Behavioural Ecology and Management of Hihi (*Notiomystis cincta*), an endemic New Zealand honeyeater.

A Thesis presented in partial fulfilment of the requirements for the degree of PhD in Ecology at Massey University

Isabel Castro
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To
Isabella, who first entered
the house and into our hearts.
Randy, who hid from me, but not
from any of the other females.
Tongue face, who showed me
how strong a hihi can be.
Mañeña, who taught me that hihi
are born to be free.
Baby, who bred with another
male and two females, and
Geegee, who is a real character.

Abstract

This thesis is concerned with the release techniques, post-release survival and behavioural ecology of hihi (*Notiomystis cincta*), a rare New Zealand honeyeater. It aims at offering management strategies for translocated populations. The only self-sustaining population of hihi exists on Little Barrier Island. The New Zealand Department of Conservation is trying to establish self-sustaining populations elsewhere.

In 1991 and 1992 hihi transfers to Kapiti Island were approached in an experimental way. Experiments provided four main conclusions: (1) immediate-release birds survived better than delayed-release birds; (2) there was no difference between the survival of birds released in pairs or in a group; (3) hihi released in the absence of resident conspecifics survived better than those released in their presence; and (4) birds released in the absence of resident conspecifics moved to an area with residents in three days.

The breeding system of hihi is highly variable, including monogamy, polyandry, polygyny and polygynandry. Males have physical features found in other species with highly variable mating systems. Male and female hihi benefit from a mixed reproductive strategy where a female hihi can solicit copulations from males other than her partner and male hihi can perform extra-pair copulations both with willing females or by forced copulation. Field tests aimed at determining the influence of the distribution of food and nest sites on the choice of mating system by hihi are proposed.

The phenology of a selected group of plants, important as honeyeater food, was followed from 1992 to 1994. The onset and length of the flowering and fruiting periods for particular plant species varied between the years. The number of fruits and flowers per tree also varied. Hihi egg laying periods coincided with the period of greatest flowering. Hihi breeding success was low every year. In 1993-94 there was great competition for nest sites with kakariki *Cyanoramphus novaezelandiae*. It is suggested that hihi failure to establish self-sustaining populations on Kapiti Island is mainly the result of competition for nest sites and food limitation. It is recommended that feeding stations and nesting boxes are established in three different areas of the island. Food should be provided during the breeding season.

The quality of nectar in some small flowers, and the rate of flower visitation by hihi, tui *Prosthemadera novaezelandiae* and bellbirds *Anthornis melanura* to those flowers were measured. The estimated nectar consumption rate for all flowers was enough to sustain hihi and bellbirds' energetic requirements. It is suggested that honeyeaters might play a previously unrecognised but important role in pollination. Forest regeneration on the New Zealand mainland could be hampered by the loss of hihi and serious reduction in the abundance of tui and bellbirds. Necessary studies to elucidate the role of honeyeaters in pollination are offered.

Acknowledgments

It was Ed Minot, my "chief" supervisor, who is mostly responsible for me taking over the study of hihi. I did not want to work with such small bird, but he pointed out to me that after having experience with large birds, the best thing in my C.V. would be to have experience also with small ones. I am very thankful to him because this project is one of the best things that have ever happened in my life. Not only Ed started the whole process, but he has been a major support all the way through. Ed, Robin Fordham, my second supervisor, and Brian Springett, my third supervisor, have helped me with advice, interesting discussions, and enticing questions about my research. They have spent long hours making sure my English is right in my papers and my thesis, and I can only say *mil gracias*. I wish all students could have such a great team as advisers for their thesis.

Chapter 4 would have never been possible without the intervention of Alastair Robertson. Although he was never part of the team of supervisors he has been one of them, teaching me all I know about the old story of the flowers and the bees. Thank you Al, I think this time I got the story right. Thanks as well to Tim Birkhead who although far away has inspired me for the last years. Chapter 3 would have been a more timid chapter without Tim's encouragement.

This project was initiated by the Department of Conservation and within the Department I want to thank Raewyn Empson, from the Wellington Conservancy for her unconditional support for the project. Raewyn has been a source for ideas and inspiration throughout these study. Shaarina Boyd, from the Auckland Conservancy, and head of the Stitchbird Recovery Group, has also been supportive of this project. Both Raewyn and Shaarina have also helped during field trips. I am thankful for all their help. The members of the Stitchbird Recovery Group also provided ideas and support to the project.

The research that led to this thesis could have never been so complete and interesting without Julie Alley's help . Julie was my field assistant for the first year of my research and has been my friend and support for the length of the study and I hope for many years to come. I really appreciate her patience, determination and love for nature. Field work was also made easier and fun thanks to the help of Karen Mason, and Vaughan Keesing. Although Karen was still a bachelor's student at Massey, she came to help me during every break. Not only did she provid labour, but excellent conversations and ideas. Vaughan was the "climbing man". He is responsible for all the very high hihi nest boxes on Kapiti. I am really grateful to him for stopping every thing to come place boxes up in trees for me.

All of us, who have worked on Kapiti Island, know that an important part of it is the ranger's house, where we get together to dine, have a good wine, conversation and company. Thank you Peter Daniel, Shona Pengely and Marisol Pengely Daniel for many lovely evenings and for being my family during my years on Kapiti (and now).

A great number of people assisted me in the field (collecting data and keeping me sane). It is fair to say that this thesis would have not been possible without their help. In no particular order I wish to thank: Alejandra Mejia, Brigitte Bakker, Colin Miskelly, David Bell, David Sutherland, Ellis Udy, Emma, Gill Rapson, George Bradd, Gretchen Rasch, Gustavo Bula, Gwen Evans, Ian Stringer, Jonathan Miles, Karen Campbell, Karen Creedy, Keith Woodley, Liz Watson, many members of OSNZ Waikato, Mark, Lucy and Steven the Canadians, Murray Potter, Murray Willans, Paul Barret, Peter Griffen, Robert Hickson, Rochelle Constantine, Roger Elliot, Sarah Gibbs, Steve and Charlotte Fuller, Steve Pilkinton, Suzie Brow, Tania Waghorn, Tertia Thureley, the two DoC teams that help catching hihi on Little Barrier Island, Tony Whiters and Yvette Cotam. Sandra Anderson kindly took blood samples from hihi. I am thankful to Maurice Alley, Susan Cork and Peter Stockdale for determining the causes of dead of several hihi. Tim Lovegrove, Gretchen Rasch, and Ron Moorhouse, generously shared their data on the ecology of Kapiti and their knowledge of hihi and kaka. The guys from the possum team, track workers and all visiting scientists provided many good times at the Whare, and my thanks go to them too.

Thanks to my family: their encouragement has kept me going. To Ellis, Bud, Rook and Chispa for being there, waiting for me every time after my field trips. To my mum (Isabel Acacio) and brother (Carlos) who share with me this amazing love for nature. To Hart, Elsie and Craig Udy, and the Buchanan's, for their faith in me and for not giving up hopes that one day I will get a "real" job.

I also want to thank the Department of Ecology for all those little things that made my life easy. The graduate students all kept me going during the hard times, gave me reasons to laugh and celebrate. Petra van Kan and Erica Reid, our secretaries, sent faxes, answered calls, and kept the administrative part of the project rolling. Barb Just, my "treasurer", made sure there was always money in my account, I still do not know how she did it!!!. Jens Jorgensen for building nest boxes and designing portable mist-netting poles. Jill Rapson spent hours helping Julie and I to get ready for our talks in Australia, she helped editing Chapter 4, taught me how to set vegetation quadrats on Kapiti and fed me many lollies over these years. Kirsty Bell had just been with us, as secretary, for a week when she undertook the task of reading this whole thesis looking for editorial mistakes. Thank you all!.

Thank you to Liz Grant and Keith Woodley for making all the drawings of hihi in this thesis. Particularly thanks to Liz for drawing hihi mating postures from my exited descriptions. I would have never been able to do it myself!.

The Federation of University Woman provided economic support for my first year and I want to thank Mary Skipworth for encouraging me to apply. Massey

University gave me the Vice-Chancellor's Award, which provided funds for the second and third year. Trust Bank, The Royal Forest and Bird Protection Society, the Ornithological Society of New Zealand, and Massey University also provided funds for various other parts of the project. The Department of Conservation provided transport, nest boxes, feeders, transmitters, free accommodation on Kapiti Island, and food during the transfers. Ross Le ger , owner of Kapiti Island Charter, took me to and from the island many times during this study. Hart and Elsie Udy also granted logistic support (Mum and Dad, thanks for DR HIHI, I couldn't have done it without it!.).

This thesis no sooner will go to the binders than I will probably remember several other people who made important contributions. I apologise for any such omissions.

P.S. Despite the length of the list of those who assisted my efforts, I managed to make all mistakes completely on my own.


WORLD PARK

PREFACE

Hihi is the name given by Maori to *Notiomystis cincta.* I use this in preference to the more usual common name, stitchbird. Hihi in Maori has several meanings all related to *N. cincta.* The word means "ray of sun", which refers to the yellow shoulders of the male hihi. It also means a head decoration used by Maori warriors which had white feathers on the sides of a black helmet, representing the white ear tufts of the male hihi. There are some derivative words such as *whahihi* which means "cheeky" in relation to the active curious behaviour of the species. As a Maori noun it keeps the same form in both the singular and the plural. Hence "many hihi" (also tui, kiwi, kakariki, kaka).

Each chapter of this thesis has been written in the form of a paper. Several of the chapters have already been published or have been submitted for publication. The objective of this preface is:
- to give the full references for those chapters already published,
- whenever the papers have more than one author to explain the role of each author in the making of the paper and
- to give information about the chapters submitted or to be submitted for publication.

Chapter 1 and **Chapter 2** were presented at the Conference on Reintroduction Biology of Australasian Fauna held in Healesville, Victoria, Australia in April 1993. Papers published from the Conference were refereed by two people chosen by the Editor from those scientists attending the Conference. The full references for those papers are:

Castro, I., Alley, J.C., Empson, R.A. & Minot, E.O. 1994. Translocation of hihi or stitchbird (*Notiomystis cincta*) to Kapiti Island, New Zealand: transfer techniques and comparison of release strategies. Pp. 113-120 *In* Reintroduction Biology of Australasian Fauna. Surrey, Beatty and Sons. Australia.

Castro, I., Minot, E.O. & Alley, J.C. 1994. Feeding and breeding behaviour of hihi or stitchbirds (*Notiomystis cincta*) recently transferred to Kapiti Island, New Zealand, and possible management alternatives. Pp. 121-128 *In* Reintroduction Biology of Australasian Fauna. Surrey, Beatty and Sons, Healesville, Australia.

I presented the second paper in the spoken session of the Conference and Julie Alley presented the first one. Julie Alley was my field assistant during the first release of hihi and later from March 1992 to April 1993. She helped me with data collection. Ed Minot, as my supervisor, was involved in the design of the experimental releases and later helped tracking hihi during the first week of each release. Raewyn Empson, from the Department of Conservation, was in charge of the logistics of the translocation, capture of hihi on Little Barrier Island, and she also helped tracking the birds once released on Kapiti Island. The manuscript gained from conversation with all of them as well as from their editing.

Chapter 1, has not been changed from the published form. Chapter 2 has been changed considerably particularly the information about feeding. I have added the information I collected from 1992-94 to that published from 1991-92.

Chapter 3 has been accepted for publication in *Ibis*. The full reference is:

Castro, I., Minot, E.O., Fordham, R.A., and Birkhead, T.R. *In press.* Polygynandry, face-to-face copulation and sperm competition in the hihi *Notiomystis cincta* (Aves: Meliphagidae). *Ibis.*

Ed Minot and Robin Fordham have both supervised my work on Kapiti Island, helped with mistnetting the birds, and in Ed's case watching and finding nests. Tim Birkhead kindly dissected and described the male hihi cloacal protuberance and counted the sperm in the seminal glomera. He also applied Møller's formula to my testes measurements and drew the cloacal protuberance and its parts. The three of them also contributed to the manuscript with editing and valuable discussions both in person and via e-mail. I have included more theoretical information in the Discussion section of the Chapter than that allowed in the publication.

Chapter 4 has been recently submitted to Functional Ecology. The reference for this paper is:

Castro, I. & Robertson A.W. (*Submitted).* Honeyeaters and the New Zealand forest flora: The utilisation and profitability of small flowers.

Alastair Robertson taught me the techniques to collect nectar from the flowers and the processing of the samples in the laboratory. He was also helpful in providing references on the subject of pollination ecology and evolution, and advice on statistics. The paper gained from valuable discussions with him. He also helped to edit it.

Chapter 5 will be submitted to the New Zealand Journal of Ecology.

Chapter 6 was written as a report to the Department of Conservation.

List of Figures

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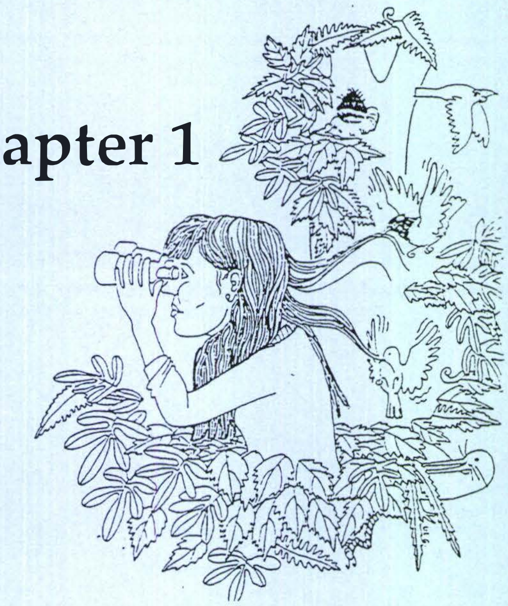
Chapter 1



Chapter 1

Translocation of hihi or stitchbird (*Notiomystis cincta*) to Kapiti Island, New Zealand: transfer techniques and comparison of release strategies.

ABSTRACT

Little Barrier Island, New Zealand, currently supports the only self-sustaining population of hihi (*Notiomystis cincta*). The New Zealand Department of Conservation is trying to establish populations of this species elsewhere to ensure its survival. In 1991 and 1992 hihi transfers to Kapiti Island were approached in an experimental way. In 1991, four release strategies were tested: immediate, delayed, paired and grouped releases. In 1992, the effect of the presence or absence of conspecifics was tested. Comparison of the different strategies based on bird sightings and movements during the first 4 weeks after release supported four main conclusions: (1) immediate-release birds survived better and travelled over a greater area than delayed-release birds; (2) there was no difference between the survival of birds released in pairs or as a group; (3) hihi released in the absence of resident conspecifics survived better than those released in their presence (not statistically significant); and (4) birds released in the absence of resident conspecifics appeared in an area with residents about three days after being released.

1.1 INTRODUCTION

THE conservation of many of New Zealand's threatened species depends on the establishment of viable populations on islands with suitable habitat (Merton 1975; Flack 1978; Nillson 1978; Rasch 1988; Roberts 1991). However, translocations are seldom well monitored and the results often remain unpublished (Young 1990). Conant (1988) and Griffith *et al.* (1989) have pointed out that the success of translocations can be enhanced by monitoring outcomes, improving transfer techniques and release strategies, and by making the results available to wildlife managers.

The hihi (*Notiomystis cincta*) is one of three species of honeyeaters endemic to New Zealand. It is considered vulnerable (IUCN 1979) because the only self-sustaining population is restricted to Little Barrier Island, New Zealand. A recovery program for hihi began in 1980, but previous attempts to establish self-sustaining populations of the species on Hen, Cuvier, and Kapiti Islands (Figure 1.1) have been unsuccessful (Angehr 1984; Rasch 1991).

The aim of this Chapter is to describe the techniques used to transfer hihi from Little Barrier Island (3053 ha) to Kapiti Island (1968 ha) in August 1991 and August 1992, and to compare the success of different release strategies for translocated hihi in the first four weeks following release.

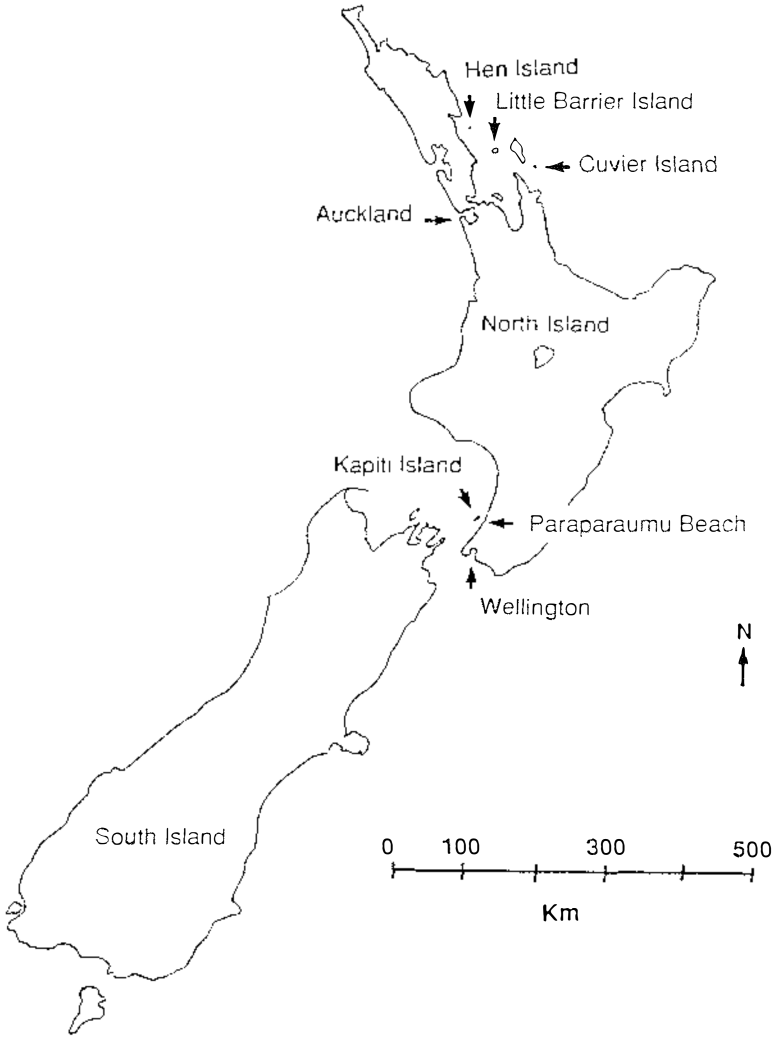


Figure 1.1. Map of New Zealand showing the location of the islands (Hen, Cuvier, Kapiti) to which hihi have been transferred from Little Barrier Island since 1983. In 1991 and 1992, two transfers took place to Kapiti Island. For these two transfers the birds were carried by helicopter from Little Barrier Island to Auckland Airport, by scheduled commercial airplane to Wellington Airport, by car to Paraparaumu Beach and by helicopter to Kapiti Island.

1.2 METHODS

1.2.1 Transfer Techniques

Hihi were captured with mist nets in three different catchments on Little Barrier Island (Empson 1992). In August 1991, 54 birds were caught, of which 48 birds (24 males and 24 females) were transferred to Kapiti Island. In August 1992, of 50 birds caught, 47 birds (24 males and 23 females) were transferred. Immediately after capture the birds were weighed, measured and fitted with coloured and metal leg bands. In 1992, blood samples for DNA analysis were also taken from the brachial vein of all birds.

After capture and handling, all birds were fed glucose solution before being released into an aviary on Little Barrier Island. The maximum length of time a bird was held in this aviary was 15 days in 1991 and 10 days in 1992. The aviary (5 x 3 x 2 m) was divided with shade cloth into four compartments, each being accessed through a shade cloth “door”. In 1991, two compartments held 14 birds each and a larger third compartment, comprising two compartments with the door between them open, contained 20 birds. Individuals in the third compartment, which was near to the entrance of the aviary, appeared particularly stressed when the aviary was serviced. For this reason, in 1992 all the doors between compartments were left open, so that all birds had access to the entire aviary.

Artificial and natural foods, and water were supplied *ad libitum* in the aviary. Food consumption was closely monitored (Castro 1992). Fresh leaf litter was put on the ground each week and the feeders were cleaned at two-day intervals. Feeders (in 1991 and 1992) and nest/roost boxes (in 1992) identical to those provided on Kapiti Island were placed in the aviary to familiarize the birds with them.

The birds were recaptured in the aviary using a hand net within 2 hours of being translocated to Kapiti Island. They were then reweighed and placed in transfer boxes. In 1991, modified cardboard cat-transporting boxes were designed to carry the birds (one male and one female) to be released in pairs (Figure 1.2). Those birds destined for group release were placed in wooden transfer boxes (1 x 0.4 x 0.4 m) originally designed for saddleback (*Philesturnus carunculatus*) transfers. In 1992, the cardboard boxes were used to carry birds to be fitted with radio transmitters. The remaining birds were carried in wooden boxes in groups of five. In both years, the cardboard boxes were placed in specially constructed crates to avoid their being crushed or significantly shifting during transportation by plane. The inter-island transfer involved three modes of transport in all: helicopter, commercial plane and car.

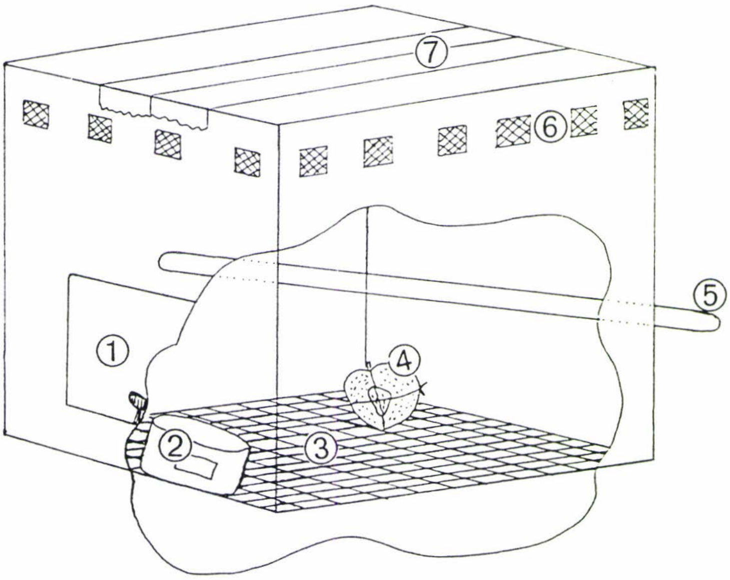


Figure 1.2. Design of the cat-transporting box modified to carry hihi. 1. A small entrance was cut on the side of the box. A metal pin held it shut. 2. Velcro attachments on tins and box were enough to hold the tins in place while at a stop. Tins were removed while in transit. 3. The floor of the box was covered with newspaper. A piece of chicken mesh was placed over the paper. 4. Apple halves were attached to the box with a piece of string. 5. Perches were attached to the box. 6. Shade cloth was placed inside the box to cover the small breathing holes. 7. The top of the box was flattened and taped to avoid unwanted opening during transportation.

The birds were provided with both water and liquid food when not travelling. Apple halves were securely attached to the inside of each transport box to provide the birds with food throughout the transfer.

1.2.2 Preparation of release sites

On Kapiti the 1991 release sites were chosen from several areas which had aviaries previously used for the release of saddlebacks (Figure 1.3). The aviaries chosen for the delayed-release birds were provided with fresh vegetation, small water baths, perches and feeders. In 1991, feeders were also placed outside the aviaries for the immediate-release birds. Because there was no restriction on the birds that could use the feeders outside the aviaries there was considerable disturbance, mainly by kaka (*Nestor notabilis*), a New Zealand parrot.

In 1992, the release sites were selected according to habitat suitability and the presence or absence of resident conspecifics. The feeders in 1992 were designed to exclude birds larger than the hihi but could not exclude the smaller bellbird (*Anthornis melanura*). Six feeders were placed in catchments between and including the Kaiwharawhara and the Te Rere streams. Nesting/roosting boxes were also placed in those catchments.

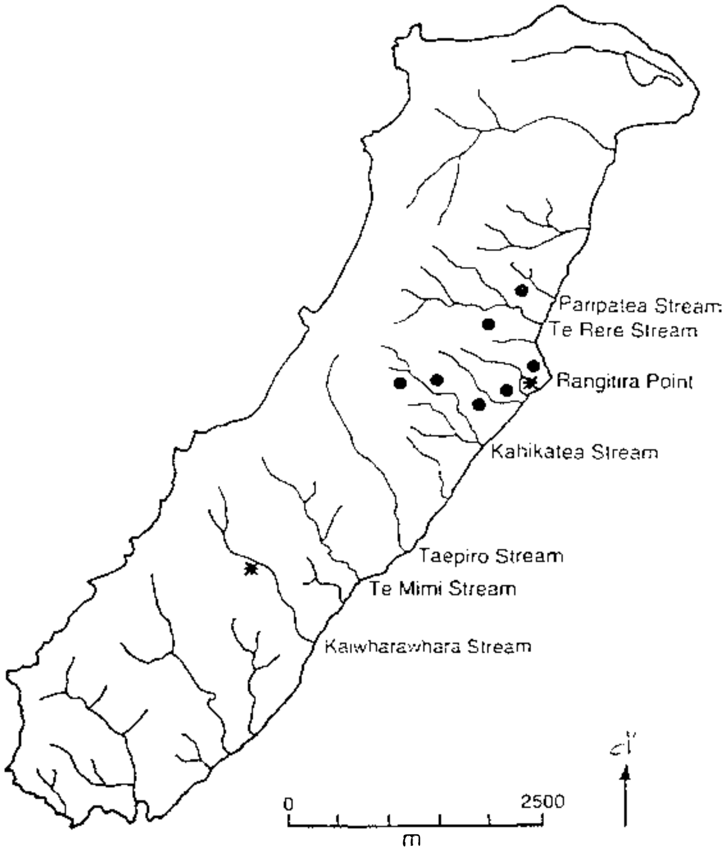


Figure 1.3. Map of Kapiti Island showing the 1991 (black circles) and 1992 (asterisks) release sites. An aviary and feeder were present at each release site.

1.2.3 Experimental Release Strategies

1.2.3.1 *Immediate vs delayed release* – In 1991, 12 pairs of birds were released as soon as possible after arrival at Kapiti Island (immediate-release), and 11 of the 12 remaining pairs after two weeks in captivity on Kapiti (delayed-release). Food was provided for both immediate-release and delayed-release birds for a period of 4 weeks.

1.2.3.2 *Paired vs grouped release* – In the 1991 delayed-release group, six pairs were kept together as a group in a large aviary (5 x 3 x 2.5 m) and then released together. The six remaining pairs were each taken to a different small aviary (2 x 1 x 2 m) at one of six locations. Similarly, in the 1991 immediate-release group, six pairs were released together from the large aviary, while the remaining six pairs were released from each of the small aviaries.

1.2.3.3 *Presence vs absence of conspecifics*– In 1992, survival of birds released into areas supporting resident hihi was compared with that of birds released into areas without resident hihi. Twelve pairs were immediately released in the Kaiwharawhara, a catchment which held no resident hihi, and 11 pairs plus a male bird were immediately released at Rangatira. Surviving birds from the 1991 release (18 adults) and their offspring (12 birds) had established between the Te Rere and Kahikatea catchments. Food was provided at each of six aviaries for 4 weeks.

1.2.4 Monitoring Techniques

Data on the survival and movements of transferred birds were obtained by tracking radio-tagged birds, observing hihi at the feeding stations, and undertaking daily searches of the Te Rere, Paripatea, Kahikatea, and Kaiwharawhara catchments (Figure 1.3). Adjacent areas were also searched occasionally.

Different release strategies were evaluated for the first 4 weeks after release. After this time it was assumed that factors other than those directly associated with the release would be responsible for the disappearance of birds.

Survival was monitored by sighting of colour-banded individuals. Birds not seen during the 4 weeks after release but seen subsequently were counted as survivors.

Radio-telemetry was used to locate hihi and map their movements during the first 2 weeks after release on Kapiti Island. The small size and high mobility of hihi made it necessary to use a small transmitter glued to the clipped bases of the contour feathers on the back of the birds (Castro 1992). The transmitter's battery lasted on average 14 days. In 1991, two birds (a male and a female) in each of the delayed/grouped, immediate/grouped, and the immediate/paired treatments were fitted with transmitters, while only a male was fitted with a transmitter in the delayed/paired treatment because the eighth transmitter was faulty. A transmitter was also attached to a male, one of four birds that were on the island prior to the 1991 release. In 1992, transmitters were attached to four birds in the conspecifics-present group and four birds in the conspecifics-absent group (two of each sex in each group).

1.3 RESULTS

1.3.1 Survival: capture to release

Of 104 birds held captive on Little Barrier Island, only one died, probably as a result of stress. The inter-island transfer took a maximum of 22 h including a 12 h stopover. All birds survived the transfer and were released on Kapiti between 09:00 and 12:00 h. On Kapiti a single female from the delayed/paired treatment group died prior to release, apparently of a stress-related illness (P. Stockdale, pers. comm.).

1.3.2 Post- release survival in 1991

1.3.2.1 *Immediate vs delayed release*- Delayed-release hihi disappeared faster than hihi that were released immediately. Of the 24 hihi released immediately, 75% were known to be alive 4 weeks after release, whereas only 46% of the 24 delayed-release birds were known to be alive 4 weeks after their release (Fisher exact test, 2-tailed, P=0.075).

The greatest difference in survival in 1991 was recorded between immediate-release females (83% resighted 4 weeks after release) and delayed-release females (50% resighted after release). A single female from the delayed-release group was found sick after release (due to possible pneumonia), recaught, and returned to captivity. However, before she recovered, she was killed and eaten by a Norway rat (*Rattus norvegicus*).

Delayed-release females kept in pairs apparently suffered greater stress than those kept in groups. Dominant males in the wild were observed displaying aggressively to paired caged birds. In addition, when caged in pairs males were aggressive towards females, monopolizing the food tray for long periods of time. This kind of behaviour was not observed in the birds kept in a group.

1.3.2.2 *Paired vs. grouped release*- There was no difference between the survival of birds released in pairs and birds released as a group (Table 1.1).

Table 1.1. Comparison of survival 4 weeks after release of birds released as a group or in pairs on Kapiti Island in 1991.

