgling	0.32
	3 – winter juveniles	0.28

Table 4. Results of ANOVA testing for differences between $\delta^{15}N$ values for adult male hihi during 4) post-2005/06 breeding season (feather sample), 5) post-2006/07 breeding season (feather and blood sample), and 6) winter 2007 (blood sample).

F	**P**
20.68	$1.39E^{-07}$

	(Mean)	**6**	**5**	**4**
6	7.04	----	0.61	0.97
5	8.85	yes	----	0.92
4	9.23	yes	no	----

Table 5. Results of ANOVA testing for differences between d13C/12C values for adult male hihi during 4) post-2005/06 breeding season, 5) post-2006/07 breeding season, and 6) winter 2007.

F	**P**
69.98	$1.61E^{-16}$

	(Mean)	**5**	**4**	**6**
5	-24.57	----	0.81	0.53
4	-23.61	yes	----	0.85
6	-21.42	yes	yes	----

Table 6. Results of Kruskal Wallis test for differences between $\delta^{13}C$ in hihi diet post-February release (feather sample), post-June release (feather sample) and September 2007 (blood sample) at Ark in the Park. df=degrees of freedom.

H	**df**	**P**
2.02	2	0.37

Table 7. Results of Kruskal Wallis test for differences between $\delta^{15}N$ in hihi diet post-February release (feather sample), post-June release (feather sample) and September 2007 (blood sample) at Ark in the Park. df=degrees of freedom.

H	**df**	**P**
5.92	2	**0.05**

Appendix H. Results of Pearson and Spearman Rank Correlations for relationship between δN and δC in diet of hihi at different life stages and variables of condition.

Results of Pearson Correlation for relationship between $\delta^{15}N$ values for nestlings and condition.

weight:tarsus at 21 days	
Correlation coefficient	0.42
valid cases	56
one-sided significance	**0.0007**
feather weight/feather length	
Correlation coefficient	0.14
valid cases	56
one-sided significance	0.16
average growth bar width	
Correlation coefficient	-0.18
valid cases	43
one-sided significance	0.13
total fault bars	
Correlation coefficient	-0.06
valid cases	56
one-sided significance	0.32
age of mother	
Correlation coefficient	-0.14
valid cases	56
one-sided significance	0.15
early or late	
Correlation coefficient	0.06
valid cases	56
one-sided significance	0.32

Results of Spearman Rank Correlation for relationship between $\delta^{13}C$ values for nestlings and condition.

weight:tarsus at 21 days	
Correlation coefficient	-0.26
valid cases	56
one-sided significance	**0.02**
feather weight/feather length	
Correlation coefficient	-0.22
valid cases	56
one-sided significance	**0.05**
average growth bar width	
Correlation coefficient	-0.20
valid cases	43
one-sided significance	0.095
total fault bars	
Correlation coefficient	0.35
valid cases	56
one-sided significance	**0.004**
age of mother	
Correlation coefficient	0.15
valid cases	56
one-sided significance	0.13
early or late	
Correlation coefficient	-0.09
valid cases	56
one-sided significance	0.26

Results of Pearson correlation for relationship between $\delta^{15}N$ in diet of juveniles in February and condition.

weight:tarsus at capture	
Correlation coefficient	-0.04
valid cases	23
one-sided significance	0.44
feather weight/feather length	
Correlation coefficient	0.12
valid cases	23
one-sided significance	0.3
average growth bar width	
Correlation coefficient	0.04
valid cases	18
one-sided significance	0.43
total fault bars	
Correlation coefficient	0.17
valid cases	23
one-sided significance	0.22
age of mother	
Correlation coefficient	0.16
valid cases	23
one-sided significance	0.23
early or late	
Correlation coefficient	0.57
valid cases	23
one-sided significance	**0.002**

Results of Spearman Rank Correlation for relationship between $\delta^{13}C$ in diet of juveniles in February and condition.

weight:tarsus at capture	
Correlation coefficient	-0.53
valid cases	23
one-sided significance	**0.004**
feather weight/feather length	
Correlation coefficient	-0.44
valid cases	23
one-sided significance	**0.02**
average growth bar width	
Correlation coefficient	-0.08
valid cases	18
one-sided significance	0.37

total fault bars	
Correlation coefficient	0.33
valid cases	23
one-sided significance	0.06
age of mother	
Correlation coefficient	-0.23
valid cases	23
one-sided significance	0.14
early or late	
Correlation coefficient	0.27
valid cases	23
one-sided significance	0.10

