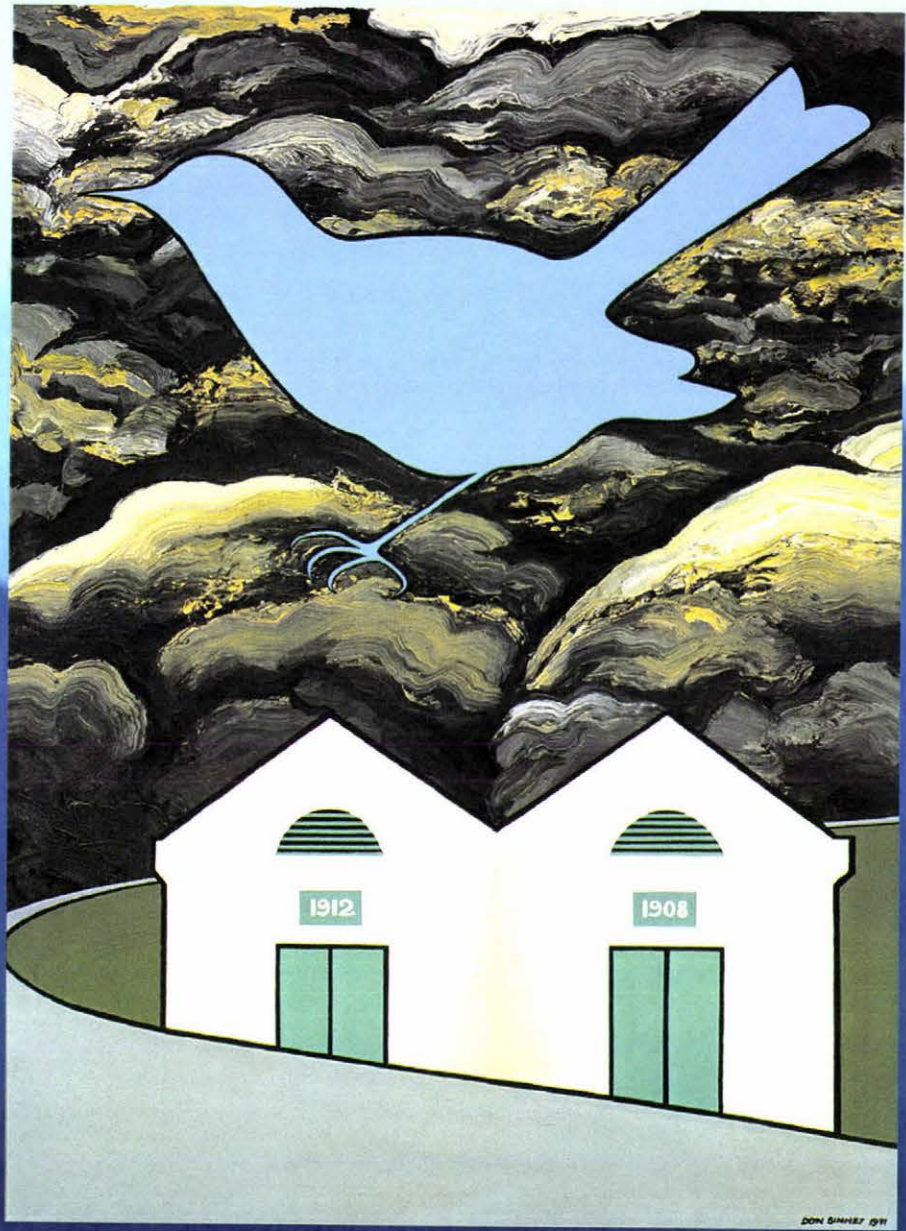
The Stitchbird (Hihi – *Notiomystis cincta*) and its Habitat: Effects on Nesting Behaviour and Reproductive Success



Vanishing Wellington Stitchbird: Don Binney 1971

A thesis presented in partial fulfilment of the requirements
for the degree of Masters of Science in Conservation
Biology at Massey University,
Palmerston North, New Zealand

Troy Dahya Makan
2006

Abstract

This thesis grew out of a basic problem in the management of a "Nationally Endangered" New Zealand bird species, the stitchbird. Following European colonisation of New Zealand it is hypothesized that predation and severe habitat loss along with disease, extirpated stitchbird from the North Island and reduced the distribution to a single population on Little Barrier Island. Efforts to recover the stitchbird have involved many translocations to other islands. Three of these translocations failed and the remaining three populations only persist due to intensive management by the Department of Conservation, mainly through supplementary feeding and provision of nesting boxes, as a way of artificially enhancing the island habitats.

The primary aim of this study was to determine the effect of habitat on stitchbird nesting behaviour and reproductive success. To investigate this, I conducted research that aimed to relate stitchbird parental provisioning, reproductive success and habitat on Little Barrier Island, the single self-sustaining population of stitchbird from where little information was previously available. I then examined these results with similar data from three other stitchbird populations (Kapiti, Tiritiri Matangi and Mokoia Islands) to assess the effects of management enhanced and unmanaged habitats on stitchbird. An in-depth analysis of habitat structure was then conducted in two of the populations (Little Barrier and Kapiti Islands). These data were then analysed with respect to the reproductive success of these populations (with Kapiti's reproductive success being taken during the period when there was little management).

When all islands are considered, conservation management, through the provisioning of nest boxes and feeders led to a significant increase in fledging success. This habitat management did not affect paternal behaviour. Although maternal investment was highly variable between individuals, females showed increased visitation rates when their habitat was enhanced through conservation management. In the unmanaged populations habitat complexity and nest tree size were found to be very important to the reproductive success of the stitchbird.

Regardless of management and location, habitat quality played an integral part in determining the pattern of parental investment, and significantly affected reproductive success. In the unmanaged populations habitat complexity may provide a proximate assessment of overall habitat quality, while nest tree size may influence the internal microclimate of the nesting cavities. It appears that in lower quality habitats, parent's trade off their own survival against current and future reproduction. Conservation managers have managed to offset the restrictions of low quality habitat by enhancing habitats to a higher quality than natural environments. Now there is a need to find new sites where self-sustaining populations can be established, without the aid of expensive conservation management. I have found that it may be important to consider not only the phenology of the habitat, but also its complexity and the availability of large potential nest trees when considering new translocation sites.

Acknowledgments

This project has been a work in progress for almost my entire life. It started with my parents instilling in me an interest in nature, the environment and the outdoors. Followed by my Uncle and Aunt who got me involved in every possible ecological project under the sun and of course Isabel Castro whom I started volunteering for from the age of twelve. This early introduction to ecology, science, stitchbirds and many other things set me on the path to completing a Masters at Massey University from an unusually young age.

I gratefully acknowledge Isabel Castro (my principal supervisor) for her friendship and all the help, inspirational ideas, months of editing and for allowing me to use her unpublished data in my thesis. Without Isabel's support, direction and patience this project may never have got off the ground and it definitely wouldn't have evolved into this finished product. I also thank Alastair Robertson (my co-supervisor) for all the advice and support throughout the duration of this project.

I would like to thank my entire family, especially my parents, for all the support throughout this project, University and the rest of my life. I was always a bit of a weird child, with plenty of wacky ideas, yet you guys were always there for me.

There are a great number of people who assisted me throughout this project. It is fair to say this thesis would have not been possible without their help. In no particular order I wish to thank: Mark Fraser, my field assistant who put up all the well humoured crap I could give him for an entire summer; Matt Low for all the brilliant ideas, comments, advice and for allowing me to use his unpublished data in my thesis; Ian Johnston, Cleland Wallace, Claire Brown, Stefanie K, Rowena Teal, Kevin Parker, Rose Thorogood, John Ewen, Rebecca Boulton, Isabel Castro, Alastair Robertson, Richard Griffiths, Rosalie Stamp, Matt Low, Asa Berggren and Phil Cassey for all their help in the Field; Ian Atkinson and John Campbell for their ideas about my vegetation sampling methods; Alasdair Noble, Mike Joy, Yvan Richard and Phil Cassey for there invaluable statistical advice; Mark Orams for transport to Little Barrier island; The Little Barrier Weeders - Cleo Rothschild, Jono Walter and James Andrews along with everyone else who made for an entertaining life in the Little

Barrier Island Bunkhouse; Don Binney for allowing me to use his artwork on all my cover pages.

This thesis could not have been completed without the support of the New Zealand Department of Conservation. I would especially like to thank Richard Griffiths, Rosalie Stamp, Eric Dorfman, Lynn Adams and all the members of The Hihi Recovery Group. My fieldwork on both Kapiti and Little Barrier Islands would not have been possible without all the logistical support provided by the island rangers - Pete and the Barrow family, Dave and the Wrightson family, Hugh Gardiner, Greg Moorcroft and Erica Cammack.

I also want to thank Massey University Ecology group. The other graduate students in the department that read bits and pieces of my work and provided plenty of entertainment throughout my thesis, especially Susan Cunningham who made comments on my drafts and taught me the horses trick (replace data with horses, it works every time). Barbara Just and Erica Reid for all the administrative and technical support, projects like mine just don't get done without the help of people like you.

This project was funded with support from the New Zealand Parks and Conservation Foundation, the Hihi Recovery Group, the Department of Conservation Wellington and the Royal Forest and Bird Society.

Contents

Page

CHAPTER 1: GENERAL INTRODUCTION

Page

CHAPTER 2: VARIATION IN NESTLING PROVISIONING AND REPRODUCTIVE SUCCESS OF THE STITCHBIRD (HIHI – *NOTIOMYSTIS CINCTA*): A COMPARISON BETWEEN MANAGED AND UNMANAGED HABITATS

Page

CHAPTER 3: THE EFFECT OF HABITAT QUALITY AND STRUCTURE ON THE REPRODUCTIVE SUCCESS OF THE STITCHBIRD (HIHI - *NOTIOMYSTIS CINCTA*): A POPULATION COMPARISON

Page

CHAPTER 4: GENERAL DISCUSSION AND RECOMMENDATIONS

Page

List of Figures

List of Tables

General Introduction

Hauturu Rata: Don Binney 1979

1

General Introduction

1.1 Population Declines

When studying population declines, it is important to distinguish between the external factors that influence populations' demographics and the intrinsic demographic factors that trigger the decline (Caughley 1994; Newton 1998). A limiting factor is one which prevents a population from increasing or causes it to decline. External or environmental limiting factors include lack of resources, natural enemies, competing species and climate. Human activities often trigger external limiting factors with destruction and encroachment of habitat and the introduction of exotic species being major threats to populations. Populations can be affected by more than one, and in some cases all of these different factors, but generally only one factor emerges as the most important at any one time (Newton 1998).

In attempts to manage bird populations the environmental limiting factors should be identified and managed before the decline at population level can be halted, and the necessary demographic changes should then follow naturally. However, gaining information on the demographics of a population can often help to single out the external factors causing the decline (Green 1995; Newton 2004).

There have been ample examples of population declines throughout history. Some classic examples include the great auk (*Pinguinus impennis*) and the passenger pigeon (*Ectopistes migratorius*) which became extinct in the early 19th and 20th centuries respectively. These extinctions occurred mainly through a synergistic interaction between large colony size, which allowed heavy human predation, and a low reproductive rate (Halliday 1980; Bengtson 1984; Bucher 1992). In the case of the passenger pigeon the loss of breeding habitat also accelerated this decline (Halliday 1980; Bucher 1992). New Zealand has also experienced some dramatic population declines with the most famous being the story of the Chatham Island black robin (*Petroica traversi*). This species became the world's most endangered species, with a single population of only 5 individuals, due to a combination of predation and habitat destruction. Heavy conservation management and translocation has now led to the recovery of this species (Butler & Merton 1992).

1.2 Habitat Limitation and Population Declines

Human destruction and degradation of habitat worldwide has lead to the extinction of many species (Wilson 1988). Habitat loss can lead to individuals competing for small patches of remaining habitat, ultimately limiting bird population size and numbers. Habitat choice develops when individuals distinguish and prefer good habitat, and beyond a certain level of occupation deter settlement by further individuals. Those individuals are then forced to move into lower quality or less preferred habitat. As population densities increase, an increasing proportion of individuals may be pushed down the habitat gradient, where their survival or breeding success is reduced (Pulliam & Danielson 1991; Newton 1998; Misenhelter & Rotenberry 2000; Luck 2002).

The quality or amount of resources provided by a habitat can vary markedly. This variation in resource availability can be produced by the different spatial configuration, productivity and diversity of vegetation (Smith & Shugart 1987; Halaj *et al.* 2000). Many studies have shown a positive association between habitat quality and reproductive success (Ens *et al.* 1992; Dias *et al.* 1994; Dias 1996). Vegetation structure, for instance, provides birds with various opportunities and constraints influencing the detection and acquisition of invertebrate prey (Robinson & Holmes 1982). However, structural habitat characteristics are not always the best predictors of reproductive success and researchers may need to consider other factors such as competition and predation (Hatchwell *et al.* 1996; Aho *et al.* 1999).

The Seychelles warbler (*Acrocephalus sechellensis*) is a species that is thought to have declined due to habitat limitation. Its population was reduced to approximately 30 individuals, confined to one tiny patch (c. 1 hectare) of mangroves on a single small island, due to sever habitat destruction. This species has now been recovered, with the population reaching over 300 birds, due to conservation management through translocation and habitat restoration (Komdeur & Pels 2005).

1.3 The New Zealand Situation

In New Zealand there has been a substantial decline in range and abundance of many of our native species (Atkinson & Cameron 1993; Craig *et al.* 2000; Armstrong *et al.* 2002). The changes brought on the New Zealand environment through the impact of human settlement, have lead to the factors which have caused the total extinction of over fifty bird species and the severe reduction in population size and range of many other species, including the extirpation of several species from mainland New Zealand (Daugherty *et al.* 1990; Gill 1991; Armstrong *et al.* 2002). The extinction and decline of populations can be largely attributed to the destruction and alteration of habitat, the introduction of exotic mammalian predators, and avian diseases (Gill 1991).

In addition to this the intensity of plant fruiting and flowering varies greatly from year to year, with many New Zealand plants adopting a masting strategy (Webb & Kelly 1993). This phenomenon has been shown to affect the regularity and intensity of breeding for many New Zealand bird species including the kakapo (*Strigops habroptilus*; Powlesland *et al.* 1992) and the North Island kaka (*Nestor meridionalis septentrionalis*; Moorhouse 1997). This may have a synergistic interaction adding to the above causes of extinction and decline.

Along with the mainland, many of New Zealand's offshore islands have also been severely impacted. Many of these islands were historical strongholds for Maori and were also utilized by European colonists which lead to the clearance of vegetation and introduction of exotic mammals on most islands (Hayward 1984). Although the habitat of these islands have been altered by human colonisation, many of them escaped the invasion of the most damaging exotics, such as ship rats (*Rattus rattus*) and mustelids (*Mustela erminea*, *M. furo* and *M. nivalis*), and recent restoration through re-vegetation and the removal of mammalian predators has provided refuges for many native species (Veitch & Bell 1990; Armstrong *et al.* 2002). These refuge populations have now provided the founder individuals for the establishment, through reintroduction, of new populations on recently restored islands and the mainland. For example stitchbird and saddleback (*Philesturnus carunculatus*), from Tiritiri Matangi and Mokoia Islands, to Karori Sanctuary (Raewyn Empson pers. comm.) and little spotted kiwi (*Apteryx owenii*), from Kapiti Island, to Long Island (Jolly & Colbourne 1991).

1.4 Stitchbird Recovery

One of the species to benefit from island refuges, restoration and reintroduction is the Stitchbird or Hihi (*Notiomystis cincta*). Following European colonisation of New Zealand, predation and severe habitat loss along with disease probably extirpated stitchbird from the mainland of the North Island and reduced the distribution to a single population on Little Barrier Island (Hauturu; 3083 ha; 36° 19' S, 175° 11' E; Figure 1.1) in the Hauraki Gulf, where they persist to the present day (Taylor *et al.* 2005). Efforts to recover the stitchbird have involved many translocations to other islands including Hen (718 ha; 35° 95' S, 174° 71' E; Figure 1.1; Angehr 1984b), Cuvier (181 ha; 36° 43' S, 175° 73' E; Figure 1.1; Angehr 1984b), Mokoia (135 ha; 36° 06' S, 175° 55' E; Figure 1.1; Armstrong *et al.* 1999), Kapiti (1965 ha; 40° 85' S, 174° 87' E; Figure 1.1; Lovegrove 1986; Castro *et al.* 1994a) and Tiritiri Matangi (220 ha; 36° 60' S, 174° 90' E; Figure 1.1; Ewen 1998) and more recently to Karori Wildlife Sanctuary (a 250ha predator fenced area on the Mainland of New Zealand; 41° 18' S, 174° 45' E; Figure 1.1; Raewyn Empson pers. comm.).

The first three of these translocations were unsuccessful, with the populations declining to extinction after release (Taylor *et al.* 2005). The first explicit hypothesis to explain the failure of these translocations was that there was an inadequate year-round supply of carbohydrate food (nectar and fruit) due to human impacts on the forest habitat (Angehr 1984a; Lovegrove 1986; Rasch 1991). More recently, an alternative view has been developed that suggests that the lack of resources at certain times of the year, works in conjunction with competition from other more dominant nectar feeding species (Craig 1984; Rasch 1985a; Rasch & Craig 1988; Perrott 1997; Wilson 1997). On Mokoia Island a high mortality rate due to the increased levels of an airborne fungus, *Aspergillus fumigatus,* and the lack of resources were attributed to the population decline (Alley *et al.* 1999; Cork *et al.* 1999; Perrott 2001).

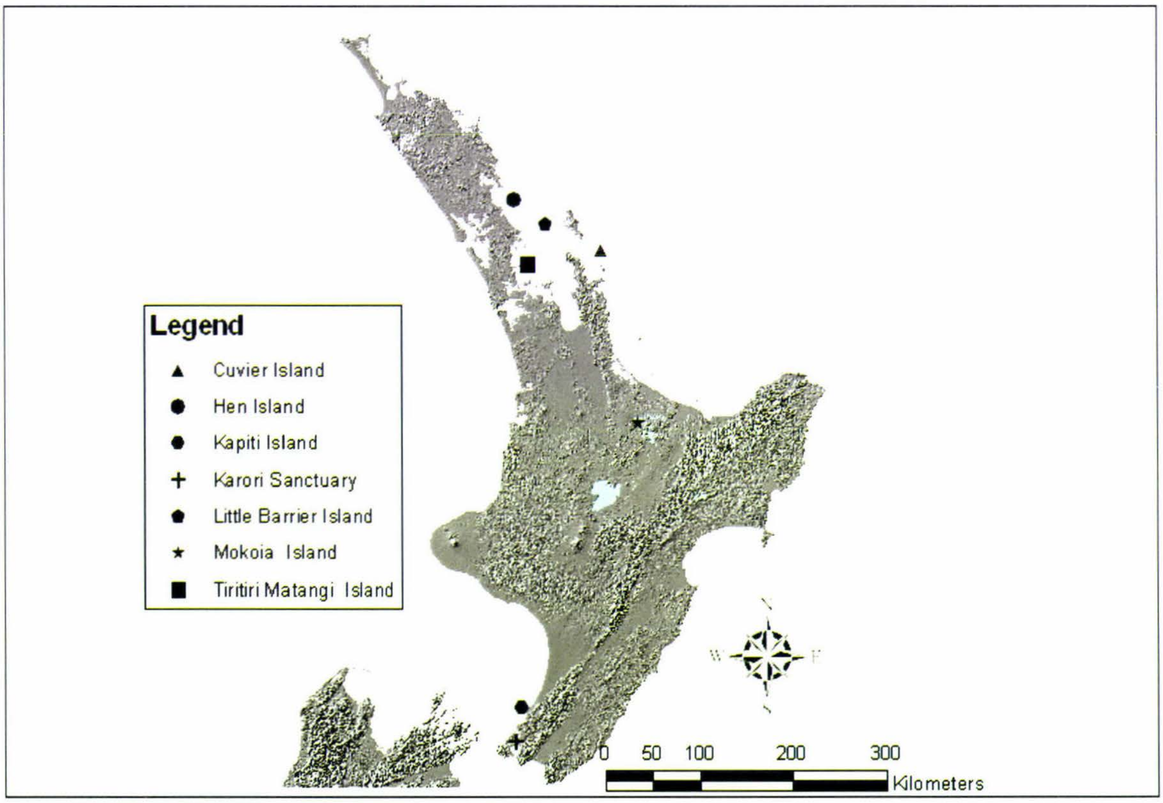


Figure 1.1: Map of New Zealand's North Island showing the study site locations (Modified from Terralink International © 2004- 2006)

The three translocations to Kapiti Island, Tiritiri Matangi Island and Karori, only persist due to intensive management by the Department of Conservation, mainly through supplementary feeding and provision of nesting boxes, as a way of artificially enhancing the island habitats. This type of management is very costly and constrains the size to which these populations can grow. It is unclear why the population on Little Barrier Island is apparently self-sustaining despite the presence of both other honeyeaters, and high rates of competition from other frugivorous and insectivorous birds. Therefore any information that can be gained on the associated differences between these populations may be invaluable in reversing the decline of this species.