Immediate				Delayed			
Paired		Grouped		Paired		Grouped	
Female	Male	Female	Male	Female	Male	Female	Male
5/6	4/6	5/6	4/6	3/6	3/6	3/6	3/6

1.3.3 **Post-release survival in 1992**

Although 71% of the 24 birds released in the absence of conspecifics were known to be alive at the end of the first 4 weeks after release, only 56% of the 23 birds released in the presence of conspecifics were sighted. However, this difference in survival was not statistically significant (χ^2_1=1.4, P > 0.05, NS).

One male and one female from the group released in the absence of conspecifics and a male from the group released in the presence of conspecifics showed symptoms of a respiratory condition 2 to 3 weeks after release. A *post mortem* examination of one of the males following euthanasia suggested an air sac mite (*Sternostoma tracheacolum*) infection to be a possible cause of the condition (S. Cork pers. comm.).

1.3.4 **Movement Patterns in 1991**

Figure 1.4 shows the areas used by the different groups of radio-tagged birds. Immediate-release birds travelled over a greater area than delayed-release birds. The behaviour of the latter group resembled that of the radio-tagged Kapiti Island resident male in that they stayed mostly in one relatively small area. However, after the first week all birds showed a preference for a particular area.

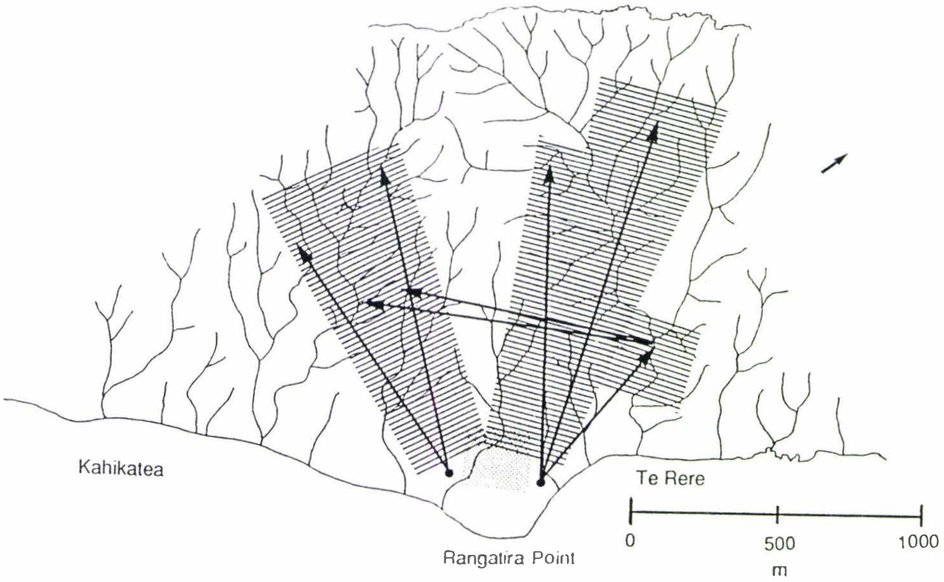


Figure 1.4. Movements of radio-tagged birds in the first 15 days after release on Kapiti Island in 1991. The arrows indicate general movements and do not correspond to individual birds. The dots represent release sites. Horizontal lines show the known area used by immediate release birds and the stippling shows the area used by delayed release birds.

Immediate-release females were the only birds to be often sighted at different feeding stations on the same day. This was true for both radio-tagged and colour-banded birds. This suggests that immediate-release females moved over a greater area than males or delayed-release females. For surviving males immediate-release birds were sighted on 19 of the 30 search days on average(64%), delayed-release males were sighted on 13 of the 16 search days on average (80%). This suggests that delayed-release males moved out of the monitored areas less often than the immediate-release males.

1.3.5 Movement Patterns in 1992

All but one of the four radio-tagged birds released at Rangatira moved to the Te Rere catchment immediately after the release and stayed there during the four weeks of intensive observations. The fourth bird moved in the opposite direction, establishing himself in an area of the upper Kahikatea catchment where there had been no sightings of hihi during the research in 1991 (Figure 1.5). Of the 20 non-radio-tagged birds released in Rangatira, five moved to the Te Rere Catchment and five to the Kahikatea. The remaining ten were not seen after release.

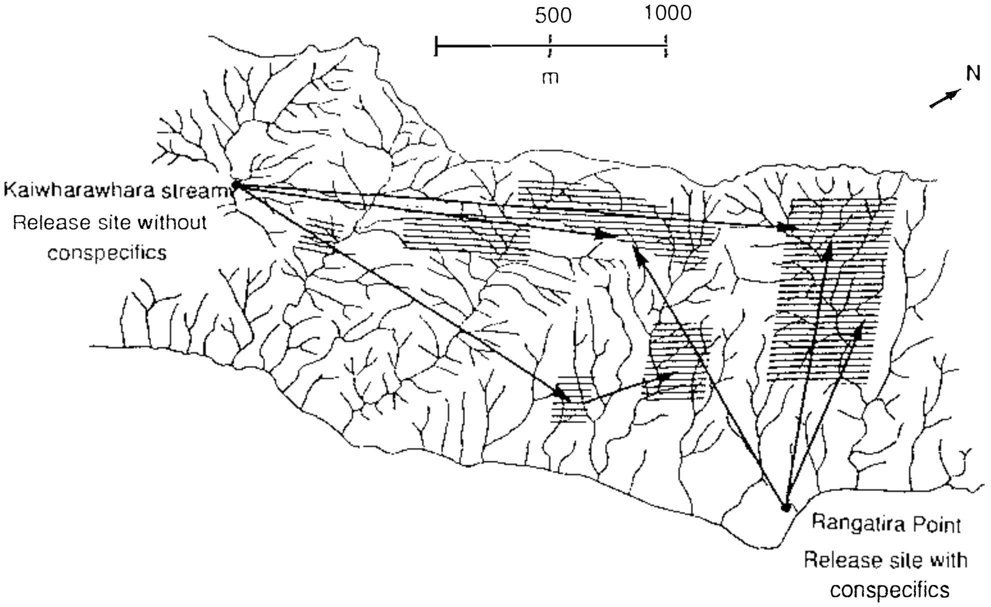


Figure 1.5. Movements of radio-tagged birds in the first 15 days after release on Kapiti Island in 1992. The arrows indicate general movements and do not correspond to individual birds. Dots represent the release sites. Horizontal lines show the known area used by birds.

The four radio-tagged birds released in the Kaiwharawhara moved into the lower Kahikatea and Te Rere catchments within 4 days of their release, and established themselves in areas frequented by resident hihi. Of the non-radio-tagged birds released in the Kaiwharawhara, nine remained within the catchment and were seen using the feeding station during the four weeks of intensive observation, six moved to the Te Rere Catchment within the first six days of release and one moved into the Kahikatea Catchment. The remaining three birds were not found.

1.4 DISCUSSION

1.4.1 Transfer techniques

Holding the hihi in a single large aviary following their capture on Little Barrier Island did not seem to affect the birds particularly. However, it is not clear whether the possible air sac mite infection in 1992 developed on Little Barrier Island prior to the transfer, or on Kapiti Island after release. This infection could have occurred as a consequence of weather conditions in 1992 and may not be a problem in future transfers. However, if the disease was caught on Little Barrier Island, it is possible that keeping the birds in the same large cage could have encouraged the transmission of the parasite (Fillipich 1991).

The hihi appeared to travel well with no obvious problems. Wooden transfer boxes and modified cardboard cat-transporting boxes proved equally suitable for transporting the birds. When transporting the birds on foot, the cardboard boxes were considerably easier to carry than wooden boxes. However, wooden boxes allow birds to be carried in groups and provide better security for air travel.

1.4.2 Experimental Release Strategies

Siegel (1980) pointed out that chronic stress may cause suppression of the immune system and predispose birds to disease caused by opportunistic pathogens. Previous *post mortem* examination reports of captive hihi indicate that this species is particularly susceptible to respiratory disorders (e.g. mycotic pneumonia) when held in captivity (S. Cork, pers. comm.). The yellow-tufted honeyeater (*Lichenostomus melanops melanops)* from Australia is also very susceptible to respiratory diseases, notably mycotic pneumonia (Smales *et al.* 1992).

Mortality of birds after release could be attributed to reduced competitive ability brought about by the period of captivity and exacerbated by confrontation with a new environment. Hihi are at the bottom of the honeyeater hierarchy in New Zealand (Craig, Stewart and Douglas 1981; Craig 1984; Angher 1984; Rasch 1985; pers. obs.). Size, sex and physical condition are important determinants of social dominance (Angehr 1984). Delayed-release birds remained captive for a longer period of time and, in addition, when released had to compete with the immediate-release birds as well as other resident honeyeaters. Kapiti Island has large populations of both tui (*Prosthemadera novaeseelandiae*) and bellbirds, the other two New Zealand honeyeaters. This potentially stressful situation could explain the lower survival of the birds.

Hihi released into an area not inhabited by resident conspecifics had an only slightly greater rate of survival. Birds released in the absence of conspecifics found other hihi relatively quickly and sometimes established themselves in areas adjacent to or in the residents' home ranges.

It is uncertain how significant supplementary feeding was to the survival of the hihi. The regular and sometimes frequent use of the feeders by hihi immediately after release indicates that it is an important source of food in this period. Having an easily accessible food supply may have alleviated some of the stress the birds could have experienced while familiarizing themselves with a new environment.

1.4.3 **Monitoring Techniques**

Transmitters were of great value in following the movements of birds and their behaviour after release. Because the transmitters fell off naturally or could be removed from the birds soon after the batteries expired, the birds did not have to carry them for a long period of time. There was no significant difference in the survival of birds with and without transmitters (for 1991 and 1992 combined, χ^2_1=0.005, NS).

Surviving birds were sighted on average 95% of the time, so I am confident that the survival data presented here reflects the real survival rate of hihi. Feeding stations proved to be of considerable value in assessing survival of hihi during the 4 weeks following the release. Hihi readily learnt to use the feeders and although birds were also seen elsewhere, most sightings of hihi were made at the feeders.

1.4.4 **Bird Movements**

The wide movements of immediate-release birds can be explained by the time of the year when they were released. Males and females have been seen searching for cavities on Little Barrier Island in August (Angehr 1984). Females compete for nesting holes (Castro *et al.* 1994; Chapter 2) and it would be an advantage for a female to know the location of all possible sites, so that she can select the best site or move to another if her first choice is taken by another bird. Male movements on Kapiti may therefore have been influenced by the need to establish a breeding territory, while female movements may have been influenced by the need to choose both males and an appropriate nesting site.

I am not certain why the delayed-release birds moved less than the immediate-release ones. It is possible that delayed-release birds stayed in the areas where they were released because their physical condition was relatively poor. By staying around the release site they had access to feeders and therefore to easy food. They also could have been prevented from leaving the release areas by immediate-release birds. However, the mere presence of resident conspecifics does not seem to prevent movement. In 1992, birds were released in the presence of conspecifics and still they moved over areas as large as the immediate release birds in 1991. Thus, the difference in movements in 1991 was a result of the delayed release rather than the presence of conspecifics.

1.4.5 Recommendations

1) Hihi should be released as soon as possible after transfer, preferably in areas free of conspecifics, and be provided with supplementary food at more than one feeding station, that excludes larger competitors.
2) Hihi should be provided with water and food as often as possible during the transfer. Although nectar mix is an ideal food, as a liquid it can only be used when not moving. Apple halves, securely attached to the lower part or base of the transfer box, are more practical during transportation.
3) For hihi, stress in captivity can be minimized by not caging birds in areas inhabited by dominant conspecifics, by caging birds in groups rather than in pairs, and by keeping them in captivity for as short a period as possible.
4) The possibility of disease transmission during captivity should be minimized whenever possible. The birds should be kept in small groups of about a dozen birds, and isolated from each other rather than housed all together in a single large aviary.
5) Transfer boxes should be sturdy and light-weight. The modified cat-transporting boxes are useful if they need to be carried for substantial distances. Otherwise wooden boxes are suitable.
6) All releases should be closely monitored to determine their success. Monitoring also allows problems, some of which could be corrected immediately, to be identified.
7) Further work needs to be done to assess the influence on survival of (1) release of birds in groups of the same sex, (2) release of birds at different times of the year, (3) release of birds of different ages, and (4) use of nest boxes as roosts after transfer.

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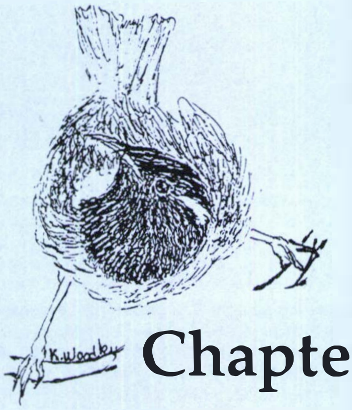

Chapter 2

Chapter 2

Feeding and breeding behaviour of hihi or stitchbirds (*Notiomystis cincta*) recently transferred to Kapiti Island, New Zealand, and possible management alternatives

ABSTRACT

The breeding and feeding behaviour of hihi differ between their source population on Little Barrier Island and Kapiti Island, where they have been transferred. In contrast to Little Barrier Island the hihi on Kapiti Island use artificial feeders during spring and adopt a variety of polygamous mating systems. The change in behaviour reflects both environmental differences between the islands and the ability of the species to adapt to a new environment. Although Kapiti may be a suboptimal habitat for hihi, the behavioural plasticity of the species could be used, in combination with habitat management, to establish a population on Kapiti.

2.1 INTRODUCTION

THE hihi or stitchbird (*Notiomystis cincta*) is one of three species of honeyeater in New Zealand. Although the other two species are still relatively common, the hihi is extinct throughout its former range with the exception of Little Barrier Island (Buller 1967)(Figure 2.1). This severe contraction of range was probably caused by introduced mammalian predators, disease, removal of forests and collection of birds for museums (Mills and Williams 1979; Rasch 1991). The roosting and breeding behaviour of hihi could also have contributed to their extinction. Because hihi roost and nest in cavities they could be easy prey for nocturnal climbing predators. During the breeding season both mothers and chicks could be taken on the nest. Hihi roost in groups and this behaviour could facilitate the transmission of diseases and allow nocturnal predators to eliminate several birds at one time. The O'o (*Moho braccatus*) from Hawaii is the only other species in the family Meliphagidae that nests or roosts in cavities and it is now nearly extinct, presumably for similar reasons (IUCN 1979). In addition, in social interactions hihi are subordinate to the other two New Zealand honeyeater species (Angher 1984; Craig 1984; Rasch 1985). The destruction of mainland forests has resulted in a diminished food supply for honeyeaters. If as a result there was increased competition among the honeyeaters, the subordinate status of hihi could have been a factor contributing to their extinction.

Several studies on Little Barrier Island have looked at the feeding and breeding ecology of hihi (Gravatt 1970; Angher 1984; Rasch 1985). The three studies suggest that the birds feed on three main categories of food, namely fruits, flower nectar and insects. The proportions of these foods in their diet vary throughout the year according to availability. These proportions also vary from year to year depending on plant phenology. Hihi appear to breed monogamously with a single male and female attending a nesting cavity.

Management directed to ensure the survival of hihi has included attempts to translocate the birds to suitable islands with reduced predation from mammalian predators and to establish a captive breeding program. Since 1980 there have been two transfers to Hen Island, two to Cuvier Island and five to Kapiti Island. The transfers to Hen and Cuvier Islands failed to establish viable populations (Rasch 1991). The first three transfers to Kapiti Island (1983, 1985 and 1990) were also unsuccessful (Rasch 1991) and the last two (1991 and 1992) form part of the present study. After every transfer, the birds bred successfully at least during their first season (Angehr 1984; Lovegrove 1986).

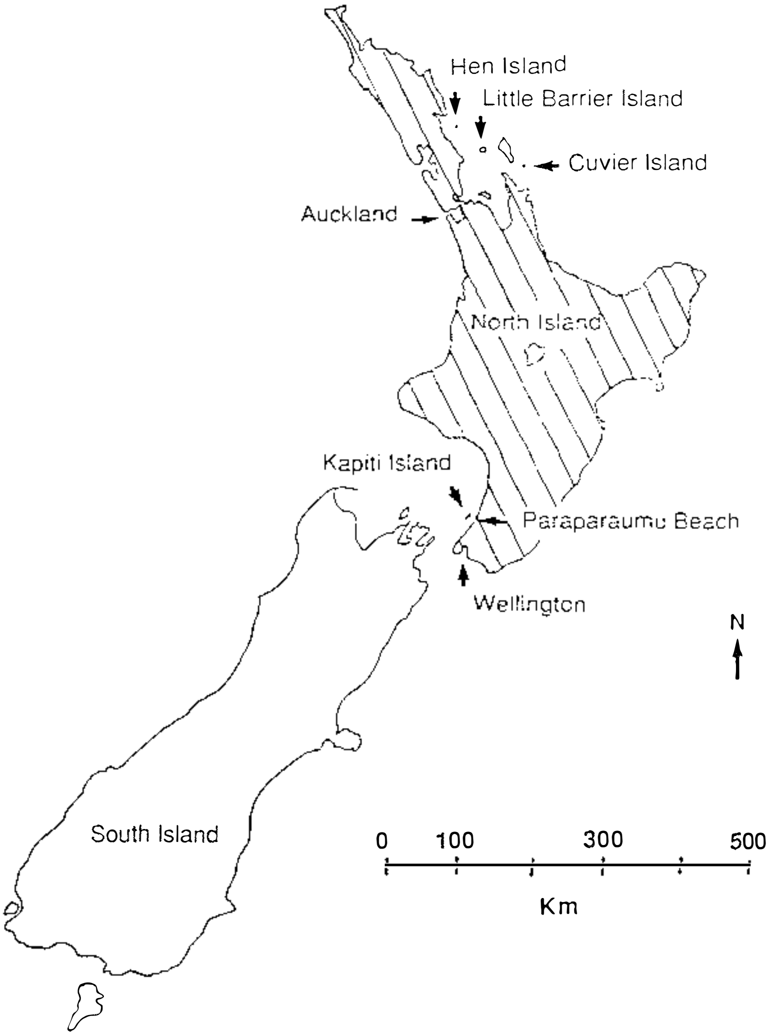

Figure 2.1. Map of New Zealand showing the distribution of hihi before the 1800's (shaded area). The species is now reduced to a population on Little Barrier Island. Birds have been transferred to Kapiti, Cuvier and Hen Islands but no self-sustaining population has been established to date.

The suitability of each recipient island was evaluated prior to the transfers. The likely impact of predators, availability of foods and habitat quality were assessed in comparison with Little Barrier Island (Angehr 1984). Kapiti, Hen and Cuvier Islands all had more than 100 ha of broadleaf forests, considered to be generally suitable habitat for hihi. Throughout the year, Hen Island has a minimum of 12 plant species preferred by hihi either in fruit or flower in any month, while Kapiti has nine and Cuvier eight species. By comparison, Little Barrier Island has 15 species (Angehr 1984). Polynesian rats (*Rattus exulans*) are present on Hen Island, Cuvier Island and Little Barrier Island. Kapiti Island supports both Norway (*Rattus norvegicus*) and Polynesian rats.

Angehr (1984), Lovegrove (1986) and Rasch (1991) suggested that the failure of hihi to establish populations on other islands may be related to food availability. Rasch (1991) also suggested that the number of birds transferred prior to 1991 could have been too small, after post-release mortality, to reach the threshold population size needed to maintain a social structure. The availability of nest sites has never been assessed as a possible explanation of the failures, probably because the transferred birds bred well during the first couple of seasons. Predation has not been reported for any release prior to 1991, when a Norway rat killed a sick bird held in captivity on Kapiti Island (Castro *et al.* 1994; Chapter 1). This incident shows that predation by Norway rats could occur, even if only on sick individuals. In 1992, Polynesian rat tooth marks were found on the remains of a dead radio-tagged bird on Kapiti Island (B.M. Fitzgerald, pers. comm.). However, the rat may have scavenged, rather than killed, the bird.

The purpose of this Chapter is to describe the feeding and breeding behaviours of hihi transferred to Kapiti Island in 1991 and 1992 and to compare them to the feeding and breeding behaviours of the hihi population on Little Barrier Island. Behavioural differences are analysed in relation to differences in vegetation, food and nest site availability between the two islands.

2.2 **METHODS**

Ninety-five hihi (48 males and 47 females) were transferred from Little Barrier Island to Kapiti Island between August 1991 and August 1992 (Castro *et al.* 1994; Chapter 1). The birds were individually marked with coloured and metal leg bands. At the time of the 1991 transfer there were four resident hihi found on Kapiti Island. Two of them were banded in the week after the 1991 release. A third one had been banded prior to its release in 1990, and the fourth, a female, disappeared soon after the 1991 release. No other hihi were found surviving on Kapiti Island (Empson 1992; Castro 1992; Castro *et al.* 1994; Chapter 1).

From September 1991 to August 1992 and from April to September 1993, data were collected during 36 field trips (two per month) of 7 to 10 days each. On every trip the Kahikatea and Te Rere catchments were searched for birds at least four times. These are the catchments where hihi became established after the 1991 release (Castro *et al.* 1994; Chapter 1) (Figure 1.3, Chapter 1). After the release of birds in August 1992, some birds established in the Kaiwharawhara catchment, possibly as a result of the release strategy (Castro *et al.* 1994; Chapter 1). For this reason, the area of the Kaiwharawhara catchment was included in the areas searched for birds, and it was visited at least one day each trip. From October 1992 to April 1993 and from October 1993 to March 1994 (the breeding season) I stayed on the island permanently. During this period of time, the Kahikatea and Te Rere catchments each were visited at least three times per week and the Kaiwharawhara once every 2 weeks. Occasionally I checked other catchments to make sure that the birds were not dispersing elsewhere.

2.2.1 **Feeding**

Birds were located by sight and/or sound. When possible, an individual was followed until its sex, band combination, and feeding activity were recorded. Feeding activities were classified as fruit eating, nectar feeding, and invertebrate feeding, which included both gleaning (picking invertebrates from leaves and bark or perhaps licking insect and plant exudates) and hawking (catching insects in the air). Whenever possible specific food items were also identified. Because the number of plants available for hihi at a given time is small and because the birds tend to move from one plant to another within a short period of time the observations were recorded as visits to feed on a plant species, rather than units of food consumed. It was assumed that the number of times birds were sighted feeding on a particular plant represents the true contribution of such a plant (fruits or flowers) to their diet. Similarly, the times birds were observed hawking or gleaning every month was counted. It was assumed that if birds were observed hawking or gleaning more times in a particular month this meant that invertebrates were contributing to a larger extent to their diet. In other words, it was assumed that the percentage of invertebrates in the diet is proportional to the frequency of observed hawking or gleaning. Data on diet is presented as a percentage of feeding observations. This percentage was obtained by adding all observations of a particular feeding activity for all known individuals each month and dividing this value by the total number of observations of the three different feeding activities.

For the first 4 weeks after each release, food was provided in several feeders at each release site (Castro *et al.* 1994; Chapter 1). After the first 4 weeks only one of the feeders, the one at Rangatira, was left open and provisioned with food daily throughout the year. Other feeders were provisioned occasionally to attract birds to a mist net or to observe interactions among them. The main feeder was observed every 2 weeks for 1-16 hours. This feeder was used by bellbirds (*Anthornis melanura*), one of the two other New Zealand honeyeater species, as well as by hihi. Tui (*Prosthemadera* *novaeseelandiae*), the third species, were too large to enter the feeder. I recorded the sex and band combinations of hihi present at the feeder area and noted any interactions between birds. The proportion of birds using the feeder was calculated by dividing the total number of individual birds visiting the feeder each month by the total number of birds known to be alive on the island.

2.2.2 Breeding

Once breeding sites were discovered they were visited regularly and birds were observed for intervals ranging from 1-5 h. During hihi courtship, nest building, incubation and brooding I monitored activity on the territory or at the nest for an average of 6 h per week per nest site. Males within 50 m of the nest were considered to be associated with the nest. When such males called frequently in the vicinity of the nest and entered the nest cavity, they were considered to be the "owners" of the nest. This "ownership" was corroborated by the observation of such male(s) feeding nestlings. I used the term "polygamy" to refer to nests where two or more birds of one sex were caring for the eggs (females) or young (females and males). True polygamy, rather than helping behaviour, was established after finding that male hihi have morphological traits only found in polygynandrous species (Castro *et al. In press*; Chapter 3).

During the 1991 breeding season several female hihi showed interest in nesting boxes placed on Kapiti Island for saddlebacks (*Philesturnus carunculatus*), an endangered New Zealand passerine, and kakariki (*Cyanoramphus novaezelandiae*) a resident parakeet species. Two recently released hihi nested that season in saddleback boxes of a design not accepted by saddlebacks. In 1992, 48 of these nesting boxes were erected on Kapiti Island, mainly along the Taepiro (5), Te Mimi (10) and Kaiwharawhara (18) streams, because these catchments have fewer large trees where cavities could be present. The remaining boxes were placed in areas of Rangatira (5), Kahikatea (5) and Te Rere (5) catchments that were covered by small trees or bushes.

2.3 RESULTS

2.3.1 Feeding

The percentage of observations of hihi feeding on the three categories of food changed through the year (Figure 2.2). Observations of birds feeding on flowers were most common during spring (46% for the three years combined) and winter (56%), while observations of insect-feeding activities were most common during spring (42%) and summer (49%). Fruit feeding was most common during the autumn (37.5%). In summer the birds were observed feeding mostly on invertebrates (49%), while in autumn the birds fed similarly (invertebrates 37.5%, flowers 25%, fruits 37.5%) on each of the three categories of food. In the winter 56% of observations were in flowers (mainly on *Dysoxylum spectabile*).

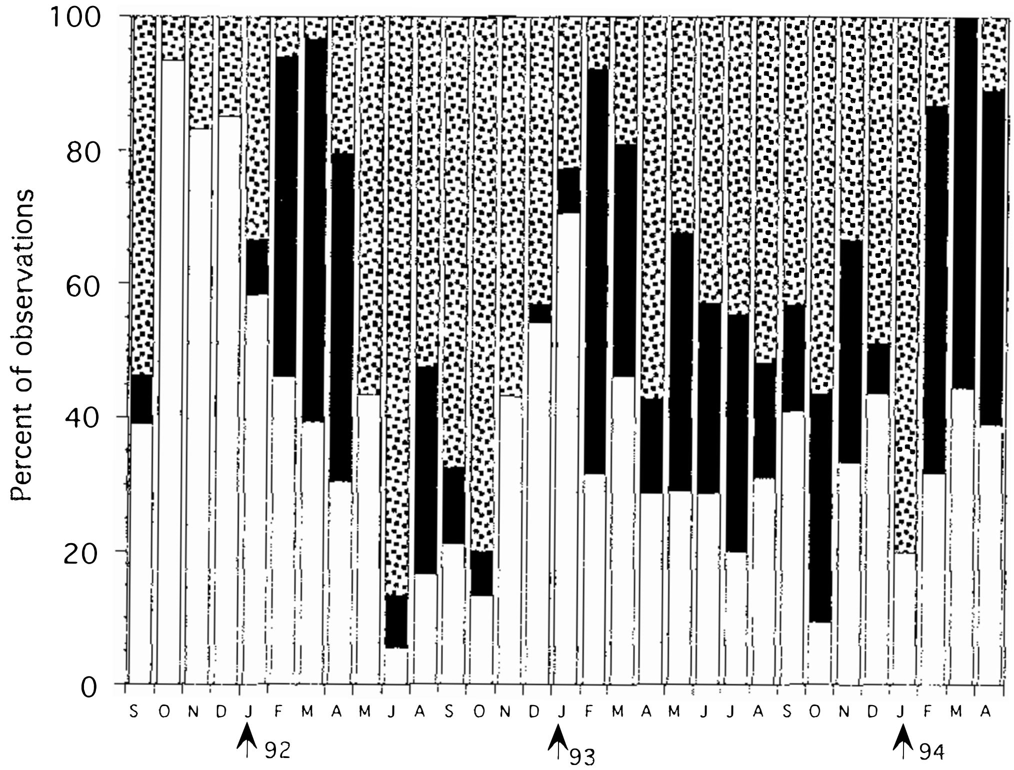

Figure 2.2. Percentage of observations of hihi taking different types of food on Kapiti Island from Sept 1991 to Aug 1994. Dotted areas = flowers; black area = fruits; white area = invertebrates. The number of observations (n) per month varied from 15 to 120 with an average of 51.3 observations per month.

The use of the main feeder also changed throughout the year (Figure 2.3). From April to June birds did not use the feeder but were seen feeding on flowers and fruits. During the spring the use of the feeder was high: up to 100% of the birds used it in November 1991.

2.3.2 **Breeding**

In 1991, 1992, and 1993, from zero to six males were seen around each nest site during the period of nest building and egg laying (Oct-Nov). At this time there was much chasing of males by other males, and females by males and other females. Later in the season, males and females, other than those feeding chicks, also made short visits to the cavities. Similar behaviour has been reported from Little Barrier Island (Rasch 1985). There is no obvious explanation for this investigative behaviour but it could be an assessment of potential breeding sites for future use. Alternatively, visiting males may be investigating the breeding status of the resident female. There is no record of hihi laying more than two clutches in the same breeding season (G. Rasch pers. comm.

for Little Barrier Island; P. Morton pers. comm. for captive birds; pers. obs. on Kapiti Island). In 1991, two nests (first clutches) were found during the early stages of nest building. More than one female was present at each nest site and all females participated in the building of the nest platform. However, only one female built the cup. This female was the dominant female and she often chased the other females (not males) and eventually became the one associated with the nest for the rest of the season. In 1992, three of the seven nests found during early nest building had more than one female (three, three, and four) participating in the building of the nest platform. Again, for these three nests only the dominant female remained in the area. In 1993, three of 13 nests found had two females building the nest. In one case both females incubated while in the other two cases only the dominant female stayed.