Results of Pearson Correlation for relationship between $\delta^{15}N$ in diet of juveniles over winter and condition.

weight:tarsus at capture	
Correlation coefficient	-0.51
valid cases	27
one-sided significance	**0.003**
feather weight/feather length	
Correlation coefficient	-0.26
valid cases	28
one-sided significance	0.09
average growth bar width	
Correlation coefficient	-0.40
valid cases	20
one-sided significance	**0.04**
total fault bars	
Correlation coefficient	-0.16
valid cases	28
one-sided significance	0.21
age of mother	
Correlation coefficient	-0.11
valid cases	28
one-sided significance	0.29
early or late	
Correlation coefficient	-0.07
valid cases	28
one-sided significance	0.36

Results of Spearman Rank Correlation for relationship between $\delta^{13}C$ in diet of juveniles and condition.

weight:tarsus at capture	
Correlation coefficient	0.27
valid cases	27
one-sided significance	0.09
feather weight/feather length	
Correlation coefficient	0.40
valid cases	28
one-sided significance	**0.02**
average growth bar width	
Correlation coefficient	0.15
valid cases	20
one-sided significance	0.26
total fault bars	
Correlation coefficient	0.05
valid cases	28
one-sided significance	0.4
age of mother	
Correlation coefficient	0.11
valid cases	28
one-sided significance	0.29
early or late	
Correlation coefficient	0.04
valid cases	28
one-sided significance	0.43

Results of Pearson Correlation for relationship between $\delta^{15}N$ in diet of adult males following the 2005/06 and 2006/07 breeding seasons and condition.

age of male	
Correlation coefficient	-0.076
valid cases	42
one-sided significance	0.32
weight:tarsus at capture	
Correlation coefficient	0.1
valid cases	42
one-sided significance	0.26
feather weight/feather length	
Correlation coefficient	-0.24
valid cases	36
one-sided significance	0.08
average growth bar width	
Correlation coefficient	-0.25
valid cases	32
one-sided significance	0.09
total fault bars	
Correlation coefficient	-0.23
valid cases	36
one-sided significance	0.09

Results of Pearson Correlation for relationship between $\delta^{13}C$ in diet of adult males over winter and condition.

age of male	
Correlation coefficient	-0.04
valid cases	42
one-sided significance	0.4
weight:tarsus at capture	
Correlation coefficient	0.09
valid cases	42
one-sided significance	0.29
feather weight/feather length	

Correlation coefficient	-0.07
valid cases	36
one-sided significance	0.34
average growth bar width	
Correlation coefficient	0.02
valid cases	32
one-sided significance	0.46
total fault bars	
Correlation coefficient	0.004
valid cases	36
one-sided significance	0.49

Results of Pearson Correlation for relationship between δ^{15}N in diet of adult males in winter and condition.

age	
Correlation coefficient	-0.08
valid cases	22
one-sided significance	0.36
weight:tarsus at capture	
Correlation coefficient	-0.30
valid cases	22
one-sided significance	0.09
feather weight/feather length	
Correlation coefficient	-0.21
valid cases	21
one-sided significance	0.18
average growth bar width	
Correlation coefficient	0.04
valid cases	19
one-sided significance	0.44

total fault bars	
Correlation coefficient	-0.1
valid cases	21
one-sided significance	0.34

Results of Pearson Correlation for relationship between δ^{13}C in diet of adult males in winter and condition.

age of male	
Correlation coefficient	-0.04
valid cases	22
one-sided significance	0.44
weight:tarsus at capture	
Correlation coefficient	0.3
valid cases	22
one-sided significance	0.09
feather weight/feather length	
Correlation coefficient	0.21
valid cases	21
one-sided significance	0.18
average growth bar width	
Correlation coefficient	-0.19
valid cases	19
one-sided significance	0.22
total fault bars	
Correlation coefficient	-0.17
valid cases	21
one-sided significance	0.23

Appendix I. δN and δC values for potential food sources collected from Tiritiri Matangi Island.