1.5 Stitchbird Ecology

The stitchbird is a medium-sized (30-40g) forest dwelling passerine, which nests in tree cavities (Higgins *et al.* 2001). Nesting starts in September and can continue through until April with females producing anywhere from two to four clutches, normally two, each of two to five eggs which are incubated by the female alone (Higgins *et al.* 2001). Incubation lasts from 13 to 19 days and brooding lasts for 26 to 32 days (Higgins *et al.* 2001). The males are not generally involved in nest building or incubation but contribute in the provisioning of chicks, although to a lesser extent than females (Castro *et al.* 1996; Ewen & Armstrong 2000; Higgins *et al.* 2001; Low *et al.* 2006).

This New Zealand endemic passerine has posed one of the most difficult conservation problems in New Zealand. It not only has one of the most unsuccessful translocation histories of all New Zealand's endangered species, but it also has surprised the scientific community through new discoveries regarding its taxonomic affiliations. Until 2001 the stitchbird was thought to belong to the Meliphagidae family with which it shares most of its morphological and foraging characteristics (Higgins *et al.* 2001). However, in a study of the phylogenetics of the Meliphagidae family Driskell (2001) found that the stitchbird was as distant to this family as the Pardalotidae (Pardelotes), her out group. More recent examination (Ewen *et al.* 2006) confirms this and suggests that the stitchbird belongs to an ancient radiation of birds in New Zealand which includes the Callaeidae (the New Zealand wattlebirds). In light of this the Department of Conservation in New Zealand has recently upgraded its threat status from 'Range Restricted' to 'Nationally Endangered' putting them in a category of species considered to be 'most at risk' (Molloy *et al.* 2001).

Stitchbird are sexually dimorphic and have a variable mating system, with competition among males for mating opportunities resulting in a wide range of sexual behaviours, including frequent extra-pair copulation and forced copulation attempts (Castro *et al.* 1996; Ewen *et al.* 1999; Ewen & Armstrong 2000, 2002; Low 2004b). Several studies have shown this variable mating is flexible and is readily altered depending on population density and the availability of resources (Castro *et al.* 1996; Ewen *et al.* 1999; Ewen *et al.* 2004; Low 2004a). The visitation rate of both males and females during the provisioning of chicks is also variable and can depend heavily on the availability of food (Castro *et al.* 2003; Thorogood 2005; Castro *et al.* in prep).

Stitchbird have a mixed diet which includes nectar, invertebrates and fruits (Gravatt 1970; Craig *et al.* 1981; Gaze & Fitzgerald 1982; Rasch 1985b; Castro & Robertson 1997; Perrott 1997; Wilson 1997). The relative proportion of each type of food in the diet varies with the time of the year, stage of the breeding cycle and availability (Gravatt 1970; Angehr 1984a; Castro 1995; Perrott 1997). Castro *et al.* (1994b) also found that diet can vary between populations, with birds in the Kapiti Island population having a higher proportion of invertebrates in their diet than those in the Little Barrier Island population. They go on to suggest that this difference may be due to differences in resource quality and availability between the two populations.

Previous studies looking at the effects of habitat on stitchbirds have concentrated on food availability - especially nectar availability - and diet (Craig *et al.* 1981; Gaze & Fitzgerald 1982; Castro *et al.* 1994b; Castro & Robertson 1997; Perrott 1997; Armstrong & Perrott 2000; Perrott & Armstrong 2000; Armstrong & Ewen 2001). Comparative studies between translocated populations and the source population, Little Barrier Island, have only looked at differences in phenology between the various sites and stitchbird diet (Castro *et al.* 1994b; Castro 1995; Perrott 1997; Perrott & Armstrong 2000). In addition, food supplementation experiments have shown that carbohydrate food may enhance stitchbird survival in some populations (Armstrong & Ewen 2001) but not in others (Armstrong & Perrott 2000). Castro *et al.* (2003) also showed that food supplementation can increase reproductive success in the stitchbird.

1.6 Thesis Plan

New Zealand's history of habitat destruction and alteration has involved many extinctions and population declines. This history may also explain the extinction of stitchbird from mainland New Zealand.

Previous research has significantly added to our understanding of the use of habitat by stitchbirds in terms of plant species used for feeding and nesting. This research provided two major outcomes. One, it showed that the number of species bearing food at a given time on LBI was greater than that on the translocation sites, mainly because translocation sites had forests in early stages of regeneration. Two, it demonstrated that food supplementation at translocation sites improves hihi survival and breeding success suggesting that the habitat was not optimal. Researchers also found that there was an effect of forest age on the presence of *Aspergillus fumigatus*, a hihi pathogen, indicating that habitat may affect stitchbirds in several different ways. These findings suggest that habitat structure, which is highly influenced by forest age, may be of crucial importance to a stitchbird population's long term survival. There is still a lack of knowledge regarding the difference in habitat *structure* between the only remaining self-sustaining population, on Little Barrier Island, and the translocated populations. The effect of this difference on the survival and reproduction of the stitchbird also remains unknown.

The primary aim of this study was to determine the effect of habitat structure on stitchbird nesting behaviour and reproductive success. To investigate this I first measured parental provisioning and reproductive success on Little Barrier Island. I then compared these results to those collected previously from stitchbird populations on Kapiti, Tiritiri Matangi and Mokoia Islands. These data were then used to examine the overall differences between management enhanced and unmanaged habitats. An in-depth analysis of habitat structure was then conducted in two of the populations (Little Barrier and Kapiti Islands) to further investigate the relationship between habitat and stitchbird reproductive success.

1.7 References

Aho, T., M. Kuitunen, J. Suhonen, A. Jantti, and T. Hakkari. 1999. Reproductive success of Eurasian Treecreepers, *Certhia familiaris*, lower in territories with wood ants. Ecology **80**:998-1007.

Alley, M. R., I. Castro, and J. E. B. Hunter. 1999. Aspergillosis in hihi (*Notiomystis cincta*) on Mokoia Island. New Zealand Veterinary Journal **47**:88-91.

Angehr, G. R. 1984a. Ecology and behaviour of the stitchbird with recommendations for management and future research. New Zealand Wildlife Service, Wellington.

Angehr, G. R. 1984b. Establishment of the Stitchbird on Hen Island. Notornis **31**:175-177.

Armstrong, D. P., I. Castro, J. C. Alley, B. Feenstra, and J. K. Perrott. 1999. Mortality and behaviour of hihi, an endangered New Zealand honeyeater, in the establishment phase following translocation. Biological Conservation **89**:329-339.

Armstrong, D. P., R. S. Davidson, W. J. Dimond, J. K. Perrott, I. Castro, J. G. Ewen, R. Griffiths, and J. Taylor. 2002. Population dynamics of reintroduced forest birds on New Zealand islands. Journal of Biogeography **29**:609-621.

Armstrong, D. P., and J. G. Ewen. 2001. Testing for food limitation in reintroduced Hihi populations: Contrasting results for two islands. Pacific Conservation Biology. **7(2)**:87-92.

Armstrong, D. P., and J. K. Perrott. 2000. An experiment testing whether condition and survival are limited by food supply in a reintroduced Hihi population. Conservation Biology **14**:1171-1181.

Atkinson, I. A. E., and E. K. Cameron. 1993. Human influence on the terrestrial biota and biotic communities of New Zealand. Trends in Ecology & Evolution **8**:447-451.

Bengtson, S. A. 1984. Breeding ecology and extinction of the Great Auk (*Pinguinus impennis*) - anecdotal evidence and conjectures. Auk **101**:1-12.

Bucher, E. H. 1992. The causes of extinction of the passenger pigeon. Current Ornithology **9**:1-36.

Butler, D., and D. Merton 1992. The Black Robin: Saving the worlds most endangered bird. Oxford University Press, Oxford.

Castro, I. 1995. Behavioural ecology and management of Hihi *Notiomystis cincta*, an endemic New Zealand honeyeater. PhD Thesis, Massey University, Palmerston North.

Castro, I., J. C. Alley, R. A. Empson, and E. O. Minot. 1994a. Translocation of Hihi or Stitchbird *Notiomystis cincta* to Kapiti Island, New Zealand: transfer techniques and comparison of release strategies. Pages 113-120 *In* M. Serena, editor. Reintroduction biology of Australian and New Zealand fauna. Surrey Beatty & Sons, Chipping Norton.

Castro, I., D. H. Brunton, K. M. Mason, B. Ebert, and R. Griffiths. 2003. Life history traits and food supplementation affect productivity in a translocated population of the endangered hihi (stitchbird, *Notiomystis cincta*). Biological Conservation **114**:271-280.

Castro, I., E. O. Minot, and J. C. Alley. 1994b. Feeding and breeding behaviour of Hihi or Stitchbirds *Notiomystis cincta* recently transferred to Kapiti Island, New Zealand, and possible management alternatives. Pages 121-128 *In* M. Serena, editor. Reintroduction biology of Australian and New Zealand fauna. Surrey Beatty and Sons, Chipping Norton.

Castro, I., E. O. Minot, R. A. Fordham, and T. R. Birkhead. 1996. Polygynandry, face-to-face copulation and sperm competition in the Hihi *Notiomystis cincta* (Aves: Meliphagidae). Ibis **138**:765-771.

Castro, I., A. Noble, and K. M. Mason. in prep. Paternity, certainty of paternity, paternity effort and benefits of paternal care in Hihi.

Castro, I., and A. W. Robertson. 1997. Honeyeaters and the New Zealand forest flora: The utilisation and profitability of small flowers. New Zealand Journal of Ecology **21**:169-179.

Caughley, G. 1994. Directions in conservation biology. Journal of Animal Ecology **63**:215-244.

Cork, S. C., M. R. Alley, A. C. Johnstone, and P. H. G. Stockdale. 1999. Aspergillosis and other causes of mortality in the stitchbird in New Zealand. Journal of Wildlife Diseases **35**:481-486.

Craig, J., S. Anderson, M. Clout, B. Creese, N. Mitchell, J. Ogden, M. Roberts, and G. Ussher. 2000. Conservation issues in New Zealand. Annual Review of Ecology and Systematics **31**:61-78.

Craig, J. L. 1984. Wing noises, wing slots, and aggression in New Zealand honeyeaters (Aves, Meliphagidae). New Zealand Journal of Zoology **11**:195-199.

Craig, J. L., A. M. Stewart, and M. E. Douglas. 1981. Foraging of New Zealand honey-eaters. New Zealand Journal of Zoology. **8(1)**:87-92.

Daugherty, C. H., D. R. Towns, I. A. E. Atkinson, and G. W. Gibbs. 1990. The significance of the biological resources of New Zealand islands for ecological restoration. Department of Conservation, Wellington.

Dias, P. C. 1996. Sources and sinks in population biology. Trends in Ecology & Evolution **11**:326-330.

Dias, P. C., F. Meunier, S. Beltra, and M. Cartanson. 1994. Blue Tits in Mediterranean habitat mosaics. Ardea **82**:363-372.

Driskell, A. 2001. Molecular systematics, biogeography and evolution of the Meliphagidae (Passeriformes). PhD Thesis, University of Chicago, Chicago.

Ens, B. J., M. Kersten, A. Brenninkmeijer, and J. B. Hulscher. 1992. Territory quality, parental effort and reproductive success of oystercatchers (*Haematopus ostralegus*). Journal of Animal Ecology **61**:703-715.

Ewen, J. G. 1998. A genetic and behavioural investigation of extra-pair copulation in stitchbirds (*Notiomystis cincta*) breeding on Tiritiri Matangi Island. MSc Thesis, Massey University, Palmerston North.

Ewen, J. G., and D. P. Armstrong. 2000. Male provisioning is negatively correlated with attempted extrapair copulation frequency in the stitchbird (or hihi). Animal Behaviour **60**:429-433.

Ewen, J. G., and D. P. Armstrong. 2002. Unusual sexual behaviour in the Stitchbird (or Hihi) *Notiomystis cincta*. Ibis **144**:530-531.

Ewen, J. G., D. P. Armstrong, B. Ebert, and L. H. Hansen. 2004. Extra-pair copulation and paternity defense in the hihi (or stitchbird) *Notiomystis cincta*. New Zealand Journal of Ecology **28**:233-240.

Ewen, J. G., I. Flux, and P. G. P. Ericson. 2006. Systematic affinities of two enigmatic New Zealand passerines of high conservation priority, the hihi or stitchbird *Notiomystis cincta* and the kokako *Callaeas cinerea*. Molecular phylogenetics and evolution **40**:281-284.

Ewen, J. G., D. P. Armstrong, and D. M. Lambert. 1999. Floater males gain reproductive success through extra pair fertilizations in the stitchbird. Animal Behaviour **58**:321-328.

Gaze, P. D., and B. M. Fitzgerald. 1982. The food of honey-eaters Meliphagidae on Little Barrier Island, New Zealand. Notornis. **29**:209-213.

Gill, B. J. 1991. New Zealand's Extinct Birds. Random Century New Zealand, Hong Kong.

Gravatt, D. J. 1970. Honeyeater movements and the flowering cycle of vegetation on Little Barrier Island. Notornis **17**:96-101.

Green, R. E. 1995. Diagnosing causes of bird population declines. Ibis **137**:S47-S55.

Halaj, J., D. W. Ross, and A. R. Moldenke. 2000. Importance of habitat structure to the arthropod food-web in Douglas-fir canopies. Oikos **90**:139-152.

Halliday, T. R. 1980. Extinction of the Passenger Pigeon *Ectopistes migratorius* and its relevance to contemporary conservation. Biological Conservation **17**:157-162.

Hatchwell, B. J., D. E. Chamberlain, and C. M. Perrins. 1996. The reproductive success of blackbirds *Turdus merula* in relation to habitat structure and choice of nest site. Ibis **138**:256-262.

Hayward, B. W. 1984. Prehistoric man on the offshore islands of northern New Zealand and his impact on the biota. Department of Lands and Survey, Wellington.

Higgins, P. J., J. M. Peter, and W. K. Steele 2001. Stitchbird (hihi). *In* Handbook of Australian, New Zealand and Antarctic Birds, Vol. 5 Tyrant-flycatchers to Chats, pp. 954-966. Oxford University Press, Melbourne.

Jolly, J. N., and R. M. Colbourne. 1991. Translocations of the Little Spotted Kiwi (*Apteryx owenii*) between offshore islands of New Zealand. Journal of the Royal Society of New Zealand **21**:143-149.

Komdeur, J., and M. D. Pels. 2005. Rescue of the Seychelles warbler on Cousin Island, Seychelles: The role of habitat restoration. Biological Conservation **124**:15-26.

Lovegrove, T. 1986. Stitchbirds on Kapiti Island 1983-1985. Internal report to the New Zealand Department of Conservation, Wellington.

Low, M. 2004a. The behavioural ecology of forced copulation in the New Zealand Stitchbird (hihi). PhD Thesis, Massey University, Palmerston North.

Low, M. 2004b. Female weight predicts the timing of forced copulation attempts in stitchbirds, *Notiomystis cincta*. Animal Behaviour **68**:637-644.

Low, M., M. K. Joy, and T. D. Makan. 2006. Using regression trees to predict male provisioning of offspring in the stitchbird (hihi). Animal Behaviour **71**: 1057-1068.

Luck, G. W. 2002. Determining habitat quality for the cooperatively breeding Rufous Treecreeper, *Climacteris rufa*. Austral Ecology **27**:229-237.

Misenhelter, M. D., and J. T. Rotenberry. 2000. Choices and consequences of habitat occupancy and nest site selection in sage sparrows. Ecology **81**:2892-2901.

Molloy, J., B. Bell, M. Clout, P. de Lange, G. Gibbs, D. Given, D. Norton, N. Smith, and T. Stephens. 2001. Classifying species according to threat of extinction: a system for New Zealand. Department of Conservation, Wellington.

Moorhouse, R. J. 1997. The diet of the North Island kaka (*Nestor meridionalis septentrionalis*) on Kapiti Island. New Zealand Journal of Ecology **21**:141-152.

Newton, I. 1998. Population limitation in birds. Academic Press, London.

Newton, I. 2004. The recent declines of farmland bird populations in Britain: an appraisal of causal factors and conservation actions. Ibis **146**:579-600.

Perrott, J. K. 1997. Effects of food supply and competition on the outcome of Hihi (*Notiomystis cincta*) translocated to Mokoia Island. MSc Thesis, Massey University, Palmerston North.

Perrott, J. K. 2001. The ecology of *Aspergillus fumigatus* and implications for wildlife conservation in modified environments. PhD Thesis, Massey University, Palmerston North.

Perrott, J. K., and D. P. Armstrong. 2000. Vegetation composition and phenology of Mokoia Island, and implications for the reintroduced hihi population. New Zealand Journal of Ecology **24**:19-30.

Powlesland, R. G., B. D. Lloyd, H. A. Best, and D. V. Merton. 1992. Breeding biology of the Kakapo *Strigops habroptilus* on Stewart Island, New Zealand. Ibis **134**:361-373.

Pulliam, H. R., and B. J. Danielson. 1991. Sources, sinks, and habitat selection - a landscape perspective on population dynamics. American Naturalist **137**: 50-66.

Rasch, G. 1985b. The behavioural ecology and management of the Stitchbird. MSc Thesis, University of Auckland, Auckland.

Rasch, G. 1985a. The Ecology of Cavity Nesting in the Stitchbird (*Notiomystis cincta*). New Zealand Journal of Zoology **12**:637-642.

Rasch, G. 1991. A recovery plan for the Stitchbird (*Notiomystis cincta*). Internal report to the New Zealand Department of Conservation, Wellington.

Rasch, G., and J. L. Craig. 1988. Partitioning of nectar resources by New Zealand honeyeaters. New Zealand Journal of Zoology **15(2)**:185-190.

Robinson, S. K., and R. T. Holmes. 1982. Foraging behavior of forest birds - the relationships among search tactics, diet, and habitat structure. Ecology **63**:1918-1931.

Smith, T. M., and H. H. Shugart. 1987. Territory size variation in the Ovenbird - the role of habitat structure. Ecology **68**:695-704.

Taylor, S., I. Castro, and R. Griffiths. 2005. Hihi/Stitchbird (*Notiomystis cincta*) Recovery Plan 2004-09. Department of Conservation, Wellington, New Zealand.

Thorogood, R. 2005. Decisions mothers take: Hihi maternal investment. MSc Thesis, University of Auckland, Auckland.

Veitch, C. R., and B. Bell. 1990. Eradication of introduced animals from the islands of New Zealand. *In* D. R. Towns, I. A. E. Atkinson, and C. H. Daugherty. Ecological restoration of New Zealands islands. Department of Conservation, Wellington, New Zealand.

Webb, C. J., and D. Kelly. 1993. The reproductive biology of the New Zealand flora. Trends in Ecology & Evolution **8**:442-447.

Wilson, E. O. 1988. Biodiversity. National Academy Press, Washington D.C.

Wilson, L. R. 1997. The ecology and management of honeyeaters in northern New Zealand. MSc Thesis, University of Auckland, Auckland.

Variation in Nestling Provisioning and Reproductive Success of the Stitchbird (Hihi – *Notiomystis cincta*): A Comparison between Managed and Unmanaged Habitats

Tiritiri Matangi from Whangaparaoa: Don Binney 1984

2

Variation in Nestling Provisioning and Reproductive Success of the Stitchbird (Hihi – *Notiomystis cincta*): A Comparison between Managed and Unmanaged Habitats

2.1 Introduction

Variation in the behaviour and reproductive output between individuals, and in different populations, is common in ecological systems (Bollmann *et al.* 1997; Armstrong *et al.* 1999; Weidinger 2000). This variation in the demographics of separate populations is generally governed by environmental or external limiting factors of the population (Caughley 1994; Newton 1998). These factors include resources (often due to habitat limitation), competing species, natural enemies (predators and parasites) and climate. Human activities often trigger external limiting factors with destruction and encroachment of habitat and the introduction of exotic species being major threats to populations. Any of these factors can be considered limiting if it prevents a population from increasing or causes it to decline. Populations can be affected by more than one, and in some cases all of these different factors, but generally only one factor emerges as the most important at any one time (Newton 1998).

Animals are expected to maximize their reproductive output by efficient use of the resources found in their habitat (Pulliam & Danielson 1991). As well as competing for better habitat, individuals have been shown to increase reproductive output by increasing their parental investment (Garcia 2003; Zink 2003). There is ample evidence that the behaviour and reproductive output of populations from the same species varies with habitat. For example the blue tit (*Parus caeruleus*) has larger clutches and earlier laying dates in deciduous oakwood compared to evergreen oakwood (Blondel *et al.* 1993), and an increased visitation rate and decreased foraging distance in a food rich habitat (Tremblay *et al.* 2005). Mann *et al.* (2000) found bottlenose dolphin (*Tursiops sp.*) had higher reproductive success, over a ten-year period, in shallow water over deep water locations. Baboons (*Papio cynocephalus ursinus*) inhabiting mountain habitats showed greater levels of infant care, which was accompanied by higher infant survival, than those inhabiting the East African Plains (Lycett *et al.* 1998).