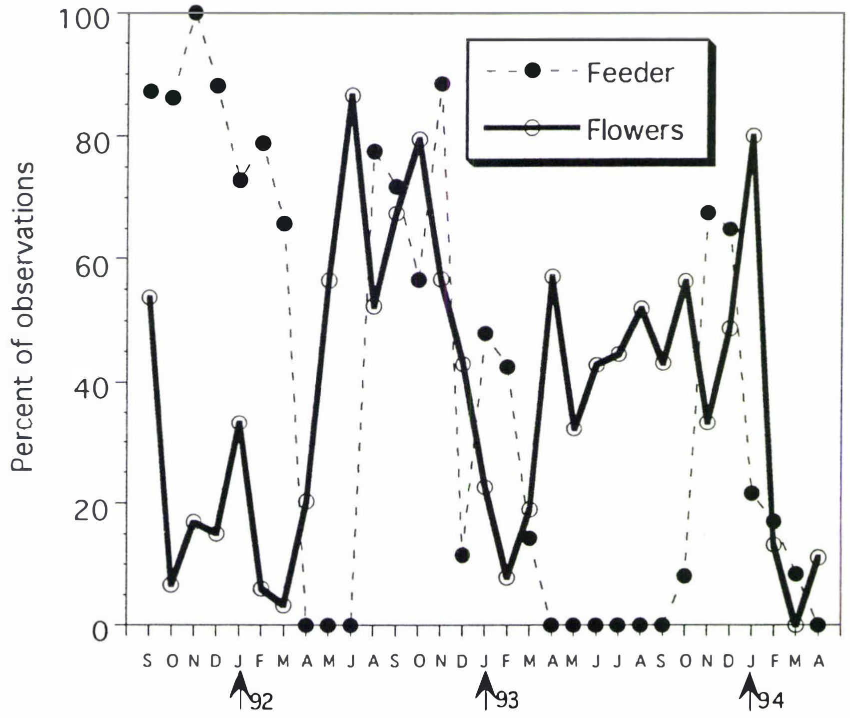

Figure 2.3. Percentage of birds using the Rangatira feeder each month (broken line), and percentage of observations of hihi feeding on flowers (solid line) on Kapiti Island (1991 to 1994). Spring = Sept, Oct, Nov; Summer = Dec, Jan, Feb; Autumn = Mar, Apr, May; Winter = Jun, Jul, Aug.

In each nesting season two (1991 and 1992) or three (1993) females built complete or partial nests in boxes. No birds used the new boxes placed in 1992 until the breeding season of 1993 when two boxes were used. In 1991, one female nesting in a box moved to a different box for her second clutch, and the second female abandoned her nest during incubation. In 1992, one of the two females nesting in a box renested in a nearby box, and the other disappeared during brooding (presumed dead). In 1993, one female built two nest platforms in boxes but nested in a nearby natural cavity. Two other females built two nests in boxes but only used one each. Females using natural cavities renested at the same site. With the exception of two birds, all females from the 1991 release nested at the same site as in the previous year. One female moved to a new site in 1992, but her 1991 nesting area was used by one of her offspring. The other female nested in a box 15 m from the cavity used in the 1991-92 breeding season. Males were also seen at the same sites as the year before. In 1993, two females moved from their nest site in 1992 to new sites. The two abandoned sites were used in 1993 by first-year females, possibly the offspring of the former resident females.

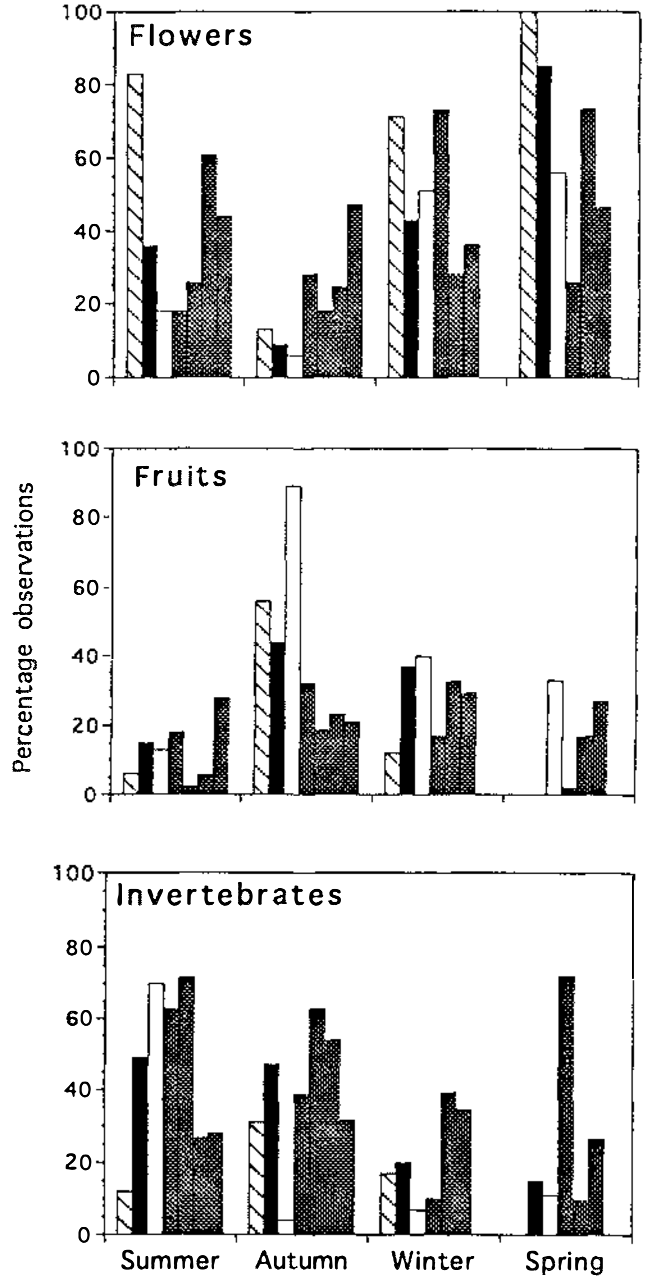

Figure 2.4. Comparison between the feeding preferences of hihi on Little Barrier Island and Kapiti Island. The white bars represent data collected on Little Barrier Island. From left to right, Gravatt (1970; data for 1969); Angehr (1984; data for 1982); and Rasch (1985; data for 1984). The black bar corresponds to the data collected on Kapiti Island between Sept 1991 and Aug 1994.

While no polygamous nests were found in 1991, three were found in 1992 and three in 1993 (Table 2.1). In 1992, two of the nests were polyandrous (two males attending each nest) and one nest was polygynous (two females sharing the same nest). In 1993, one was polygynous, one was polyandrous and one polygynandrous (two males and two females feeding fledglings).

Table 2.1. Hihi breeding results for Kapiti Island. [1]For 1991 first clutches and 1993 breeding season, an additional two broods fledged, but the nests were never located. For these nests only the females were considered successful as I never found males feeding the young. [2]"Involved" means the number of birds of either sex participating in breeding activities. [3]The successful males are those known "owners" of a cavity that successfully fledged young. See text for definition of "owner". [4]Successful nests are those which fledged young. [5]Nesting males are those males involved in breeding that fed young. [6] No second clutches found in 1993.

	Year/Clutch				
	1991/1	1991/2	1992/1	1992/2	1993/1[6]
Females on Kapiti	11	11	27	27	20
Males on Kapiti	13	13	25	25	16
Nests found	5[1]	4	15	7	13[1]
Females involved[2] (%)	9 (82)	5 (45)	20 (74)	7 (26)	19 (95)
Males involved[2] (%)	11 (85)	8 (61)	18 (72)	12 (40)	15 (94)
Females nesting (%)	7 (64)	4 (36)	16 (59)	7 (26)	14 (80)
Males nesting[5] (%)	6 (46)	4 (31)	14 (56)	0 (0)	13 (81)
Successful females (%)	6 (86)	1 (25)	11 (69)	1 (14)	10 (12)
Successful males[3] (%)	4 (67)	1 (25)	12 (86)	0 (0)	8 (61)
Successful nests[4] (%)	6[1] (86)	1 (25)	10 (67)	1 (14)	10[1] (77)
Polygynous nests	0	0	1	0	1
Polyandrous nests	0	0	2	0	1

2.4 **DISCUSSION**

2.4.1 **Feeding**

Although variations in the seasonal use of different food items from year to year is expected, there is a consistent difference in autumn time feeding patterns between Little Barrier Island and Kapiti Island (Figure 2.4). In autumn, hihi on Kapiti Island fed mainly on invertebrates while hihi on Little Barrier Island fed mostly on fruits. Fruits and flowers seem to be the greatest contributors to feeding observations on Little Barrier I.. On Kapiti I. the greatest percentage of feeding observations are on invertebrates and flowers. Lovegrove (1986) also found insects to be an important food category for hihi throughout the year on Kapiti Island.

The higher consumption of invertebrates on Kapiti Island during autumn can be explained in several ways. The greater percentage of observations of birds feeding on invertebrates could be the result of a shift in diet due to shortage of fruits or flowers and the competition for this resource with the other honeyeaters. There was a weak negative correlation ($r = 0.61$) between the percent of observations in fruits and invertebrates (Chapter 5). Alternatively, it could be that the birds increased their consumption of invertebrates because the nutritional quality of the insects present on Kapiti was relatively low, and therefore they needed to consume many to obtain the minimum amount of a limited nutrient.

Support for the first option comes from data from a phenology transect run on Kapiti from April 1992 to August 1994 (Chapter 5). During the year there were fewer species of plants in flower or fruit on Kapiti I. when compared to Little Barrier I.. During the spring the species in flower were plants with a restricted distribution on the island or the tree stands were young (Chapter 5). Because hihi are at the bottom of the honeyeater dominance hierarchy, competition for this limited food resource could affect hihi more than the other honeyeaters. In autumn hihi seem to have shifted to invertebrates to compensate for a lack of fruits. In contrast, during the spring hihi increased their use of the feeder, a place where they could obtain nectar without having to compete with other species except for bellbirds. Thus, the large proportion of observations of birds feeding on invertebrates could be an overestimate because I am not considering the use of the sugar water as a substitute for nectar feeding.

In conclusion, seasonal scarcity of food could be hampering the successful establishment of hihi on Kapiti Island. Competition with tui and bellbirds probably contributes to this problem. This may be particularly important during spring when the birds are preparing for breeding. Data on the availability and abundance of the different foods and the feeding of the two other species of honeyeaters should be collected to test these hypotheses more rigorously. Meanwhile, the use of a feeder during the spring, when nectar is scarce on Kapiti Island is recommended.

2.4.2 **Breeding**

I believe there are two significant differences between the breeding of hihi on Little Barrier Island and Kapiti Island. Firstly, on Little Barrier Island breeding is apparently monogamous (Angehr 1984; Rasch 1985) while on Kapiti Island polygamy is observed. Secondly, hihi on Little Barrier Island tended not to reuse the same nest cavity for second clutches (Angehr 1984; Rasch 1985), while on Kapiti Island females used the same nests for first and second broods in 1991 and again in the 1992 breeding season (there were no attempts to renest in 1993). Both of these differences are probably the result of intense competition for nest sites which could be reflecting limited availability of suitable cavities on Kapiti Island.

Kapiti holds healthy populations of three other cavity nesters: kakariki, saddlebacks and kaka (*Nestor meridionalis*). The New Zealand kingfisher (*Halcyon sancta*) is also present but in small numbers. Of these cavity nesters kakariki and kingfishers are known to use the same cavities as hihi on Little Barrier Island, however there are no records of either species interfering with hihi nesting there. On Kapiti kakariki have been observed fighting for cavities with hihi every year. In 1993, competition for cavities was very high: in two of 13 nests known in 1993 hihi nesting was hampered by the constant fights for the nest cavity. In seven of the remaining 13 nests kakariki nested on hihi cavities two days after hihi chicks had fledged.

This competition for nesting cavities could be the result of a shortage of nesting cavities for hihi on Kapiti Island or could result from either kakariki or hihi having a behavioural incapacity to find suitable nest sites. Hihi have found suitable nest sites after each of the five transfers, indicating that the species has the behavioural capacity to locate sites. However, it is possible that hihi are constrained behaviourally when choosing nesting sites. Van Balen *et al.* (1982) studied the availability and occupancy of natural nest sites by various species of passerines. They reported that different species have specific cavity preferences (e.g. entrance size and shape, depth and height of cavity, height of cavity from the ground). Hihi preferences for nest sites are not fully understood. While Kapiti Island may have many cavities, the number of cavities that actually fit hihi requirements could be very small. Recently released birds and juveniles probably have difficulty locating a suitable nest site. It should be even harder for birds released just before the breeding season. This is supported by the fact that birds released in 1992 reproduced later than birds already established from 1991.

The possibility of a shortage of suitable nests sites should be considered. Kapiti Island forests are not older than 100 years (Fuller 1985). The propensity of trees to form natural cavities increases with age and varies from species to species. In the young forests on Kapiti Island the majority of trees of species that eventually produce hollows are not of cavity-forming age. In addition, tree cavities are not permanent and deteriorate over time. For example, Sedgwick and Knopf (1992) found that 46% of cavities found in a cottonwood bottomland in Colorado were no longer useable after 4 years. Because there are no primary cavity nesters on the island, cavities are only produced by the natural decay of particular tree species.

It is likely that suitable nest sites on Kapiti Island are so few and hard to find or defend thus it is better for a male or a female to share a nest cavity than not to nest at all. According to Emlen and Oring (1977), some species can change their breeding strategy depending on the environment. This possibility should be studied for hihi. There are insufficient data to test the difference in fledging success between the polygamous nests and monogamous nests. Although males may frequently engage in extra-pair copulations, feeding of young is likely to increase their long-term reproductive success and therefore encourage them to co-operate with other males rather than depend totally on extra-pair copulations to achieve reproductive success.

An immediate way to overcome nest site limitation in this case is to provide nest boxes. However, more permanent measures would require gathering information about the availability of suitable cavities, and cavity turnover on Kapiti Island, with the objective of planting of species that will eventually develop hollows.

Erecting nest boxes does not guarantee that the birds will use them. The ability of the box to exclude competitors and predators, its particular orientation, height above the ground, internal shape, and the familiarity of the birds with its presence are important factors to be considered if boxes are to be used (Snyder 1978 a, b; Zeleny 1978). It is possible that hihi did not use the nesting boxes provided in 1992 because the boxes were not located in positions or places that were attractive to hihi or because the boxes have not been in the area long enough. Experiments varying the height of the boxes from the ground are under way, but it is possible that other variables should be also tested.

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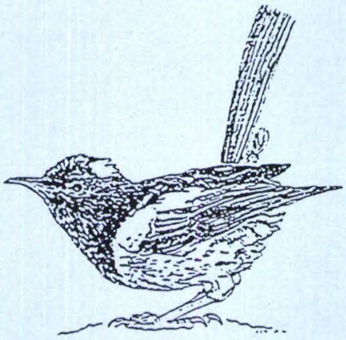

Chapter 3

Chapter 3

Polygynandry, face-to-face copulation and sperm competition in the Hihi *Notiomystis cincta* (Aves: Meliphagidae)

ABSTRACT

The Hihi *Notiomystis cincta* breeding system is highly variable, including monogamy, polyandry, polygyny and polygynandry. Males have large testes (4.2% of body mass), large numbers of sperm and an enlarged cloacal protuberance. These features are found in other species with highly variable mating systems where males are under intense sperm competition. Hihi mate in two different positions: face-to-face, and male on-the-female's-back. This face-to-face copulation is unique among birds and appears to be a form of forced copulation. The very large cloacal protuberance in males, and the cloacal protuberance in females could aid the transfer of sperm. Both male and female Hihi benefit from a mixed reproductive strategy (Trivers 1972) where a female Hihi can solicit copulations from males other than her partner and male Hihi can perform extra-pair copulations both with willing females or by forced copulation.

3.1 INTRODUCTION

ALTHOUGH the majority of bird species are socially monogamous, extra-pair copulations and sperm competition are frequent and result in extra-pair paternity (Birkhead & Møller 1992; Birkhead 1994). A number of male morphological correlates of sperm competition have been recorded in birds. In species where sperm competition is especially intense, such as those with polyandrous or polygynandrous mating systems, testes are relatively large and, in passerine birds, the male sperm store (seminal glomera) and cloacal protuberance are also relatively large (Birkhead *et al.* 1993; Briskie 1993). These features have been recorded in passerine birds such as the Dunnock *Prunella modularis* (Davies 1983; Birkhead *et al* 1991; Davies 1992), Alpine Accentor *Prunella collaris* (Nakamura 1990), Smith's Longspur *Calcarius pictus* (Briskie 1992, 1993), Superb Fairy-wren *Malurus cyaneus* (Mulder & Cockburn 1993) and Aquatic Warbler *Acrocephalus paludicola* (Schulze-Hagen, *et al.* 1995) which all have highly variable mating systems as well as large testes and large cloacal protuberances. Large testes and seminal glomera are probably essential to sustain high copulation rates, and/or to produce relatively large ejaculates, both of which play a central role in paternity assurance in birds (Birkhead & Møller 1992) and other taxa.

In this study I describe the breeding system, male morphology and unique copulation behaviour of another passerine, the Hihi or Stitchbird *Notiomystis cincta* (Meliphagidae), in which sperm competition is also intense.

3.2 METHODS

3.2.1 Study site

This study took place on Kapiti Island Nature Reserve, on the west coast of New Zealand's North Island during the 1991 to 1994 breeding seasons. The island was largely cleared for agriculture in the 1800's but by 1930 all browsing animals with the exception of Brush-tailed Possums *Trichosurus vulpecula* were eradicated. Kapiti Is. was freed of possums in 1986 (Cowan 1992). The forests on the island are divided into scrub and low forests (approx. 1041 ha), and tall forests (rata forest; tawa-hinau-kamahi forest; and kohekohe forest, approx. 550 ha) (Fuller 1985). The remainder of the island is covered by low scrub, grass, tussock and flax. With the exception of Norway Rat *Rattus norvegicus* and Polynesian Rat *R. exulans*, Kapiti Is. is free of mammalian predators.

3.2.2 Study bird

The Hihi is one of three honeyeaters endemic to New Zealand. The species originally inhabited the whole of North Island and its offshore islands. It is now restricted to Little Barrier Island in the northern part of its original range. Translocations to various islands within the former range of the species with the aim of establishing further self-sustaining populations have taken place since 1983. In 1991 and 1992, there were two translocations of Hihi to Kapiti Is. (Castro *et al* 1994a) where this study took place.

The Hihi is a forest species, nesting in tree cavities during the southern hemisphere summer. Nesting activity starts in October and lasts until April. Females usually produce two clutches, each of 2-5 eggs, which are incubated by the female alone. The male helps with chick feeding.

There is marked sexual dimorphism. Males have more striking, colourful plumage and are larger in size (at 40g, males are 30% heavier than females 30g; Craig *et al.* 1982; Castro *et al.* 1994b). Females are subordinate to males in feeding areas (Craig *et al.* 1982). At nest sites on Little Barrier Island, females were dominant over males (Angher 1984; Rasch 1985a). On Kapiti Is., however, females were subordinate, although they sometimes displayed aggressively to their mates. On Little Barrier Is. all nests found to date have been attended only by a single male and a single female although more than one male has been observed visiting several different nest sites during the breeding season (Angher 1984; Rasch 1985a).

3.2.3 Copulation behaviour of Hihi

The only published description of copulation is for captive Hihi (Anderson 1993). All of the copulations seen in this situation were in a face-to-face position that is unique in birds. These observations left open the question of whether the behaviour was an aberration of captive birds or is normal for the species.

Hihi numbers on Kapiti Is. since 1991 have ranged from 25 to 79 with an average of 40 birds. Sex ratios have stabilised at a 1:1 level. At any time during the period of study at least 90% of the hihi on the island were colour ringed for individual identification. Furthermore, some males could be identified by feather pattern or call. Observations of Hihi breeding behaviour started each year in October and continued through the breeding season. As many nest sites as possible were located and monitored. Each nest was observed for at least six hours every two weeks. Nest observation periods ranged from one to five hours. Data on male and female visits to the nest (incubation and brooding times), interactions between all conspecifics present during the watches and between Hihi and other species, and fledgling success were recorded. Since most of the study birds used inaccessible cavities, fledging success was measured as the number of chicks leaving the nest.

Several feeding stations were established on Kapiti Is. to provide Hihi with supplementary food for four weeks after release (Castro *et al.* 1994a). After these four weeks, a single feeder was retained. This feeder was observed for at least one hour per day throughout the breeding season to assess bird survival and to observe matings. Birds were mistnetted at this location, where their weight, general condition, brood patch development and presence of cloacal protuberances were recorded. In 1994, the diameter and height of the cloacal protuberances were also measured.

The testes of three males that died during the breeding season on Kapiti Is. were measured (length and breadth) and their mass calculated using Møller's (1991) equation. The cloacal protuberance from one of the males was examined by T.R. Birkhead (The University, Sheffield, England) and the seminal glomera and spermatozoa described and counted following Birkhead *et al.* (1991).

3.3 RESULTS

3.3.1 Mating system

The Hihi mating system included social monogamy (22 of 33 nests or 67%), polyandry (3 or 9%), polygyny (4 or 12%) and polygynandry (1 or 3%). Four nests (12%) failed during incubation or early brooding before the mating system was determined. Mating systems were assigned to each nest according to behaviour during incubation and brooding. Nests were classified as monogamous where a single male and a female or only a female alone, cared for the young. Polygyny included nests where two females shared the same cavity or where a male attended the nests of two different females. A nest would be classed as polyandrous if a single female plus more than one male fed the chicks. Although this could be interpreted as helping behaviour, Hihi have physical characteristics associated with variable mating systems (see below). Furthermore, males in polyandrous nests were present at the nest site, and called there during nest building and egg laying. Some males guarded their females before and during egg laying by following them closely, but the presence of many males at a nest site during the female's fertile period suggests a high degree of promiscuity.

On Kapiti Is., Hihi established home ranges in three catchments. Each single stream catchment was shared by a group of birds with overlapping home ranges (Figure 3.1). Their nest sites were located within the home range. Hihi did not defend a territory, but males called within 30 m radius of their nesting tree (nest site) and behaved aggressively towards any other male within this area. Female hihi were also protective of the cavity itself, defending it against other female Hihi and other species.

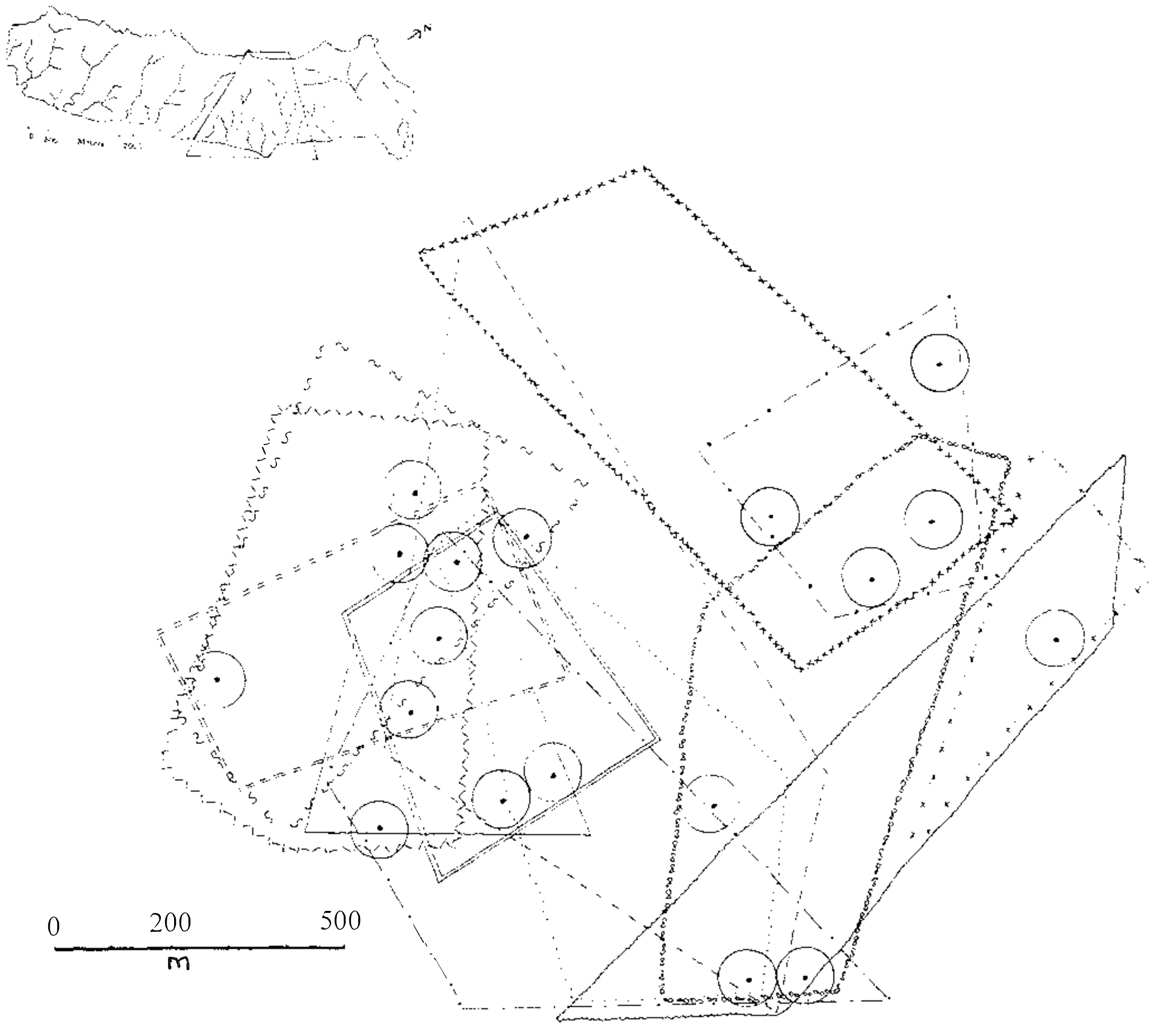

Figure 3.1. Map showing male hihi home ranges. The dots represent nest cavities and the circles around them a 100 m diameter area where the females were found feeding during the breeding season. Males called within 30 m of the cavity. All birds visited the feeder regularly, but unless a male was calling or copulating at a nest site near the feeder, the area was not considered part of his home range.

In the polyandrous and polygynous nests there was a dominant male and/or a dominant female, which was aggressive towards the other bird of the same sex. The minimum distance between nest sites was 110 m. and the largest distance was 1620 m. From October, males called within nest sites. A male (s) calling consistently from an area with a nesting cavity was considered the owner (s) of that site. The number of calls per hour at a nest site changed during the season, being greatest a few days before the first egg was laid (Figure 3.2). Although males spent a great deal of time calling at their nest site, they also visited other nesting sites. Between nest building and egg laying, up to six males were seen visiting a particular nest site (Table 3.1). Calling at the nest site and visits to other sites continued until a clutch was completed at each site. After clutch completion male visits to that nest were less frequent. Calling virtually ceased during incubation and chick feeding (Figure 3.2).

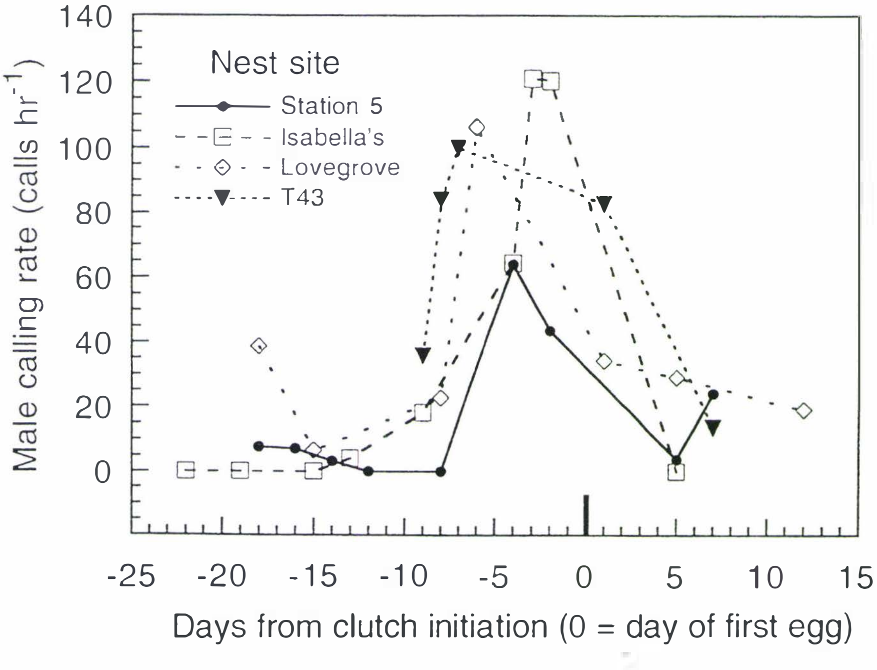

Figure 3.2. Number of calls per hour at hihi nest sites. Data comes from observations at four different nest sites. T43 and Lovegrove were polyandrous nests while Isabella and Station 5 were socially monogamous.

Table 3.1. Comparison of male presence at nest sites during nest building and laying with male nest attendance during chick rearing. Only nests found during nest building are included.