Month collected (2007)	**Food type**	**Species**	**Ripe/unripe**	**δN**	**δC**
February	Fruit	Mapou (*Myrsine australis*)	ripe	2.41	-23.98
February	Fruit	Five finger (*Pseudopanax arboreus)*	ripe	4.89	-29.50
February	Fruit	Five finger (*Pseudopanax arboreus)*	ripe	4.87	-24.68
February	Fruit	*Coprosma robusta*	ripe	1.75	-32.20
February	Fruit	*Coprosma robusta*	ripe	2.46	-30.66
February	Fruit	Mapou (*Myrsine australis*)	unripe	0.60	-25.28
February	Fruit	Mapou (*Myrsine australis*)	unripe	1.09	-25.01
February	Fruit	*Coprosma robusta*	unripe	2.15	-29.32
February	Fruit	*Coprosma robusta*	unripe	2.34	-28.74
February	Fruit	Cabbage tree (*Cordyline australis*)	unripe	2.95	-25.54
February	Fruit	Mahoe *(Melictyus ramiflorus*)	ripe	2.37	-28.19
February	Fruit	Mahoe *(Melictyus ramiflorus*)	unripe	1.58	-26.90
February	Fruit	Puriri (*Vitex lucens*)	ripe	3.99	-28.22
February	Fruit	Wharangi (*Melicope ternata*)	ripe	6.77	-28.04
February	Fruit	Cabbage tree (*Cordyline australis*)	ripe	3.69	-26.00
February	Fruit	Wharangi (*Melicope ternata*)	unripe	8.70	-30.32
February	Fruit	Hangehange (*Geniostoma rupestre*)	ripe	4.64	-27.35
June	Fruit	Mahoe (*Melictyus ramiflorus*)	unripe	-0.36	-31.25
June	Fruit	Mahoe (*Melictyus ramiflorus*)	ripe	2.20	-32.59
June	Fruit	Five finger (*Pseudopanax arboreus*)	ripe	0.40	-26.86
February	Flower	Hebe (*Hebe* spp.)		3.75	-26.43
February	Flower	Hebe (*Hebe* spp.)		3.67	-27.22
February	Flower	Puriri (*Vitex lucens*)		5.17	-27.29
February	Flower	Mahoe (*Melictyus ramiflorus*)		8.34	-21.33
February	Flower	Manuka (*Leptospermum scoparium*)		5.32	-24.97
June	Flower	Manuka (*Leptospermum scoparium*)		5.48	-25.99
June	Flower	Kohekohe (*Dysoxylum spectabile*)		3.37	-25.38
June	Flower	*Rhabdothamnus solandri*		6.14	-31.28
June	Flower	Kohekohe (*Dysoxylum spectabile*)		4.50	-30.34
June	Flower	Puriri (*Vitex lucens*)		5.16	-27.65
June	Flower	Wattle (*Albizia lophantha*)		-1.59	-27.03
February	Invertebrate			1.70	-25.69
June	Invertebrate			9.52	-26.95
	Raw sugar			n.d.	-32.90
	Raw sugar			n.d.	-32.95
	Raw sugar			n.d.	-32.90
	Raw sugar			n.d.	-32.97
	Raw sugar			n.d.	-32.93

n.d. = no data

Appendix J. δN and δC values for potential food sources collected from Ark in the Park.

Month collected (2007)	**Food type**	**Species**	**Ripe/unripe**	**δN**	**δC**
April	Fruit	Kahikatea (*Dacrycarpus dacrydioides*)	ripe	0.83	-27.33
April	Fruit	Hangehange (*Geniostoma rupestre*)	ripe	-1.49	-29.35
April	Fruit	*Coprosma robusta*	ripe	-2.04	-30.50
April	Fruit	Mingimingi (*Cyathodes juniperina*)	ripe	-0.26	-26.73
April	Fruit	Mingimingi (*Cyathodes juniperina*)	ripe	0.03	
April	Fruit	Pate (*Schefflera digitata*)	ripe	-3.62	-30.32
April	Fruit	Putaputaweta (*Carpodetus serratus*)	ripe	-4.91	-28.74
April	Fruit	Mapou (*Myrsine australis*)	ripe	-1.79	-26.39
April	Fruit	Mapou (*Myrsine australis*)	ripe	-0.88	
April	Fruit	*Melicytus macrophyllus*	ripe	0.14	-29.43
August	Fruit	*Coprosma arborea*	ripe	-0.66	-34.00
April	Flower	Lacebark (*Hoheria populnea*)		-1.49	-32.21
August	Flower	Rata vine (*Meterosideros fulgens)*		-3.36	-26.51
August	Flower	Tree fuchsia (*Fuchsia excorticata*)		4.26	-28.60
August	Flower	Toropapa (*Alseuosmia macrophylla*)		-1.99	-33.39
April	Invertebrate			-1.78	-23.70
August	Invertebrate			-4.42	-24.35