Conservation management can be used to enhance habitat quality for particular species (Towns *et al.* 1990; Bro *et al.* 2004). Managers have many tools at their disposal when it comes to enhancing habitats. For example re-vegetation, predator control, supplementary feeding and provisioning of artificial shelter have all been used as ways of providing sufficient resources for New Zealand forest passerines to invest in reproduction.

The stitchbird is a species that has, in the past, been limited by an array of environmental factors including predation, disease and severe habitat loss reducing the species to a single population on Little Barrier Island (Taylor *et al.* 2005). As part of a concerted conservation recovery programme, multiple attempts at establishing new populations have now been made by translocating birds to suitable predator-free areas (Taylor *et al.* 2005). These translocations have been largely unsuccessful except when supported by management, mainly through supplementary feeding and provision of nesting boxes. Angher (1984), Lovegrove (1986) and Rasch (1991) hypothesized that the cause of failure of these translocations was an inadequate year-round supply of carbohydrate food (nectar and fruit) due to prior human impacts on the forest habitat.

Several studies have looked at reproductive success and parental investment in these translocated populations (Castro *et al.* 2003; Low 2004a; Thorogood 2005; Castro *et al.* in prep; Low *et al.* 2006) and how the intensity of management affects them (Perrott 1997; Armstrong & Perrott 2000; Armstrong & Ewen 2001; Castro *et al.* 2003; Castro & Brunton in prep; Armstrong *et al.* submitted).

Research so far has shown that if left unmanaged, translocated populations will go extinct (Armstrong *et al.* 2002; Castro *et al.* 2004; Armstrong *et al.* submitted). Therefore, information regarding reproductive success and parental behaviour in the unmanaged population is crucial to find locations where self-sustaining populations may be established.

In this study I collected information on parental investment and reproductive success on the unmanaged population on Little Barrier Island to compare the results with data collected by other researches in previous years from Kapiti (during the separate unmanaged and managed periods) and the managed populations on Mokoia and Tiritiri Matangi.

2.2 *Methods*

2.2.1 Study sites

2.2.1.1 Little Barrier Island

Little Barrier Island (Figure 1.1) has some of the most pristine forest habitat in New Zealand, with parts of the island having no evidence of human disturbance and the whole island having had little impact from humans for about 150 years (Hamilton 1961). Cats (*Felis catus*) and the Pacific Rat or Kiore (*Rattus exulans*) were the only exotic predators to reach the island, however cats were eradicated in 1980 (Veitch 2001) and a poison drop to eradicate Kiore was completed in 2004 (Richard Griffiths pers. comm.). Until recovery efforts were started in the early 1980's, Little Barrier held the world's only population of stitchbird.

2.2.1.2 Kapiti Island

Kapiti Island lies 5km off the Wellington coast (Figure 1.1). The island was largely cleared in the early 1800's, but was then designated as a nature reserve in the early 1900's and has been naturally regenerating ever since. Mammalian predators were present on the island up until 1996 with the Australian brushtail possum (*Trichosurus vulpecula*) being eradicated in 1986 (Cowan 1993) followed by the two species of rat, the Norway rat (*Rattus norvegicus*) and Kiore, in 1996 (Empson & Miskelly 1999). Stitchbirds were established on the island through a series of six translocations from 1983 to 1992 (Lovegrove 1986; Castro *et al.* 1994a; Taylor *et al.* 2005).

However the populations declined following the early translocations. Lack of food and competition with other nectar feeding species were suggested as possible reasons for the declines. Following the 1991 and 1992 translocations, the population had seven supplementary feeding stations available for the four weeks after release to enable monitoring (Castro *et al.* 1994b) and help the population get established. In addition, the island ranger maintained a feeder at his residence year round, which was commonly used by most stitchbirds on the island, until 1998 when all feeding was halted. During the period of food supplementation a small population was maintained. After supplementary feeding was stopped, this population underwent severe decline until supplementary feeding as a management strategy was resumed in 2000 in the form of sugar water feeders, at a sugar concentration of 20% by volume (Taylor *et al.* 2005).

2.2.1.3 Mokoia Island

This island lies in the middle of Lake Rotorua, in the central North Island (Figure 1.1). The island has had a long history of human use and was cleared for cultivation until the 1950's when it was designated as a wildlife reserve and allowed to regenerate naturally (Andrews 1992). The rate of recovery of this island ecosystem accelerated with the removal of mammalian predators and herbivores, with goats (*Capra hircus*), sheep (*Ovis aries*) and rats being eradicated in 1989 (Veitch & Bell 1990). Stitchbirds were translocated to the island in 1994 and were intensively managed (provided with supplementary food, nest boxes and ectoparasite control).

Despite management the population was not increasing and in 1998 the food supplementation was stopped resulting in sharp population decline. Management was resumed in 1999 until 2000 (Castro *et al.* 2003), but data confirmed that although the population was slowly recovering it was not viable in the long run because of Aspergillosis, a respiratory disease which killed over half of the adult population each year (Alley *et al.* 1999; Castro *et al.* 2004; Armstrong *et al.* submitted) and the last 12 birds were removed to Kapiti Island in 2002 (Taylor *et al.* 2005). This population was provided with Wambaroo®, a complete diet replacement formula for honeyeaters (protein = 40g/l, fat = 20g/l, carbohydrates = 22g/l, minerals and vitamins), rather than the sugar water provided on the other managed islands.

2.2.1.4 Tiritiri Matangi Island

This island lies in the inner Hauraki Gulf (Figure 1.1). Up until 1971 the island was farmed, with all but 6% of it being in pasture. Since then the island has been re-vegetated and is now predominately covered with early successional native forest (Rimmer 2004). Island management included the removal of Kiore in 1996, and multiple reintroductions of other native bird species (Hawley 1997). Stitchbirds were translocated to the island in 1995 as part of the ongoing management by the Department of Conservation (Ewen 1998). This included the provisioning of nest boxes and supplementary food, through sugar water feeders (at a sugar concentration of 20% by volume), and ectoparasite control.

2.2.2 Study species

For information on the ecology of the stitchbird see Chapter One. All birds on Kapiti, Mokoia and Tiritiri Matangi Islands were colour banded, as part of ongoing management, for individual identification. On Little Barrier Island there were very few colour banded birds and only one pair of banded birds was sampled in this study. In some cases, stitchbird have been shown to adopt a variety of polygamous mating systems, where two or more birds of one sex have been shown to care for young (Castro *et al.* 1994b; Castro *et al.* 1996). However on Little Barrier Island it was assumed that individuals recorded visiting each nest were the parent birds.

2.2.3 Reproductive success

2.2.3.1 Little Barrier Island

Stitchbird productivity data were collected by the author from 23 first clutch nests over the 2004/05 breeding season on Little Barrier Island. Nest trees were located at the beginning of the breeding season by identifying the areas where males were territorially calling. Observations of the nesting pair at these locations led me to the nesting cavity (Taylor & Castro 2000b; Taylor *et al.* 2005). Once the cavity entrance was found the tree was climbed to inspect the nest contents using an endoscope. Observations of adult parental behaviour (see next section) together with finding of egg shells under the cavity entrance allowed the estimation of the hatching date (Taylor & Castro 2000b). From 28 days after hatching the nests were visited every day, to check for fledglings. Once the chicks fledged they were located and counted to estimate the final productivity of each nest.

2.2.3.2 Kapiti Island

Data were collected on Kapiti Island during two distinct periods. The pre-management data were collected from 21 first clutch nests over the 1992/93 and 1993/94 stitchbird breeding seasons, as part of Isabel Castro's PhD research (Castro 1995). The post-management data were collected from 54 first clutch nests by the Department of Conservation contractors in each of the stitchbird breeding seasons from 2000/01 to 2004/05 (Knegtmans *et al.* 2001; Newell & Moorcroft 2002; Barr & Moorcroft 2003; Howard & Moorcroft 2004; Gorman & Moorcroft 2005). Like Little Barrier Island, productivity was measured by locating nest trees at the beginning of the breeding season. Once found, behavioural watches where done to assess parental behaviour and estimate hatching date. Nests were then visited regularly until fledging to determine the number of chicks fledged.

2.2.3.3 *Mokoia Island*

Stitchbird productivity data were collected from 39 first clutch nests over four years (1994/95 to 1997/98) on Mokoia Island as part of Isabel Castro's post-doctoral research (Castro *et al.* 2003; Isabel Castro unpublished data).

2.2.3.4 *Tiritiri Matangi Island*

Data were collected from 92 first clutch nests over the 2000/01 to the 2002/03 stitchbird breeding seasons as part of Matt Low's PhD research (Low 2004a). Data from Mokoia and Tiritiri Matangi were obtained by monitoring all nesting attempts, which only occurred in nesting boxes, and recording the number of young fledged.

2.2.4 Parental investment

At each island stitchbird visitation data were collected during the period of chick rearing at first clutch nests (Table 2.1).

Table 2.1: Amount of parental investment data collected on each island.

Island	Little Barrier	Kapiti	Mokoia	Tiritiri Matangi
No. of Nests observed	14	5	26	36
Hours of observation	35.5	17	174.5	243
Average No. of observation periods per nest	5.0	6.8	13.4	13.5

Behavioural observations were carried out using the same methodology across all islands although the length of watches differed. On Kapiti and Mokoia Islands, observations ranged from 20 minutes to 5 hours (Castro 1995; Castro & Brunton in prep) while on Tiritiri Matangi (Low 2004a) and Little Barrier Islands, watches lasted for 30 minutes. Each nest was observed several times during the chick rearing period (28+ days) at any time during the day. Observers sat 10 -20m away from the nest, often partly concealed behind saplings but with a clear line of sight to the entrance hole, and recorded the time of entry and exit of both males and females during the observation period. This did not appear to affect the birds' behaviour in any way as stitchbirds are easily approachable and the distance between the observer and the nest was large.

If a parent was found to be on the nest at either the beginning or end of an observation session, this was counted as a half visit. Only one observation per nest was used for any given day. The timing of observation periods throughout the day were randomly distributed with respect to territory to control for possible temporal confounds.

I calculated the number of visits to the nest and the time spent on the nest per hour for both males and females using 30-minute observation periods. If an observation period was longer than 30 minutes, only the first half an hour was used.

I assumed that parental investment (feeding, brooding, cleaning or a combination) was delivered to the nestlings during each visit. This assumption was necessary because the birds nested in either nest boxes (on Tiritiri Matangi, Mokoia and some nests on Kapiti Island) or tree cavities (on Little Barrier and Kapiti Islands) with small entrances that made it impossible to observe behaviour directly.

For this analysis I averaged all the available observations for each nest during the period from day 5 to day 28 after the chicks hatched, the number of observations per nest ranged from 5 to 13.5 with a mean of 7 (Table 2.1). Fledging success was calculated as the number of chicks counted outside the nest after fledging. This assumption was necessary as the birds nested inside tree cavities with small entrances on Little Barrier and Kapiti Islands which made it impossible to count chicks within the nest.

2.2.5 Statistical analysis

2.2.5.1 Reproductive success

Differences in reproductive success among the islands were investigated using a one-way analysis of variance followed by a Bonferroni post-hoc test. A significance level of 0.05

was used for all statistical tests (SPSS for windows v13; SPSS Inc. 1989 -2004; Chicago, USA).

2.2.5.2 Parental investment

A multi-level models programme, MLwiN (Rasbash *et al.* 2000), was used to build a model (below) to explain the relationship between parental investment (visits per hour and the natural log of time on per hour) and brood age, fledging success and island management regime.

$$I = \beta_{0ijk} + \text{Brood age}_{ijk} + \text{Fledging success}_{ijk} + \text{Management}_{k}$$

Both parental investment data sets (I) were normally distributed (time on per hour was log-transformed to improve normality). The model built was a linear model of the variance around the mean and had three hierarchical levels to represent the repeated measures in the model: (*i*) each individual 30-min observation (level 1) clustered by (*j*) each nest (level 2) clustered by (*k*) each island (level 3). A constant ($\beta_0 = 1$) was also included in the model.

The independent variables tested as fixed effects were: brood age (= age of the chicks in the nest – this was calculated backwards from the fledging date) and fledging success (= number of chicks fledged from that nest). A variable was also calculated for the management regime on each island (unmanaged = Little Barrier and Kapiti Islands; and managed = Tiritiri Matangi and Mokoia Islands).

I preferred this model over the more traditional linear regression model as the data set contained a natural hierarchy with four different islands, each of which had multiple nests with multiple observations being done on each nest.

2.3 *Results*

2.3.1 Reproductive success

Reproductive success was variable across all populations (Figure 2.1). The Kapiti island population had the lowest fledging success during the period without management, but showed an increase in success after the onset of management although this increase was not statistically significant. The managed populations had a significantly higher reproductive success when compared to unmanaged populations (ANOVA: $F_{1,229} = 4.739$, $P = 0.031$).

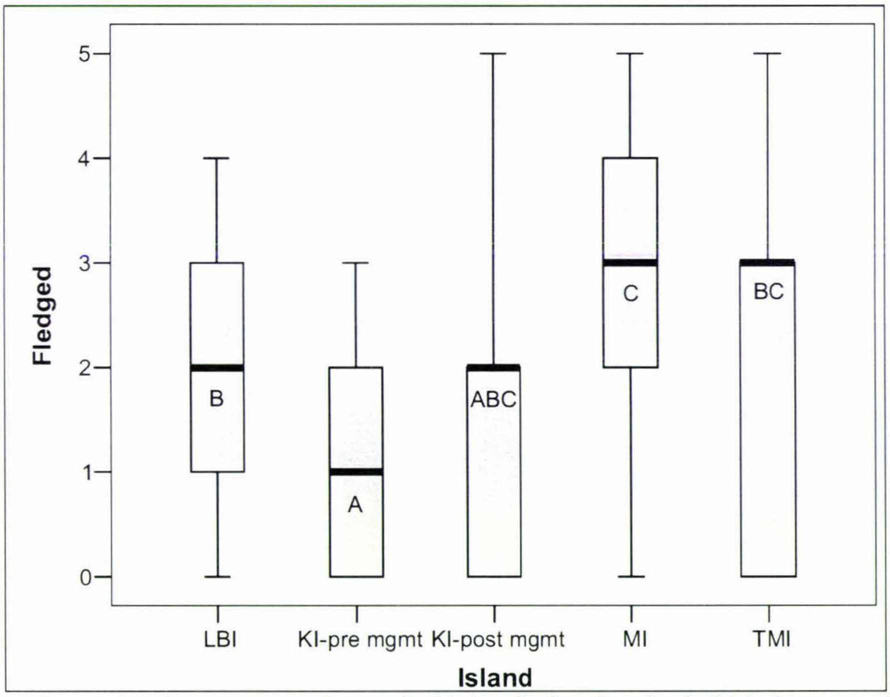


Figure 2.1: Reproductive success (no. of chicks fledged) of stitchbird across four island populations (Little Barrier = LBI; Kapiti = KI, Mokoia = MI; Tiritiri Matangi Islands = TMI). Kapiti fledging success was split into two periods; the first being prior to 2000 when sugar water feeding was rare and irregular and the second being post 2000 when full population management was instated. The letters A-C within the boxes indicate significance with boxes sharing the same letter being not significantly different.

2.3.2 Parental Investment

Both sexes exhibited significant variation in parental behaviour (time on the nest per hour and visits per hour) among individual 'observations' and among 'nests' (Tables 2.2 & 2.3). Females spent on average 8.1 times more time on the nest per hour ($\overline{X}$ = 14.2 min; s.d =

8.1; Range = 1.3 to 45.4)[1] than males ($\overline{X}$ = 1.8 min; s.d = 1.8; Range = 0 to 10.4), and provided on average 2.5 times ($\overline{X}$ = 3.8; s.d = 1.1; Range = 1 to 6.9) more visits to the nest per hour than males ($\overline{X}$ = 1.4; s.d = 1.0; Range = 0 to 4). There was no significant difference in parental behaviour between islands ('island' in Tables 2.2 & 2.3).

2.3.2.1 Maternal behaviour

Females spent more time on the nest when chicks were younger (Figure 2.2a-d) and this relationship was found to be significant when all other variables were considered using the model, although there was no significant difference in the number of visits per hour (Table 2.2).

Table 2.2: Estimated coefficients for the multilevel model (I = β_0 + (Brood age*a) + (Fledging success*b) + (Management*c) where I = number of visits per hour or the natural log of time on the nest per hour; β_0 = 1 (constant); a = Brood Age coefficient; b = Fledging Success coefficient; c = Management coefficient) applied to female stitchbird visits and time spent on the nest per hour. Significant effects in bold.

	Visits per hour		Time on per hour (natural log)	
Parameter	Estimate (s.e.)	p	Estimate (s.e.)	p
Fixed:				
Brood Age (a)	-0.005 (0.007)	>0.05	-0.074 (0.006)	**<0.05**
Fledging Success (b)	0.215 (0.081)	**<0.05**	0.239 (0.067)	**<0.05**
Management (c)	1.501 (0.261)	**<0.05**	1.094 (0.301)	**<0.05**
Random Variance Estimates:				
Island (k)	0.000 (0.000)	>0.05	0.041 (0.048)	>0.05
Nest (j)	0.508 (0.105)	**<0.05**	0.360 (0.072)	**<0.05**
Observation (i)	2.447 (0.110)	**<0.01**	1.492 (0.067)	**<0.01**

There was a significant positive relationship between fledging success (number of chicks fledged) and both aspects of maternal investment (time on the nest per hour and visits per hour) when brood age, management regime and the random variance between islands, nests and observations are considered (Table 2.2). However, when these factors are explored individually they showed a different trend. There was a negative nonlinear relationship

---

[1] The means, standard deviations and ranges shown in this section were calculated from the pooled data for all islands using the averages for each parent at each nest.

between fledging success and time spent on the nest per hour (Figure 2.3a-d), and a positive nonlinear relationship between fledging success and the number of visits per hour (Figure 2.4a-d).

Female visitation rate was higher in managed ($\overline{X}$ = 4.1; s.d = 1.0; Range = 2 to 6.9) compared to unmanaged populations ($\overline{X}$ = 2.5; s.d = 0.9; Range = 1 to 4.5). Females also spent more time on per hour on the nest in managed ($\overline{X}$ = 14.3 min; s.d = 7.6; Range = 1.6 to 42.7) compared to unmanaged populations ($\overline{X}$ = 14 min; s.d = 10.6; Range = 1.3 to 45.4). Both these relationships were significant when analysed, using the multi-level model (Table 2.2).

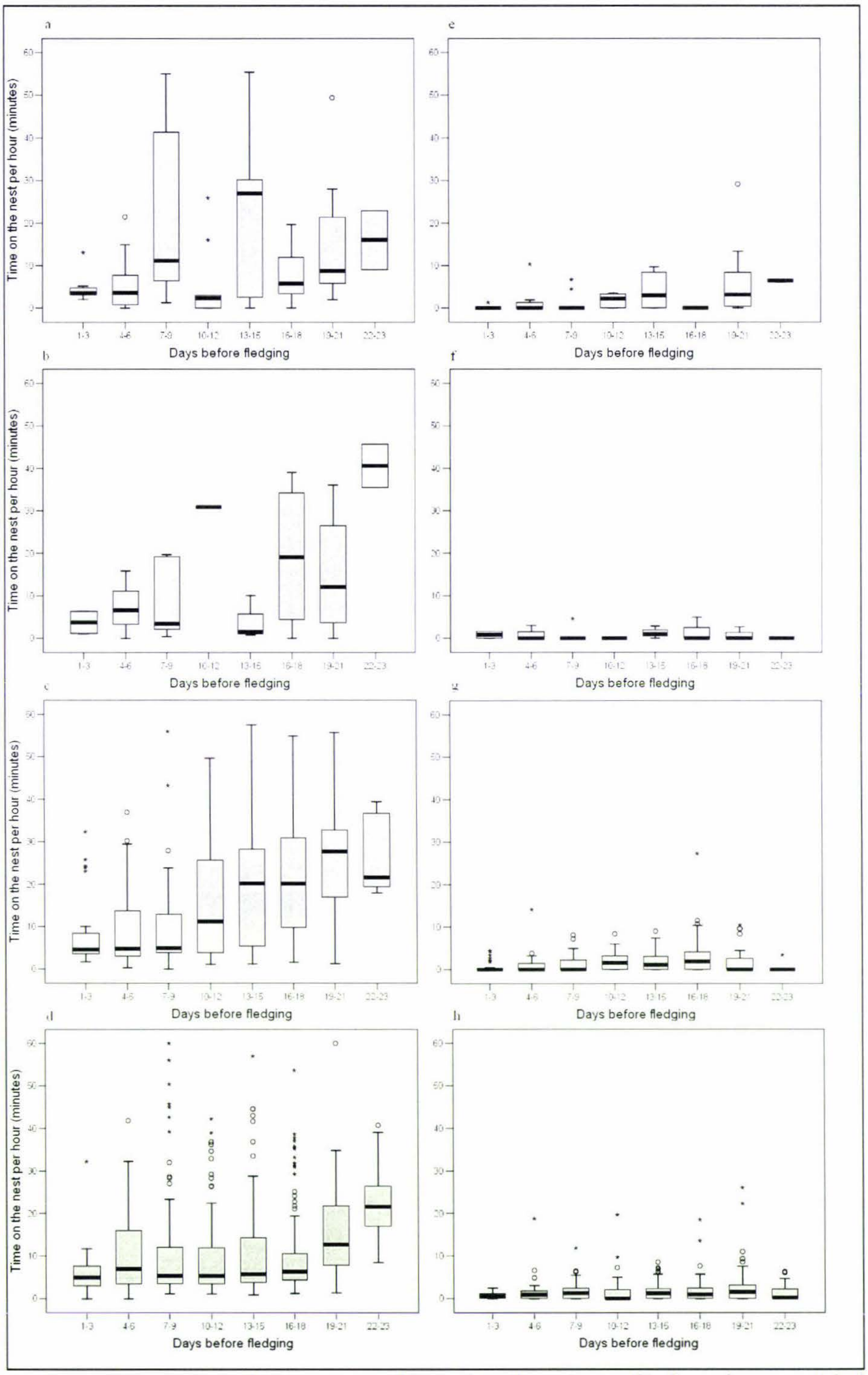


Figure 2.2: Time spent on the nest per hour by; by a) to d) females on Little Barrier, Kapiti, Mokoia and Tiritiri Matangi Islands respectively and; e) to h) males on Little Barrier, Kapiti, Mokoia and Tiritiri Matangi Islands respectively over the visitation observation period relative to brood age (days before fledging. ^{o} = outliers, * = extreme cases.