Nest name	Males present at n.b.¶and laying.	Female (s) I⁻ and B•	Male (s) feeding chicks	Number of young fledged
Matai	BA-R WA-YY	A-WW	Failed	0
Off 56 (92-93)	G-RA A-BW A-WR WW-A WA-YY	BA-B AB-BB	None	1
Off 56 (93-94)	AB-Y A-WR BA-R AR-G	GY-A	Failed.	0
Big Rata	WA-YY AB-Y G-RA	A-YY	None	2
1/4 Way	R-WA A/WR Unb. male *	A-WY	A-WR Unb. male	1
Station 5 (92-93)	AB-Y R-WA AR-G A-WR	WA-RR	Failed	0
Station 5 (93-94)	AB-Y R-WA AR-G A-WR	WA-RR	R-WA	2
T43	AR-G A-WR GW-A WW-A	YR-A	GW-A AR-G	2
Box 3	GW-A YG-A AB-BY GG-WA WW-A WA-BB	WA-W	YG-A	0
Box 4	AB-Y GW-A YG-A WW-A WA-BB	WA-W	Failed	0
Lovegrove (93, First clutch)	AB-BY YG-A GG-WA AR-BR	Y-A	YG-A AR-BR	2
Lovegrove (93, Second clutch)	YG-A AR-BR	Y-A	None	?
40/43 (92-93)	A-BW A-WR	A-GG	A-BW	2
40/43 (93-94)	AB-Y A-BW	Unb. female	A-BW	2
Isabella's (92-93)	YG-A A-RR GG-WA	RW-A	GG-WA	3
Isabella's (93-94)	GG-WA AB-BY	Unb. female	GG-WA	2
Gretta's (92-93)	AW-RR GG-WA	GR-A	AW-RR	2
Gretta's (93-94)	A-GY GG-WA	GR-A	A-GY	1
R2 (92-93 A)	Unb. male ** A-RR AB-BY	AY-YR	Failed	0
R2 (92-93 A)	Unb. male ** AB-BY	W-BA A-RB ^	Unb. male**	1
R2 (93-94)	Unb. male ** AB-BY	W-BA AG-GR	Unb. male ** AB-BY	1

* Recognized by feather patern
** Recognized by call. Same male for all nests.
^ This female dissapeared during incubation, might have died.
⁻ Incubation
• Brooding
¶ Nest building

Females took up to two weeks to build their complex nest, including a platform made of sticks, which in one case was 40 cm high. Nest cups were lined with feathers and the scales of ponga ferns (*Dicksonia* and *Cyathea* spp.). The average period between nest completion and the start of egg laying was 9.6 days (range 1-23; s.e. = 3;

n = 7). During this period, and again during egg-laying, copulations were observed. For instance at Nest 1 in 1992, the first copulation was observed on 24 November and the first egg on 29 November. In 1993, the first copulation was on 1 December and the first egg on 5 December. However, copulations at the feeding area in 1993 were first observed on the 2 December while most egg laying took place from 11 December to 19 December. Copulations were seen infrequently and were the result of observing nest sites rather than individual females. I observed copulations mainly in the morning and in the late afternoon. Breeding synchrony was low and the degree of asynchrony varied within years (egg laying for first clutches in 1992 lasted from 16 November to 9 December while in 1993 laying started on 5 December and finished around 19 December). Female Hihi laid one egg each day until the clutch was completed. Laying took place in the morning but 1 h (s.d. = 0.6) later each day. First eggs were laid around 0630 to 0700 h, and last eggs were laid around 1100 or 1200 h. Female Hihi remained in the cavity for an average of 1.4 h (s.d. = 0.4; n=12. Data relate to 9 different females, 2 from Kapiti Is. and 7 from Mokoia Is.) while laying. Incubation started the day the last egg was laid.

Females can raise and successfully fledge young alone (Table 3.1). Hihi males provide parental care by feeding chicks. For socially monogamous pairs on Kapiti Is. the male contribution was about one third that of the female (Castro, in prep). In 1991/92 there were on average 2.3 fledglings per nest, 1.13 fledglings per nest in 1992-93, and 1.0 fledgling per nest in 1993-94. Second clutches on Little Barrier Is. are usually successful (Angher 1984). On Kapiti Is., however, of four nests where second clutches were attempted in 1991-92, only one was successful. In 1992-93, of seven attempted second clutches only one was successful. In 1993/94 there were no attempts to re-nest (Castro *et al.* 1994b).

3.3.2 **Reproductive anatomy**

3.3.2.1 *Male Cloacal protuberance* (Figures 3.3 A and B)

In males the cloacal protuberance started to develop in early September 1994, and acquire its maximum size in early November. Average cloacal protuberance dimensions (height X width ± s.e.) at their maximum size for each of nine males sampled was 12.6 (± 0.28) X 11.2 (± 0.26).

3.3.2.2 *Testis mass, seminal glomera mass, and spermatozoa numbers*

The mean linear dimensions of testes from three males found dead during the breeding season were used to estimate the mass of the two testes combined. The mean linear dimensions of left and right testes (length x breadth), respectively measured 10 X 15 mm, 11 X 13 mm, and 10 X 14 mm, and the testes were estimated to have a combined mean mass of 1.726 g. With an adult male body mass of about 41 g the testes represents 4.2% of adult mass. Using Møller's (1991) equation for the relationship between body mass and testes mass across birds in general, the observed mass of Hihi testes is three times greater than that predicted (0.52 g) from body mass alone. The cloacal protuberance and seminal glomera of a single specimen were dissected and weighed. The seminal glomera were relatively large (left: 0.1499 g, right: 0.1518 g, total mass = 0.3017 g). However, in contrast to other species examined (e.g. the Dunnock *Prunella modularis*, Birkhead *et al.* 1991) the seminal glomera did not form the main part of the cloacal protuberance (see above). Instead, the cloacal protuberance contained relatively loosely coiled tubes of the seminal glomera, the main part of which was a cigar-shaped structure aligned antero-posteriorly (Figure 3.4). The seminal glomera contained very large numbers of spermatozoa (left: 856 x 10^6 and right 606 x 10^6, total: 1462 x 10^6). These values underestimate the true total since the right seminal glomera was damaged and a small part had been removed before I examined it. Assuming that the intact right seminal glomera contained the same number of spermatozoa as the left, then the total number of spermatozoa would have been *c* 1700 x 10^6.

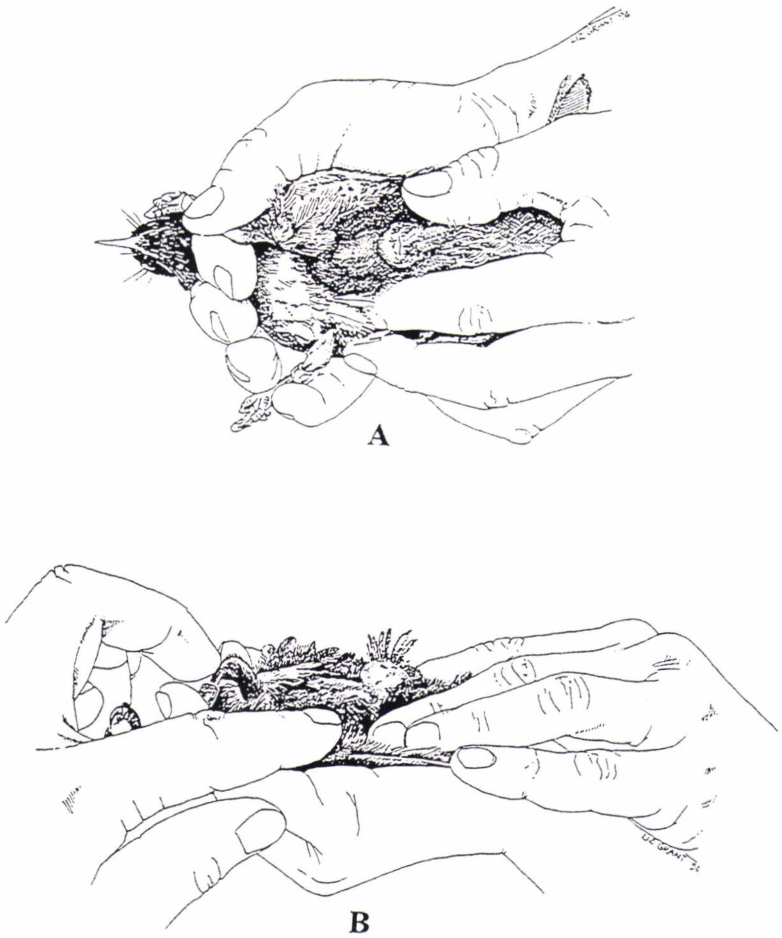

Figure 3.3. Male hihi cloacal protuberance. (A) View from the top; (B) View from the side (Drawings by Elizabeth (Liz) Grant).

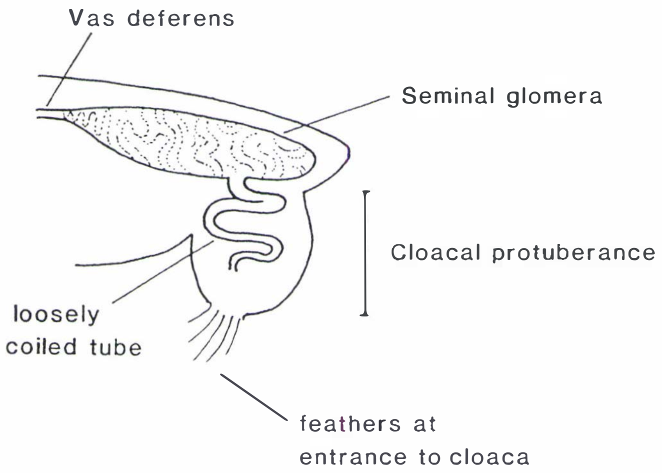

Figure 3.4. Cross-section of male hihi cloacal protuberance (drawing by T.R. Birkhead).

3.3.2.3 *Female cloaca* (Figure 3.5)

The size of the cloaca varied between pre-laying and laying periods. Average cloaca size for pre-laying females (± s.d.) was 4.91(±0.21) mm in breadth X 4.49(±0.24) mm in height (n = 6). In laying females the cloaca was distended to an average breadth of 8.07(±0.47) mm by 5.1(±0.76) mm in height.

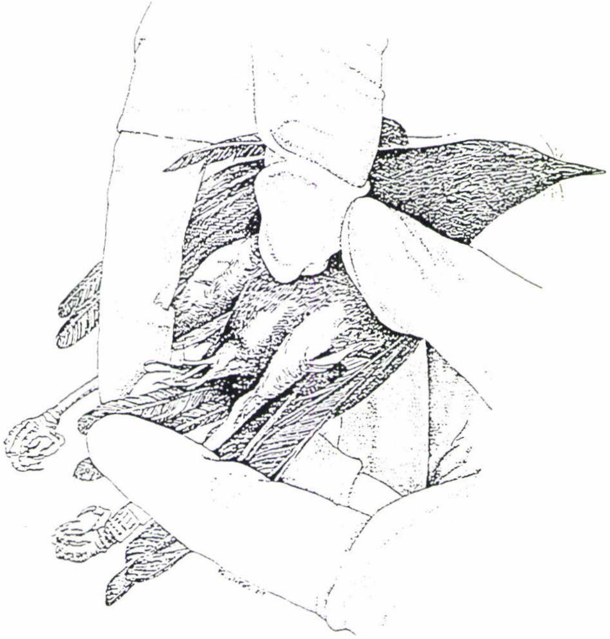

Figure 3.5: View of female hihi cloacal protuberance (Drawing by Liz Grant)

3.3.3 **Copulation behaviour of Hihi**

Wild Hihi copulate in two radically different positions: face-to-face, and male-on-the female's back. In both positions the male was on top of the female for six to eight seconds. Castro (pers. obs., Mokoia Island) has observed pairs performing multiple copulations in succession. Each mounting was separated from the next by a display where the male and female rubbed their necks and touched bills while vibrating their wings. The whole process of display and copulation lasted 7-15 seconds.

3.3.3.1 *Face-to-face Copulation* (Figures 3.6 B, C, and D)

When a single male was present, the female was chased to the ground by the male and held on her back with her wings outspread. During copulation, the male spread his wings, or pointed his bill straight up and extended his wings slightly. The female made calls similar to the distress calls (rapid repeated "p*ew*") produced when females are chased by other birds, or when a female tries to enter a nest other than her own. Male vocalisations (low volume, short, high pitched squeaky sounds) resembled those produced when a male is chased by conspecific males during the breeding season, or when a male enters a nest that is not his own. After face-to-face copulation the female and male flew away separately.

Most face-to-face matings, however, started with up to five males chasing one female to the ground. I observed an average of four attempted matings per hour in 7.3 hours of observation (maximum 8 attempts in 1 h; minimum 3 attempts in 1.2 h.). Attempted copulations were those chases where I could not see the end result because the birds were too far away or visibility was impeded by vegetation. One male would start the chase and the others would join in. The female always called the "distress call" described above for face-to-face copulations. This calling continued until the end of the chase or until the birds were on the ground. This call seemed to attract other males to the area. Once forced to the ground by the male, the females tried to fly, or kicked the male, as if attempting to escape. Often the females would be forced to the ground several times before being mated. In the chase, all males flew in line after the female and only the first male would "grasp" the female once she was on the ground. All other males then remained close to the pair watching from a distance of 10 cm to 1 m but not interfering. In all cases the female was upside down with the male on top of her (face-to-face). Once mating was over the male hopped away while the female rolled over and stood for a few seconds before flying away.

3.3.3.2 *Copulation with the male on the female's back* (Figure 3.6 A)

In the male-on-the-female's-back copulations both birds went to the ground. In one of four instances the male and female made a neck-rubbing display including bill-touching before he climbed on her back. There were no vocalisations from the female and, on one occasion, the male produced a repetitive "*pew*" call very quietly. After copulation the female either went back to her nest box, or preened, or flew away with the male. On one occasion the male and female performed the neck-rub bill-touching display after mating. For one copulation of this type the male landed on the female's back while she stood on a branch about 50 cm from the ground. His wings were outstretched, apparently for balance, and both birds were silent until another male arrived and landed on the mating male's back. At that point the female gave a distress call similar to the call produced during the face-to-face copulations. The birds did not separate immediately.

On another occasion a male chased a female to the ground. The female produced the same distress calls heard during face-to-face copulations. At first the female lay on her back with the male on top, but she soon turned herself to an upright position, the male climbed up and mated in a male-on-female's-back copulation. Vocalisations stopped during this mating position. The affiliation of this male to the female was unknown.

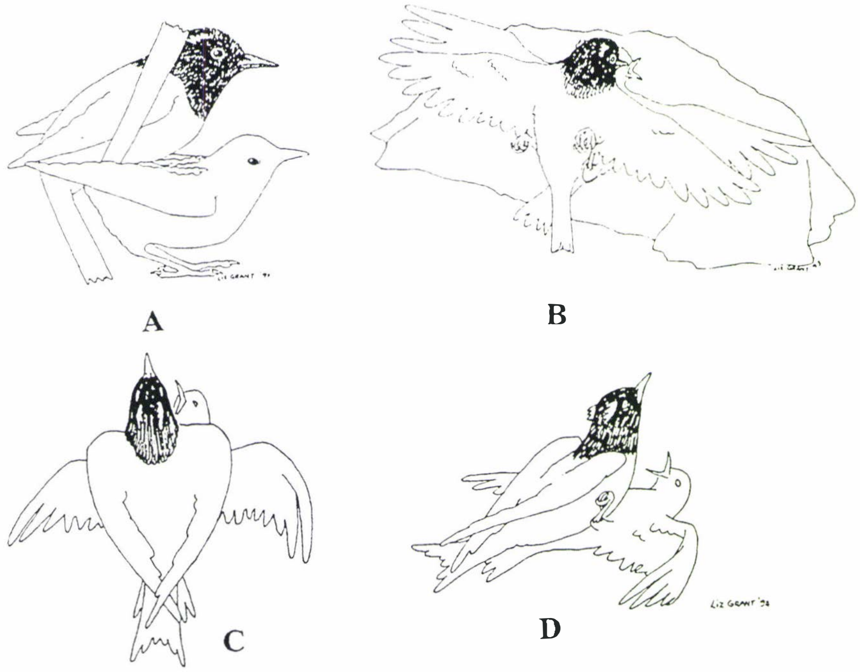

Figure 3.6. Hihi mating postures. (A) Copulation with the male on the female's back. (B, C, & D) Face-to-face copulation (Drawings by Liz Grant).

3.3.3.3 **Copulation sites**

Hihi copulations occurred on the ground near nest sites or at feeding areas. At nest sites copulations occurred during the pre-laying and egg-laying periods. For instance, at site 1 the female completed two clutches in 1992-93. Six copulations were clearly observed during 25 h of observation (0.24 copulations per hour). These involved the female and each of three males. Only one of the males later helped in rearing the chicks and therefore was considered her partner. Of these copulations two were face-to-face (involving her partner and another of the males) and four male-on-the-female's-back copulations (involving all three males). All three males were often seen at the nest site calling and chasing each other although her partner and another of the males had other nests of their own. On two occasions copulations were observed within 10 minutes of the female leaving the box after laying an egg. On one of these occasions the partner male copulated with the female in the male-on-the-female's-back position and briefly left the area. When he came back he found another of the males in the area and, after chasing him away, forced the female out of the cavity and copulated in the face-to-face position with her.

At site 2, males waited outside the cavity where presumably, the female was laying (3 observations). The female was chased to the ground when she left the cavity but observation of copulation was prevented by vegetation.

3.3.3.4 *Copulation at the feeder*

During the observations at the feeding station, 22 birds (11 females and 11 males) used the feeder. I observed 31 mating attempts. All males and at least six females were involved with one or more of these attempts. Five of the 31 attempts were observed in detail. Of the five females known to have mated face-to-face only one was regularly in the company of a single male. The other females were apparently unpaired. The large number of copulations observed at the feeders could be the result of having an unusual concentration of birds there. However, a similar situation, of smaller scale, could happen at nest sites when a female is fertile (Table 3.1).

3.4 **DISCUSSION**

3.4.1 **Mating system**

The hihi breeding system and associated male reproductive structures are similar to those found in other polygynandrous species (Table 3.2). Based on its breeding system, the mating rate for the species should be very high. However, observations of matings are difficult to make because hihi live in dense forest located in steep terrain. More observations of hihi matings are required to analyse the role of large testes and the large cloacal protuberance in this species.

Copulations at nest sites started five days before the female laid the first egg and continued until the last egg was laid. This suggests that the female fertile period is about 9 days. However, copulations at the feeding area started up to 17 days before laying, suggesting that the females might be able to store sperm for longer. The shorter period of copulations at the nest area could reflect the time spent at the nest site by the female, rather than her fertility status. Copulations were observed during the insemination window (*ie.* just after the female had laid an egg) suggesting intense sperm competition in this species (Cheng 1983, Birkhead & Møller 1993). Males would benefit from copulating with females at the feeding areas, but those males able to copulate with females at the nest site, and particularly during the insemination window, would be most likely to achieve paternity. DNA fingerprinting studies could be useful to identify the role of copulations during the insemination window for this species.

Table 3.2. Review of information about testes and cloacal protuberance sizes and number of sperm in seminal glomera of polygynandrous species. Data taken from Nakamura 1990, Mulder &Cockburn 1993, Briskie 1993, Schulze-Hagen 1995, Birkhead et.al. 1991, and this study.

Species	Testes size (% body)	Cloacal protuberance dimensions (breadth X height) in mm (± s.e.).	Number of sperm in glomera
Alpine Accentor	7.75	14.18 (± 0.31) X 12.78 (± 0.49)	Not available
Superb Fairy-wren	4.9	Not available	Not available
Smith's Longspur	4.2	11.49 ± (0.18) X 9.89 (± 0.22)	217 X 10^6
Aquatic Warbler*	4.1	6.74±(0.92)X7.76(±0.73)X5.62(±0.88)	197.8 X 10^6
Dunnock	3.36	8.50 (± 0.39) X 6.50 (± 0.3)	1060 X 10^6
Hihi	4.2	12.6 (± 0.28) X 11.2 (± 0.26)	1462 x 10^6

* The measurements for this species includes breadth front to back, and breadth side to side, by height.

Although a proportion of males guard their partner by close following during the breeding season, most male hihi do not spend much time with one female during the period from pre-laying to the end of incubation. Often the identity of the male partner (s) is not known until the chicks hatch and he (they) begins feeding them.

3.4.2 **Copulation behaviour and reproductive anatomy**

For many species it is difficult to determine if a particular type of copulation is forced. Because of the contexts in which the two types of copulation occur I believe that face-to-face copulation is a form of forced copulation. Forced copulation in other species is also accompanied by distress calls and is often violent (reviewed in Birkhead & Møller 1992). In Bearded Tits *Panurus biarmicus* (Birkhead & Hoi 1994) and White-fronted Bee-eaters *Merops bullockoides* (Emlem & Wrege 1986), up to 12 males have been reported chasing the females to the ground to copulate with them in much the same way as in hihi. However, while several male White-fronted Bee-eater might force copulations on the female, only one male does in Bearded Tits and hihi. When mating face-to-face, hihi attract the attention of the observer and potential predators by making considerable noise and movement. Weka *Gallirallus australis*, opportunistic rallid predators, often approached the calling birds when they were on, or close to, the ground. Because face-to-face copulation is so overt, it may be observed out of proportion to male-on-female's-back copulation's.

Birkhead & Møller (1992) review the benefits and costs of forced copulations and extra-pair copulations. There are several possible explanations for face-to-face copulations in hihi. An interesting possibility is that females might test a male's quality through his ability to perform a face-to-face copulation. The face-to-face copulations of hihi are not only common, but also very energetic. Males chase females in succession for many hours. Possibly female hihi determine the quality of males in this way. However, both injury, and death by predation, could occur during this type of copulation. Hihi are sexually dimorphic and females may be aware of male fitness by the state of their external features.

Another possible explanation is that a male-biased sex ratio could be leading to competition for females. Although the sex ratio on Kapiti I. is 1:1 the long term reproductive success (LTRS) of first-year females could be low compared to that of older birds. Males paired to young females might increase their own LTRS by forcing copulations with older females while still holding a nest. In 1993, two older males paired with first year females provided less parental care for their chicks than males paired to older females. They also spent more time at the feeder, where there were opportunities for them to achieve copulations with older females.

It is difficult to know if sperm are transferred from the male to the female during a face-to-face copulation. However, the cloaca of both male and female is unusually prominent, making it easy to establish contact during a face-to-face encounter. The weight difference between the sexes would help a male to hold a female on the ground, especially on her back. Although the function of a cloacal protuberance for sperm storage in males is clear (Birkhead *et al.* 1993, Briskie 1992, Mulder & Cockburn 1993), little is known about the importance of an enlarged cloaca in the females of some species. Recently Nakamura (1990) described the use of the cloaca for breeding displays in female accentor, and Wilkinson & Birkhead (1995) reported the use of enlarged cloacas in both male and female Greater vasa parrots, *Coracopsis vasa* to form a tie during copulation. I suggest that the protruding cloacas of both male and female hihi help to achieve successful cloacal contact for mating birds during copulations, and might facilitate insemination during a face-to-face copulation.

In polygynandrous birds the relative sizes of the testes, cloacal protuberance, seminal glomera and the numbers of spermatozoa in the seminal glomera are large (Table 3.1), almost certainly because the intensity of sperm competition is high in these species. The relative sizes of these structures and spermatozoa numbers in the hihi are similar to, or greater than, that recorded in other polygynandrous species (Table 3.2), providing additional evidence that sperm competition is intense in the hihi.

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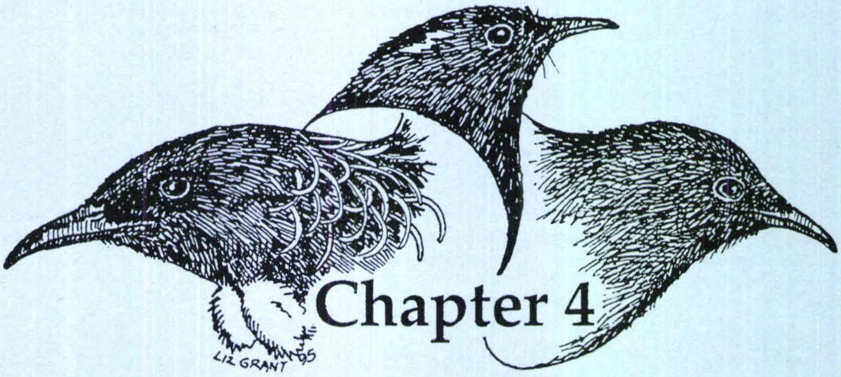

Chapter 4

Chapter 4

Honeyeaters and the New Zealand forest flora: The utilisation and profitability of small flowers

ABSTRACT

New Zealand flowers are frequently considered unspecialised having a simple often symmetrical morphology allowing easy access to pollen and nectar by a wide range of visitors. Most New Zealand flowers conform with a syndrome of insect pollination (entomophily), being small in size, light in colour and scented. However, pollination of forest flowers by birds has been described for a range of species whose flowers conform with ornithophily, being large, red or yellow and unscented. On Little Barrier Island and Kapiti Island, all three species of New Zealand honeyeaters have been described feeding on flowers whose pollination is currently assumed to be by insects (entomophilous) or where the pollination system is unknown. The persistence and regularity of visits suggests that the birds are obtaining suitable rewards in the form of nectar and could be serving as pollinators. The nectar production of three "ornithophilous" species and five "entomophilous" species was measured to determine the value of the nectar rewards to birds.

It was found that the estimated nectar consumption rate for all flowers sampled was enough to sustain the two smaller New Zealand honeyeaters. It is suggested that because (a) the nectar produced by "entomophilous" flowers provides sufficient calories to sustain the energetic requirements of birds, and (b) these plants flower in the cooler months when insect activity is reduced, birds might be playing an important pollination role not previously considered. If this is the case, forest regeneration on the New Zealand mainland could be hampered by the loss of one species of honeyeater (hihi) and the serious reduction in the abundance of the other two species.

4.1 INTRODUCTION

THE flowers of many New Zealand native plants are structurally simple, clustered and small, scented, mostly green, white or cream in colour (Cockayne 1928; Godley 1979), and a large percentage of species have separate sexes (reviewed in Lloyd 1985). Moreover, most New Zealand flowers are regarded as unspecialised and frequently rather promiscuous, receiving visits from several kinds of insects. New Zealand's pollinating fauna is considered depauperate and advanced pollinators are rare (Webb & Kelly 1993; Godley 1979). Long-tongued bees and hawkmoths are absent and butterflies few, their role in pollination possibly assumed by some species of Diptera (Thompson 1927; Heine 1938). Some pollination of New Zealand plants has also been ascribed to reptiles (Whitaker 1987), birds (Godley 1979; Delph & Lively 1989), and bats (Daniel 1976; Ecroyd 1993).

Flowers pollinated by birds are usually red or orange in colour, large in size, containing large amounts of dilute nectar, and often unscented (Faegri & van der Pijl 1971). Of the 30 New Zealand native species of plants Godley (1979) reported as being visited by New Zealand birds, only some display this typical ornithophilous syndrome. Godley suggested that the remaining species are probably visited by birds only incidentally, and that true ornithophily is not involved. He suggested that birds may foster self pollination rather than cross pollination (except for the species with sexually dimorphic flowers). Stiles (1978) states that the optimal pollinator is one which most effectively transfers pollen producing the maximum seed set over a blooming season. However, specialisation for a particular pollinator may not occur if the most consistent pollination results from having visits from diverse pollinators (Stiles 1978).

To ensure the attraction of pollinators, plants need to offer some reward. Most birds pollinate flowers as they collect the sugar-rich nectar they contain (Simson & Neff 1983). Nectar is expensive to produce and a plant should produce sufficient nectar to ensure pollinators will repeatedly visit it, without being too easily satiated after one or a few visits (Heinrich & Raven 1972). There has been very little research on nectar production or availability in New Zealand species, other than for flowers used by bees in honey production (Cockayne 1916; Palmer-Jones & Line 1962; Fisher 1965; Walsh 1967; Clinch, Palmer-Jones & Foster 1972).

Honeyeaters (family Meliphagidae) are common birds throughout Australasia, particularly Australia, where they pollinate many plant species (Paton & Ford 1976). New Zealand has three endemic species of honeyeaters - the tui *Prosthemadera novae-zelandiae* [1], the bellbird *Anthornis melanura*, and the hihi (stitchbird) *Notiomystis cincta*. All three species feed on flower nectar, fruits and insects in different proportions according to availability (Gravatt 1970; Angehr 1984; Castro, Minot & Alley 1994). The abundance of honeyeaters in the New Zealand mainland has decreased since human colonisation (Diamond & Veitch 1981; Gill & Martinson). Predator-free or predator-reduced islands have greater densities of honeyeaters when compared to the mainland, raising questions regarding the effects of this decrease on seed dispersal and pollination.

In this paper I investigate nectar production and the visitation of the flowers of forest plants by the three species of New Zealand honeyeaters on Kapiti Island. Kapiti I. is one of two remaining places in New Zealand where the three species of honeyeaters co-exist (the other place is Little Barrier Island in the Hauraki Gulf). Most flowers used by the birds on Kapiti I. do not display the typical ornithophilous syndrome described above and so I set out to determine the profitability of birds foraging on these and other

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[1] Bird names follow Turbott 1990

flowers. Finally, I discuss the possible role of New Zealand honeyeaters in pollination of these plants.

4.2 METHODS

4.2.1 Study area

Observations were made on Kapiti Island (1965 ha, Lat. 40°50', Long. 174°55') on the south western coast of the North island of New Zealand from August 1991 to August 1994. The island was largely cleared for agriculture in the 1800s but by 1930, all browsing animals with the exception of brush-tailed possums (*Trichosurus vulpecula*) had been eradicated (Cowan 1992). Kapiti was freed of possums in 1986 (Cowan 1992). Kapiti I. forests are divided into scrub and low forest (approx. 1041 ha) and tall forest (*Metrosideros robusta* forest; tawa *Beilschmiedia tawa* -hinau *Elaeocarpus dentatus* -kamahi *Weinmannia racemosa* forest; and kohekohe *Dysoxylum spectabile* forest, totalling 550 ha). The remainder of the island is covered by low scrub, grass, tussock and flax (Fuller 1985). With the exception of Norway rats (*Rattus norvegicus*) and polynesian rats (*Rattus exulans*), Kapiti I. is free of mammalian predators. In the last ten years there have been several bird transfers to Kapiti I. aimed at reducing their vulnerability to extinction. Species transferred include hihi, saddlebacks *Phylesternus carunculatus*, and kokako *Calleas cinerea.*

4.2.2 Nectar sampling

Phenological observations were made of the most important honeyeater plant species, measuring the presence and availability of fruits and flowers (Chapter 5). During 1993 and 1994 nectar samples from flowering species used by honeyeaters were taken by absorption onto filter paper "wicks" (McKenna & Thomson 1989). Occasionally it was necessary to redissolve dried nectar on the flower with a small drop of water (Cresswell 1990) prior to the application of the wick. Three "ornithophilous" flowers were sampled: *Metrosideros fulgens**, *Metrosideros excelsa* and *Fuchsia excorticata*; and five "entomophilous" flowers: *Pittosporum umbellatum*, *Pseudopanax arboreus*, *Dysoxylum spectabile*, *Pittosporum eugenioides* and *Geniostoma rupestre.* For each species, the nectar in the flowers of three to eight separate plants was sampled. The number of flowers sampled per plant varied according to species (Table 4.2). Some of the flowers had pollinators excluded by means of mesh bags ("bagged") and some were left open to possible visitations ("unbagged"). The mesh bags were left on the flowers for 24 hours before sampling. In the case of *Dysoxylum spectabile* flowers from the same plants were sampled both early and late in the flowering season. The nectar contained in the flowers is referred to as the "standing crop".