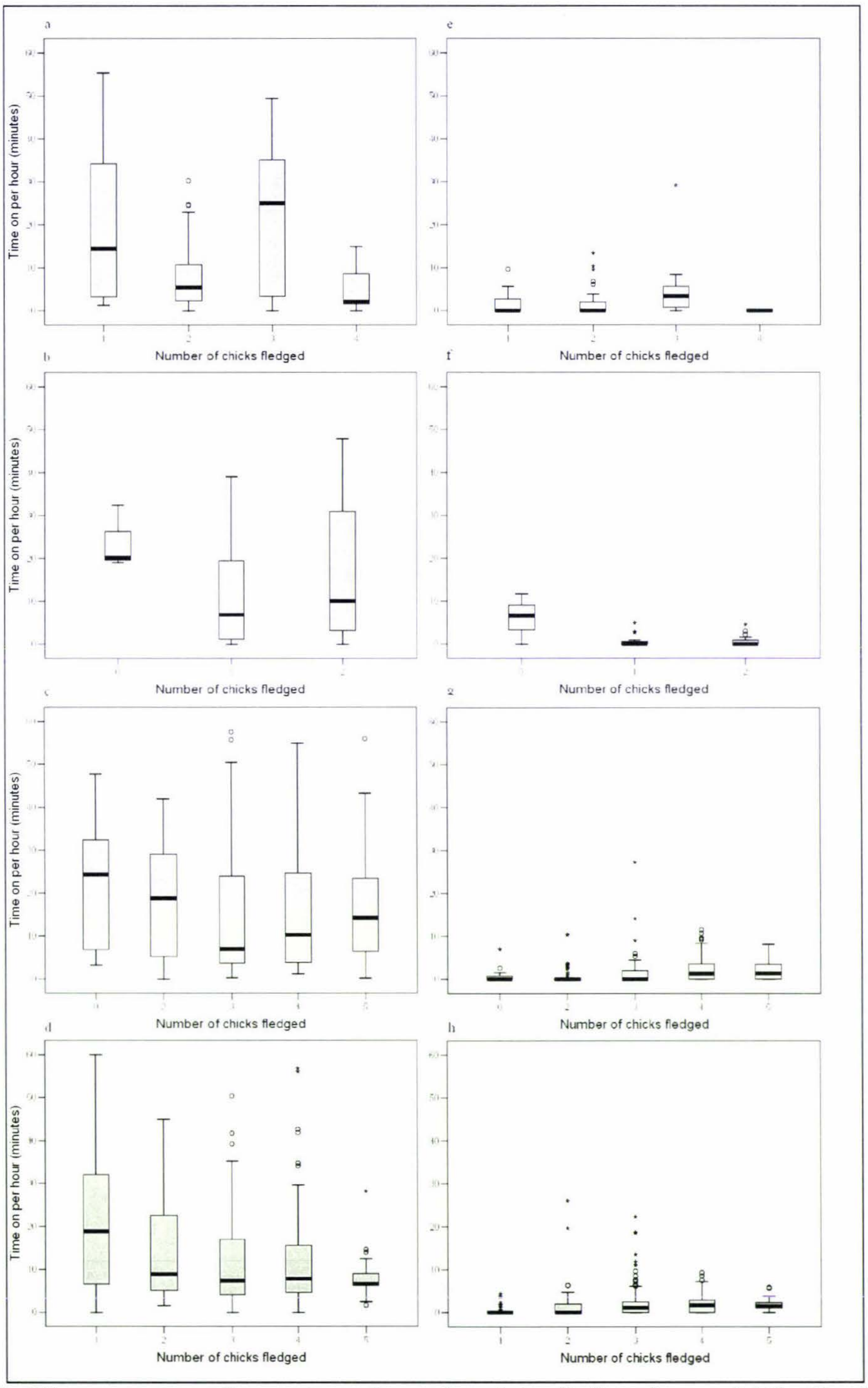


Figure 2.3: Time spent on the nest per hour; by a) to d) females on Little Barrier, Kapiti, Mokoia and Tiritiri Matangi Islands respectively and; e) to h) males on Little Barrier, Kapiti, Mokoia and Tiritiri Matangi Islands respectively, relative to fledging success. ° = outliers, * = extreme cases.

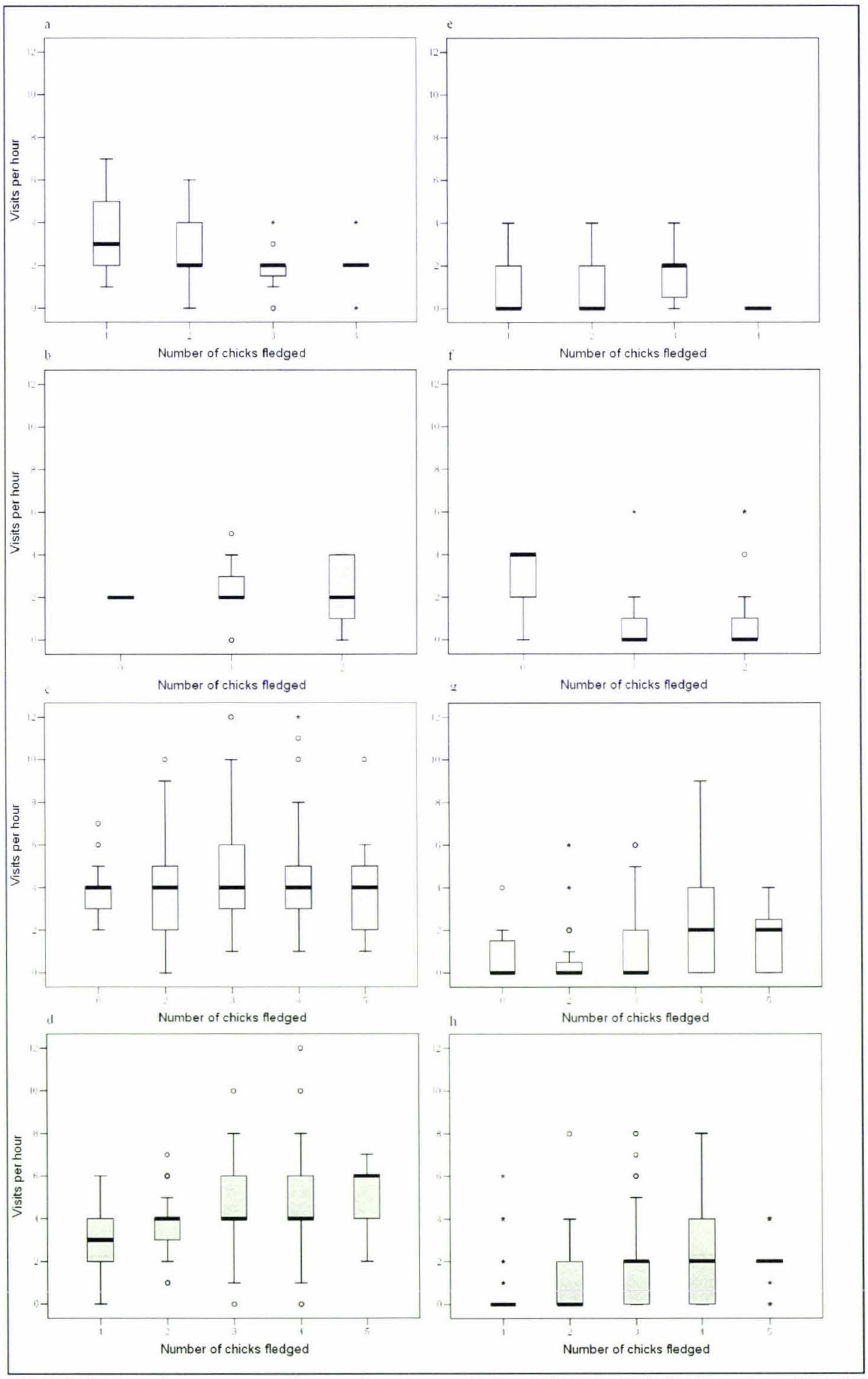


Figure 2.4: Visits to the nest per hour; by a) to d) females on Little Barrier, Kapiti, Mokoia and Tiritiri Matangi Islands respectively and; e) to h) males on Little Barrier, Kapiti, Mokoia and Tiritiri Matangi Islands respectively, relative to fledging success. ^{o} = outliers, * = extreme cases.

2.3.2.2 *Paternal investment*

Males generally invested less than females with some males not visiting nests at all. This reduced investment generally followed a similar pattern to the maternal investment, except that management regime had no effect on either the time spent on the nest or the number of visits per hour by the male (Table 2.3).

Males spent more time in the nest cavity when chicks were younger (Figure 2.2e-h). Analysis using the multi-level model showed this was a significant relationship, although there was no significant difference in the number of visits per hour (Table 2.3).

Males showed a general increase in time spent on the nest and visitation rate per hour with increased fledging success (Figures 2.3e-h & 2.4e-h). Using the model I found a significant positive relationship between fledging success and male visitation (Table 2.3).

Table 2.3: Estimated coefficients for the multilevel model (I = β_0 + (Brood age*a) + (Fledging success*b) + (Management*c) where I = number of visits per hour or the natural log of time on the nest per hour; β_0 = 1 (constant); a = Brood Age coefficient; b = Fledging Success coefficient; c = Management coefficient) applied to male stitchbird visits and time spent on the nest per hour. Significant effects in bold.

	Visits per hour		Time on per hour (natural log)	
Parameter	Estimate (s.e.)	p	Estimate (s.e.)	p
Fixed:				
Brood Age (a)	-0.013 (0.007)	>0.05	-0.047 (0.014)	**<0.05**
Fledging Success (b)	0.374 (0.086)	**<0.05**	0.768 (0.210)	**<0.05**
Management (c)	0.078 (0.274)	>0.05	0.110 (0.656)	>0.05
Random Variance Estimates:				
Island	0.000 (0.000)	>0.05	0.000 (0.000)	>0.05
Nest	0.632 (0.120)	**<0.05**	4.437 (0.729)	**<0.05**
Observation	2.239 (0.101)	**<0.01**	8.221 (0.371)	**<0.01**

2.4 Discussion

Individual stitchbirds showed significant variation in nest provisioning behaviour. I suggest this variation in parental investment along with the species ability to vary its mating system has enabled this species to establish new populations, in sub-optimal translocation sites, with the aid of conservation management.

Stitchbird reproductive success and maternal investment both showed significant increases when their habitat is under conservation management. This management, through the provisioning of nest boxes and sugar-water feeders, showed a clear effect of being able to enhance the modified habitats of Mokoia, Tiritiri Matangi and Kapiti Islands. Little Barrier appears to be the only population where unmodified habitat seems to be able to support a high enough level of visitation and fledging success to sustain the population without management. Due to the intensity of research involved in recording stitchbird reproductive success and parental investment, across multiple populations, I was unable to present data for each of the island populations from the same season. This presents a shortcoming to this study as a year effect could not be distinguished from an island effect. Using a managed versus unmanaged approach to interpret these data allowed for a larger sample size (with both samples containing multiple years) in both groups reducing the effect of this limitation.

The survival estimates from Kapiti Island, during the period prior to management, showed that the population was in decline (Taylor *et al.* 2005). Fledging success data collected over the same period suggested that the low fledging rate of the Kapiti population during its unmanaged years was contributing to the population decline. The Mokoia population also declined after management was halted. This decline was believed to be caused by an interaction between food shortages, due to the low diversity of food plants in the habitat (Perrott & Armstrong 2000), and low adult survival due to disease (Alley *et al.* 1999; Armstrong *et al.* submitted). There was only a small difference (a mean of less than one chick per nest) in the fledging success of the declining Kapiti population and the self-sustaining Little Barrier Island population. Therefore, to better understand the factors responsible for the persistence of stitchbird on Little Barrier Island more data need to be collected on the demographics of this population across multiple years. This will enable us to model the population dynamics to gain a better understanding of effects of further harvesting from this population.

Many studies have identified food as a limiting factor to reproductive success (Arcese & Smith 1988; Castro *et al.* 2003). Food limitation is also known to affect the level of parental investment (Cantoni & Brown 1997). Management, to improve food limitation in the lower quality habitats of Kapiti, Tiritiri Matangi and Mokoia islands, apparently has no effect on male provisioning behaviour, but under management, females significantly increase both the visitation rate and the time spent on the nest.

Several studies have found that male provisioning of offspring is often more variable and reduced relative to that of females, with males being more likely to reduce investment in a current brood to take advantage of future mating opportunities (Moller & Thornhill 1998; Ligon 1999; Magrath & Komdeur 2003). Male stitchbirds share this variability and reduction in investment relative to females (Castro *et al.* 1996; Low *et al.* 2006) and this could explain the lack of effect of management on males. In addition, male stitchbird visitation rate has also been found to be correlated with perceived certainty of paternity (Ewen & Armstrong 2000).

With an increased availability of carbohydrate food in managed populations, females appear to increase their investment in provisioning chicks, and this appears to increase reproductive success. Therefore in unmanaged populations, where a range of habitats can be found, females may be forced to make choices between survival and investment in the poorer habitats. Castro & Brunton (in prep) showed that females stitchbirds with a constant, high quality and nearby food source made significantly shorter but more frequent incubating and feeding bouts to nests. They suggested that this strategy may allow for better winter survival. This is a common theme in animal life history theory with all species having to weigh up a trade-off between current reproduction and survival to maximize their fitness (McNamara & Houston 1996).

When both sexes increase investment, nests tend to experience a higher fledging success. Greater parental investment has been shown to increase reproductive output in many species and the difference between individual parents has been shown to be exaggerated in lower quality habitats (Henderson & Hart 1993). Castro *et al.* (2003) found food supplementation increased the number of eggs stitchbirds laid per nesting attempt, while both Castro *et al.* (2003) and Low *et al.* (2006) found increased investment in nests with larger clutch size and by older birds. These results suggest some caution should be taken when interpreting the results presented here, as neither clutch size (in terms of the number of eggs laid) nor parent age could be controlled for on Little Barrier Island.

Parental investment depends on a number of interacting variables. This is exemplified in my results when time on the nest per hour is first examined on its own in terms of fledging success and then analysed in conjunction to other factors known to affect reproductive success using the multilevel model. In the direct comparison, the number of chicks fledged is negatively correlated with female time on the nest. However, when using the multi-level model it becomes apparent that females that spent longer on the nest per hour fledge more chicks. The direct comparison between these factors did not consider other factors, such as the age of the brood which can change the relationship between given factors. This shows the advantage of multi-level modelling, which allows the interaction and variation between variables to be considered and therefore allows for a more realistic interpretation of the results.

When all the variables measured are considered, time on the nest is longer for both members of the pair when chicks are younger. This result was expected for females because older chicks are generally larger and require less brooding (Skutch 1976). Therefore visits change from longer *brooding* visits to shorter *feeding* visits as chicks get older. This result was more unexpected for the males, who are generally accepted to be less involved in brooding and more involved with feeding during nest visits (Isabel Castro pers. comm.). However, male visitation may involve different behaviours when chicks are younger, such as the removal of faecal sacs, which may account for the longer time spent in the nest per hour. This nest-cleaning behaviour is required less as chicks get older due to their increased mobility and ability to defecate over the edge of the nest (Isabel Castro pers. comm.).

In many species, increased paternal investment has been shown to offset some of the increased food demand of larger clutches (Moreno *et al.* 1995). My results show that an increase in paternal investment is associated with a higher fledging success. Increased paternal investment could also result in higher female survival over the winter as a result of a lighter maternal load. This may benefit males as female stitchbird reproductive success increases with age (Castro *et al.* 2003) and mate fidelity between years is high, as long as both partners survive to the next breeding season (Higgins *et al.* 2001). Therefore by increasing his investment a male could help ensure the survival of his partner which may result in a higher lifetime reproductive success.

Stitchbird behaviour is highly variable with both sexes being influenced by many different social and environmental factors. The data presented here suggest habitat quality has a direct effect on parental investment and reproductive success. Lower quality habitats increase the likelihood of parents trading off their own survival with current and future reproduction, though for this species conservation managers appear to have successfully offset the restrictions of low quality habitat by enhancing habitats to a higher quality than natural environments allow.

2.5 References

Alley, M. R., I. Castro, and J. E. B. Hunter. 1999. Aspergillosis in hihi (*Notiomystis cincta*) on Mokoia Island. New Zealand Veterinary Journal **47**:88-91.

Andrews, P. 1992. Mokoia: A brief history. Bibliophil, Rotorua.

Angehr, G. R. 1984. Ecology and behaviour of the Stitchbird with recommendations for management and future research. New Zealand Wildlife Service, Wellington.

Arcese, P., and J. N. M. Smith. 1988. Effects of population density and supplemental food on reproduction in Song Sparrows. Journal of Animal Ecology **57**:119-136.

Armstrong, D. P., I. Castro, J. C. Alley, B. Feenstra, and J. K. Perrott. 1999. Mortality and behaviour of hihi, an endangered New Zealand honeyeater, in the establishment phase following translocation. Biological Conservation **89**:329-339.

Armstrong, D. P., I. Castro, and R. Griffiths. submitted. Combining experimental management with population viability analysis to decide future management of a reintroduced hihi population. Conservation Biology.

Armstrong, D. P., R. S. Davidson, W. J. Dimond, J. K. Perrott, I. Castro, J. G. Ewen, R. Griffiths, and J. Taylor. 2002. Population dynamics of reintroduced forest birds on New Zealand islands. Journal of Biogeography **29**:609-621.

Armstrong, D. P., and J. G. Ewen. 2001. Testing for food limitation in reintroduced Hihi populations: Contrasting results for two islands. Pacific Conservation Biology. **7(2)**:87-92.

Armstrong, D. P., and J. K. Perrott. 2000. An experiment testing whether condition and survival are limited by food supply in a reintroduced Hihi population. Conservation Biology **14**:1171-1181.

Barr, B., and G. Moorcroft. 2003. Management of Stitchbird (*Notiomystis cincta*) on Kapiti Island - 2002/2003. The Department of Conservation, Wellington, N.Z.

Blondel, J., P. C. Dias, M. Maistre, and P. Perret. 1993. Habitat heterogeneity and life history variation of Mediterranean Blue Tits (*Parus caeruleus*). Auk **110**:511-520.

Bollmann, K., H. U. Reyer, and P. A. Brodmann. 1997. Territory quality and reproductive success: Can water pipits *Anthus spinoletta* assess the relationship reliably? Ardea **85**:83-98.

Bro, E., P. Mayot, E. Corda, and F. Reitz. 2004. Impact of habitat management on grey partridge populations: assessing wildlife cover using a multisite BACI experiment. Journal of Applied Ecology **41**:846-857.

Cantoni, D., and R. E. Brown. 1997. Paternal investment and reproductive success in the California mouse, *Peromyscus californicus*. Animal Behaviour **54**:377-386.

Castro, I. 1995. Behavioural ecology and management of Hihi *Notiomystis cincta*, an endemic New Zealand honeyeater. PhD Thesis, Massey University, Palmerston North.

Castro, I., J. C. Alley, R. A. Empson, and E. O. Minot. 1994a. Translocation of Hihi or Stitchbird *Notiomystis cincta* to Kapiti Island, New Zealand: transfer techniques and comparison of release strategies. Pages 113-120 *In* M. Serena, editor. Reintroduction biology of Australian and New Zealand fauna. Surrey Beatty & Sons, Chipping Norton.

Castro, I., and D. H. Brunton. in prep. Effects of life history traits and food supplementation on female Hihi (*Notiomystis cincta*) parental behaviour.