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* Plant names follow Allan 1961; Moore and Edgar 1970; and Connor and Edgar 1987.

Nectar concentrations (sucrose equivalent) per flower were calculated using an anthrone colorimetric assay of the sugar redissolved from the filter paper wicks (McKenna & Thomson 1989). The calorific values of flowers were calculated assuming that 1 mg sucrose = 4.2 calories (Ford 1979). The average number of calories per inflorescence of each species was estimated from the product of the average calorific value of the standing crops and the average number of flowers in an inflorescence. To calculate the average number of flowers per inflorescence I counted the flowers in ten inflorescences of each species. Similar values were not obtained for *Dysoxylum spectabile* and *Geniostoma rupestre* because the flowers are not arranged in a compact inflorescence but are rather loosely arranged (*Dysoxylum spectabile*) or arising directly and spread along the branches (*Geniostoma rupestre*).

4.2.3 **Bird observations**

Feeding by honeyeaters on flowers or fruits was recorded fortnightly during the non-breeding months (April-September), and daily during the breeding season (October-March). From August 1993 to August 1994 the number of flowers of a particular plant species visited by each honeyeater species per unit of time was recorded as flowers became available. Observations were done on randomly chosen trees whenever the trees were in flower. I aimed to follow at least five individual birds of each species and to collect at least 10 minutes of observation per species of bird. This was not always possible. Most hihi on Kapiti are colour banded for individual identification, but there is no way to individually identify tui or bellbirds. To minimise the possibility of collecting all the data on the same individuals for these two species, the observations were done on trees located in several different areas.

4.2.4 **Honeyeaters energy requirements**

The metabolic requirements of New Zealand honeyeaters were estimated using a formula that scales the requirements of another species *Lichmera indistincta* by a factor proportionate to body mass (Collins & Newland 1986). Winter conditions were assumed (nine hour day length; 13°C day temperature; 9°C night temperature). It was also assumed that the New Zealand honeyeaters were, like *L. indistincta*, spending 93.8% of their time in activities other than flying . The energetic requirements for hihi (average 35.25 g) were estimated to be 29 cal/min; for bellbirds (28 g), 24.56 cal/min; and for tui (104.1), 63.2 cal/min.

When calculating the energy obtained by the honeyeaters feeding in the different species of plants, I assumed (a) the birds were taking all the nectar in each flower visited; (b) the birds were not selective when foraging on these flowers, and (c) nectar content and handling time per flower were independent. The nectar reward gained is therefore the product of flowers visited per unit of time and the average calorific content of each flower.

As each parameter was collected independently, each with its own degree of error, the error associated with the resulting product is compounded. To provide some idea of the possible range of energy obtained whilst feeding, a Montecarlo randomisation procedure was used. From the range of observed bird feeding rates one value was randomly chosen and that number of entries was chosen from the observed array of flower calorific values. These values were summed to give an estimated return to the bird for one minute's foraging. This procedure was repeated 1000 times to obtain a range of calorific returns. These randomisations were performed for both bagged and unbagged flowers.

Nested ANOVA's were used to partition the variance in the amount of sucrose per flower into a treatment effect (bagged vs. unbagged); tree effects; the tree by treatment interaction; and in some cases a season effect (early or late); and/or an inflorescence effect. Type III, or partial sums of squares, are presented in the analysis of variance table.

4.3 **RESULTS**

A large number of species with small flowers are visited by the honeyeaters in addition to the larger flowered, typical ornithophilous flowers (Table 4.1). Many of these flowers were visited consistently each year (Chapter 5, Appendix 1) whenever they became available (eg. *Geniostoma rupestre*, *Pseudopanax arboreus*, *Pittosporum eugenioides*, *Pittosporum crassifolium*, *Pittosporum tenuifolium* , and *Weinmannia racemosa*). Birds of all three species of honeyeater were seen on both male and female flowers of *Pseudopanax arboreus* and *Pittosporum crassifolium.*

In general, the entomophilous flowers were less rewarding than the ornithophilous species (Table 4.2) although there is considerable overlap particularly in the unbagged flowers. There were significant differences between the unbagged and bagged standing crops of *Metrosideros robusta*, *Dysoxylum spectabile*, *Fuchsia excorticata* and *Pseudopanax arboreus* flowers (Table 4.2). There were no significant differences in bagged and unbagged flowers of the remaining species (Table 4.2). There was a significant difference in nectar production per tree in *Pittosporum crassifolium.* This difference was due to the presence of a female tree in the sample. This tree's flower nectar had significantly more calories (average 13.65, n=12) than the male trees (6.53, 6.46, 3.96, and 3.24; n=11 for each tree).

Table 4.1. List of plant species on Kapiti Island whose flowers are visited by honeyeaters. To describe abundance I used a scale of: 1 = very rare; 2 = rare; 3 = occurs; 4 = abundant; 5 = common; 6 = very common (Angher, 1984); y = young plants; 0 = not present. To describe frequency I used: 3 = frequent (if every time the flowers were available there were visits by honeyeaters); 2= occasional (if the flowers were visited sometimes only);0 = I have not recorded the birds feeding on such flowers on Kapiti; 1 = rarely (if I rarely saw birds on the flowers). T = tui. Flower sizes: Largest diameter > 20mm; Medium= 10-20 mm; Small= 5.1-9.9 mm; Minute= < 5mm.

SPECIES	ABUNDANCE	FREQUENCY OF VISITATION ON KAPITI			FLOWER size	SOURCE
		Hihi	Bellbird	Tui		
Fuchsia excorticata	2	3	3	3	Large	Godley 1979
Knightia excelsa	5, y	3	3	3	Large	Godley 1979
Metrosideros excelsa	2	3	3	3	Large	Godley 1979
Metrosideros fulgens	5	3	3	3	Large	Godley 1979
Metrosideros robusta	3	3	3	3	Large	Godley 1979
Phormium tenax	6	3	3	3	Large	Godley 1979
Sophora spp.	2	0	3	0	Large	Godley 1979
Vitex lucens	2	3	3	3	Large	Godley 1979
Dysoxylum spectabile	4	3	3	3	Medium	Godley 1979
Earina autumnalis	6	1	0	0	Medium	This Study
Elaeocarpus dentatus	5	3	3	3	Medium	Craig 1981
Hoheria populnea	1	3	0	0	Medium	This Study
Metrosideros perforata	5	3	0	0	Medium	Godley 1979
Myoporum laetum	3	3	3	0	Medium	This Study
Passiflora tetranda	6	2	0	0	Medium	This Study
Pittosporum cornifolium	2	3	3	0	Medium	This Study
Pittosporum crassifolium	1	3	3	3	Medium	Godley 1979
Pittosporum umbellatum	2	3	3	3	Medium	Godley 1979
Rhopalostylis sapida	6-y	3	0	0	Medium	This Study
Ripogonum scandens	4	3	0	0	Medium	This Study
Syzygium maire	1	3	0	0	Medium	This Study
Aristotelia serrata	3, y	3	0	0	Small	This Study
Geniostoma rupestre	4	3	3	3	Small	This Study
Kunzea ericoides	6	0	3	0	Small	This Study
Laurelia novae-zelandiae	3,y	0	3	0	Small	This Study
Melicytus ramiflorus	4	2	0	0	Small	Godley 1979
Personia toru	5	0	0	0	Small	Godley 1979
Pittosporum eugenioides	5-y	3	3	3	Small	This Study
Pittosporum tenuifolium	5	3	3	3	Small	This Study
Pseudopanax arboreous	4	3	3	3	Small	Godley 1979
Pseudopanax crassifolius	3, y	2	0	0	Small	Godley 1979
Rubus cissoides	4	3	0	0	Small	This Study
Shefflera digitata	5	2	0	0	Small	Godley 1979
Aestelia spp.	4	1	0	0	Minute	Ths Study
Beilschmiedia tawa	6	2	0	0	Minute	Craig 1981
Corynocarpus laevigatus	5	0	2		Minute	Godley 1979
Cyathodes spp.	2	0	0	0	Minute	Godley 1979
Griselinea littoralis	2	2	2	2	Minute	This Study
Hebe spp.	2	0	0	0	Minute	Godley 1979
Myrsine australis	5	1	0	0	Minute	This Study
Myrsine salicina	5	2	0	0	Minute	This Study
Nestegis lanceolata	3	0	0	0	Minute	Godley 1979
Weinmannia racemosa	5	3	3	3	Minute	Godley 1979
Plants not present on Kapiti						
Clianthus spp.	0				Large	Godley 1979
Metrosideros umbellata	0				Large	Godley 1979
Rhabdothamnus solandri	0				Large	Godley 1979
Peraxila spp	0				Medium	Godley 1979
Cordyline spp.	5				Medium	Craig 1981
Alseuosmia macrophylla	0				Small	Godley 1979
Dracophyllum spp.					Small	Godley 1979

For *Dysoxylum spectabile*, the number of calories per flower increased as the season progressed (Table 4.2). The number of visitors to the flowers also increased, and observations of kaka (*Nestor meridionalis*), a large omnivorous parrot, on *D. spectabile* only occurred later in the season (I. C. pers. obs.).

The entomophilous species studied (except *Geniostoma rupestre* and *Dysoxylum spectabile*) had multiple numbers of flowers presented in compact inflorescences and so the inflorescence as a unit accessible from one perch may be a relatively rich source of food. When the standing and bagged nectar calorific content for inflorescences of the entomophilous species were calculated the differences in calorific content with ornithophilous flowers were markedly reduced (Figure 4.1). This feature of many compactly arranged flowers allows for rapid turnover of flowers by a probing bird which often spend less than a second on each flower (Table 4.3).

Table 4.2. Results of ANOVA

Plant Species	Unbagged X (cal)±SE	n	Bagged X (cal)±SE	n	Probability Unb/Bg	Time effect P	Tree*trt effect P	Tree effect P	Inflorescence P
G. rupestre	0.43±0.05	94	0.52±0.06	78	NS	NA	NS	NS	NA
D. spectabile (early)	0.94±0.2	23	1.16±0.21	38	< 0.0001	< 0.0001	NS	NS	NA
D. spectabile (late)	1.74±0.34	21	4 07±0.59	15					
P. arboreus (male)	0.77±0.16	38	0.83±0.13	23	< 0.007	NA	NS	NS	NA
P. eugenioides	0.67±0.63	13	0.59±0.52	78	NS	NA	<0.0001	NS	NA
P. crassifolium	5.5±1.35	26	8.1±1.17	30	NS	NA	NS	< 0.0006	NS
M. fulgens	1.60±2.15	22	18.4±2.22	17	< 0.0001	NA	NS	NS	NS
F. excorticata	0.42±0.11	25	2.09±0.27	19	< 0.0001	NA	NS	NS	NA
M. excelsa	5.25±1.09	28	30.14±4.58	12	*	NA	NA	NS	< 0.005

* We did not compare unbagged and bagged flowers for this species because the samples from bagged flowers came from different plants than those from unbagged flowers.

The average bagged and unbagged standing crops produced by the all of the species sampled when obtained by the birds at the average visitation rate appeared sufficient to satisfy the estimated energetic requirements of bellbird and hihi, but not tui (Table 4.3 and Figure 4.2). Honeyeaters feeding on *Pittosporum crassifolium* could be obtaining up to six times the required amount of nectar necessary to sustain this type of activity. In many cases the 95% confidence intervals are large, due in the most part, to the large variability of calorific content of flowers as determined by the Montecarlo procedure.

4.4 DISCUSSION

It is clear from Table 4.1 that New Zealand honeyeaters are investigating small flowers as a regular foraging activity. This trait could be related to their evolution in an environment where small, rather than large, flowers are the rule (Godley 1979). In many cases it appears they are obtaining sufficient energy from the nectar to justify this behaviour, but the importance of other components of the nectar that satisfy needs in the diet other than energy can not be discounted. The latter could explain the persistence of tui on *Geniostoma rupestre*, *Pseudopanax arboreus*, and *Dysoxylum spectabile*, which seemingly do not fulfil energetic demands. However, I have assumed that the birds do not forage selectively. Nevertheless, it is known that, at least for some species of plants, tui and bellbirds can differentiate between flowers containing nectar and empty flowers on the basis of colour (*Peraxilla spp.*. A.W.Robertson pers. obs.; *Fuchsia excorticata*, Delph & Lively 1989). Hummingbirds have been seen selectively visiting the flowers of *Ribes sanguineum*, a plant in which the small corona-like petals change colour (Weiss 1995). If honeyeaters forage selectively, the standing crops obtained for all the plants in Figure 4.2 could be sufficient to sustain the energetic needs of the honeyeaters (top of 95% confidence interval for unbagged standing crops). Moreover, the birds may potentially forage when flowers have the greatest amount of nectar eg. in the early morning. Bagged crops of all of the plant species on Table 4.2 provide excess reward to all three species of honeyeaters (top of 95% confidence interval for bagged standing crops) and may be better approximations to the true value of flowers to selectively foraging birds.

Table 4.3. Average number of flowers visited by honeyeaters while foraging for one minute. Values were obtained by counting the number of flowers visited by members of each species per unit of time while in sight. Birds were observed for as long as possible. E = early; L = Late.

Plant	Bellbird X±SE	n	Obs.time (min)	Hihi X±SE	n	Obs.time (min)	Tui X±SE	n	Obs.time (min)
G. rupestre	47.35±6.29	8	10.22	70.45±8.35	5	17.28	72.43±12.61	8	10.18
D. spectabile E	37.2±5.35	1	6.0	-	-	-	41.3±8.49	5	2.6
D. spectabile L	42.0±5.84	1	8.6	-	-	-	43.1±5.11	2	12.7
P. arboreus (male*)	85.65±3.27	5	3.1	48.5±9.13	2	1.4	79.1±5.97	4	3.8
P. crassifolium	28.5±3.35	8	17.48	25.9±5.30	2	2.9	38±9.08	5	25.28

* No data are available for female flowers.

The lack of difference between the calories in the nectar of bagged and unbagged flowers of *Pittosporum eugenioides*, *Geniostoma rupestre*, and *Pittosporum crassifolium* (Table 4.2), may be due to either a low visitation rate to the flowers or to the plant continuing to produce nectar as it is cropped by visitors. The mechanisms and time of nectar production for New Zealand plants is unknown and more research in this area is necessary.

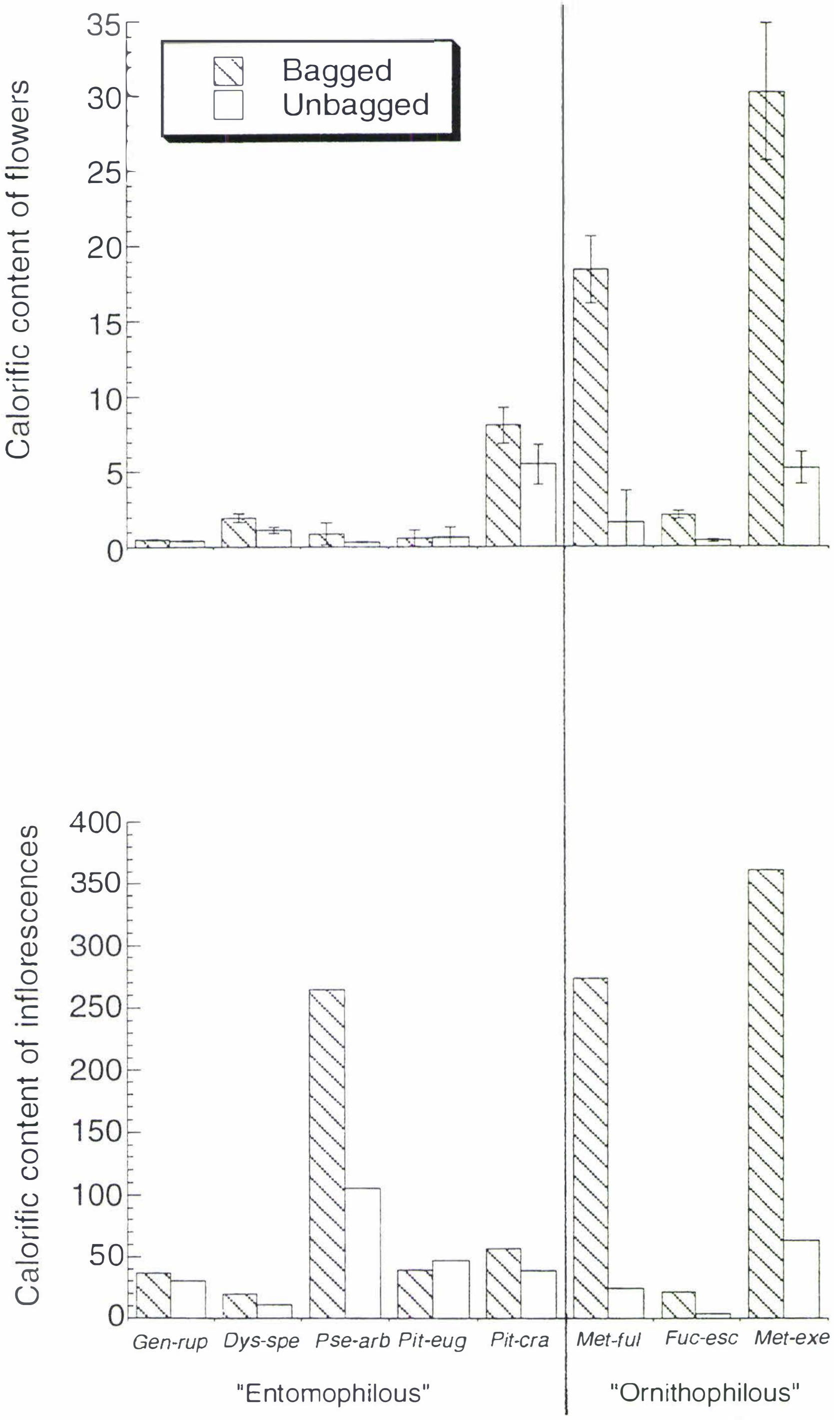

Figure 4.1. Estimated number of calories in the flowers and inflorescences of selected New Zealand forest plants on Kapiti Island. Flowers of *Geniostoma rupestre. Dysoxylum spectabile* and *Fuchsia escorticata* are not arranged in inflorescences.

The flowers of some plants might have evolved alternative mechanisms to ensure pollination by birds other than large corolla size or specific calyx shape. The nectar on female *Pseudopanax arboreus* flowers is spread over the surface of the flower in such a way that to obtain it the flower has to be licked (I. C. , *pers. obs.*). This takes some time and in the process the birds head has the opportunity to contact the stigma of the flower. This "lolly-pop" syndrome is shared by the entire inflorescences of *Pittosporum eugenioides*. Nectar collects on top of the flowers and the birds appear to lick the nectar from the surface of the inflorescence rather than from individual flowers.

New Zealand's generally windy conditions (Kuschel 1975) may make large flowers with wide petals suceptible to damage by wind. Smaller flowers arranged in inflorescences could produce a similar visual impact and can provide a large reward (Figure 4.1), while resisting the effects of wind. Inflorescences could also make it easy for birds to brush their heads against flowers and be covered by pollen while still allowing insect visitation. Tui have been observed brushing their white neck feathers and lower breast against *Pseudopanax arboreus* flowers while feeding on them and a female hihi captured in an area of *Pseudopanax arboreus* was carrying this species pollen on her head (I. C. pers. obs.). I have also collected *Geniostoma rupestre* pollen from the heads of hihi (I. C. pers. obs).

New Zealand weather is unpredictable and cold spells are common especially during spring when many plants flower. New Zealand plants may benefit from being visited by birds as well as insects if this trait ensures the most consistent pollination, as suggested by Stiles (1978). Anna hummingbirds *Calypte anna* existing in cold, rainy conditions (Stiles 1971, 1973), as well as many other birds living at high elevation areas (Cruden 1972), are active during unfavourable weather conditions, so becoming important pollinators when insects enter torpor. Several of the species investigated flower in the cooler months. *Pseudopanax arboreus* (July-December) and *Dysoxylum spectabile* (May-July) flower in late Autum and winter while *Pittosporum eugenioides* (October), *Geniostoma rupestre* (August-November) and *Pittosporum crassifolium* (September-October), flower in spring. Temperatures and general weather conditions during winter and spring could favour bird activity over insect activity, at least in some years.

Honeyeaters tend to feed in discrete areas of forest and, because they have the same feeding interests, it is common to find the three species feeding together. While the larger, more dominant tui (Craig 1984; Rasch 1985; I. C. pers. obs.) can defend a whole tree and visit most flowers in it, bellbirds and hihi are often displaced and move from tree to tree more often, increasing the possibility of cross pollination. This may provide higher quality pollination (Stephenson 1982)

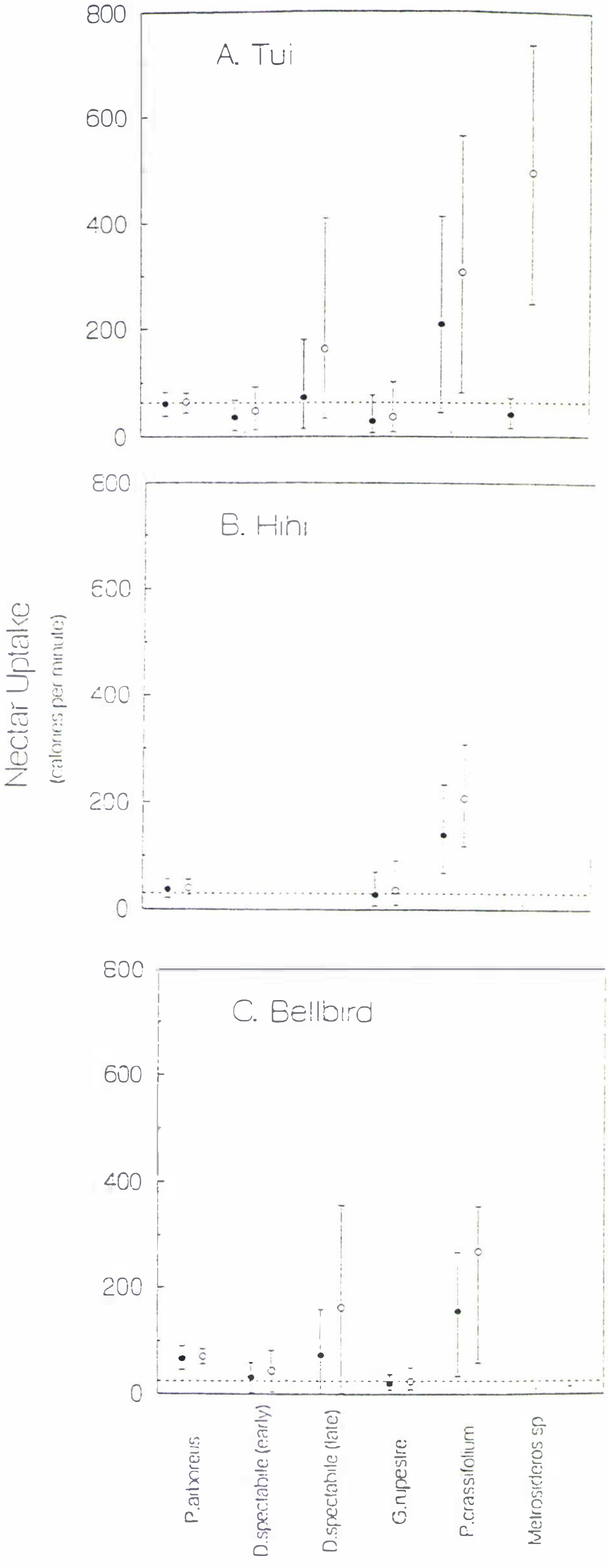

Figure 4.3. Estimated number of calories per minute obtained by birds foraging of selected species of flowers on Kapiti Island. Bars at either side of the mean indicate 95% confidence intervals by a Montecarlo randomisation procedure (see text for details). Dashed line indicates the estimated number of calories required per minute by each honeyeater species. Darked dots indicate unbagged flowers; circles indicate bagged flowers.

New Zealand forests have lost a large number of birds species and suffered a severe reduction in the abundance of others (Holdaway 1989). Offshore islands free of mammalian predators are the only examples of what the New Zealand mainland forests may have been like (Diamond & Veitch 1981). Diamond and Veitch (1981) show that although the number of species of birds still present on the mainland of New Zealand is similar to those on islands, the relative abundances of such species is much lower in the mainland forests. The three New Zealand honeyeaters coexist today only on Little Barrier Island and on Kapiti Island because hihi was never present in the South Island and became extinct from the North Island mainland in the late 1800s (Oliver 1955). If New Zealand honeyeaters are contributing to pollination on offshore islands, the lack of these species or the reduction of their numbers on the mainland could be hindering forest regeneration.

This study demonstrates the value of small flowers to honeyeaters as complements to the larger showy "ornithophilous flowers". Descriptions of these visits as incidental is not justified. Rather these flowers are an important component of the honeyeater diet. There is a need for more research in this area specifically to measure the effectiveness of birds as pollen vectors, and to compare the efficiency of insects and birds as pollinators. Flowers such as *Corynocarpus laevigatus* and *Griselinia* spp. which are not visited intensively might not be actively pollinated by birds, but the possibility should be studied. Comparative mainland and island studies could help us to understand the importance of pollination by birds. The generalized nature of the New Zealand flowers could allow introduced insects, such as bees, to carry on pollination, so alleviating the effects of reduced bird abundances, this possibility should also be investigated. The results of such studies will help us to understand forest dynamics and will be useful in the management of natural areas.

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Chapter 5

Chapter 5

Hihi (*Notiomystis cincta*) feeding and breeding behaviour in relation to flowering and fruiting phenology on Kapiti Island

ABSTRACT

The phenology of a selected group of plants, important as honeyeater food, was followed from 1992 to 1994 on Kapiti Island. The onset and length of the flowering and fruiting periods for a particular plant species varied between the years. The total number of fruits and flowers per tree also varied. There were flowers present throughout the year with a peak during the spring. Of 17 species examined in 1993-94 15 bore fewer flowers than in 1992-93. For most species the flowering season started a month later in 1993 than in 1992. Ripe fruits were present throughout the year, but there were no obvious peaks.

The hihi *Notiomystis cincta* is a rare New Zealand honeyeater with a single self-sustaining population on Little Barrier Island. Translocation to other rat-free islands has been employed as a management option. Islands were chosen for translocation if they lacked predators, and there were similarities between their vegetation and that of Little Barrier Island. This chapter discusses the ways these comparisons were done and offers alternatives.

5.1 INTRODUCTION

THE hihi (*Notiomystis cincta*) is a rare New Zealand native honeyeater. The species once occupied the whole of the North Island and its offshore Islands. It became extinct throughout this range except for Little Barrier Island during the 1800's. The causes of contraction are unknown but there is strong anecdotal evidence suggesting a combination of factors: predation by introduced mammalian predators (mainly ship rats *Rattus rattus*), loss of habitat, and disease.

From 1980 there have been ten translocations of hihi from Little Barrier I. to other offshore islands in an attempt to establish new self-sustaining populations of the species (Castro *et al.* 1994a; Chapter 1). In all but the last two translocations to Kapiti Island the numbers of transferred birds diminished rapidly over the first two years after release, until the populations became extinct. The last two transfers to Kapiti I. have produced a small, but self-sustaining population of about 30-40 birds (Chapter 6). The main difference between previous transfers and the last two transfers to Kapiti I. is that food was provided throughout the year after the last two.

Hihi feed on three main food types: nectar, fruits and invertebrates (Gravat 1970; Angher 1984; Rasch 1985; Lovegrove 1986; Castro *et al.* 1994b; Chapter 2). Although this omnivorous tendency could be favourable to hihi establishing in a new environment, the hihi is subordinate to its food-competitors - tui *Prosthemadera novae-zelandiae* and bellbird *Anthornis melanura* . The diets of these honeyeaters overlap almost totally with that of the hihi. Moreover, tui and bellbirds are dominant over hihi at feeding sites (Craig 1984; Angher 1984; Rasch 1985). Kaka (*Nestor meridionalis*), a New Zealand parrot, shares part of its diet with hihi (Moorhouse 1995) and it is also dominant over hihi (pers. obs.).

The islands to which hihi were translocated were chosen primarily for having no ship rats, and secondarily on the general similarity of their vegetation to that of Little Barrier I (Angher 1984). Hihi have survived on Little Barrier I. in the presence of kiore *Rattus exulans* and cats *Felis catus* (Rasch 1991). All of the islands where hihi have been translocated, excepting Mokoia Island, had kiore and/or Norway rats *Rattus norvegicus* at the time of the translocations. The similarity of vegetation was measured as the number of flowering or fruiting species in common between each island and Little Barrier I. (Angher 1984).

Food limitation is one reason offered to explain hihi failure to establish self-sustaining populations after translocation. Food limitation can occur because food is short or as a result of direct competition. This chapter looks at the first possibility. I examine the phenology of the most important flowering and fruiting species on Kapiti I. in relation to hihi feeding and breeding behaviour.

5.2 METHODS

5.2.1 Study area

The study took place on Kapiti I. Nature Reserve on the southern part of the west coast of the North Island (Figure 1.1). Kapiti I. vegetation is mainly composed of regenerating forests and shrublands (Fuller 1985). The distribution of the different vegetation areas is shown in Figure 5.1. The highest point on Kapiti I. is 510 m a.s.l. Figure 5.2 shows the main elevations on the island.