Castro, I., D. H. Brunton, K. M. Mason, B. Ebert, and R. Griffiths. 2003. Life history traits and food supplementation affect productivity in a translocated population of the endangered hihi (stitchbird, *Notiomystis cincta*). Biological Conservation **114**:271-280.

Castro, I., K. M. Mason, D. P. Armstrong, and D. M. Lambert. 2004. Effect of extra-pair paternity on effective population size in a reintroduced population of the endangered hihi, and potential for behavioural management. Conservation Genetics **5**:381-393.

Castro, I., E. O. Minot, and J. C. Alley. 1994b. Feeding and breeding behaviour of Hihi or Stitchbirds *Notiomystis cincta* recently transferred to Kapiti Island, New Zealand, and possible management alternatives. Pages 121-128 *In* M. Serena, editor. Reintroduction biology of Australian and New Zealand fauna. Surrey Beatty and Sons, Chipping Norton.

Castro, I., E. O. Minot, R. A. Fordham, and T. R. Birkhead. 1996. Polygynandry, face-to-face copulation and sperm competition in the Hihi *Notiomystis cincta* (Aves: Meliphagidae). Ibis **138**:765-771.

Castro, I., A. Noble, and K. M. Mason. in prep. Paternity, certainty of paternity, paternity effort and benefits of paternal care in Hihi.

Caughley, G. 1994. Directions in conservation biology. Journal of Animal Ecology **63**:215-244.

Cowan, P. E. 1993. Effects of intensive trapping on breeding and age structure of Brushtail Possums, *Trichosurus vulpecula*, on Kapiti Island, New Zealand. New Zealand Journal of Zoology **20**:1-11.

Empson, R. A., and C. M. Miskelly. 1999. The risks, costs and benefits of using brodifacoum to eradicate rats from Kapiti Island, New Zealand. New Zealand Journal of Ecology **23**:241-254.

Ewen, J. G. 1998. A genetic and behavioural investigation of extra-pair copulation in stitchbirds (*Notiomystis cincta*) breeding on Tiritiri Matangi Island. MSc Thesis, Massey University, Palmerston North.

Ewen, J. G., and D. P. Armstrong. 2000. Male provisioning is negatively correlated with attempted extrapair copulation frequency in the stitchbird (or hihi). Animal Behaviour **60**:429-433.

Garcia, J. T. 2003. Is female investment in defense correlated with breeding success in Hen Harriers *Circus cyaneus*? Bird Study **50**:142-145.

Gorman, N., and G. Moorcroft. 2005. Management of Stitchbird (*Notiomystis cincta*) on Kapiti Island - 2004/2005. The Department of Conservation, Wellington, New Zealand.

Hamilton, W. M. 1961. Little Barrier Island (Hauturu). Government Printer, Wellington, New Zealand.

Hawley, J. 1997. Tiritiri Matangi working plan. Department of Conservation, Auckland, New Zealand.

Henderson, I. G., and P. J. B. Hart. 1993. Provisioning, parental investment and reproductive success in Jackdaws *Corvus monedula*. Ornis Scandinavica **24**:142-148.

Higgins, P. J., J. M. Peter, and W. K. Steele 2001. Stitchbird (hihi). *In* Handbook of Australian, New Zealand and Antarctic Birds, Vol. 5 Tyrant-flycatchers to Chats, pp. 954-966. Oxford University Press, Melbourne.

Howard, M., and G. Moorcroft. 2004. Management of Stitchbird (*Notiomystis cincta*) on Kapiti Island - 2003/2004. The Department of Conservation, Wellington, New Zealand.

Knegtmans, J., R. Stamp, and J. Newell. 2001. Kapiti Island Stitchbird (*Notiomystis cincta*) 2000/2001. Department of Conservation, Wellington, New Zealand.

Ligon, D. J. 1999. The evolution of avian breeding systems. Oxford University Press, Oxford.

Lovegrove, T. 1986. Stitchbirds on Kapiti Island 1983-1985. Internal report to the New Zealand Department of Conservation, Wellington.

Low, M. 2004. The behavioural ecology of forced copulation in the New Zealand Stitchbird (hihi). PhD Thesis, Massey University, Palmerston North.

Low, M., M. K. Joy, and T. D. Makan. 2006. Using regression trees to predict male provisioning of offspring in the stitchbird (hihi). Animal Behaviour **71**: 1057-1068.

Lycett, J. E., S. P. Henzi, and L. Barrett. 1998. Maternal investment in mountain baboons and the hypothesis of reduced care. Behavioral Ecology and Sociobiology **42**:49-56.

Magrath, M. J. L., and J. Komdeur. 2003. Is male care compromised by additional mating opportunity? Trends in Ecology & Evolution **18**:424-430.

Mann, J., R. C. Connor, L. M. Barre, and M. R. Heithaus. 2000. Female reproductive success in bottlenose dolphins (*Tursiops sp.*): life history, habitat, provisioning, and group-size effects. Behavioral Ecology **11**:210-219.

McNamara, J. M., and A. I. Houston. 1996. State-dependent life histories. Nature **380**:215-221.

Moller, A. P., and R. Thornhill. 1998. Male parental care, differential parental investment by females and sexual selection. Animal Behaviour **55**:1507-1515.

Moreno, J., R. J. Cowie, J. J. Sanz, and R. S. R. Williams. 1995. Differential response by males and females to brood manipulations in the Pied Flycatcher – energy expenditure and nestling diet. Journal of Animal Ecology **64**:721-732.

Newell, J., and G. Moorcroft. 2002. Management of Stitchbird (*Notiomystis cincta*) on Kapiti Island - 2001/2002. The Department of Conservation, Wellington, New Zealand.

Newton, I. 1998. Population limitation in birds. Academic Press, London.

Perrott, J. K. 1997. Effects of food supply and competition on the outcome of Hihi (*Notiomystis cincta*) translocated to Mokoia Island. MSc Thesis, Massey University, Palmerston North.

Perrott, J. K., and D. P. Armstrong. 2000. Vegetation composition and phenology of Mokoia Island, and implications for the reintroduced hihi population. New Zealand Journal of Ecology **24**:19-30.

Pulliam, H. R., and B. J. Danielson. 1991. Sources, sinks, and habitat selection - a landscape perspective on population dynamics. American Naturalist **137**: 50-66.

Rasbash, J., W. Browne, H. Goldstein, M. Yang, I. Plewis, M. Healy, G. Woodhouse, D. Draper, I. Langford, and T. Lewis 2000. A user's guide to MLwiN (Second Edition). Institute of Education, London.

Rasch, G. 1991. A recovery plan for the Stitchbird (*Notiomystis cincta*). Internal report to the New Zealand Department of Conservation, Wellington.

Rimmer, A. 2004. Tiritiri Matangi Island: A model of conservation. Tandem Press, Auckland.

Skutch, A. F. 1976. Parent birds and their young. University of Texas Press, Austin, USA.

SPSS Inc. 2004. SPSS for windows version 13. SPSS Inc. Chicago, Illinois, USA.

Taylor, S., and I. Castro. 2000. Hihi standard operating procedures. Department of Conservation, Auckland, New Zealand.

Taylor, S., I. Castro, and R. Griffiths. 2005. Hihi/Stitchbird (*Notiomystis cincta*) Recovery Plan 2004-09. Department of Conservation, Wellington, New Zealand.

Thorogood, R. 2005. Decisions mothers take: Hihi maternal investment. MSc Thesis, University of Auckland, Auckland.

Towns, D. R., I. A. E. Atkinson, and C. H. Daugherty 1990. The ecological restoration of New Zealand islands. Department of Conservation, Wellington, New Zealand.

Tremblay, I., D. Thomas, J. Blondel, P. Perret, and M. M. Lambrechts. 2005. The effect of habitat quality on foraging patterns, provisioning rate and nestling growth in Corsican Blue Tits *Parus caeruleus*. Ibis **147**:17-24.

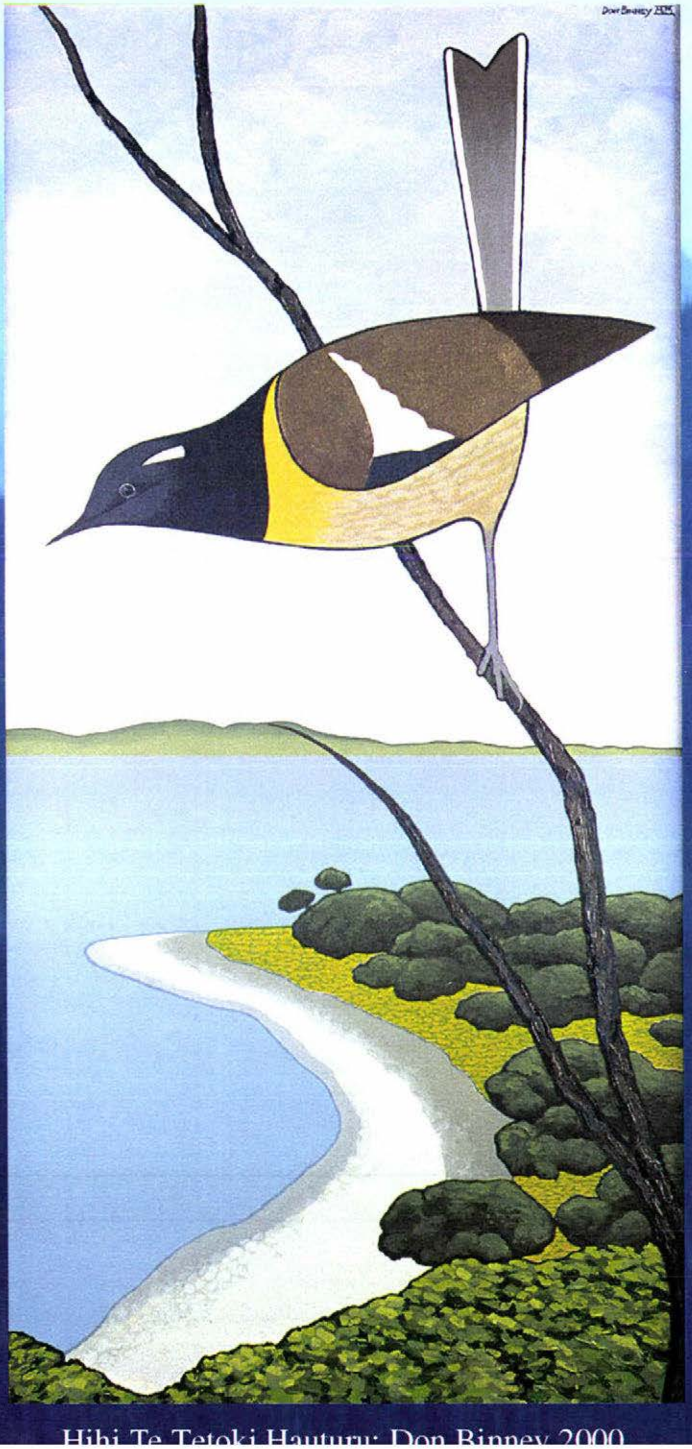
Veitch, C. R. 2001. The eradication of feral cats (*Felis catus*) from Little Barrier Island, New Zealand. New Zealand Journal of Zoology **28**:1-12.

Veitch, C. R., and B. Bell. 1990. Eradication of introduced animals from the islands of New Zealand. In D. R. Towns, I. A. E. Atkinson, and C. H. Daugherty. Ecological restoration of New Zealands islands. Department of Conservation, Wellington, New Zealand.

Weidinger, K. 2000. The breeding performance of blackcap *Sylvia atricapilla* in two types of forest habitat. Ardea **88**:225-233.

Zink, A. G. 2003. Quantifying the costs and benefits of parental care in female treehoppers. Behavioral Ecology **14**:687-693.

The effect of habitat quality and structure on the reproductive success of the Stitchbird (Hihi - *Notiomystis cincta*): A population comparison



Hihi Te Tetoki Hauturu: Don Binney 2000

3

The effect of habitat quality and structure on the reproductive success of the Stitchbird (Hihi - *Notiomystis cincta*): A population comparison

3.1 Introduction

Human destruction and degradation of habitat worldwide has led to the extinction of many species (Wilson 1988). This vast reduction in available habitat has increased the competition between animals and the pressure to select and defend a territory, which has important consequences for individuals' survival and reproduction (Cody 1985).

This pattern of choice is shaped by natural selection and depends on some individuals claiming preferable habitat (Newton 1998; Luck 2002a). As the density in these populations increases an increasing proportion of individuals are pushed down the habitat gradient into lower quality or less preferred habitat, where their survival or reproductive success may be reduced (Newton 1998; Misenhelter & Rotenberry 2000; Luck 2002a). For example there is variation in the amount of resources available to nesting birds and amongst potential breeding habitats, which can lead to variations in reproductive success (Hogstedt 1980; Luck 2002a).

The quality or amount of resources provided by a habitat can vary markedly. This variation in resource availability can be produced through the different spatial configuration, productivity and diversity of vegetation (Smith & Shugart 1987; Halaj *et al.* 2000). Many studies have shown a positive association between habitat quality and reproductive success (Ens *et al.* 1992; Dias *et al.* 1994; Dias 1996). However, structural habitat characteristics are not always the best predictors of reproductive success and researchers may need to consider other factors such as competition and predation (Hatchwell *et al.* 1996; Aho *et al.* 1999). Vegetation structure also provides birds with various opportunities and constraints influencing the detection and acquisition of invertebrate prey (Robinson & Holmes 1982).

The assessment of habitat requirements and the factors that influence the associated reproductive success in habitat patches is complex and has been approached in a variety of ways. These include the observation of clusters of successful nests (Hochachka *et al.* 1989), the ranking of territories on the basis of permanency or priority of occupancy (Bensch & Hasselquist 1991) and identification of specific habitat features related to success (Komdeur 1992; Armstrong *et al.* 1999).

Despite the large number of possible explanatory variables and the potential complexity of these relationships, most of these studies have focussed on univariate analyses, or have assessed the relative effect of several independent variables by using a multivariate linear model. Low *et al.* (2006) identify weaknesses in this approach and suggest the use of classification and regression trees as a better statistical approach. Regression trees are an effective way to explore complex ecological data that may include a lack of balance, nonlinear relationships between variables, and higher order interactions (De'ath & Fabricius 2000). They also allow the relationships between variables to be explored graphically, this type of display is easily interpreted by a wider audience (other than scientists) making it a good management tool.

The stitchbird is a species whose range once encompassed the North Island of New Zealand but then became confined to a single small island (Little Barrier Island) population. It has been suggested that the extinction of this species from its previous range was caused by an array of environmental factors, including predation, disease and severe habitat loss. Due to a concerted conservation recovery programme, multiple populations have now been established through translocation to suitable predator-free areas (Taylor *et al.* 2005). However, these translocations have been either unsuccessful or have required the aid of management, mainly through supplementary feeding and provision of nesting boxes, as a way of artificially enhancing habitats at the translocation sites. Angher (1984), Lovegrove (1986) and Rasch (1991) hypothesized that the cause of failure of these translocations was an inadequate year-round supply of carbohydrate food (nectar and fruit) due to human induced impacts on the forest habitat, including forest clearance and modification by introduced mammalian herbivores.

The effect of supplementary food on the reproductive success of stitchbird has been examined in several studies (Castro 1995; Perrott 1997; Armstrong & Perrott 2000; Armstrong & Ewen 2001; Castro *et al.* 2003; Thorogood 2005; Castro & Brunton in prep). This effect has also been analysed in connection to habitat management in the translocated populations (Castro *et al.* 1994a; Armstrong *et al.* 2002; Armstrong *et al.* submitted). These studies found that food can limit stitchbird reproductive success, and that there are periods when natural food sources are limited for stitchbird in some locations, supporting the hypothesis that habitat quality, structure and composition may be limiting the translocated populations. However, there is limited information regarding reproductive success of the species in the one remaining unmanaged population on Little Barrier Island.

Information gathered from Little Barrier Island may be crucial for the search to find locations where self-sustaining populations of stitchbird can be established. To fill this gap in the knowledge, this study aimed to collect comparative information on reproductive success and habitat of the unmanaged populations on Kapiti Island (before management begun) and on Little Barrier Island.

3.2 Methods

3.2.1 Study sites

3.2.1.1 Little Barrier Island

Little Barrier Island (Figures 1.1 & 3.1) is a 3083 hectare nature reserve in the Hauraki Gulf, 80 km north of Auckland. Until recovery efforts were started in the early 1980's, Little Barrier held the world's only population of Stitchbird. Little Barrier Island has some of the most pristine forest habitat in New Zealand, with some parts of the island having no evidence of human disturbance and the whole island having had little impact from humans for about 150 years (Hamilton 1961).

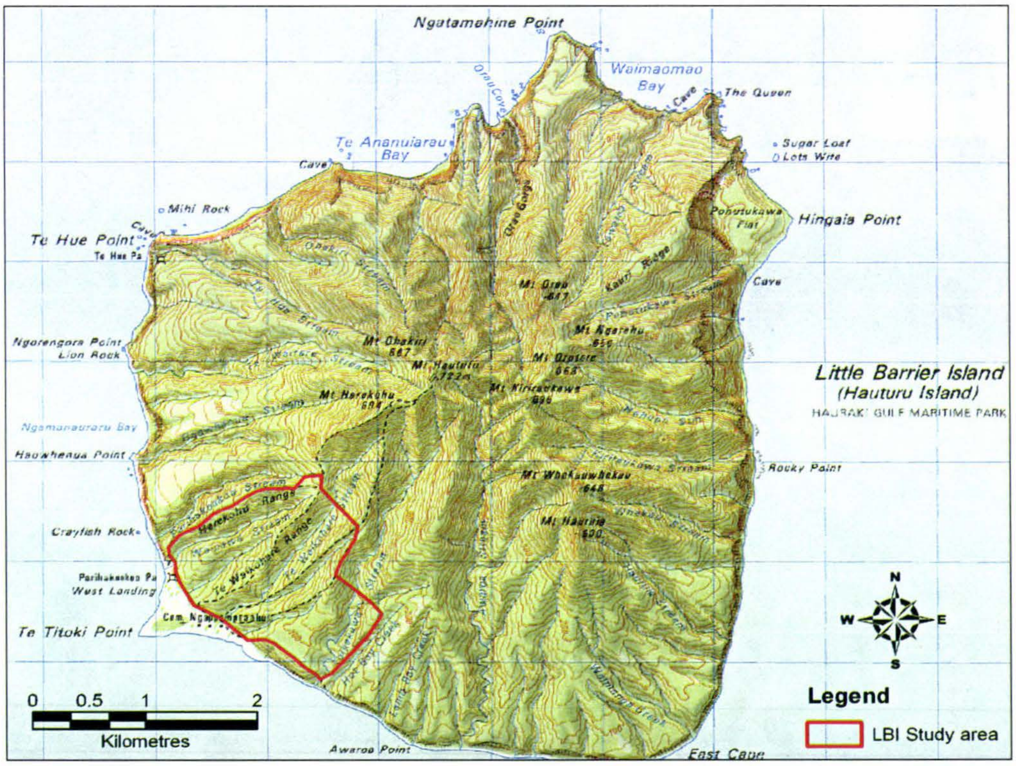


Figure 3.1: Map of Little Barrier Island with the study site shown on the south-western side of the island (Modified from Land Information New Zealand NZMS 260 series).

Cats (*Felis catus*) and the pacific rat or kiore (*Rattus exulans*) were the only exotic predators to reach the island, with both being eradicated prior to this study - cats in 1980

(Veitch 2001), and a poisoning operation was completed for kiore in winter of 2004 (Richard Griffiths pers. comm.).

My study site on the island was a 230 hectare area of forest on the south western corner of the island (Figure 3.1). This area encompassed the Waipawa catchment and the lower portion of both the Te Waikohare and the Tirikakawa catchments. The study area is covered by four forest types, as defined by Hamilton (1961), including Rata/Tawa forest, Kauri forest, Pohutukawa/Broad-leaved forest and Leptospermum forest (now classified as *Kunzea* forest).

3.2.1.2 Kapiti Island

Kapiti Island (Figures 1.1 & 3.2) is 1965 hectares and lies 5km off the Wellington coast line. The island was largely cleared of forest in the early 1800's, but was designated as a nature reserve in the early 1900's and has been naturally regenerating ever since. Mammalian predators were present on the island until 1996 with the Australian brushtail possum (*Trichosurus vulpecula*) being eradicated in 1986 (Cowan 1993) followed by the two species of rat, the Norway rat (*Rattus norvegicus*) and kiore in 1996 (Empson & Miskelly 1999). Stitchbirds were established on the island through a series of six translocations from 1983 to 1992 (Lovegrove 1986; Castro *et al.* 1994a; Taylor *et al.* 2005). There was no management following the stitchbird translocations to Kapiti Island until 1991. The population was provided with seven supplementary sugar-water feeders (20% sugar by volume) for the four weeks following the 1991 and 1992 translocations to enable monitoring (Castro *et al.* 1994a). Following that, the island ranger continued to maintain a single feeder at his residence year round which was commonly used by most stitchbirds on the island, until 1998 when all feeding was halted. Subsequently the population went into a gradual decline until supplementary feeding as a management strategy resumed in 2000 (Taylor *et al.* 2005).

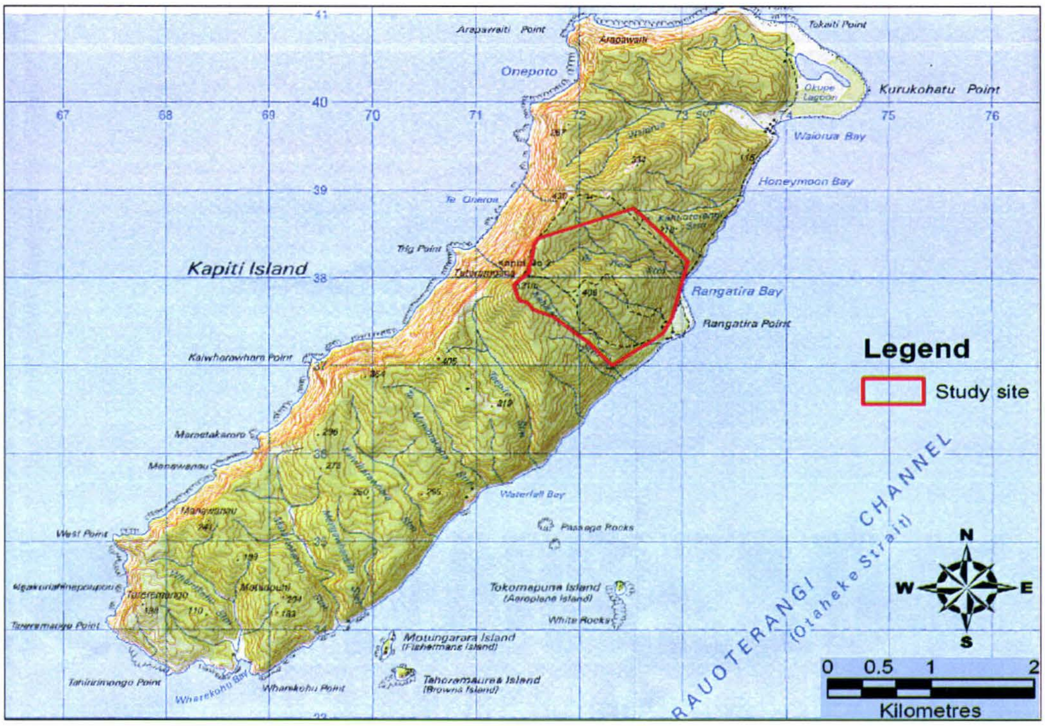


Figure 3.2: Map of Kapiti Island with the study site shown on the central western section of the island (Modified from Land Information New Zealand NZMS 260 series).

My study area on the island was a 185 hectare area of forest on the central western section of the island (Figure 3.2). This area encompassed the core area of Kapiti Island consisting of the Kahikatea and Te Rere catchments. The study area consisted of six forest types, as defined by Fuller (1985), including Kohekohe forest, Kanuka scrub and forest, Tawa/Hinau forest, Five-finger dominated communities, Mahoe forest and Kamahi/Tawa forest.

3.2.2 Study species

For information on the ecology of the stitchbird see Chapter One. All stitchbirds on Kapiti Island were colour-banded, as part of ongoing management, for individual identification. On Little Barrier Island there were very few colour-banded birds and only one pair of banded birds was observed in this study. In some cases, stitchbird have been shown to adopt a variety of polygamous mating systems, where two or more birds of one sex have been shown to care for young (Castro *et al.* 1994a; Castro *et al.* 1996). Therefore, on Little Barrier Island it was assumed that all individuals recorded visiting each nest were the parent birds. Because of the impossibility to differentiate among males, I calculated paternal visitation and time spent in the nest as if there was a single male visiting each nest.

3.2.3 Habitat transects

All the habitat variables presented below were collected at nest sites during the 2004/05 breeding season. The method used was an adaptation of the height-frequency method described by Scott (1965). Once a nest was found, 80-metre transects were run in five different, randomly generated directions radiating from the nest site. Random directions were selected from a list of random numbers if a new direction was within ten degrees of a previous transect then it would be ignored and a new direction was selected.

Along each transect, points were sampled every four metres (Figure 3.3). At each point an imaginary cylinder (10cm radius) was projected into the canopy, the height-frequency of all species was then recorded by noting the presence of any foliage in each two metre tier, with 0-30cm being used as an additional ground cover tier. A two-metre measuring pole was used as a mid-point from which to project the cylinder, for the ground tier and for the 30cm-to-2m tier. This pole was then held at a height of two metres and again used as the mid point for the 2-4m tier with tier heights and the projection of the cylinder being estimated by eye from four metres and above.

Table 3.1: Example data sheet for the 4m, 8m and 12m sampling points, in Figure 3.3.

Tier	**4m**	**8m**	**12m**
0-30cm			Grass A
30cm-2m	Shrub A, Tree fern		
2-4m	Shrub A		
4-6m	Tawa		Tree fern
6-8m	Tawa		Tawa
8-10m	Tawa		Tawa
10-12m	Tawa, Hinau	Hinau	Tawa, Hinau
12-14m	Hinau	Hinau	Hinau
14-16m	Hinau, Rimu	Hinau	Hinau
16-18m	Rimu	Hinau	Nikau
18-20m	Rimu	Hinau	Nikau
20-22m	Rimu		
22-24m	Rimu		

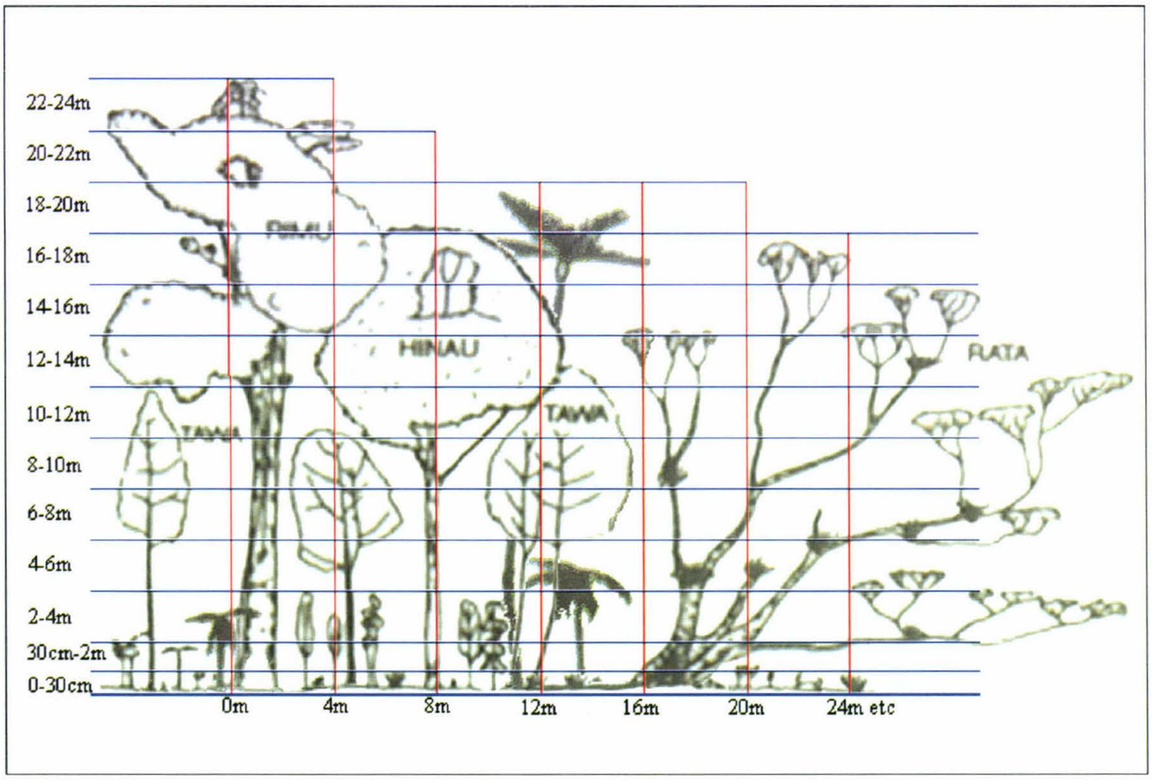


Figure 3.3: Example habitat transect showing height classes and the first 24 metres along the tape line. The nest is located at 0m along the transect.

3.2.4 Reproductive success

Reproductive success was measured as the total number of chicks found to have fledged from a given nest.

3.2.4.1 Little Barrier Island

Stitchbird productivity data were collected from 23 first-clutch nests over the 2004/05 breeding season. Nest trees were located at the beginning of the breeding season by identifying the areas where males were territorially calling. Observations of the nesting pair at these locations led to the nesting cavity (Taylor & Castro 2000b; Taylor *et al.* 2005). Once the cavity entrance was found the tree was climbed to inspect the nest contents using an endoscope. Observations of adult parental behaviour (see section: 2.2.4 Parental Investment) together with finding of egg shells under the cavity entrance allowed the estimation of the hatching date (Taylor & Castro 2000b). From 28 days after hatching the nests were visited every day, to check for fledglings. Once the chicks fledged they were located and counted to estimate the final productivity of each nest.

3.2.4.2 Kapiti Island

Stitchbird productivity data were collected from 13 first-clutch nests on Kapiti Island during the 1992/93 and 1993/94 stitchbird breeding seasons, as part of Isabel Castro's doctoral research (Castro 1995). Like Little Barrier Island, productivity was measured by locating nest trees at the beginning of the breeding season. Once found, behavioural watches where done to assess parental behaviour and estimate hatching date. Nests were then visited regularly until fledging to determine the number of chicks fledged.

3.2.5 Habitat variables

Table 3.2: Method of measurement and description of habitat variables used in this study. The character of the variables is donated by B= biotic and P= Physical and the type by N= numeric or C= categorical.

Variable	Levels of trait	Character	Type	Value ranges
Island	Either Little Barrier (LBI) or Kapiti Island (KI).	P	C	LBI or KI
Rich	Total number of plant species summed across all five vegetation transects at each nest site.	B	N	26 – 54
S-W	A single Shannon-Weiner diversity index was calculated for the vegetation data from the summed values for all five transects at each nest site.	B	N	2.39 - 3.47
Physiog	The physiography at each nest site was recorded as ridge, face or gully.	P	C	Face, Gully or Ridge
DBH	The diameter at breast height (measured in centimetres) of the each nest tree.	B	N	36 – 230cm
Alt	A single altitude reading was taken (using a calibrated altimeter) at each nest site.	P	N	18 – 320 m
Asp	A single measure of the direction of the slope at the nest site was recorded as north (N), south (S), east (E) or west (W).	P	C	North, East, South or West
Comp	Habitat complexity was calculated as a single summed height-frequency value. This was derived for each nest site by summing the occurrences of all species in all tiers along each transect. The summed values for all five transects at a site were then combined.	B	C	395 - 623
Ground	Ground tier was calculated as the complexity of the 0 to 30cm tier.	B	C	33 - 77
Shrub	Shrub tier was calculated as the complexity of the 30cm to 6m tier.	B	C	94 - 285
SubCan	Sub-canopy tier was calculated as the complexity of the 6 to 12m tier.	B	C	82 - 248
Can	Canopy tier was calculated as the complexity of the 12 to 26m tier.	B	C	10 - 231
Emerg	Emergent tier was calculated as the complexity of the 26+m tier.	B	C	0 - 17

3.2.6 Statistical analysis

3.2.6.1 Regression tree analysis

Two regression tree analyses were used to examine the relationship between fledging success and the thirteen explanatory variables (Table 3.2). The first tree examined the relationship between the habitat variables; island, richness, Shannon's index, physiography, DBH, altitude, aspect and overall habitat complexity with nest fledging success. The second tree analysed the same variables but with habitat complexity broken down by height tiers.

Both trees were first modelled at maximum size and then pruned back to a smaller number of nodes using a tree-optimising procedure. This process is necessary when building regression trees, as a large tree which is over-fitted to the dataset may be very good at predicting the data used to build the model, but poorly predictive of any new data. Also, divisions made at a later stage of the tree are based on a dwindling dataset and are therefore more prone to be influence by "noise" in the data (De'ath & Fabricius 2000).

Cross validation of regression trees is a common method for the evaluation of the effectiveness of a model (De'ath 2002). To determine the optimal tree size, I attempted a leave-one-out cross-validation procedure (jack-knife) to chose the tree size that best predicted the excluded data. This method involved randomly excluding one observation, reconstructing the model and then predicting the response of the excluded observation. This was repeated for the entire dataset, generating a correlation coefficient derived from comparing predictions with observations for each tree size. The tree size with the highest correlation coefficient is then selected as the most effective model. Both regression tree analyses were completed using computer macros from the Statistics Toolbox in the MatLab® programming language (The MathWorks, Inc. © 1993- 2002: Natick, MA, USA)

One-way analysis of variance was done using the SAS statistical package (SAS Institute © 2002- 2003: Cary, NC, USA) to analyse the significance of the differences between the groups, at each split in the tree.

3.2.6.2 Generalized linear mixed model

The relationship between fledging success and the thirteen explanatory variables was also examined using a generalized linear mixed model, as a more traditional method which looks at the statistical significance of each explanatory variable.

The data were again assessed by two models; the first looking at all the habitat variables and overall habitat complexity, the second separating habitat complexity into five tiers. Both models were first built using all variables as fixed effects in the analysis except island. Little Barrier Island had on average 0.77 more chicks per nest than Kapiti Island, with the two populations being almost significantly different (ANOVA: $F_{1, 36} = 3.771$, $P = 0.06$). Therefore island was included as a random effect because it was thought that this difference should be considered in the analysis.

The full model was then compared, using Akaike's information criterion (AIC), with other biologically sensible combinations of variables to select those that best described the data. The model was built using a macro, GLIMMIX, in the SAS statistical package (SAS Institute © 2002- 2003: Cary, NC, USA).

3.3 Results

Using the cross validation procedure, I found that the predictive ability of the regression models was limited (the highest coefficient selected a tree size with no splits in the data). This result is explained by the small sample size available, due to the relative difficulty and amount of time required to find and observe nests. Therefore, trees were pruned manually to levels where each leaf (or end result) constituted a reasonable sample size (reducing any overtraining of the model De'ath & Fabricius 2000). Pruning allowed for sensible biological predictions at each node.

Until a larger sample size can be obtained the trees with their high r-squared values are a good tool for explaining the patterns in my data. However, caution should be taken when using them as predictive models

3.3.1 Regression tree analysis

3.3.1.1 Overall habitat complexity

When pruned to level three, regression tree analysis grouped the data relative to fledging success into six categories (Figure 3.4), with a predicted versus observed output from the model of $R^2 = 0.69$. Habitat complexity was the strongest predictor of fledging success with a complexity value over 593 producing significantly more chicks (Figure 3.4; ANOVA: $F_{1, 36} = 9.77$, $P < 0.01$). Habitat complexity again features at the second break which occurred at complexity = 498.5.

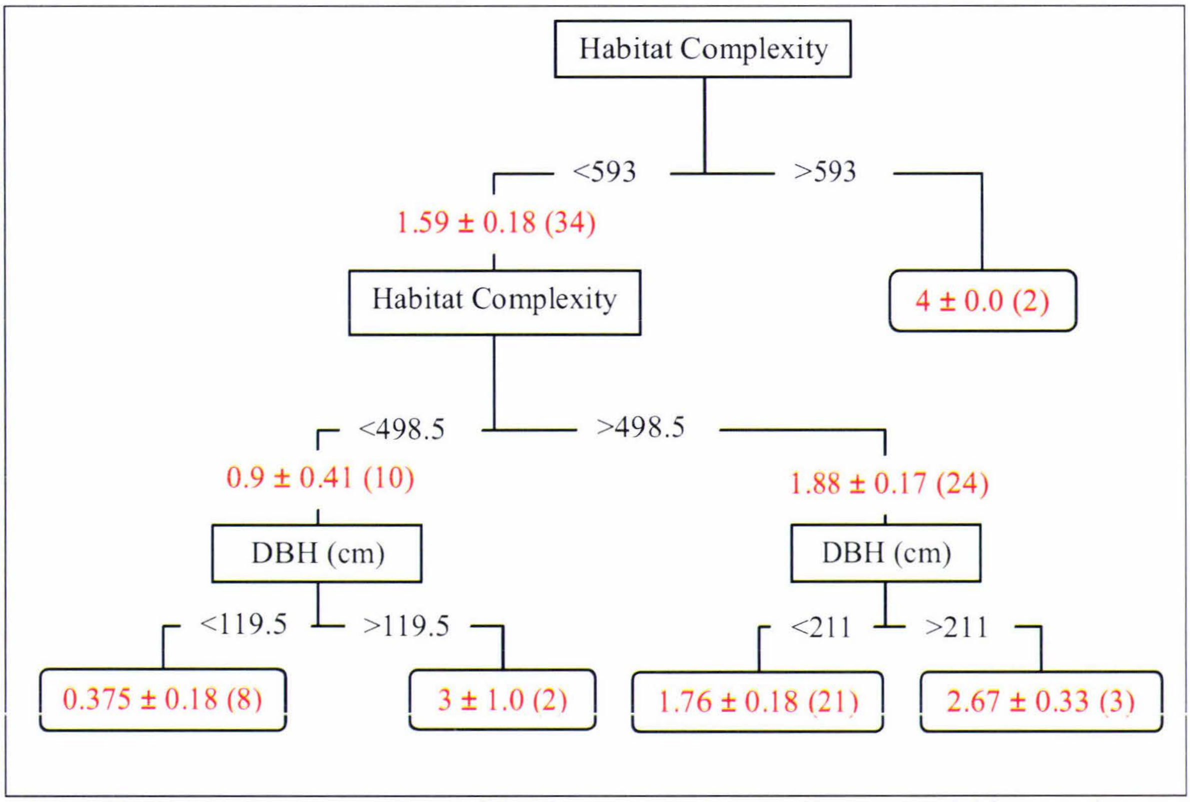


Figure 3.4: Regression tree of overall habitat complexity. Explanatory variables are shown in node boxes with the node split values shown in black. The values for the response variable, fledging success ± s.e. (n), are shown in red.

Nests with complexity under 498.5 produced significantly less chicks than those between 498.5 and 593 (Figure 3.4; ANOVA: $F_{1,34} = 5.083$, $P < 0.05$). With a complexity level of less than 498.5 the DBH of the nest tree also explained a significant difference in fledging success - nest trees with a DBH greater than 119.5 produced 2.6 more chicks on average (Figure 3.4; ANOVA: $F_{1,10} = 22.76$, $P < 0.01$). When complexity was between 498.5 and 593 the nest tree DBH also explained some variation in fledging success although it was not significant. Island was included in the analysis but it didn't turn out to be a strong predictor of fledging success.

3.3.1.2 Tiered Habitat Complexity

In the tiered data model, pruned to level two, regression tree analysis grouped the data relative to fledging success into four categories (Figure 3.5), with a predicted versus observed output from the model of $R^2 = 0.49$. The complexity of the sub-canopy tier was the strongest predictor of fledging success, a sub-canopy complexity over 150 produced significantly more chicks than less complex forest (Figure 3.5; ANOVA: $F_{1, 36} = 12.196$, $P < 0.01$).

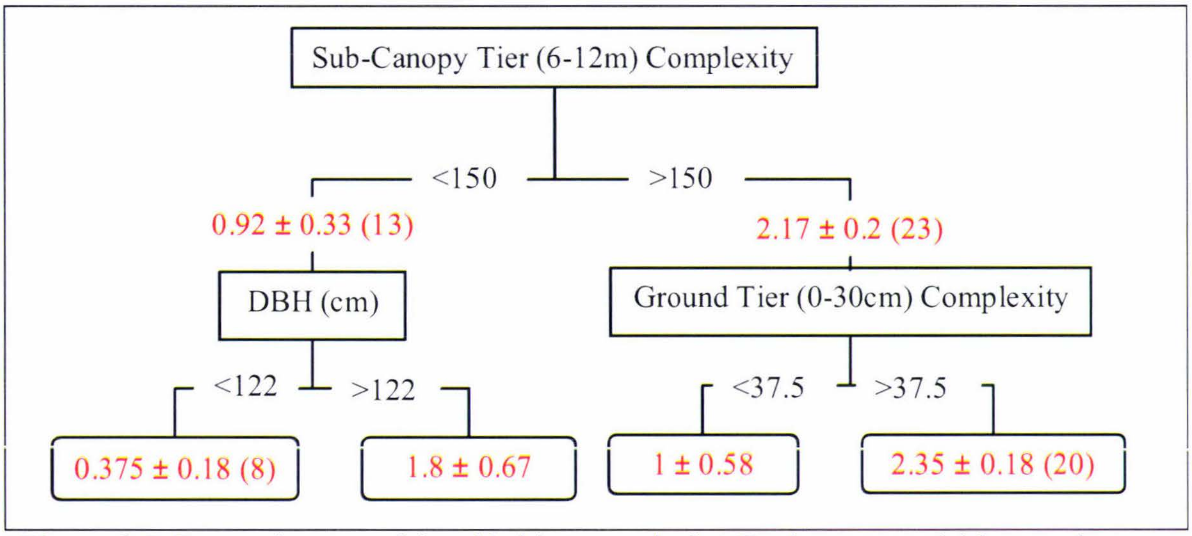


Figure 3.5: Regression tree of tiered habitat complexity. Explanatory variables are shown in node boxes with the node split values shown in black. The values for the response variable, fledging success ± s.e. (n), are shown in red.