Hihi were released in 1991 and 1992 in the Kahikatea and Te Rere catchments. In 1992 birds were also released in the Kaiwharawhara catchment (Castro *et al.* 1994b; Chapter 2). Today, however, all surviving birds live in the area between the margins of the Kahikatea and Te Rere catchments. While most of the nesting sites of hihi are located in the valleys, where the largest trees are, hihi feed throughout the area (Chapter 6).

According to Fuller (1985) the vegetation of Kapiti I. has been considerably affected by the cloud that forms over the forest at altitudes above 400 m a.s.l.. Also, on coastal and south facing slopes the vegetation has been affected by both salt deposited during southerly gales and the wind itself. The Kahikatea, Taepiro and Te Rere catchments are those most affected by cloud, with increased precipitation, colder temperatures and fewer sunshine hours than the forests below this zone.

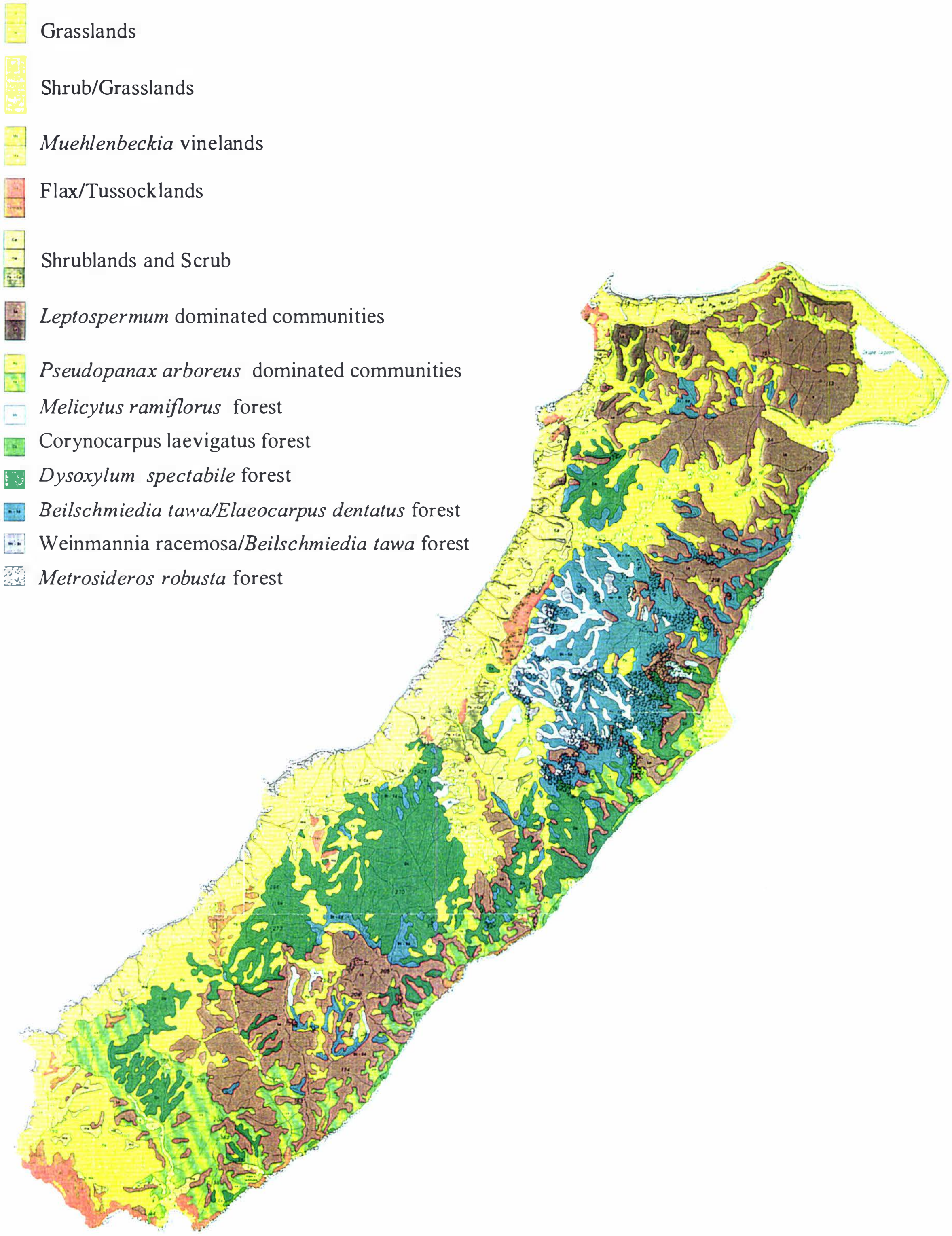

Figure 5.1. Map showing the different vegetation zones present on Kapiti Island. Map from the New Zealand Land Inventory (1987).

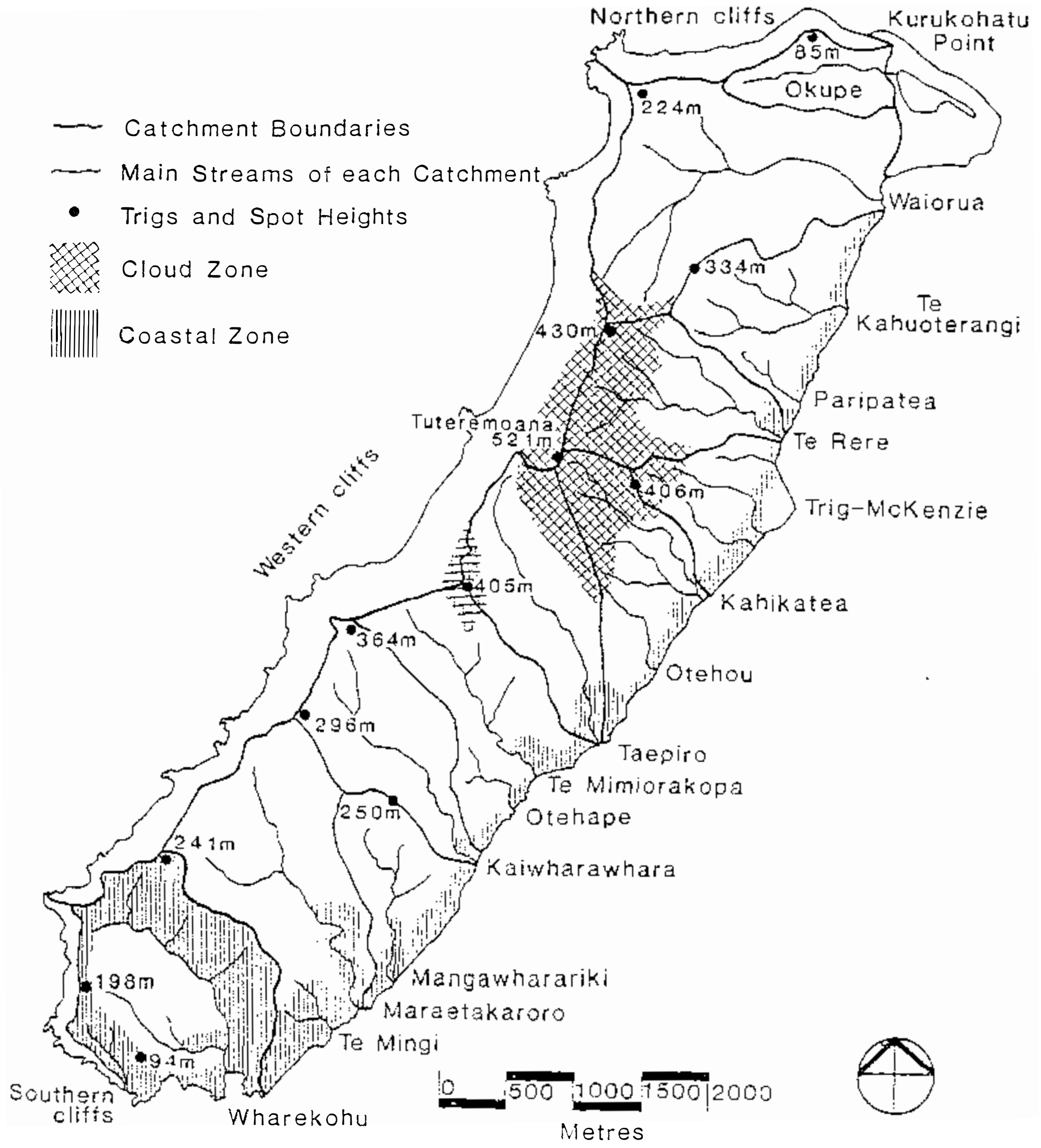

Figure 5.2. Map of Kapiti Island showing the maximum elevations. From Fuller (1985).

5.2.2 **Phenology**

Fruiting and flowering information for 28 forest plants was recorded from April 1992 to July 1994 (Table 5.1). Additional information was obtained from direct observation of birds feeding on flowers and/or fruits for the same period of time.

Table 5.1. Sampling scheme to determine the phenology of plants important as hihi food on Kapiti I. Further information was gathered from observations of hihi feeding.

Plant name	***Month sampled*** **AMJJASONDJFMAMJJASONDJFMAMJJ**	**Part used**
Elaeocarpus dentatus ^{T}	– – – – – ————————	Fl
Geniostoma rupestre ^{SS}	– – – – – ————————	Fl,Fr
Knightia excelsa ^{T}	– – – – – ————————	Fl
Melicytus ramiflorus ST	– – – – – ————————	Fl,Fr
Metrosideros excelsa ^{T}	– – – – ————————	Fl
Metrosideros robusta ^{T}	– – – – – ————————	Fl
Myoporum laetum ^{T}	– – – – ————————	Fl,Fr
Myrsine australis ^{T}	– – – – – ————————	Fr
Myrsine salicina ^{T}	– – – – ————————	Fr
Pittosporum eugenioides ^{T}	– – – – – ————————	Fl
Pittosporum tenuifolium ^{T}	– – – – – ————————	Fl
Pseudopanax arboreus ^{T}	– – – – – ————————	Fl,Fr
Pseudopanax crassifolius ^{T}	– – – – – ————————	Fr
Vitex lucens ^{T}	– – – – ————————	Fl
Weinmannia racemosa ^{T}	– – – – – ————————	Fl
Carpodetus serratus ST	– – – – –	Fr
Hedycarya arborea ST	– – – – –	
Beilschmiedia tawa ^{T}	– – – – –	Fl
Prumnopitys ferruginea ^{T}	– – – – –	None
Entelea arborescens ^{T}	– – – – –	None
Alectryon excelsus ^{T}	– – – – –	None
Kunzea ericoides ^{T}	– – – – –	Fl
Corynocarpus laevigatus ^{T}	– – – – –	Fl,Fr
Coprosma grandifolia ^{LS}	————————	Fr
Dysoxylum spectabile ^{T}	————————	Fl,Fr
Fuchsia excorticata ^{T}	————————	Fl,Fr
Metrosideros fulgens ^{T}	————————	Fl
Pittosporum crassifolium ^{T}	————————	Fl

LS = large shrub; SS = small shrub; ST = small tree. T = tree. Fl = Flowers. Fr = Fruits.

5.2.2.1 *Criteria for selecting plants*

To ensure that all the plants were capable of producing flowers and fruits selection followed these criteria:

1. Trees: dbh > 10 cm.
2. Small trees: dbh > 5cm.
3. Shrubs: height > 2 m.
4. Small shrubs. *Geniostoma rupestre*: height > 1 m.

5.2.2.2 *Data collection*

In 1992 I obtained the phenology data by following a transect established by Ron Moorhouse (Figure 5.3). Several trees of each species were marked along this transect. Although this allowed continuity in the sampling, I felt the transect did not represent completely the vegetation of the area. To improve this, in 1993 and 1994 I ran transects following any combination of a series of tracks between T20 and T60 (see Figure 5.3). I walked the tracks stopping every 10 minutes to sample one plant of each selected species, if present, until at least 15 plants per species were sampled. I searched for plants in a 5 m radius from the sample point. When more than one plant was present I measured the one closest to the sample point, but also looked at neighbouring plants and recorded any differences in their phenologies. The tracks used to study the phenology ran through all forest types and all altitudes (Figure 5.2).

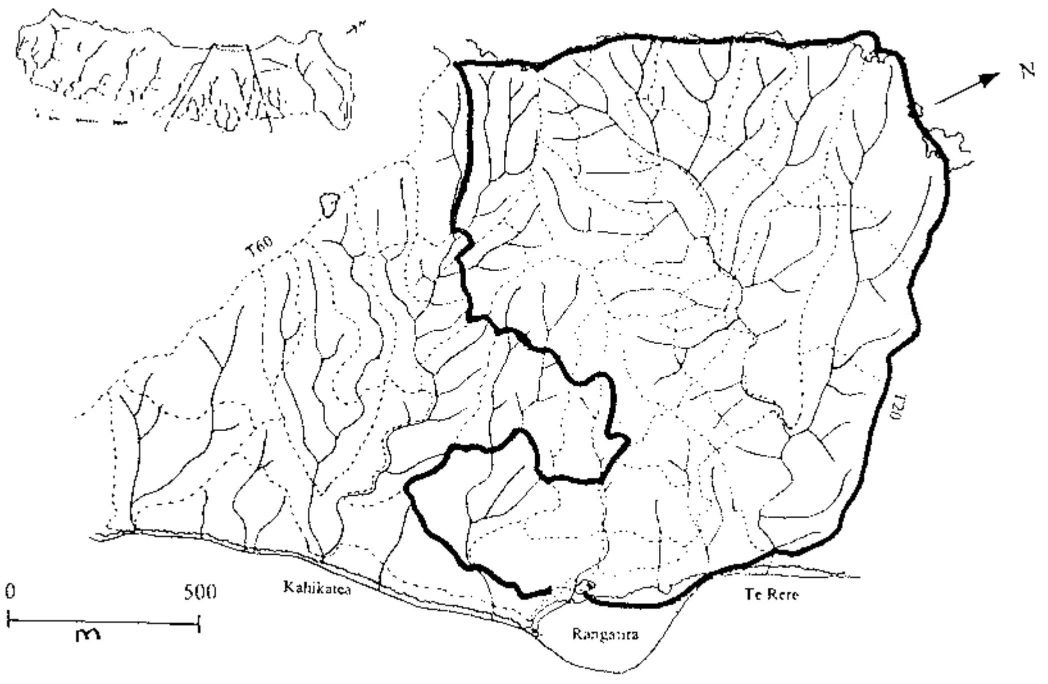

Figure 5.3. Map of Kapiti Island showing all tracks used for the phenology transect. Dotted lines represent tracks. Lines represent streams. The thick line corresponds to the transect established by Ron Moorhouse (In prep.).

During sampling sessions from 1992 to 1994, I estimated for each plant the number of flower buds, flowers, green fruits and ripe fruits using the following scale: 0; 1-5, 5-10; 10-50, 50-100; 100-500, 500-1000; 1000-5000, 5000-10000; 10000-50000, 50000-100000; 100000-500000, and 500000-1000000. To provide an objective basis for these estimates I selected three plants of each species and counted the numbers of fruits or flowers per inflorescence, umbel, or branch (depending on the structure of each particular species). This gave a total number of fruits or flowers per tree. Subsequently I estimated the numbers by sight. Binoculars were used to sight fruits and flowers when it was not possible to see them with the naked eye. When calculating the monthly total number of flower buds, flowers, green and ripe fruits per species I used the arithmetic means for each interval, ie. 3 (for interval from 1-5), 7.5 (interval from 5-10), etc..

5.2.3 **Climatic records**

Weather data were obtained from the New Zealand Meteorological Service, Wellington. Records are from Paraparaumu Beach, a small town located on the mainland 5.6 Km from Kapiti I. Average monthly records were used for all calculations.

5.2.4 **Feeder visitation**

From September to April each year there were up to three feeders supplied with food (Chapters 2 and 6). These feeders were watched for at least one hour per day during this period and the presence of individual birds was recorded. I obtained a percentage of visitation by dividing the number of birds visiting the feeder by the total number of birds known to be alive and then multiplied that by 100. During the rest of the year there was a single active feeder at the ranger's house. Information on feeder use by hihi was provided by the ranger. Data were treated in the same fashion as for September to April.

5.2.6 **Hihi behaviour and energy requirements**

Hihi were located by sight and sound. When possible, an individual was followed until its sex, band combination, and feeding activity were recorded. Feeding activities were classified as fruit eating, nectar feeding, and invertebrate feeding, which included both gleaning (picking invertebrates from leaves and bark or perhaps licking insect and plant exudates) and hawking (catching insects in the air). Whenever possible specific food items were also identified. Because the number of plants available for hihi at a given time is small and because the birds tend to move from one plant to another within a short period of time the observations were recorded as visits to feed on a plant species, rather than units of food consumed. I assumed that the number of times birds were seen feeding on a particular plant represented the true contribution of such a plant (fruits or flowers) to their diet. Similarly, every month I counted the times birds were observed hawking or gleaning. I assumed that if birds hawked or gleaned more often in a particular month invertebrates were making a relatively larger contribution to their diet. I assumed that the percentage of invertebrates in the diet is proportional to the frequency of observed hawking or gleaning. I present the data on diet as a percentage of feeding observations. I obtained this percentage by adding all observations of a particular feeding activity for all known individuals each month and dividing this value by the total number of observations of the three different feeding activities.

5.3 RESULTS

5.3.1 Phenology

5.3.1.1 *Flowers*

There were species flowering in all months of the year (Figure 5.4). The largest number of species in flower occurred from August to January in 1992-93 and from July to January in 1993-94. This period corresponds to late winter, spring and early summer, with the peak of species number in October 1992 and September and October 1993, the equivalent to mid spring. The lowest number of species occurred from February to May (late summer to autumn) with lowest numbers in April or May (autumn).

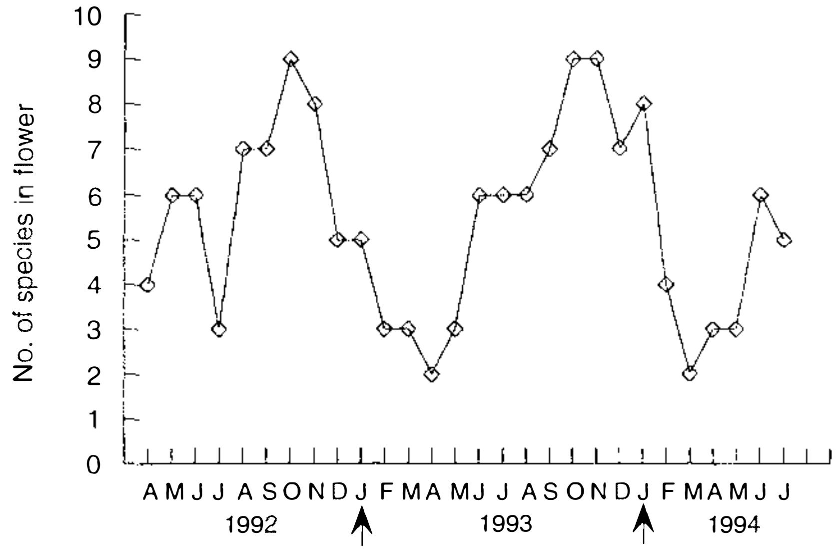

Figure 5.4. Number of species in flower each month on Kapiti Island based on 17 species of plants used by hihi.

Hihi visited the flowers of a larger number of species than those selected for the phenology study. Figure 5.5 includes all species used by hihi during the period of study. The number of plant species in flower visited by hihi was usually less than the number of species available (Figure 5.5) but these two variables were positively correlated (r=0.686). Hihi seem to favour some flowers over others. The choice of these flowers was consistent from one year to the next (Appendix 1). I recorded hihi feeding on a further 19 plant species not included as main food items in the phenology study (Table 5.2).

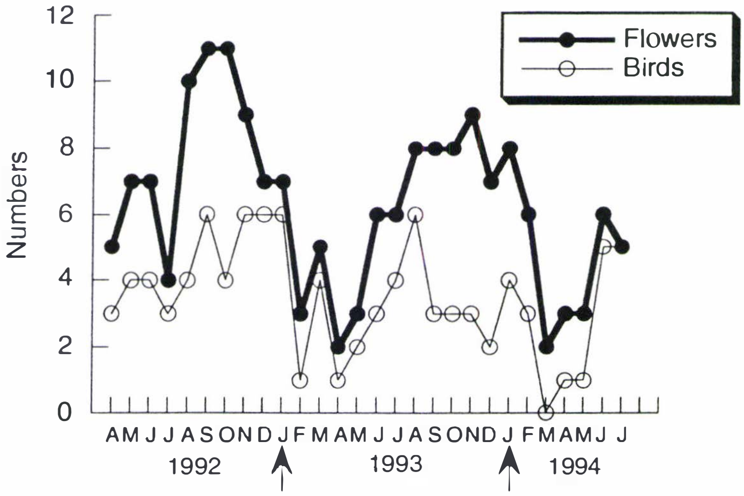

Figure 5.5. Comparison between the number of species in flower and the number of such species visited by hihi on Kapiti Island - 1992- 1994. Abundance information comes from Angehr (1984).

Table 5.2 Additional species used by hihi as food plants. Kapiti I. 1991 to 1994.

Species	Part of plant used	When used by hihi	How common on Kapiti
Aristotelia serrata	Flowers and Fruits	Each year	Rare
Astelia spp.	Flowers and Fruits	Each year	Abundant
Chamaecytisus palmensis	Flowers	Each year	Unknown
Clematis vitalba	Flower	Once	Unknown
Coprosma lucida	Fruits	Each year	Common
Coprosma robusta	Fruits	Few times	Occasional
Earina autumnalis	Flowers	Once	Unknown
Griselinea littoralis	Flowers and Fruits	Each year	Rare
Hoheria populnea	Flowers	Each year	Rare
Laurelia novazelandiae	Flowers	Each year	Unknown
Macropiper exelsum	Fruits	1992	Abundant
Maire tawaki	Flowers	Each year	Rare
Metrosideros perforata	Flowers	Each year	Unknown
Passiflora tetranda	Flowers and Fruit	Each year	Unknown
Phormium tenax	Flowers	Each year	Common
Pittosporum cornifolium	Flowers	Each year	Rare
Rhopalostris sapida	Flowers	1992	Common
Ripogonum scandens	Flowers and Fruits	Each year	Unknown
Rubus cissoides	Flowers and Fruits	1993	Common

Overall, the flowering season was one month earlier in 1992 than in 1993 (Figure 5.6). Hihi breeding seems to follow this pattern as well: egg laying started in November in 1992, while in 1993 it started in December (Castro *et al. in press.*; Chapter 3).

Of the 17 species examined, seven flowered later in 1993 than 1992, two flowered earlier and the remaining species flowered during the same month (Appendix 2). The length of the flowering season also varied from year to year. In sum, *Pseudopanax arboreus* and *Elaeocarpus dentatus* had standing flowers for a month longer in 1993 than in 1992. On the other hand *Metrosideros excelsa, Pseudopanax crassifolius, Pittosporum crassifolium, Pittosporum eugenioides, Pittosporum* *tenuifolium*, and *Weinmannia racemosa* had shorter flowering seasons in 1993 when compared to 1992 (Appendix 2).

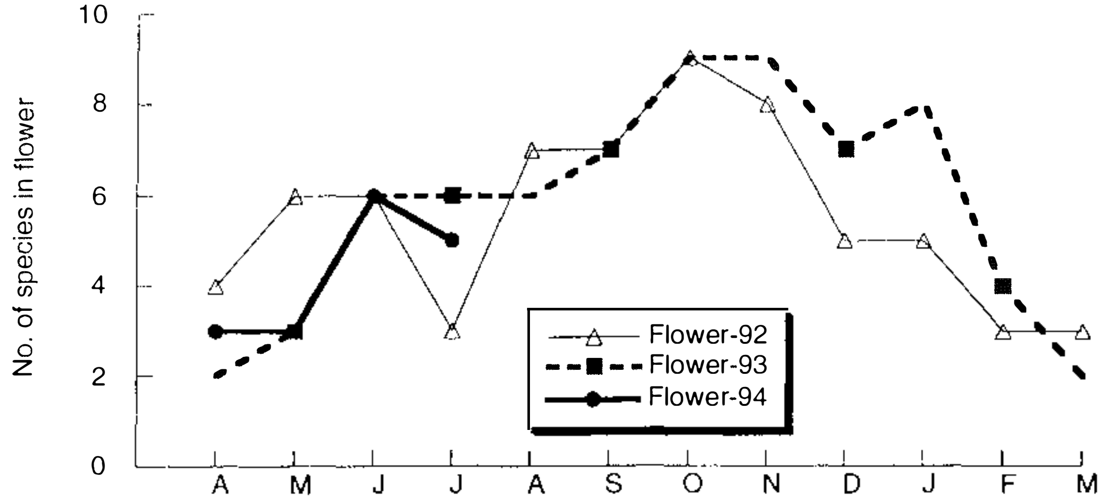

Figure 5.6. Comparison between the number of species in flower in 1992, 1993 and 1994, out of a selection of 17 species preferred by hihi on Kapiti Island.

5.3.1.2 *Fruits*

Ripe fruits were present in all months of the year (Figure 5.7). The lowest number of species in fruit was in June 1992 and March to June 1993. The largest number of species in fruit was in January 1992 and September 1993.

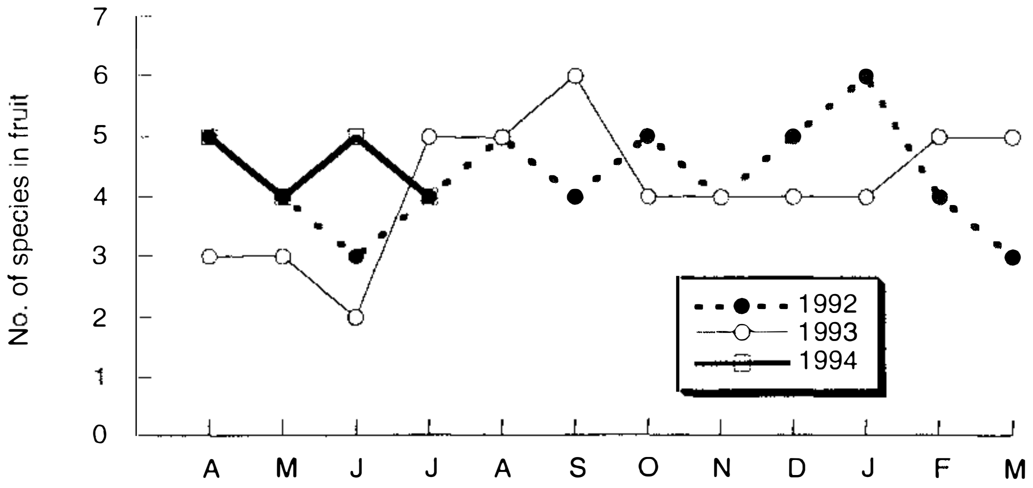

Figure 5.7. Comparison between the number of species in fruit in 1992, 1993 and 1994 on Kapiti Island. The eight species were selected from those preferred by hihi.

Hihi took fruits of plants other than those selected for the phenology study. Figure 5.8 includes all of the species hihi used during the study. Hihi fed on fruits each month with the exception of May and November 1992 and January 1994 (Figure 5.8). There was a positive correlation between the number of species available and the number visited by hihi (r=0.799).

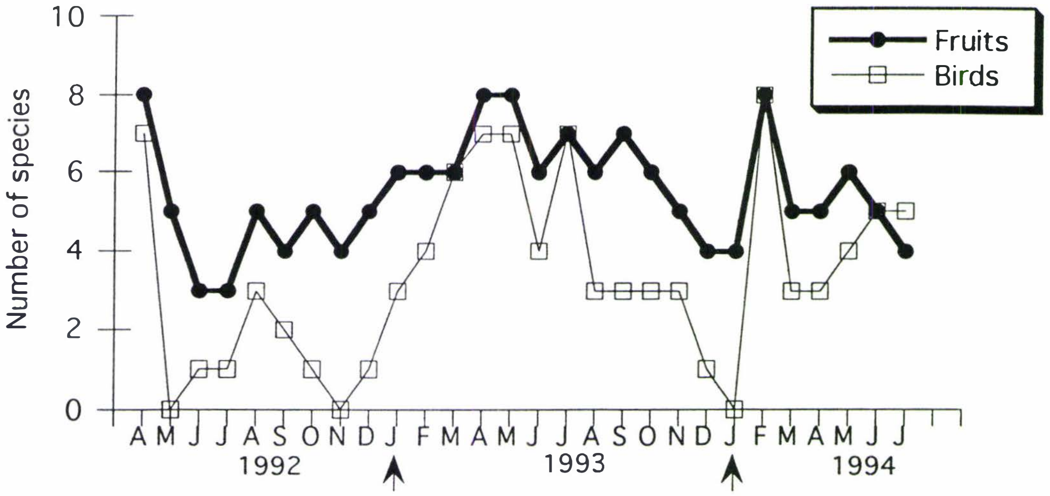

Figure 5.8. Comparison between the number of plant species in fruit and the number of plant species used by hihi on Kapiti Island, 1992-1994.

The number of fruits or flowers borne by a species varied greatly from year to year (Appendix 3). Overall, there were more flowers on the trees of most species in 1992 than in 1993. In 1994 I sampled only until July, but by then there were obviously many buds in some of the species, suggesting a good flowering season ahead. There were three species that had more flowers in 1993 than in 1992 (ie. against the general trend) - *Pseudopanax arboreus, Elaeocarpus dentatus and Metrosideros excelsa. Melycitus ramiflorus* produced very few flowers in both 1992 and 1993, but had a large number of flowers in 1994. Fruits often represent the success of the previous flowering season. Both *Melycitus ramiflorus* and *Pseudopanax arboreus* had large number of fruits in 1992, suggesting a good flowering season in 1991.

5.3.2 **Influence of climate on Phenology**

There was a lag between each climatic parameter measured and the number of species flowering. The largest number of species in flower was found in both years four months before the hottest period (Figure 5.9).

The largest number of species in flower was recorded five months before the greatest number of sunshine hours was registered in 1992, but only four months earlier in 1993 (Figure 5.10).

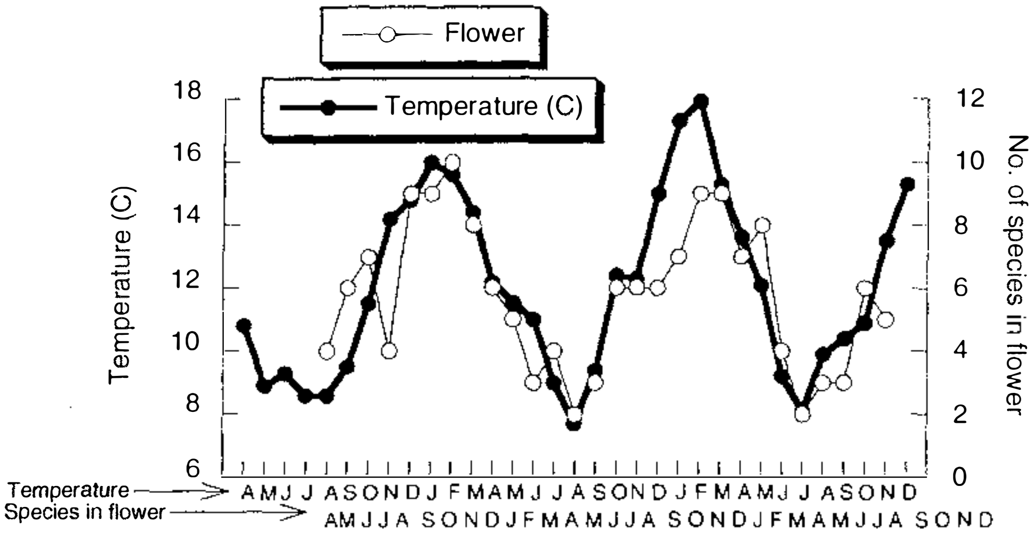

Figure 5.9. Lag period between the flowering of most species studied and the warmest months. Temperature data was obtained form the New Zealand Meteorological Service.

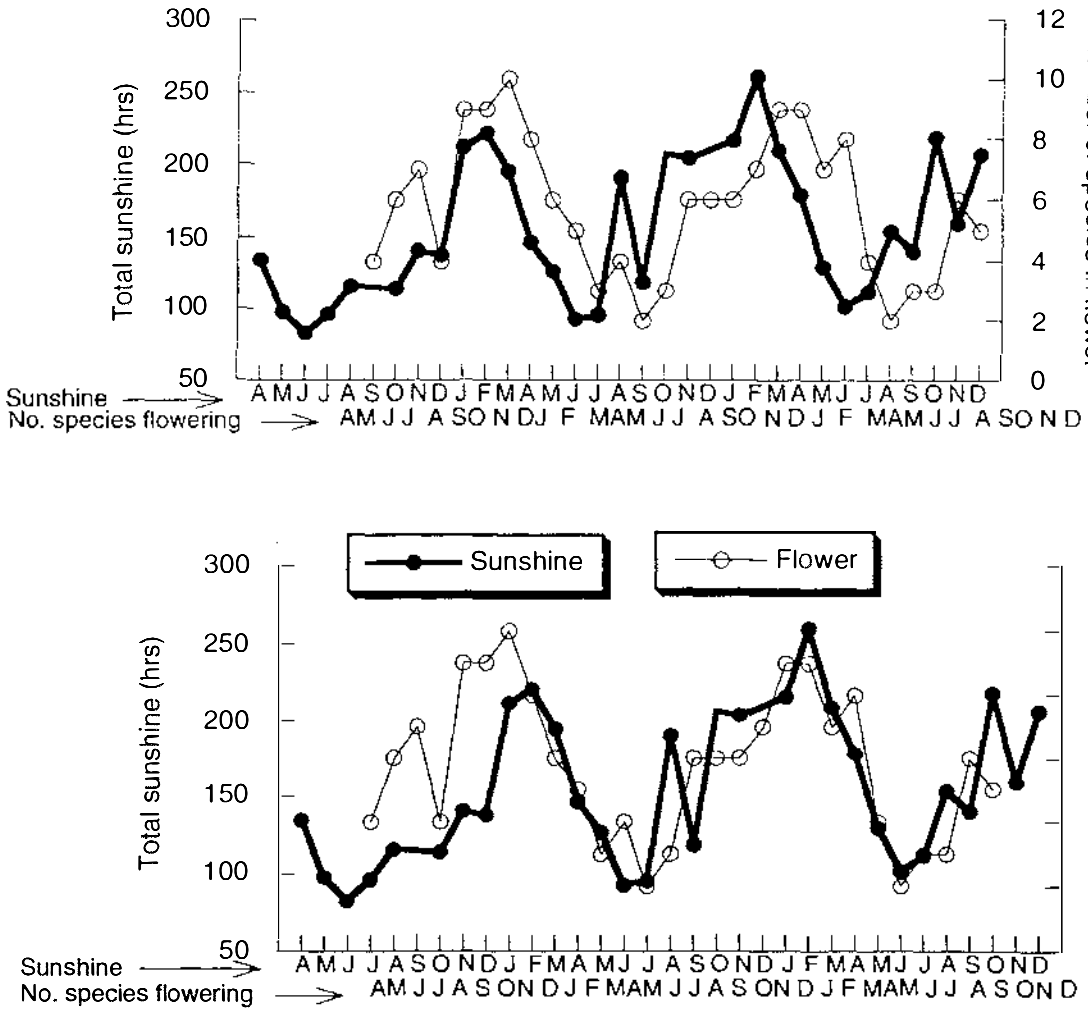

Figure 5.10. Lag periods between the largest number of species flowering and the total sunshine in hours. Top figure sows the best fit for 1992. The bottom graph shows the best fit for 1993.

5.3.3 **Hihi behaviour and energy requirements**

On Kapiti I. hihi fed on the three categories of food (nectar, fruits and invertebrates) in different proportions year round (Figure 5.11).

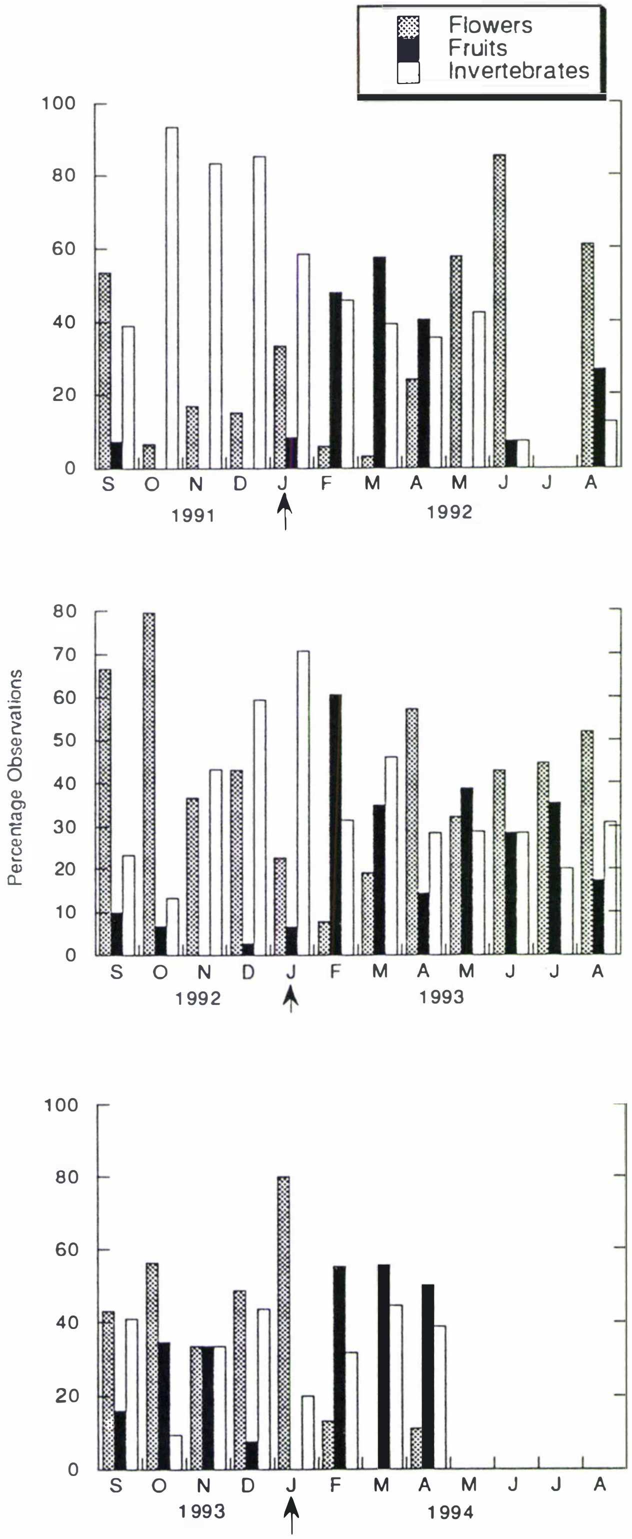

Figure 5.11. Percentage of observations of hihi feeding on flower nectar, fruits and invertebrates on kapiti Island from 1991-1994

On average (± SE) hihi were observed 37.2 percent (± 4.3) feeding on flowers; 22.7 percent (± 3.7) feeding on fruits and 39.6 percent (± 3.8) feeding on invertebrates. This result is consistent with the results of Lovegrove's (1985) study on Kapiti Island and those of Angher (1984) on Little Barrier Island. There was no strong correlation between the percent observation of hihi on flowers and percent observation on fruits or between percentage of observations on flowers and invertebrates. However, there was a weak negative correlation between the percentage of observations on fruit and invertebrates ($r = -0.61$).

5.3.4 **Use of the feeder**

The use of the feeder was strongly seasonal—birds only used the feeder during the breeding season, October to March (Figure 5.12). As a trend the percentage of birds visiting the feeder has diminished every year from 100% in 1991 to 70% in 1994. In September 1991 and 1992 there was a peak of visitation to the feeder corresponding to the first few weeks after the releases. The second peak each year corresponded to the month when egg laying started. Finally the third peak corresponded to the egg laying for the second clutches. In contrast with previous years in 1993/94 there was a single peak corresponding to the laying of the only clutch of eggs for that year.

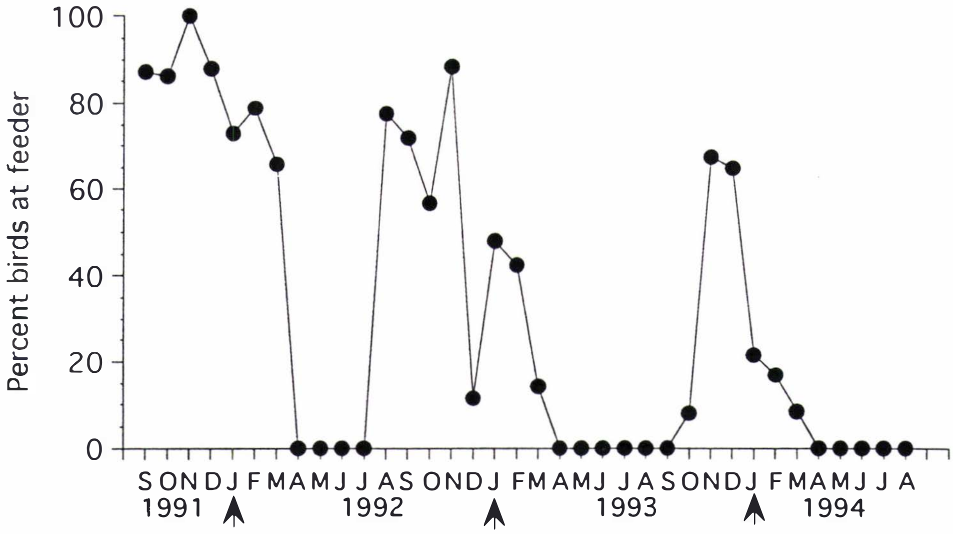

Figure 5.12. Monthly percentage of hihi visiting the feeder on Kapiti Island. 1991-1994.

5.4 **DISCUSSION**

This phenology study shows considerable variation in initiation and duration of fruiting and flowering for the species studied. It also shows between-year differences in flower and fruit numbers. Both these factors could be of great importance to hihi survival on Kapiti I. Several studies have looked at the relationship between nectar available or inflorescence density and abundance of honeyeaters in Australia. Most studies have found a positive correlation between them (Collins and Briffa 1982; Collins and Newland 1986; McFarland 1986) although honeyeater abundance should also be related to other habitat factors (eg. availability of nesting sites). In continental areas honeyeaters can move long distances looking for food, but in an island situation they have a more limited food supply. Ford (1991) found that honeyeaters either left the area or lost weight in periods of nectar shortage during the flowering season of *Banksia spinulosa*. To illustrate the effect of the difference in numbers of flowers per tree between the years I will use *Pseudopanax arboreus*. In Chapter 4 I reported that an average flower (open to visitations) in a tree contains 0.83 calories. In 1992 an average tree could have provided 124,500 calories in nectar while in 1993, the average tree could have provided from 298,800 to 1,494,000 calories, ie. from 2.5 to 12 times more calories. In other words, in 1992 an average tree could have maintained the daily metabolic requirements (Castro and Robertson *submitted*; Chapter 4) of four hihi, but in 1993 it would have maintained from nine to 47 hihi. These calculations do not take into consideration competition for resources, but they give an idea of the impact of a year with low flower numbers. Most plant species studied had more flowers in 1992 than 1993, so the overall number of calories on Kapiti I. must have been much greater in 1992 and the birds feeding on these flowers should have benefited. In 1992, the percentage of observations of hihi feeding on flowers was 40-80%, but only 20-60% in 1993, suggesting that hihi might have responded to the flower bonanza (Figure 5.11).

Species like *Melicytus ramiflorus* which provides food to hihi in the way of both fruits and flowers could have a marked effect on the birds' survival. In 1992 and 1993 *M. ramiflorus* bore small numbers of flowers and as a result there were very few fruits in 1993 and 1994. *M. ramiflorus* fruits are a preferred food. Often by following hihi, I found isolated trees that had a few fruits. There is some evidence that fruits can be taken by honeyeaters as replacement for nectar. B. Lee (pers. comm.) has found that for some *Coprosma* species the calorific content of fruits is similar to that of flower nectar. Angher (1984) found that on Little Barrier I. hihi used slightly more species of plants for their fruits (34) than for their flowers (27). On Kapiti I. I found the opposite relation (33 species of flowers and 17 species of fruit). Also, in contrast with Little Barrier I., Kapiti hihi do not have a clear seasonal pattern when feeding on fruits. Although Kapiti I. has 21 of the 27 fruit species listed by Angher, 8 of them are rare. It is possible that on Kapiti hihi are more dependent on nectar because of the lack of preferred fruit species. Since tui and bellbird are more nectarivorous than hihi (Gravatt 1970; Angher 1984, Rasch 1985) competition for this resource could be great. The vegetation on Little Barrier Island comprises mature forests including large numbers of trees of nectar-rich species such as *Metrosideros excelsa, Vitex lucens*, *Sophora spp.*, *Fuchsia excorticata,* and *Metrosideros robusta*. Furthermore, the understorey of the Little

Barrier I. forests contains a large number of species where the fruits and flowers are used by hihi. This contrasts markedly with the situation on Kapiti I., where the forests are relatively young, and do not have the diversity of species present on Little Barrier I..

Egg laying in hihi coincided with a one-month shift in flowering for most plant species. Hihi visited the feeders only during the breeding season. Energetic demands for both male and female birds increase during the breeding season (Paton 1982). Hihi visitation to the feeder could be a reflection of an increased metabolic requirement that can not be fulfilled by feeding on natural foods. Of the thirteen species that flower from September to January on Kapiti, five are rare (*Fuchsia excorticata, Metrosideros excelsa, Myoporum laetum, Pittosporum crassifolium, Vitex lucens*), two are restricted in distribution (*Metrosideros robusta, Weinmannia racemosa*), one provides low energetic rewards (*Geniostoma rupestre*), and for three most of the tree stands are young (*Pittosporum eugenioides, Knightia excelsa, Pseudopanax crassifolius*) and flowering and fruiting occur only in the older trees. This leaves only two species *Elaeocarpus dentatus* and *Pseudopanax arboreus* from which the three species of honeyeaters and kaka could obtain nectar during the breeding season. Tui, bellbirds and kaka breed during the same period as hihi, and competition for food should be very intense this time of the year. Furthermore, on Mokoia Island I found that hihi nesting close to a feeder fledge more young and heavier young than hihi nesting more than 200m from a feeder, suggesting that food constrains nesting success (Table 5.3).

Table 5.3.. Results from eight hihi nests on Mokoia Island. SM=Social Monogamy; Py=Polygyny; FA=Femele Alone. ** Nests heavily infested with ectoparasites.

Nest	Mating	Dist. to feeder	Age at weighing	Average weight	No. of fledglings	No. eggs	No. eggs hatched
1	Py	3	21	42.875	4	5	4
5	SM	100	24	41.4	5	5	5
47	Py	20	21	42.625	4	5	5
45	Py	5	23	37.84	3 **	5	5
Average				**41.185**	**4**	**5**	**4.75**
39	FA	700	21	38.3	2	4	3
54	FA	500	24	39.6	3	4	4
36	SM	500	21	27.5	3**	4	3
24	SM	250	24	33.5	2	5	4
Average				**34.725**	**2.5**	**4.25**	**3.5**

When Angher (1984) compared the vegetation of the islands proposed for translocations of hihi, he counted the total number of species known or suspected to be used by hihi, and compared that with the number of those species present on each of the islands. For instance, he found a total of 125 species used by hihi. Of those 102 exist on Little Barrier I. and 75 on Kapiti I.. Although he offered estimations of the abundance of those species, the values were not used to qualify the habitat available for hihi on each island. Thus Angher (1984) estimated that all broadleaf forests provided good or medium quality habitat for hihi without considering the composition of such forests. Finally he determined the monthly number of plant species in fruit or flower on each island using phenological information from Little Barrier I.. He assumed that phenology would be the same in all locations. This study shows the great variability in time and duration of fruiting and flowering within an island. It also shows relationships between temperature and total sunshine and flowering. Comparisons between areas should be made bearing in mind the difference in plant composition and latitude.

Although Kapiti I. contains a relatively large number of species when compared to the other islands proposed for hihi translocations, its forests are young and many species preferred by hihi are rare. Tui and bellbird populations on Kapiti are large while kaka populations seem to be at carrying capacity levels (R. Moorhouse, pers. comm.). Hihi might never reach large numbers on Kapiti I. because the island might be at or near its carrying capacity for nectar/fruit eaters. This is accentuated by the highly variable food availability: years when fruits and flowers are short could be detrimental to the small hihi population. There could be negative effects from good flowering and fruiting years as well, if those years favour competing species. In 1993-94 kakariki (*Cyanoramphus novaezelandiae*), a native cavity nesting parakeet, were found fighting for nest sites with hihi (Castro *et al.* 1994; Chapter 2). Hihi laid only one clutch in 93-94. It is possible that a good fruiting season in 1992 coupled with a very mild winter in 1993 might have allowed a large number of kakariki to survive to the breeding season and this was reflected in a greater degree of competition for nest sites.

There is need for experimental studies to determine the relationship between food availability and hihi survival. Research on competition with other species for various resources would allow us to interpret information on food abundance. Such studies might be necessary on each island receiving translocated hihi.

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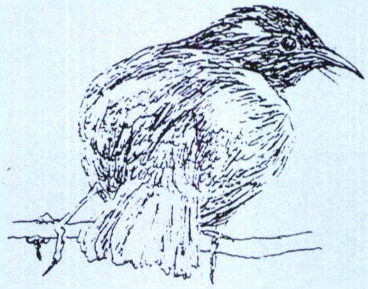

Chapter 6

Chapter 6

Monitoring and management of hihi (*Notiomystis cincta*) on Kapiti Island, New Zealand

ABSTRACT

There were three major management strategies followed to support hihi (*Notiomystis cincta*) translocated to Kapiti Island in 1991 and 1992. 1.) Feeders were established to supplement the natural food of hihi, and the major nesting areas were provisioned with nesting boxes. 2.) All released birds were individually marked and monitored to learn about the use of resources and survival. 3.) A phenological study was done to investigate the availability of foods. This paper presents the results of hihi management during 1991-94 on Kapiti Island and suggests a monitoring program.

6.1 INTRODUCTION

THIS Chapter is aimed at constructing a rationale for monitoring as part of the management of translocated species. With the number of endangered and threatened species increasing worldwide, ecological studies are emphasising management, as much as biological, aspects of research. In the New Zealand archipelago, where the three main islands are inhabited and have several introduced species of predatory mammals, the only hope for most endemic species is to be translocated to offshore islands (Merton 1975; Flack 1978; Nillson 1978; Rasch 1988; Roberts 1991). Some islands are sufficiently small that unwanted predators can be eradicated (Taylor and Thomas, 1990; Veitch and Bell 1990). On larger islands predators can be successfully controlled until skills and technology allow their removal (Veitch and Bell 1990). Most of the small offshore islands have been modified by people, but their size also permits plant restoration.

Translocation of species is not new, since most human colonists have introduced species from their land of origin. Translocations have also been done to restore native fauna extirpated by hunting (Griffith, *et al.* 1989). However, only recently has it been used as a tool to save rare native species.

Study of the ecology of a species can teach us about its general requirements at a particular site. This important knowledge allows decisions about possible translocation sites and informed criticism of shortcomings of translocation efforts. For most species, however, it is difficult to find translocation sites that are identical to localities where the species is known to do best. Furthermore, for most endangered and threatened species I can not be sure that the habitat it presently occupies is the one where it does best. Little is known about the effects of mobilisations on animal behaviour (Conant, 1988) and until now there has been no monitoring of released organisms (Young, 1990). This lack of monitoring (or lack of report of the outcome) has led to situations where the success or failure of translocations can not be properly analysed. There are no standard ways to determine the success of translocations. In many cases the success of a translocation is known only if, after some time (often years), the released species has become common enough to be seen regularly or so rare it is not seen at all. In some cases translocation is successful if the translocated species breeds successfully during the season following release. Even if breeding occurs post-reproductive events might impede the establishment of the species. These could include the depredation of young, cold weather, fire, or too few offspring to establish a population. Scott and Carpenter (1987) consider that the ultimate measure of translocation success is the establishment of a self-sustaining population.

Careful long term monitoring is, therefore, necessary to show the ways in which species respond to translocations (Scott and Carpenter 1987). Careful monitoring aids a programme of species establishment by indicating problems the species face. In extreme cases where the species does not survive in the new locality the monitoring helps in the review of future sites for translocation. Monitoring can also reveal behaviours of biological interest and provide ideas for scientific investigation.

Monitoring of a species involves more than simply recording that individuals of the species are alive and breeding. In the case of birds which depend on plants for food and shelter, monitoring seasonal plant production (phenology) and the weather, should be included.

6.1.1 The hihi: a case study

In this chapter I first discuss the results of a three-year study of translocated hihi (*Notiomystis cincta*) to Kapiti Island (Castro *et al* 1994;. Figure 1.3; Chapter 1). The results are applicable to long term monitoring of the species. Secondly, I describe a monitoring program designed to help managers evaluate the health of the population and make sound management decisions.

Hihi is a species of honeyeater endemic to New Zealand. There is a single population of this species on Little Barrier Island in the Hauraki Gulf. The New Zealand Department of Conservation is trying to establish self-sustaining populations of this species elsewhere to ensure its survival. Hihi were released on Kapiti Island in 1983, 1985 and 1990 (a total of 72 birds) but in each case although the birds bred during their first season (and in some cases in later seasons) they slowly disappeared in subsequent years. Lack of monitoring resulted in no information about why the birds disappeared. In 1991 and 1992 The New Zealand Department of Conservation arranged two further transfers, each of which was monitored intensively. The following document on monitoring and management is based on the three years of monitoring surrounding these transfers.

I will now discuss in sequence three major strategies for supporting and monitoring translocated hihi. The strategies are:

1. Supplementary feeding
2. Measures of survival and breeding
3. Plant phenology assessment.

6.2 1. Supplementary Feeding

6.2.1 METHODS

Feeders were placed on Kapiti Island at each hihi release site in 1991, and at the release sites and in every major catchment from the Kaiawharawhara to the Te Rere in 1992. Four weeks after each release all feeders were closed except the feeder near the ranger's house. The feeder at the ranger's house was provided with food year round. Observations were carried out at this feeder fortnightly during the winter months, and several times per week during the breeding season (Sept-Mar). Observation times ranged from 30 min to 12 hours.

The food offered at the feeder for four weeks after the transfers comprised nectar mix, jam water, honey water and sugar water (Lovegrove and Veitch 1994). After these periods the food used was mainly sugar water. On rare occasions the birds were offered honey water.

6.2.2 RESULTS

The feeder structure used until 1994 is shown in Figure 6.1. The protective wire mesh was necessary because kaka *Nestor meridionalis* and tui *Prosthemadera novae-zelandiae* are also attracted to sugar water, and are dominant over hihi. Food was provided in small glass jars.

This type of feeder and jar proved hard to clean. The main problems were:

- growth of fungus on the wooden base and frame caused by spilled food,
- bird faeces accumulating on the wooden base and contributing to fungal growth,
- birds perching on the edge of the jars to drink, after walking on the dirty wooden base. This could have caused some contamination of food,
- birds spilled food on the wooden base because the jars were open,
- all birds used the feeder and jars at the same time, providing opportunities for stressful interactions and transmission of disease (M. Friend, pers. comm.),
- dominant birds were able to monopolise the whole feeder.

Figure 6.1. Feeders used to provide supplementary food for hihi on Kapiti Island until 1994.

Use of the feeder was strongly seasonal (Figure 5.12; Chapter 5) with frequent visits by birds during the breeding months, but no birds using it in late autumn and winter. Greater activity at feeders coincided with laying of eggs and fledging of first clutches. Second clutches have not been successful on Kapiti, with the exception of a female breeding near the feeder in 1991-92 and possibly a female in a polyandrous system at the Te Rere in 1992-93. In 1991-92 and 1993-94, all known Kapiti pairs brought their first clutch offspring to the feeders. In 1993-94 parents remained with fledglings in the nesting areas and there were no attempts at second clutches.

Observation of birds at feeders show a high level of interaction. Dominant birds monopolised the feeder at low bird densities, but defence became unprofitable once numbers were high. However, at high densities mating activity increased and, I believe, male stress as well. Females might also be stressed by this, because frequently several males chased a single female.

At each feeder a different dominance hierarchy was found (ie. a dominant male or female at one feeder could be submissive at another). The percentage of birds visiting the feeders has decreased between 1991 and 1994. In 1991-92 up to 100% of the birds known to be alive used the feeder, but in 1993-94 only 71% used it. This difference might result because young birds, produced the season before, are less inclined to use the feeder.

6.2.3 DISCUSSION

The seasonal use of the feeder could reflect increased energetic demands and/or low availability of food of sufficient quality or quantity. The phenology transect shows clearly that the food available on Kapiti during this period is produced by plant species that are relatively rare, but are also preferred by breeding tui and bellbird *Anthornis melanura*. The only successful second clutch known to have been produced was raised near the ranger's house, which suggests that supplementary feeding might be important to reproduction. More significant however, is that in both seasons where second clutches were laid the first brood of fledglings was brought to the feeder. Possibly in 1991-92 and 1992-93 there was sufficient food for incubating females, but not enough to allow them to lay a second clutch and rear them. By bringing chicks to the house, however, parents have a better chance. In 1993-94 food was low and no females attempted to lay a second time. Work on Mokoia Island indicates that food limits breeding (Table 5.3).

6.2.4 RECOMMENDATIONS

I recommend the use of the feeders during the breeding season with the following modifications:

1. Three to four feeding stations should be established in each of the three main catchments where hihi are found. With this strategy the pressure on individual feeders will decrease as fewer birds will use each one. Also birds will be able to feed closer to their breeding grounds, and thus enhance their reproductive success. Finally, juvenile birds might be more likely to use the feeders because there are more of them around and they are closer to breeding sites which are often visited.
2. Feeders should be opened in September. Several studies have shown the importance of good quality food during the breeding season (Lack 1950; Paton, 1982; van Riper III 1984; Davies and Graham 1991; Castro *pers. obs.* Mokoia Island).
3. Feeders should be closed when no more breeding activity is detected. An exception to this is the feeder at the ranger's house. Here food should be available all year.
4. Feeders and nest sites should be monitored. Without monitoring it would be impossible to determine the effect of supplementary feeding on the birds. Only through monitoring will it be possible to determine when it is safe to close the feeders (ie. birds are not breeding anymore). Moreover, as with the phenology transect, constant monitoring will help to identify years when the birds are making greater use of the feeder.
5. Rough estimates of food consumption should be recorded. This will allow comparison of use between years, and a measure of how much the project costs.

Feeders are good places to mistnet and band birds. They are also key places to observe disease in birds and assess survival. Supplementary feeding is, however, expensive and not sustainable in the long run. It should be done only if necessary. To evaluate the effect of supplementary feeding on Kapiti I recommend the continuation of supplementary feeding and strict monitoring of the birds for three more years (ie. until 1998). After that time feeding should be suspended, but monitoring of breeding continued, and data compared. If the effects of the suspension of food are very clear in the first year, (ie. lots of birds die or the birds fail to breed) feeding should be resumed immediately.

In 1994 the feeders (described in the Methods section) were changed for the model obtained from Perky Pet Products (Figure 6.2).

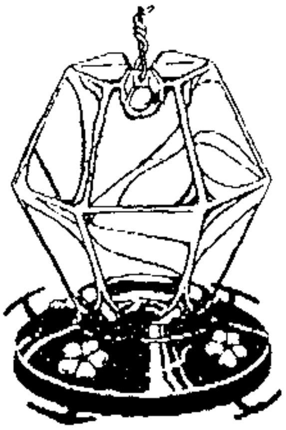

Figure 6.2. Hummingbird feeders made by Perky Pet Products.

These feeders, designed for hummingbirds, were modified to make them suitable for the larger hihi. The benefits of these feeders include:

1. No spillage of food since the birds have a very small opening through which they can drink.
2. The food is protected from the outside and birds' feet do not contact it.
3. They can be located separately, thus avoiding crowding and monopolisation of food by dominant birds.