When the sub-canopy complexity was over 150, the complexity of the ground-tier then became important with ground-tier complexity values over 37.5 producing significantly more chicks (Figure 3.5; ANOVA: $F_{1, 23} = 6.862$, $P < 0.05$). When sub-canopy complexity is less than 150 the DBH of the nest tree became important with larger DBH's producing significantly more chicks (Figure 3.5; ANOVA: $F_{1, 13} = 6.438$, $P < 0.05$). Island was included in the analysis but again it didn't turn out to be a strong predictor of fledging success.

3.3.2 Generalized linear mixed model

3.3.2.1 Overall Habitat Complexity

The best model was built using the single significant variable, complexity, along with island retained as a random effect (see above). Complexity showed a positive, highly significant effect on fledging success (Table 3.3).

Table 3.3: Estimation of the generalized linear mixed model looking at the effect of overall habitat complexity on stitchbird fledging success. Significant effects in bold.

Effect	Estimate (s.e.)	DF	*t*	p
Intercept	-3.51 (1.319)	1	-2.66	>0.05
Complexity	0.008 (0.002)	33	3.11	**<0.01**

3.3.2.2 Tiered Habitat Complexity

The best tiered complexity model was built using the single significant variable, Sub-canopy complexity, along with island being retained as a random effect (see above). Sub-canopy complexity showed a positive, highly significant effect on fledging success (Table 3.4).

Table 3.4: Estimation of the generalized linear mixed model looking at the effect of tiered habitat complexity on stitchbird fledging success. Significant effects in bold.

Effect	Estimate (s.e.)	DF	*t*	p
Intercept	-0.91 (0.507)	1	-1.79	>0.05
Sub-canopy	0.008 (0.003)	33	3.06	**<0.01**

3.4 Discussion

3.4.1 Habitat and reproductive success

Habitat complexity, in particular the complexity of the sub-canopy tier, shows a significant positive effect on fledging success in the 36 stitchbird nests from Little Barrier and Kapiti

Islands. Nest tree size and ground tier complexity were also important predictor variables, but notably, the island difference was not significant.

Many studies have shown habitat quality to be important to the reproductive output of birds (Conner *et al.* 1986; Matthysen 1990; Braden *et al.* 1997; Langen & Vehrencamp 1998; Davenport *et al.* 2000; Luck 2002a). This assessment of habitat quality often involves correlations between structural or floristic characteristics of the habitat with reproductive output (Hatchwell *et al.* 1996; Bollmann *et al.* 1997; Braden *et al.* 1997). These preferred structural characteristics have also been found to be positively correlated with the abundance of invertebrate prey and, therefore, suggest that measures of habitat structure, such as habitat complexity, provide proximate assessment of invertebrate food abundance and are a meaningful representation of habitat quality (Conner *et al.* 1986; Huhta *et al.* 1998; Halaj *et al.* 2000).

Anger (1984) and Wilson (1997) show that the competition among the honeyeater species leads to the partitioning of vertical space on both Little Barrier and Tiritiri Matangi Islands, with stitchbirds mainly utilizing the lower to mid layers of the forest. This could explain why the complexity of the sub-canopy has a significant effect on fledging success. Increased complexity in this layer may increase food availability and opportunities for obtaining prey items. This preference towards the mid-tiers may also explain the relative importance of the sub-canopy over the ground tier. However, the importance of the ground tier on fledging success could be due to the increased feeding opportunities made available in a more complex habitat. Brockie (1992) suggests there are higher numbers of invertebrates in this tier. Castro *et al.* (1994a) showed a significant increase in the number of stitchbird invertebrate-feeding observations during the October to December period (the same period that my fledging success data were collected), with invertebrate observations accounting for 87% of all feeding observations during this period. This higher demand during the breeding season is likely to be the result of the increased protein required to feed growing chicks (Skutch 1976). This increase in demand for invertebrate prey may also influence the effect the ground tier complexity has on fledging success.

Although the process of territory selection in stitchbirds is unknown, there could be additional pressures on females to select a relatively complex habitat for other reasons in addition to an increased food supply. Habitat complexity may afford females some protection from forced copulation attempts by males. During the fertile period of a female stitchbird, forced copulations are frequently attempted by up to ten extra-pair males (Castro *et al.* 1996; Ewen 1998; Ewen & Armstrong 2002; Ewen *et al.* 2004; Low 2004b, 2005). These attempts are often aggressive and can affect both the survival and fitness of the female (Castro *et al.* 1996) leading to the female actively seeking dense vegetation in which to avoid extra pair contact via concealment (pers. obs.; Isabel Castro pers. comm.; Matthew Low pers. comm.). Female stitchbirds have been shown to be flight impaired during egg laying and into the incubation period, due to the weight increases and physiological changes associated with egg production (Low 2004a, 2004b). Increased vegetation cover has also been shown to reduce the level of predation on both nestlings and fledglings during this more vulnerable period in a bird's lifecycle (Martin & Roper 1988; Rodriguez *et al.* 2006). Therefore a more complex habitat may provide a selective advantage by providing protection to both female stitchbirds and chicks throughout the entire breeding period.

According to both the overall and the tiered model, the DBH of the nest tree is important in explaining stitchbird fledging success with larger trees producing higher fledging success. DBH is often used as a relative measure of tree size, with trees with larger trunks generally being related to greater tree size and stature and in this case an increased DBH is indeed correlated with increased size of the trunk/branch (diameter at cavity height or DCH) containing the cavity (Pearson; N=30, r =0.54, P<0.05). The physical structure and size of the cavity-bearing tree has been shown to influence the microclimate of the cavity (Sedgeley 2001). Large DBH's, DCH's, and high canopy cover may produce warmer and more stable microclimate conditions within the cavity (Sedgeley 2001; Wiebe 2001). In other birds, such as tree swallows (*Tachycineta bicolor*; Dawson *et al.* 2005) and acorn woodpeckers (*Melanerpes formicivorus*; Hooge *et al.* 1999) evidence suggests that increased stability and warmth of the cavity microclimate can lead to increased reproductive success. This stability and warmth of the cavity microclimate may, therefore, be important to stitchbird reproductive success.

The two populations in this study were separated by almost the entire length of the North Island of New Zealand, which is approximately equivalent to the length of the stitchbirds historical range (Taylor *et al.* 2005). Yet the effect of island was insignificant suggesting that habitat is important to stitchbird irrespective of location within their known historical range. Angehr (1984) and Lovegrove (1986) point out that the habitats of Kapiti and Little Barrier Islands differ in terms of the plant species, and therefore in the diversity of food plants available. The fact that the habitat of these locations is different shows further support for the suggestion that habitat complexity may be a better predictor of the quality of the habitat and the abundance of invertebrates than species composition. However, testing this idea will require further study.

A limitation of my approach is the large temporal gap between the collection of the reproductive success data (during the 1992/93 and 1993/94 stitchbird breeding seasons) and the habitat data (during the 2004/05 season) for Kapiti Island. In theory, the succession in the Kapiti Island habitat should be moving towards a climax forest state over the intervening period. This means the Kapiti Island habitat may have become more complex and moved closer to the state of the current Little Barrier Island habitat during this period. Angher (1984) suggests the increase in diversity of food plants and increased frequency of broad-leaved species that occurs during succession would benefit stitchbirds. This could possibly lead to an underestimation of the habitat differences. Therefore the effect of habitat complexity found in this study may have been more pronounced if I had been able to measure the reproductive success and habitat of Kapiti Island during the same period.

Additionally due to the intensity of research involved in recording stitchbird reproductive success, across multiple populations, I was unable to present data for both the island populations from the same season. Therefore some caution should be taken in interpreting these data as the island effect cannot be separated from any year effects in this design.

3.4.2 Statistical methodology

The regression tree and the generalized linear mixed model (GLMM) showed similar results with the strongest predictors for the regression trees, overall habitat complexity and sub-canopy habitat complexity, being the only significant effects in the GLMM. A benefit of regression trees is the ability to present the relationships graphically, which allows for easy visualisation of the hierarchy of decision-making rules used to predict fledging success. Therefore, the regression tree output provides a better decision-making tool for managers.

3.4.3 Habitat assessment methodology

Many studies that assess habitat differences either use time consuming methods, which are not suitable for habitat assessment of large territories (e.g. permanent plots Wardle & Guest 1977; point-sampling Halliwell *et al.* 1995), or rapid subjective methods such as percentage cover assessments (Allen 1992).

The development of the method used here arose out of the need for a rapid vegetation index that still provided good quality quantitative data from which the habitat requirements and the factors that influence the reproductive success of forest bird species, could be compared. Frequency sampling is a simple field technique which integrates several aspects of a plant's abundance. It is a complex characteristic determined by plant density, cover and pattern, therefore frequency sampling is seldom suitable for intensive work (Scott 1965). In his paper Scott (1965) suggests that although he developed the method primarily for use in survey work in areas of New Zealand tussock grassland and shrubland, the principles could be adapted to other vegetation types. The method developed in this study allowed for rapid collection (a two-person team could complete ten, eighty metre transects or two nest sites per day) of quantitative vegetation data through a height frequency sampling method.

3.4.4 Synthesis

This study used a new approach to both the collection and analysis of habitat data in relation to the factors that influence stitchbird reproductive success. Habitat complexity may be providing a proximate assessment of overall habitat quality, while nest tree size may be influencing the internal microclimate of the nesting cavities. This approach produced results which suggest habitat complexity and nest tree size are very important to the reproductive success of the stitchbird.

3.5 References

Aho, T., M. Kuitunen, J. Suhonen, A. Jantti, and T. Hakkari. 1999. Reproductive success of Eurasian Treecreepers, *Certhia familiaris*, lower in territories with wood ants. Ecology **80**:998-1007.

Allen, R. B. 1992. An inventory method for describing New Zealand vegetation. Forest Research Institute, Rotorua, New Zealand.

Angehr, G. R. 1984. Ecology and behaviour of the Stitchbird with recommendations for management and future reasearch. New Zealand Wildlife Service, Wellington.

Armstrong, D. P., I. Castro, J. C. Alley, B. Feenstra, and J. K. Perrott. 1999. Mortality and behaviour of hihi, an endangered New Zealand honeyeater, in the establishment phase following translocation. Biological Conservation **89**:329-339.

Armstrong, D. P., I. Castro, and R. Griffiths. Submitted. Combining experimental management with population viability analysis to decide future management of a reintroduced hihi population. Conservation Biology.

Armstrong, D. P., R. S. Davidson, W. J. Dimond, J. K. Perrott, I. Castro, J. G. Ewen, R. Griffiths, and J. Taylor. 2002. Population dynamics of reintroduced forest birds on New Zealand islands. Journal of Biogeography **29**: 609-621.

Armstrong, D. P., and J. G. Ewen. 2001. Testing for food limitation in reintroduced Hihi populations: Contrasting results for two islands. Pacific Conservation Biology. **7(2)**:87-92.

Armstrong, D. P., and J. K. Perrott. 2000. An experiment testing whether condition and survival are limited by food supply in a reintroduced Hihi population. Conservation Biology **14**:1171-1181.

Bensch, S., and D. Hasselquist. 1991. Territory infidelity in the polygynous Great Reed Warbler *Acrocephalus arundinaceus* - the effect of variation in territory attractiveness. Journal of Animal Ecology **60**: 857-871.

Bollmann, K., H. U. Reyer, and P. A. Brodmann. 1997. Territory quality and reproductive success: Can water pipits *Anthus spinoletta* assess the relationship reliably? Ardea **85**:83-98.

Braden, G. T., R. L. McKernan, and S. M. Powell. 1997. Association of within-territory vegetation characteristics and fitness components of California Gnatcatchers. Auk **114**:601-609.

Brockie, R. 1992. A living New Zealand forest. David Bateman Ltd, Auckland, New Zealand.

Castro, I. 1995. Behavioural ecology and management of Hihi *Notiomystis cincta*, an endemic New Zealand honeyeater. PhD Thesis, Massey University, Palmerston North.

Castro, I., J. C. Alley, R. A. Empson, and E. O. Minot. 1994b. Translocation of Hihi or Stitchbird *Notiomystis cincta* to Kapiti Island, New Zealand: transfer techniques and comparison of release strategies. Pages 113-120 *In* M. Serena, editor. Reintroduction biology of Australian and New Zealand fauna. Surrey Beatty & Sons, Chipping Norton.

Castro, I., and D. H. Brunton. In prep. Effects of life history traits and food supplementation on female Hihi (*Notiomystis cincta*) parental behaviour.

Castro, I., D. H. Brunton, K. M. Mason, B. Ebert, and R. Griffiths. 2003. Life history traits and food supplementation affect productivity in a translocated population of the endangered hihi (stitchbird, *Notiomystis cincta*). Biological Conservation **114**:271-280.

Castro, I., E. O. Minot, and J. C. Alley. 1994a. Feeding and breeding behaviour of Hihi or Stitchbirds *Notiomystis cincta* recently transferred to Kapiti Island, New Zealand, and possible management alternatives. Pages 121-128 *In* M. Serena, editor. Reintroduction biology of Australian and New Zealand fauna. Surrey Beatty and Sons, Chipping Norton.

Castro, I., E. O. Minot, R. A. Fordham, and T. R. Birkhead. 1996. Polygynandry, face-to-face copulation and sperm competition in the Hihi *Notiomystis cincta* (Aves: Meliphagidae). Ibis **138**:765-771.

Cody, M. L. 1985. Habitat selection in birds. Academic Press, Los Angeles.

Conner, R. N., M. E. Anderson, and J. G. Dickson. 1986. Relationships among territory size, habitat, song, and nesting success of Northern Cardinals. Auk **103**: 23-31.

Cowan, P. E. 1993. Effects of intensive trapping on breeding and age structure of Brushtail Possums, *Trichosurus vulpecula*, on Kapiti Island, New Zealand. New Zealand Journal of Zoology **20**:1-11.

Davenport, D. E., R. A. Lancia, J. R. Walters, and P. D. Doerr. 2000. Red-cockaded woodpeckers: a relationship between reproductive fitness and habitat in the North Carolina Sandhills. Wildlife Society Bulletin **28**:426-434.

Dawson, R. D., C. C. Lawrie, and E. L. O'Brien. 2005. The importance of microclimate variation in determining size, growth and survival of avian offspring: experimental evidence from a cavity nesting passerine. Oecologia **144**:499-507.

De'ath, G. 2002. Multivariate regression trees: a new technique for modeling species-environment relationships. Ecology **83**:1105-1117.

De'ath, G., and K. E. Fabricius. 2000. Classification and regression trees: A powerful yet simple technique for ecological data analysis. Ecology **81**:3178-3192.

Dias, P. C. 1996. Sources and sinks in population biology. Trends in Ecology & Evolution **11**:326-330.

Dias, P. C., F. Meunier, S. Beltra, and M. Cartanson. 1994. Blue Tits in Mediterranean habitat mosaics. Ardea **82**:363-372.

Empson, R. A., and C. M. Miskelly. 1999. The risks, costs and benefits of using brodifacoum to eradicate rats from Kapiti Island, New Zealand. New Zealand Journal of Ecology **23**:241-254.

Ens, B. J., M. Kersten, A. Brenninkmeijer, and J. B. Hulscher. 1992. Territory quality, parental effort and reproductive success of Oystercatchers (*Haematopus ostralegus*). Journal of Animal Ecology **61**:703-715.

Ewen, J. G. 1998. A genetic and behavioural investigation of extra-pair copulation in stitchbirds (*Notiomystis cincta*) breeding on Tiritiri Matangi Island. MSc Thesis, Massey University, Palmerston North.

Ewen, J. G., and D. P. Armstrong. 2002. Unusual sexual behaviour in the Stitchbird (or Hihi) *Notiomystis cincta*. Ibis **144**:530-531.

Ewen, J. G., D. P. Armstrong, B. Ebert, and L. H. Hansen. 2004. Extra-pair copulation and paternity defense in the hihi (or stitchbird) *Notiomystis cincta*. New Zealand Journal of Ecology **28**:233-240.

Fuller, S. A. 1985. Kapiti Island vegetation: Report on a vegetation survey of Kapiti Island 1984/85. Department of Lands and Survey, District Office, Wellington.

Halaj, J., D. W. Ross, and A. R. Moldenke. 2000. Importance of habitat structure to the arthropod food-web in Douglas-fir canopies. Oikos **90**:139-152.

Halliwell, D. H., M. J. Apps, and D. T. Price. 1995. A Survey of the Forest Site Characteristics in a Transect through the Central Canadian Boreal Forest. Water Air and Soil Pollution **82**:257-270.

Hamilton, W. M. 1961. Little Barrier Island (Hauturu). Government Printer, Wellington, New Zealand.

Hatchwell, B. J., D. E. Chamberlain, and C. M. Perrins. 1996. The reproductive success of blackbirds *Turdus merula* in relation to habitat structure and choice of nest site. Ibis **138**:256-262.

Hochachka, W. M., J. N. M. Smith, and P. Arcese. 1989. Song Sparrow. Pages 135-152 *In* I. Newton. Lifetime reproduction in birds. Academic Press, London.

Hogstedt, G. 1980. Evolution of clutch size in birds - adaptive variation in relation to territory quality. Science **210**:1148-1150.

Hooge, P. N., M. T. Stanback, and W. D. Koenig. 1999. Nest-site selection in the acorn woodpecker. Auk **116**:45-54.

Huhta, E., J. Jokimaki, and P. Rahko. 1998. Distribution and reproductive success of the Pied Flycatcher *Ficedula hypoleuca* in relation to forest patch size and vegetation characteristics; the effect of scale. Ibis **140**:214-222.

Komdeur, J. 1992. Importance of habitat saturation and territory quality for evolution of cooperative breeding in the Seychelles Warbler. Nature **358**:493-495.

Langen, T. A., and S. L. Vehrencamp. 1998. Ecological factors affecting group and territory size in White-throated Magpie-Jays. Auk **115**:327-339.

Lovegrove, T. 1986. Stitchbirds on Kapiti Island 1983-1985. Internal report to the New Zealand Department of Conservation, Wellington.

Low, M. 2004a. The behavioural ecology of forced copulation in the New Zealand Stitchbird (hihi). PhD Thesis, Massey University, Palmerston North.

Low, M. 2004b. Female weight predicts the timing of forced copulation attempts in stitchbirds, *Notiomystis cincta*. Animal Behaviour **68**:637-644.

Low, M. 2005. Factors influencing mate guarding and territory defence in the stitchbird (hihi) *Notiomystis cincta*. New Zealand Journal of Ecology **29**:231-242.

Low, M., M. K. Joy, and T. D. Makan. 2006. Using regression trees to predict male provisioning of offspring in the stitchbird (hihi). Animal Behaviour **71**: 1057-1068.

Luck, G. W. 2002a. Determining habitat quality for the cooperatively breeding Rufous Treecreeper, *Climacteris rufa*. Austral Ecology **27**:229-237.

Martin, T. E., and J. J. Roper. 1988. Nest predation and nest-site selection of a western population of the Hermit Thrush. Condor **90**:51-57.

Matthysen, E. 1990. Behavioral and ecological correlates of territory quality in the Eurasian Nuthatch (*Sitta europaea*). Auk **107**:86-95.

Misenhelter, M. D., and J. T. Rotenberry. 2000. Choices and consequences of habitat occupancy and nest site selection in sage sparrows. Ecology **81**:2892-2901.

Newton, I. 1998. Population limitation in birds. Academic Press, London.

Perrott, J. K. 1997. Effects of food supply and competition on the outcome of Hihi (*Notiomystis cincta*) translocated to Mokoia Island. MSc Thesis, Massey University, Palmerston North.

Rasch, G. 1991. A recovery plan for the Stitchbird (*Notiomystis cincta*). Internal report to the New Zealand Department of Conservation, Wellington.

Robinson, S. K., and R. T. Holmes. 1982. Foraging behavior of forest birds - the relationships among search tactics, diet, and habitat structure. Ecology **63**:1918-1931.

Rodriguez, A., A. M. Garcia, F. Cervera, and V. Palacios. 2006. Landscape and anti-predation determinants of nest-site selection, nest distribution and productivity in a Mediterranean population of Long-eared Owls *Asio otus*. Ibis **148**:133-145.

SAS Institute©. 2003. SAS statistical package. SAS Institute© 2002-2003. Cary, NC, USA.

Scott, D. 1965. A height frequency method for sampling tussock and shrub vegetation. New Zealand Journal of Botany **3**:253-260.

Sedgeley, J. A. 2001. Quality of cavity microclimate as a factor influencing selection of maternity roosts by a tree-dwelling bat, *Chalinolobus tuberculatus*, in New Zealand. Journal of Applied Ecology **38**:425-438.

Skutch, A. F. 1976. Parent birds and their young. University of Texas Press, Austin, USA.

Smith, T. M., and H. H. Shugart. 1987. Territory size variation in the ovenbird - the role of habitat structure. Ecology **68**:695-704.

Taylor, S., and I. Castro. 2000. Hihi standard operating procedures. Department of Conservation, Auckland, New Zealand.

Taylor, S., I. Castro, and R. Griffiths. 2005. Hihi/Stitchbird (*Notiomystis cincta*) Recovery Plan 2004-09. Department of Conservation, Wellington, New Zealand.

The Math Works Inc©. 2002. Statistics tools box for MatLab®. The Math Works Inc© 1993-2002. Natick, MA, USA.

Thorogood, R. 2005. Decisions mothers take: Hihi maternal investment. MSc Thesis, University of Auckland, Auckland.

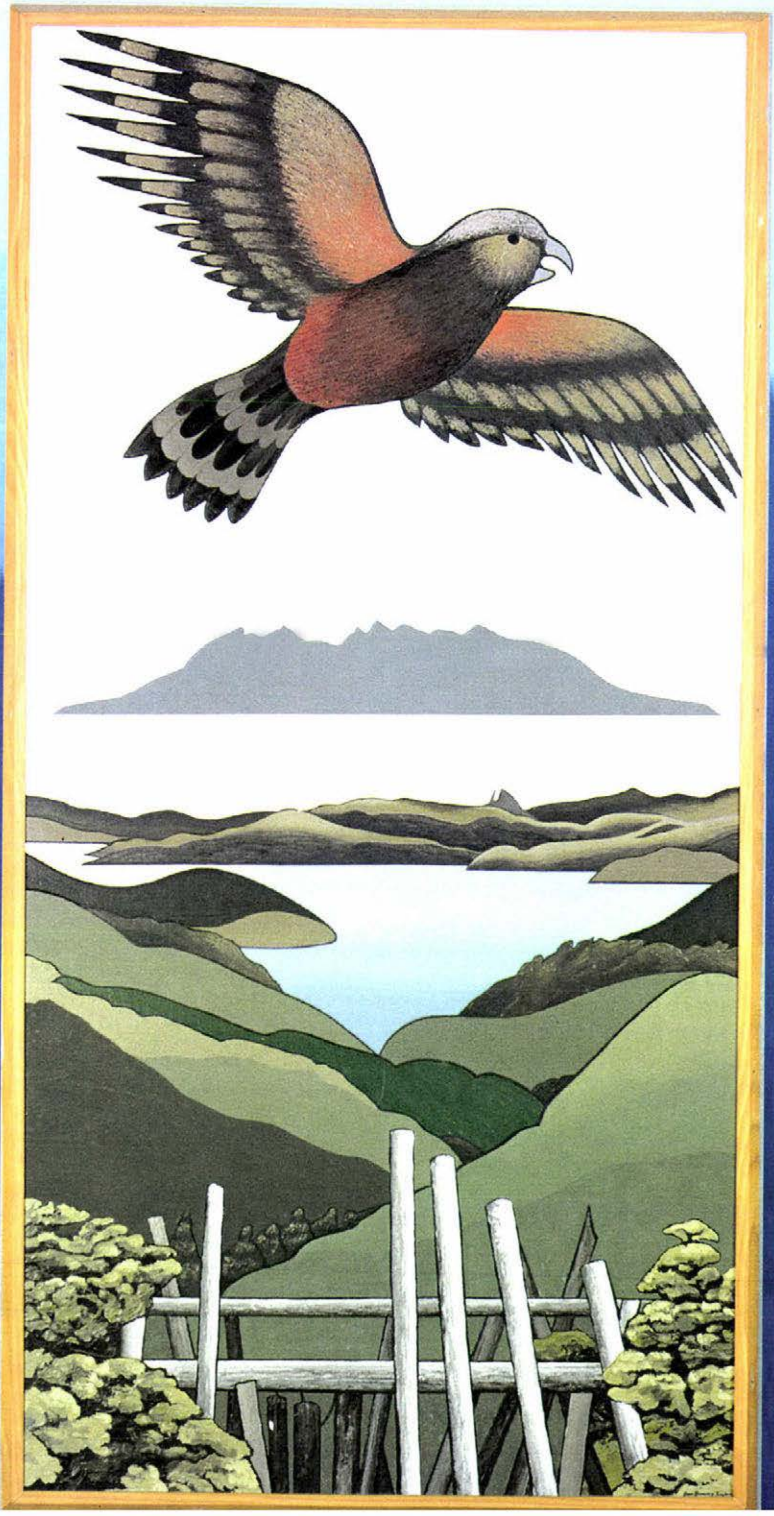
Veitch, C. R. 2001. The eradication of feral cats (*Felis catus*) from Little Barrier Island, New Zealand. New Zealand Journal of Zoology **28**:1-12.

Wardle, J. A., and R. Guest. 1977. Forests of the Waitaki and Lake Hawea catchments. New Zealand Journal of Forestry Science **7**:44 -67.

Wiebe, K. L. 2001. Microclimate of tree cavity nests: Is it important for reproductive success in northern flickers? Auk **118**:412-421.

Wilson, E. O. 1988. Biodiversity. National Academy Press, Washington D.C.

General Discussion and Recommendations



4

4.1 General Discussion

This thesis grew out of a basic problem in the management of a "Nationally Endangered" New Zealand bird species. Following European colonization of New Zealand it is hypothesized that predation and severe habitat loss along with disease, extirpated stitchbird from the North Island and reduced the distribution to a single population on Little Barrier Island (Taylor *et al.* 2005). Efforts to recover the stitchbird have involved many translocations to other islands. Three of these translocations failed and the rest of the populations only persist due to intensive management by the Department of Conservation, mainly through supplementary feeding and provision of nesting boxes, as a way of artificially enhancing the island habitats (Angehr 1984; Castro *et al.* 1994a; Ewen 1998; Armstrong *et al.* 1999; Taylor *et al.* 2005).

This research is the largest study of the reproductive success of stitchbirds on Little Barrier Island and has shown that the reproductive success on Little Barrier is lower than that in the managed populations.

Habitat and habitat management are having a clear effect on stitchbird populations, with habitat structure probably having a major influence on the availability of resources required for reproduction. Previous research has shown a clear effect of food limitation in the translocated populations (Castro *et al.* 1994b; Armstrong *et al.* 2002; Armstrong *et al.* submitted) and now, as a result of conservation management, the reproductive success of these populations is being maintained at a higher level than the Little Barrier Island population. Yet in the absence of this conservation management, the reproductive success of these translocated populations' drops and ultimately the population size declines.

I found that the main difference in habitat between Little Barrier and Kapiti Islands, other than species composition, is in the complexity of the habitat. Thus a more complex forest habitat (on Little Barrier Island) may be influencing the availability of resources which has been shown to be influencing the behaviour and reproductive output in stitchbird populations.

Therefore in the search for new sites to try and establish new self-sustaining populations it may be important to not only consider the phenology of the forest species in each habitat but to also consider the availability of large potential nest trees and the complexity of the habitat. This will provide a proximate assessment of the overall quality of the habitat, considering not only nectar and fruit food sources but also the abundance of invertebrate food and the protection afforded by the habitat.

4.2 Recommendations

4.2.1 Habitat Assessment

The methodology developed in Chapter Three was specifically designed to enable managers to rapidly assess the quality of the habitat in potential translocation sites. This method has proven to provide good explanatory power for the data from Little Barrier and Kapiti Islands. The collection of more data from Little Barrier Island will be important for increasing the predictive ability of the model, which will allow for more accurate habitat assessment.

Reproductive success may not be the only characteristic of the stitchbird life history that is affected by habitat quality. In future studies on the effect of habitat on the stitchbird, I recommend other life history characteristics such as territory size and density should be considered. I didn't collect quantitative data on territory size but there seemed to be a higher density of stitchbird territories in the presumed higher quality habitats on Little Barrier Island. Newton (1998) suggests that competition is playing a larger role in higher quality habitat and may therefore be reducing reproductive success. This may also be important for future translocations to sites with the potential to have self-sustaining populations. When birds are released in a high quality area there will be lower density so individuals should experience a high reproductive success. As population size increases a density dependent decline in reproductive success is expected (Newton 1998).

In other systems it has been shown that structural measures of habitat, such as complexity, can provide proximate measures of food abundance and therefore habitat quality (Hayward 1984; Conner *et al.* 1986; Bollmann *et al.* 1997; Braden *et al.* 1997; Huhta *et al.* 1998; Halaj *et al.* 2000). Therefore, I recommend studies of phenology, invertebrate prey abundance and their effect on stitchbird reproductive success are required to provide support for the use of habitat complexity as a proximate assessment of stitchbird habitat quality.

4.2.2 Population Modelling

The data presented in Chapter Two suggest there is a very small difference (less than one chick per nest) between the reproductive success of Little Barrier, a self-sustaining population, and Kapiti Island, during its period of decline. Armstrong *et al.* (submitted) found the decline of the Mokoia stitchbird population resulted from an interaction between low reproductive success and low adult survival. Therefore, I suggest there is a need for an in-depth study of the demographics of the Little Barrier Island stitchbird population. This would enable us to model the population dynamics to gain a better understanding of the factors responsible for the persistence of stitchbird on Little Barrier Island. Population modelling will also be important for estimating the effects of further harvesting from this population.

4.2.3 Nest box Design

In this study, the DBH of the nest tree was important in explaining fledging success with larger trees producing higher fledging success. DBH is often used as a relative measure of tree size, with trees with larger trunks generally being related to greater tree size and stature. The physical structure and size of the cavity bearing tree has been shown to influence the microclimate of the cavity itself (Sedgeley 2001). Castro & Brunton (in prep) and Matthew Low (pers. comm.) found that most stitchbird nestling deaths on Mokoia and Tiritiri Matangi Islands (where the majority of nests are in nest boxes), occur within the first ten days of hatching. Current nest boxes are designed to imitate the shape of natural cavities. This current design does not provide the same thickness of wood in the cavity wall that occurs in most natural cavities and therefore may not be providing the same stable environment that larger trees can provide. I suggest an experimental trial of some new, better insulated, nest boxes may increase the reproductive success of these translocated populations.

4.3 References

Angehr, G. R. 1984. Establishment of the Stitchbird on Hen Island. Notornis **31**:175-177.

Armstrong, D. P., I. Castro, J. C. Alley, B. Feenstra, and J. K. Perrott. 1999. Mortality and behaviour of hihi, an endangered New Zealand honeyeater, in the establishment phase following translocation. Biological Conservation **89**:329-339.

Armstrong, D. P., I. Castro, and R. Griffiths. Submitted. Combining experimental management with population viability analysis to decide future management of a reintroduced hihi population. Conservation Biology.

Armstrong, D. P., R. S. Davidson, W. J. Dimond, J. K. Perrott, I. Castro, J. G. Ewen, R. Griffiths, and J. Taylor. 2002. Population dynamics of reintroduced forest birds on New Zealand islands. Journal of Biogeography **29**:609-621.

Bollmann, K., H. U. Reyer, and P. A. Brodmann. 1997. Territory quality and reproductive success: Can water pipits *Anthus spinoletta* assess the relationship reliably? Ardea **85**:83-98.

Braden, G. T., R. L. McKernan, and S. M. Powell. 1997. Association of within-territory vegetation characteristics and fitness components of California Gnatcatchers. Auk **114**:601-609.

Castro, I., J. C. Alley, R. A. Empson, and E. O. Minot. 1994a. Translocation of Hihi or Stitchbird *Notiomystis cincta* to Kapiti Island, New Zealand: transfer techniques and comparison of release strategies. Pages 113-120 *In* M. Serena, editor. Reintroduction biology of Australian and New Zealand fauna. Surrey Beatty & Sons, Chipping Norton.

Castro, I., and D. H. Brunton. In prep. Effects of life history traits and food supplementation on female Hihi (*Notiomystis cincta*) parental behaviour.

Castro, I., E. O. Minot, and J. C. Alley. 1994b. Feeding and breeding behaviour of Hihi or Stitchbirds *Notiomystis cincta* recently transferred to Kapiti Island, New Zealand, and possible management alternatives. Pages 121-128 *In* M. Serena, editor. Reintroduction biology of Australian and New Zealand fauna. Surrey Beatty and Sons, Chipping Norton.

Conner, R. N., M. E. Anderson, and J. G. Dickson. 1986. Relationships among territory size, habitat, song, and nesting success of Northern Cardinals. Auk **103**:23-31.

Ewen, J. G. 1998. A genetic and behavioural investigation of extra-pair copulation in stitchbirds (*Notiomystis cincta*) breeding on Tiritiri Matangi Island. MSc Thesis, Massey University, Palmerston North.

Halaj, J., D. W. Ross, and A. R. Moldenke. 2000. Importance of habitat structure to the arthropod food-web in Douglas-fir canopies. Oikos **90**:139-152.

Hayward, B. W. 1984. Prehistoric man on the offshore islands of northern New Zealand and his impact on the biota. Department of Lands and Survey, Wellington.

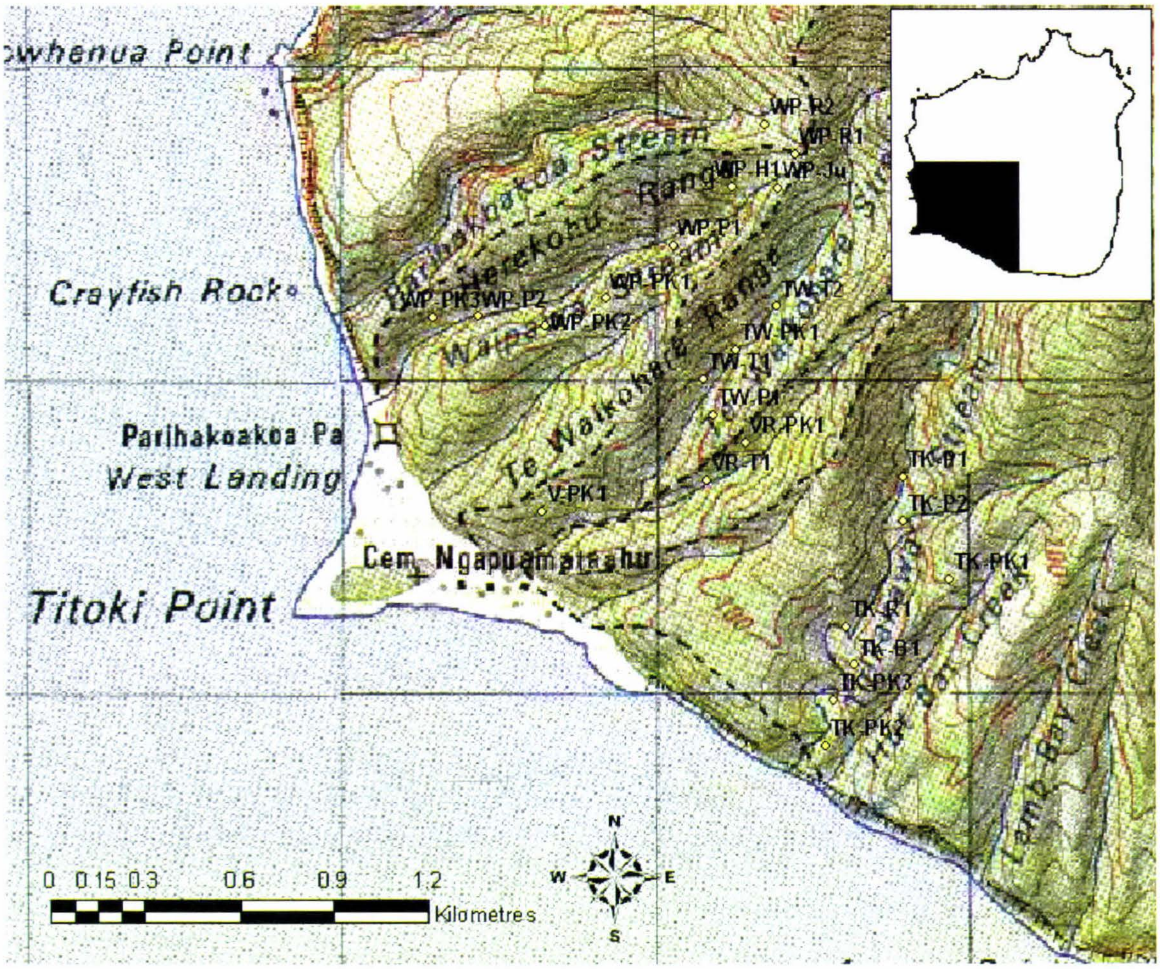
Huhta, E., J. Jokimaki, and P. Rahko. 1998. Distribution and reproductive success of the Pied Flycatcher *Ficedula hypoleuca* in relation to forest patch size and vegetation characteristics; the effect of scale. Ibis **140**:214-222.

Newton, I. 1998. Population limitation in birds. Academic Press, London.

Sedgeley, J. A. 2001. Quality of cavity microclimate as a factor influencing selection of maternity roosts by a tree-dwelling bat, *Chalinolobus tuberculatus*, in New Zealand. Journal of Applied Ecology **38**:425-438.

Taylor, S., I. Castro, and R. Griffiths. 2005. Hihi/Stitchbird (*Notiomystis cincta*) Recovery Plan 2004-09. Department of Conservation, Wellington, New Zealand.

Appendix 1



Appendix 1: Location of stitchbird nest sites on Little Barrier Island during 2004/05 breeding season.

Appendix 2

Appendix 2: Nest site characteristics for the Little Barrier and Kapiti Island Nests.

		Cavity										
Nest	Species	Height (m)	DBH (cm)	DCH (cm)	Width (cm)	Length(cm)	Depth(cm)	Alt	Physio	Slope	Aspect	No. Fledged
TK-B1	Hard Beech	7	111	49	5.6	6.1	?	30	face	36	224	0
TK-P1	Puriri	10	230	48	7.39	18.9	?	83	gully	0	220	3
TK-P2	Puriri	9.2	131	48	3.5	7.4	?	81	gully	2	162	1
TK-Pk1	Pohutukawa	6.2	77	70	8.1	5.4	80	95	face	43	280	3
TK-Pk2	Pohutukawa	8.1	91	51	7	9	65	18	gully	3	230	0
TK-Pk3	Pohutukawa	5.95	91	65	6	13	65	18	gully	3	230	1
TK-R1	Rata	5.45	133	84	10.2	10.2	71.5	25	gully	0	350	4
TW-P1	Puriri	9.1	131	29	14	10	?	65	face	15	260	2
TW-Pk1	Pohutukawa	11.2	155	60	19	48	?	100	face	42	274	2
TW-T1	Taraire	9	79	31	6.5	6.9	?	70	face	6	104	0
TW-T2	Taraire	9	53	22	?	?	?	75	gully	5	170	3
V-Pk1	Pohutukawa	5.7	136	24	?	?	?	90	ridge	25	173	1
VR-Pk1	Pohutukawa	11.7	147	55	6	12	?	90	face	43	154	2
VR-T1	Taraire	8.2	49	28	6	4.5	52	50	face	36	113	2
WP-H1	Heketara	2	36	36	12	13	46	280	face	38	130	4
WP-Ju	Rata	7.4	183	37	?	?	?	300	ridge	36	180	3
WP-P1	Puriri	12	129	37	10.2	9.6	?	85	face	40	250	4
WP-P2	Puriri	5.1	52	25	4.65	7.2	72	37	face	17	95	2
WP-Pk1	Pohutukawa	7.7	80	46	5.45	7.4	?	90	face	35	290	2
WP-Pk2	Pohutukawa	12.6	98	32	11.44	20.8	90	40	face	24	346	1
WP-Pk3	Pohutukawa	7.7	142	43	4.8	7.9	80	30	face	28	95	2
WP-R1	Rata	10	164	54	5	23	?	310	face	10	217	2
WP-R2	Rata	9	92	58	?	?	?	320	face	12	180	2
45-R3 92/93	Pukatea	?	212	?	?	?	?	222	gully	13	190	3
45-R3 93/94	Pukatea	?	212	?	?	?	?	222	gully	13	190	2

45-R5 92/93	Pukatea	14	132	102	?	?	?	215	face	35	60	2
56-1 92/93	Rata	?	206	?	?	?	?	310	face	18	24	1
56-4 92/93	Hinau	11	111	36	?	?	?	310	ridge	9	160	1
56-4 93/94	Hinau	11	111	36	?	?	?	310	ridge	9	160	0
56-67 92/93	Rata	?	197	?	?	?	?	255	gully	7	65	2
K67 92/93	Pukatea	16	210	85	?	?	?	211	gully	10	140	0
K67 93/94	Pukatea	16	210	85	?	?	?	211	gully	10	140	2
T-43	Pukatea	?	128	110	?	?	?	238	ridge	15	200	2
B 3-4 92/93	Nestbox	?	?	?	?	?	?	82	face	32	50	0
B 3-4 93/94	Nestbox	?	?	?	?	?	?	82	face	32	50	0
Qway 93/94	Rata	4.5	78	55	?	?	?	185	face	44	206	1