To prevent tui and kaka from using the feeders, a cage of coarse wire netting could be built around them. The final feeder (Figure 6.3) would be bottomless, so that no faeces accumulate in it. The whole station can also be moved easily so that faeces do not accumulate on the ground under it.

Because the feeder is used only during the breeding season better quality food is recommended. The Wellington Conservancy of the NZ DoC has already started to use Womberoo®, which is complete food mix for birds. For information on nutritional contents of this product and where to obtain it see Appendix 4. During the non-breeding season sugar water would be sufficient.

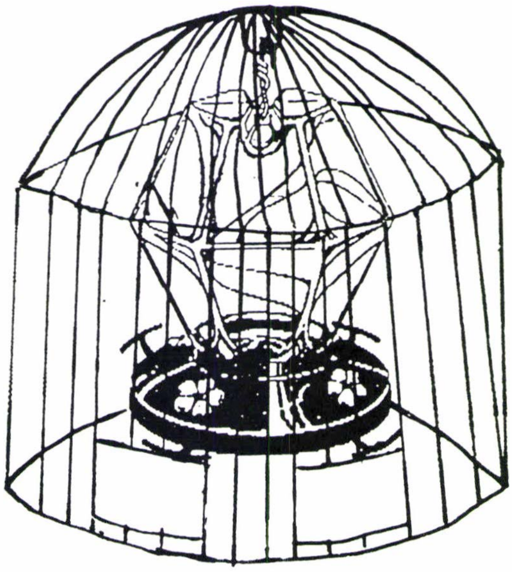

Figure 6.3. Wire netting around the feeder can prevent kaka and tui from using the feeders.

6.3 **2. Measures of Survival and Breeding**

6.3.1 **METHODS**

Survival of hihi on Kapiti Island has been measured by closely following the birds on foot, observing the feeders, and by searching and monitoring breeding sites. I searched the area between tracks 20 and 60 every other week from April to October recording the colour bands of all birds observed. From October to March I also observed the feeders recording all birds visiting it. I summarised the data as monthly survival.

Each year in October I began the search for nest sites. To find a nest site, I first located calling males. I found that males defending a cavity would, on average, call a three note territorial call every 17 to 20 seconds. This call was sung from perches located about 30 metres from the actual cavity. Sometimes the male would approach his cavity and briefly go inside it. However, most of the times it was a female who indicated where the nest site was. Females visit several nest cavities while males advertise them so, by following females, the hole can be found. Females were also less likely than males to be discouraged from entering the cavity because an observer was there. Once the cavity was located I watched it for one to six hours to determine the type and duration of activities, and to identify the birds using the site.

Nest boxes were erected in 1992 prior to the release, to increase the number of nest sites available. In total 18 boxes were placed in the Kaiwharawhara, five in the Kahikatea, eight in the Te Rere and five at Rangatira. In 1993 some nest boxes were moved near nest areas as part of an experiment This experiment was designed to find out if the birds would use boxes in areas already chosen for nesting and at which of two heights. Two identical boxes were located at 10 nest sites. One box was placed at one to one and a half metres and the other at least five metres from the ground.

6.3.2 RESULTS

6.3.2.1 Survival

Between 1991 and 1992 95 birds were translocated to Kapiti Island (Castro *et al.* 1994. Chapter 1). The largest number of birds known to be alive on the island (79) was in August 1992 after the second release, and the minimum number was 25 in December 1991 (Figure 6.4).

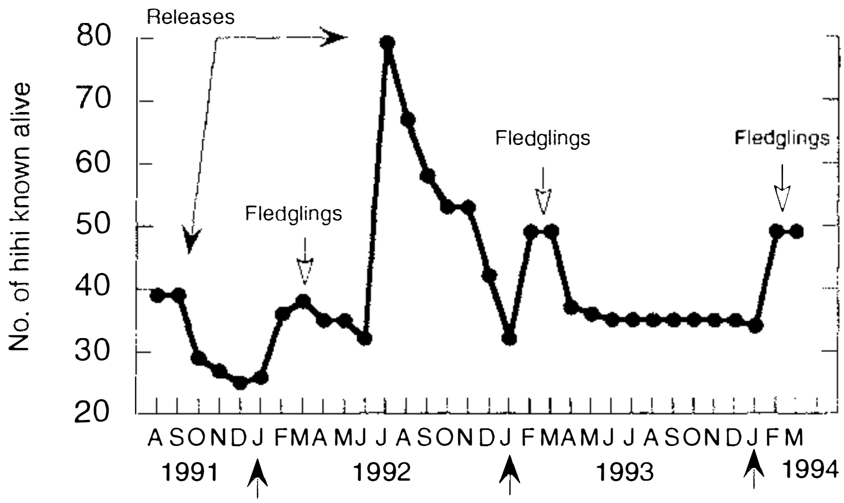

Figure 6.4. Number of birds known to be alive on Kapiti Island from 1991 to 1994

Survival of birds is highly variable (Table 6.1). On average 51.8% of adult birds and 55.34% of their offspring have survived from one year to the next. Juvenile survival for the first year may be under- or over-estimated since many juveniles are unbanded until they first visit the feeders where they can be caught and banded.

Table 6.1. Percentage annual survival of hihi on Kapiti Island from 1991 to 1993. Recruitment is written in italics and survival from one year to next in bold. Percentage survival from one year to next in parenthesis.

Survival of fledglings:

Fledge (year)	1991	1992	1993
91/92	*16*	**9** (56)	**5** (55)
92/93		*18*	**10** (56)
93/94			*15*

Survival for birds released in 1991:

August 91	November 91	November 92	November 93
48	**23** (48)	**16** (69)	**6** (37)

Survival for birds released in 1992:

August 92	November 92	November 93
47	**26** (55)	**13** (50)

6.3.2.2 **Predation and Disease**

Disease and predation are both factors that are associated with bird survival on other offshore islands in New Zealand. Kapiti I. has both Norway (*Rattus norvegicus*) and Polynesian (*Rattus exulans*) rats. Although during this study I did not find hard evidence of predation by any rat, the remains of a sick female who died in a cage on Kapiti, show the tooth marks of a Norway rat. Furthermore, a bird carrying a transmitter was found dead with the tooth marks of a Polynesian rat. The first case suggests that a Norway rat might be able to prey on sick or weakened individuals. In the second case either predation or scavenging can be suspected. Hihi transferred to Mokoia Island on Lake Rotorua in August 1994 have had a high survivorship. Mokoia I. has no mammalian predators with the exception of mice (*Mus musculus*). A single hihi on Mokoia I. even nested in a box left on the ground and successfully fledged three young.

In 1992, a few days after the second release had taken place, I found a male with the symptoms of a respiratory disease. He had partially lost his voice, looked fluffed up, and was less active. A week later he sat close to the feeder gaping (opening and closing his beak) continuously and coughing periodically. During the next few weeks I found two more males and two females with the same symptoms. All birds died or disappeared with the exception of one of the females who survived, but never recovered her voice completely. Post-mortem examination of two of the males showed that the disease was produced by air-sac mites *Sternostoma tracheacolum* (S. Cork, pers. comm.). In 1993, I found two females and a male with similar symptoms. All three disappeared during the following winter.

6.3.2.3 Hihi Distribution

Hihi have been seen in many places on Kapiti at one time or another. However, the birds have well established home ranges where they are relatively easy to find. Figure 6.5 shows the location of all known nesting areas in relation to the streams and tracks. The four main catchments where hihi have established on Kapiti are the Kahikatea, the two main streams at Rangatira (R1 and R2), and the Te Rere. Each nest site has a number preceded by the first letter of the name of the stream where it is located. Each nest site can have more than one cavity. For example, nest site K1, in the Kahikatea catchment consists of a natural cavity and two nest boxes all used by hihi.

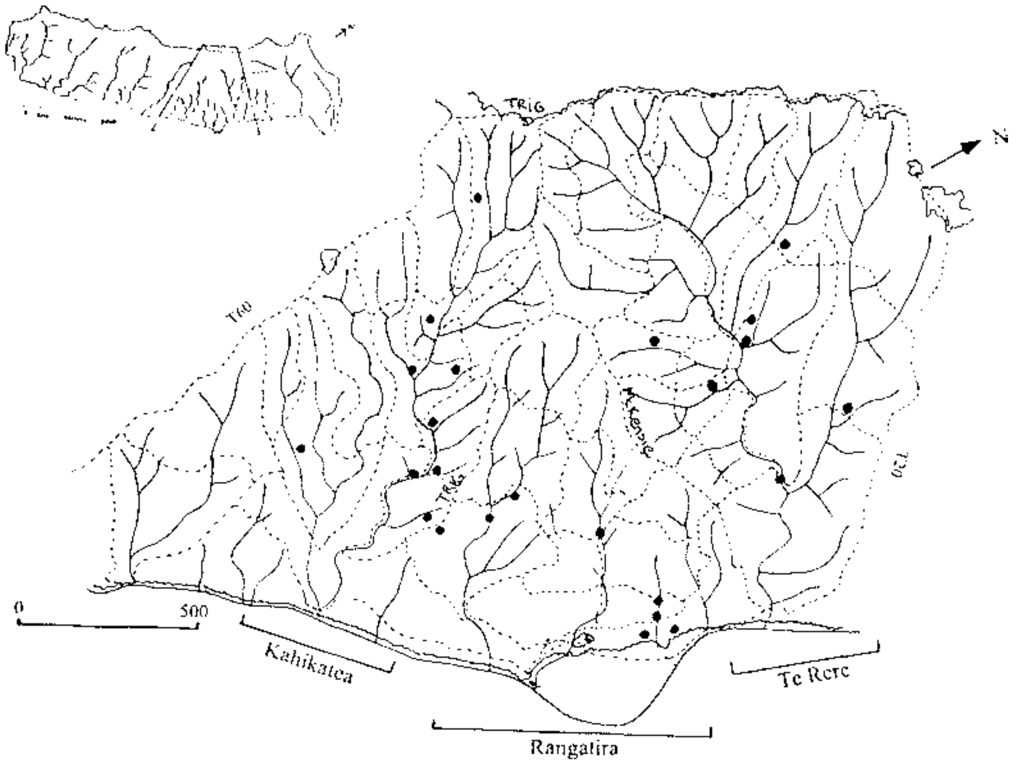

Figure 6.5. Location of all known hihi nest sites on Kapiti Island. Each dot indicates a nest site. Dotted line = tracks. Solid line = streams or shore line.

Male and female differ in their use of home ranges. A particular male hihi will have a stream as a home range including a small preferred area which normally is where he nested the year before. Female hihi also have a home range centred on a stream, but they have preferred "winter" areas that can be quite far from their nesting area. Table 6.3 lists all known home ranges, preferred areas and nesting areas for each bird. Juveniles become independent two to three weeks after fledging, form groups with adults, and remain in the same area as adults.

Table 6.2. Home ranges, wintering areas, and known breeding sites of surviving hihi on Kapiti Island

Bird	**Sex**	**Home range**	**Wintering area**	**Nest site**
A-WY	F	Kahikatea	Bottom Kahikatea	K1
A-WR	M	"	Wilkinson's Lookout	K1
Unb	M	"	Unknown	K1
WA-RR	F	"	Tracks S18,53 & 54	K2
R-WA	M	"	S5 Feeder Area	K2
A-YY	F	"	Tracks 56,Trig & 40	K3
AR-G	M	"	Top Track 56	K3
BA-R	M	"	All over Kahikatea	K8 & K6
Unb	F	"	Tracks 68 & 55	K6
GY-A	F	"	Track 56	K5 & K4
AB-Y	M	"	Upper Kahikatea,Whare	K4 & K7
Y-BA	M	"	Tracks 56,60,55	Unknown
WW-A	M	Rangatira	Track 43,S5 area,Whare	R1,2,4,5
AW-G	F	"	Track 43, Whare	R1
Unb	F	"	Track 40	R3
A-BW	M	Te Rere	All over Te Rere, T 40	R3
AB-BY	M	"	Lower Te Rere, T 44	R4,5,T1
BW-A	F	"	Junction, T44	Unknown
Unb	M	"	Tracks 20 & 44	T2
A-WG	F	"	T 45,Mck/Wilk,Kaiwhara	Unknown
-BA	M	"	Tracks R4 & 45	Unknown
BA-G	M	"	Tracks 44,45 and R4	Unknown
GG-WA	M	"	Track 45/R3, Whare	T4
A-GY	M	"	Summit, Track 47	T3
G-BA	F	"	Track 47	T5
A-BR	F	"	Track 20	Unknown
Y-A	F	"	Upper Te Rere	T6
AW-B	F	"	Track R7b	Unknown
A-GG	F	Te Rere & Kahikatea	Track 47,S5 area	K7,R3,R5
AG-GR	F	Te Rere & Kahikatea	Track 56	T2, K6
W-BA	F	Unknown	Unknown	T2

6.3.2.4 **Visability of Hihi**

Male hihi were easier to see than females because males gave a territorial call (three note call) or "chip" at any disturbance and had brighter plumage. However, when a male was found, often a female and/or juvenile bird was also sighted. By remaining in an area for at least 10 minutes after hearing a male or other birds, I usually observed all birds present. Squeaky callers (obtainable from the Audubon Society or any DoC shops) attracted hihi, enhancing the probability of seeing them. Juvenile and female hihi were particularly attracted to callers during the autumn and winter.

6.3.2.5 **Breeding**

During nest building one or more females brought nesting materials (sticks, ponga scales and feathers) to the cavity. Most activity took place in the morning. After the nest was finished there was a period of about 7 days where the females were rarely seen at the site, except for early morning and late afternoon. After this time the females spent several hours in the morning at the site. From nests in boxes I know this was the period of egg laying. Female hihi laid 2 to 5 eggs. Hihi laid 1 egg per day, an hour later each day. For instance female WA-W's first egg was laid at 0700 h on day 1 and her last egg at 1100 h three days later. Incubation started the day the last egg was laid and continued for about 15 days. Females did all incubation alone. In polygynous nests the two females took turns to incubate. Incubation stints lasted 20 min. while the average absence periods were 5 min. Hatching at natural sites was determined by the presence of egg shells beneath the cavity. Brooding (chick rearing) was initiated by the female (s). Males started brooding one or more days after hatching. Brooding times were similar to those of incubation for the first week, but after that absences were longer than visitations. In average, males visited the nest at a lower rate than females. Brooding lasted from 28 to 34 days. Chicks fledged in the morning usually about 1000 h. In 1992 and 1993 fledglings remained near the nest cavity (within 100m) for the first few days after which they were moved to the house feeder. In 1994 the chicks and parents remained near the site (within 200m) for two weeks. Fledglings were fed by both parents for one week. After this time the males alone continued feeding them while the females started second clutches (except for 1994 when females did not attempt another clutch and they remained with the chicks as well). This year there was great competition for nest sites between hihi and kakariki *Cyanoramphus novaezelandiae* (Castro *et al.* 1994b; Chapter 2).

Chapter 2 (Table 2.1) summarises the results of the breeding seasons from 1991 to 1993. Hihi used the same cavities for nesting every year.

6.3.2.6 **Boxes**

None of the boxes erected in 1992 were used that season, or until 1994. However, of the boxes placed at the nest sites in 1993, one was used during that breeding season and another one in 1994. Nest building material was found in a further box at a nest site, and in both 1993 and 1994 sticks were found in many kakariki boxes.

6.3.3 **DISCUSSION**

At present most birds are colour banded. It is important to carefully record the band combination of each bird sighted because these records enable the survival of birds of different ages, and the distribution, movements, mate choice, and breeding output of individuals to be determined. Colour banding should continue whenever possible. Banding should be done at feeders early in the season, to avoid mistnetting females while they carry eggs.

Survival of hihi on Kapiti I. is low. Recruitment of juveniles in the population (1992-95) is enough to maintain the numbers at around 40 individuals, but the population does not seem to be increasing. I believe that a combination of:

1. Low food availability during late spring and early summer,

2. Cavity limitation,
3. Predation and disease,
probably contribute to the low numbers of the species on Kapiti I.

Providing food close to nest sites during the breeding season, adding boxes at nest site areas and eradicating the rats from the Island will all be important in the management of hihi.

6.4 **3. Plant Phenology Assessment**

6.4.1 **METHODS**

From 1986 to 1990, a phenology transect to assess seasonal changes in plant production was designed by Ron Moorhouse (pers. comm.) as part of a feeding study on kaka. I continued this work with few modifications from 1991 to 1994. The transect was run once a month, usually taking two days and following any combination of tracks between Track 20 and Track 60. I monitored 22 plant species which are important hihi food (Table 5.3). The methodology followed is described in Chapter 5.

6.4.2 **RESULTS**

The number of species in either fruit or flower varied throughout the year and from year to year (Figures 5.6 and 5.7; Chapter 5). The fewest species were in fruit or flower during the colder months with slight variation between the years (Figure 6.6). The greatest number of species in flower and in fruit was recorded in the spring and early summer (Figure 6.6). There were marked differences between years in the level of flower production (Chapter 5). For instance *Pseudopanax arboreus* flowered during the same months in 1992 and 1993 with tens of thousands of flowers in 1993, but only thousands in 1992. The entire flowering season was a month later in 1993 when compared to 1992.

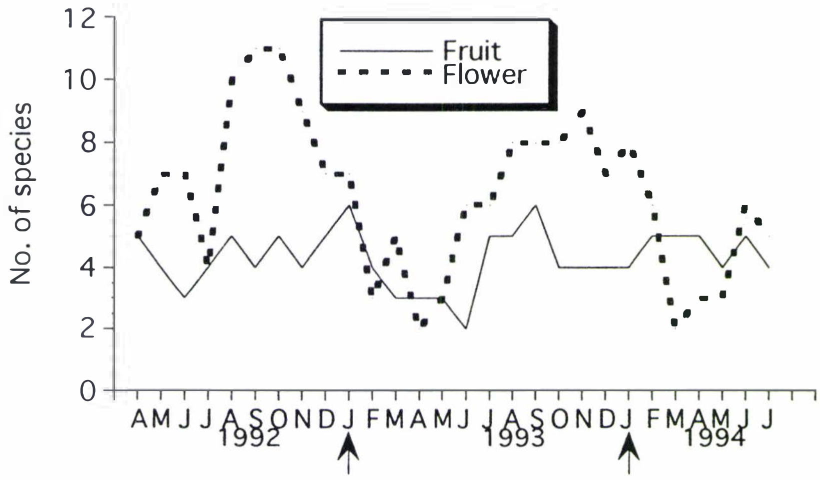

Figure 6.6. Number of species in fruit or flower on Kapiti Island from 1992-1994.

6.4.3 DISCUSSION

Even from this very short period of time, the results of the phenology transect point to the important aspects of flower and fruit availability. On the one hand, the results show that there is a source of food for hihi through the year. On the other hand it shows that the food available varies both in quality (different species available) and quantity (different number of plants and different number of flowers and fruits). Although there is always food present, the quality and quantity will determine its use by hihi and other honeyeaters. For instance, in 1992 hihi had more access to *Elaeocarpus dentatus* flowers than in 1993 because the flowers were present in large quantities (Appendix 3) and therefore were harder for tui and bellbirds to defend. Larger quantities of flowers probably also meant greater number of calories per bird (Chapter 5).

Another important aspect is the onset of the flowering for the various species. A good example is kamahi. In 1992 kamahi began flowering in October, but in 1993 the first flowers were seen in August, two months earlier. The influence of the availability of this preferred nectar on the birds physical condition prior to the breeding season could be important.

The importance of assessing plant phenology can not be overemphasised. Long term results of phenology associated with nesting success and bird survival can help in understanding the dynamics of communities and will help in making important management decisions.

6.4.4 RECOMMENDATIONS

I recommend the continuation of the phenology transect. The species used in the transect figure in the diet of many birds and the results of the transect will be of wide use on the Island.

6.5 Monitoring program

Based on my own monitoring, the following is a monitoring plan to determine the survival and breeding success of the hihi on Kapiti I. Table 6.3 gives a summary of the plan with the priority I think should be given to each activity.

Table 6.3. Monitoring plan for hihi on Kapiti Island

Activity	Priority	No. people	Time involved
Monitor breeding (Sep-Mar)	1	2	1 day / 2 wk's
Monitor feeders (Sep-Mar)	1	1	2-3 hrs / 3 days
Monitor activity (Apr-Aug)	2	2	2 days / month
Monitor boxes (Sep-Mar)	3	1	1 day / 2 wk's

6.5.1 **Hihi monitoring from April to August**

To monitor the survival and activity of birds during the non-breeding season (Apr to Aug), I suggest that once each month two people walk the tracks highlighted on Figure 6.7. The observers should start at different ends of the transect ie. crossing each other. The dots on the map are places where the observer should stop for a period of 10 min. This period of observation maximises the possibility of seeing a bird. When a bird is heard or seen at any point on the transect its band combination and activity should be recorded in Data Sheet 1 (Appendix 5). This transect should take a maximum of two days to complete and could be done at the same time as a phenology transect.

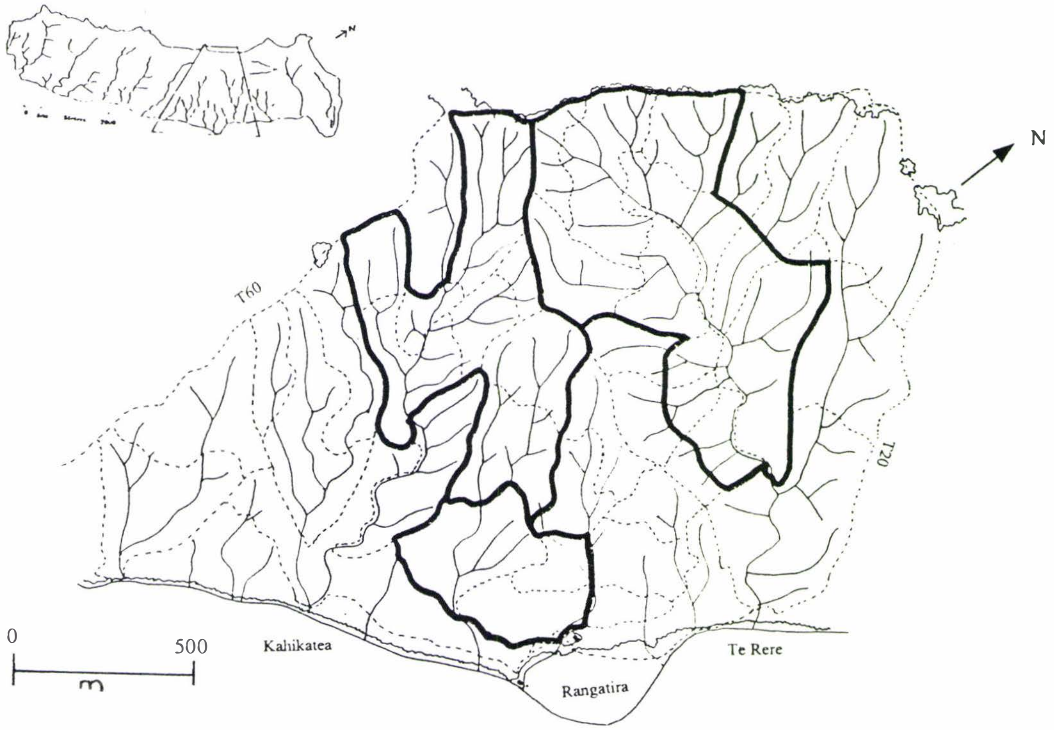

Figure 6.7. Tracks suggested for hihi monitoring from April to August. Dotted line = tracks. Solid line = streams. Dots indicate suggested sites for ten minute watches.

6.5.2 **Hihi monitoring from September to March**

6.5.2.1 **Breeding Activity**

Every two weeks, from September to March, one observer should sit at each nest site for 30 minutes to monitor breeding activity. An effort should be made to record the band combination of all calling males and all visiting females because often there is more than one bird of each sex associated with a cavity (see Data sheet 2; Appendix 4). Two people could complete this work in one day if each one does a different area as suggested in Figure 6.8.

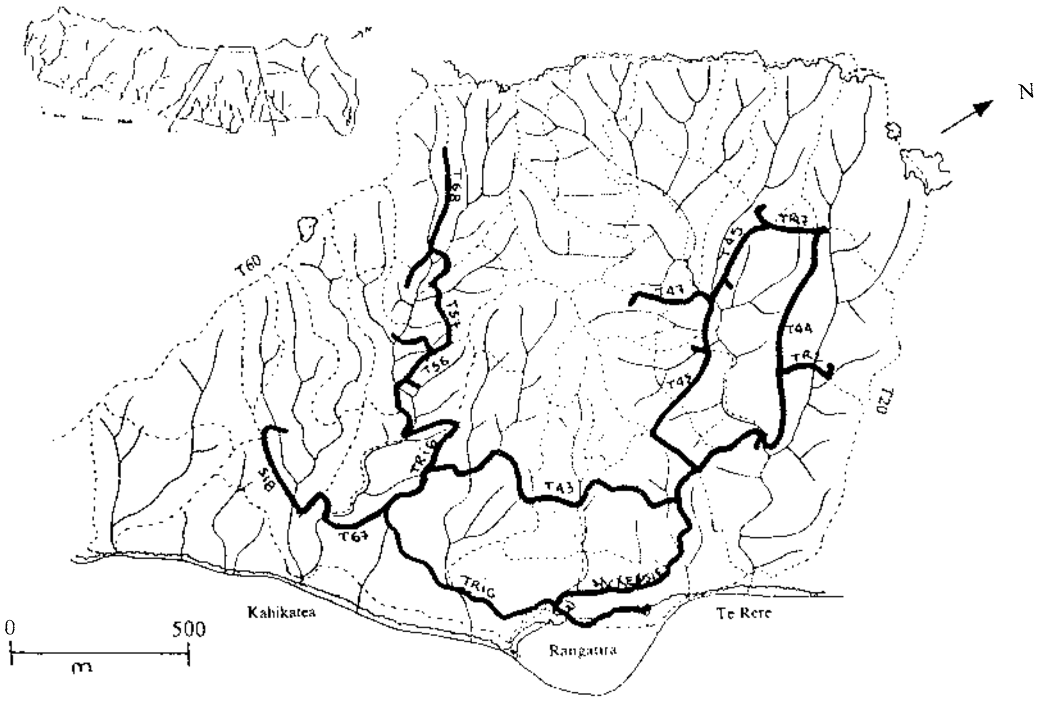

Figure 6.8. Suggested route to monitor hihi from September to March.

6.5.2.2 **Nest boxes**

During 1992 and 1993 nest boxes were erected at 54 sites. Figure 6.9. shows the approximate location of all nest boxes. It is important to monitor the use of these boxes, especially those located near natural nest sites. While watching for nesting activity observers should take a few minutes to look into the lower nest boxes and also look from below into the high boxes for nest material sticking out. Activity should be recorded on Data Sheet 2 (Appendix 5).

6.5.2.3 **Monitoring the use of feeders by hihi**

From the end of September until the end of March one person should watch each of the feeders (Figure 6.10) for at least 30 min every three days. Once hihi start using the feeders the observation time should increase to at least one hour. The band combination of birds visiting the feeders should be recorded (Data Sheet 3; Appendix 5). If there are unbanded birds visiting the feeder they should be mistnetted and banded.

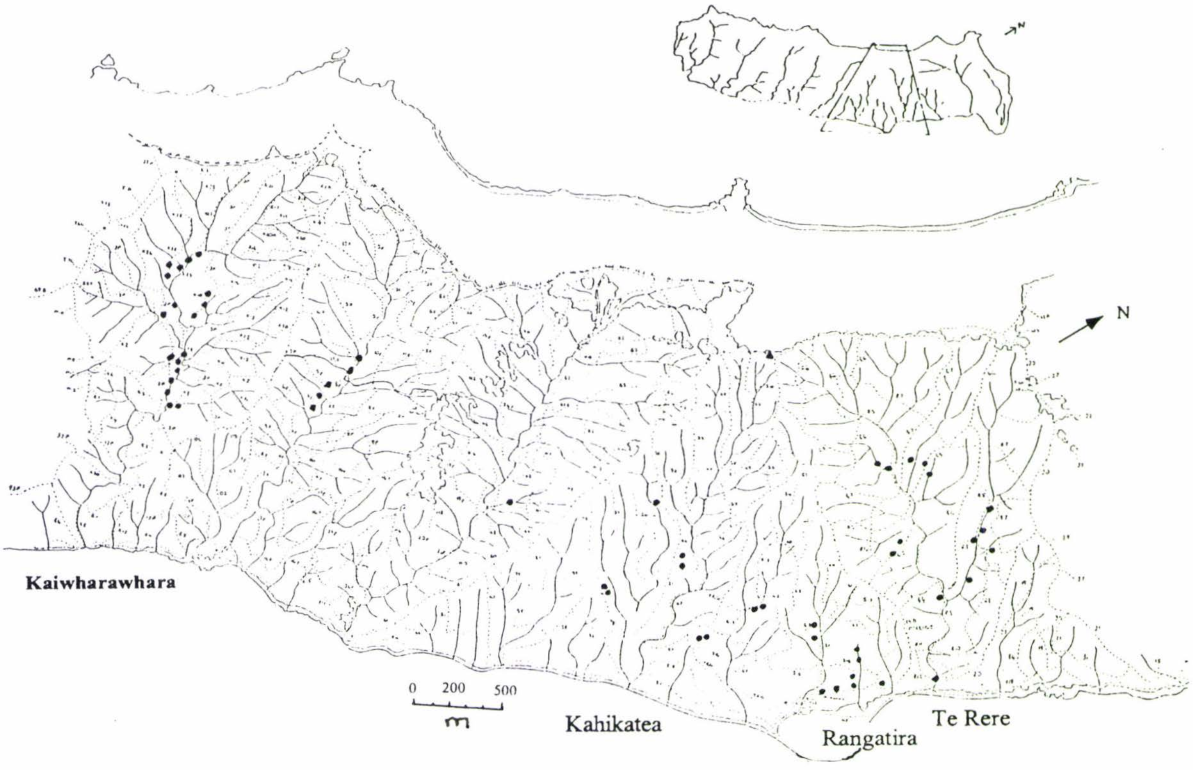

Figure 6.9. Map showing the location of nesting boxes on Kapiti Island. Each dot indicates a nest box. Dotted line = tracks. Solid Line = streams.

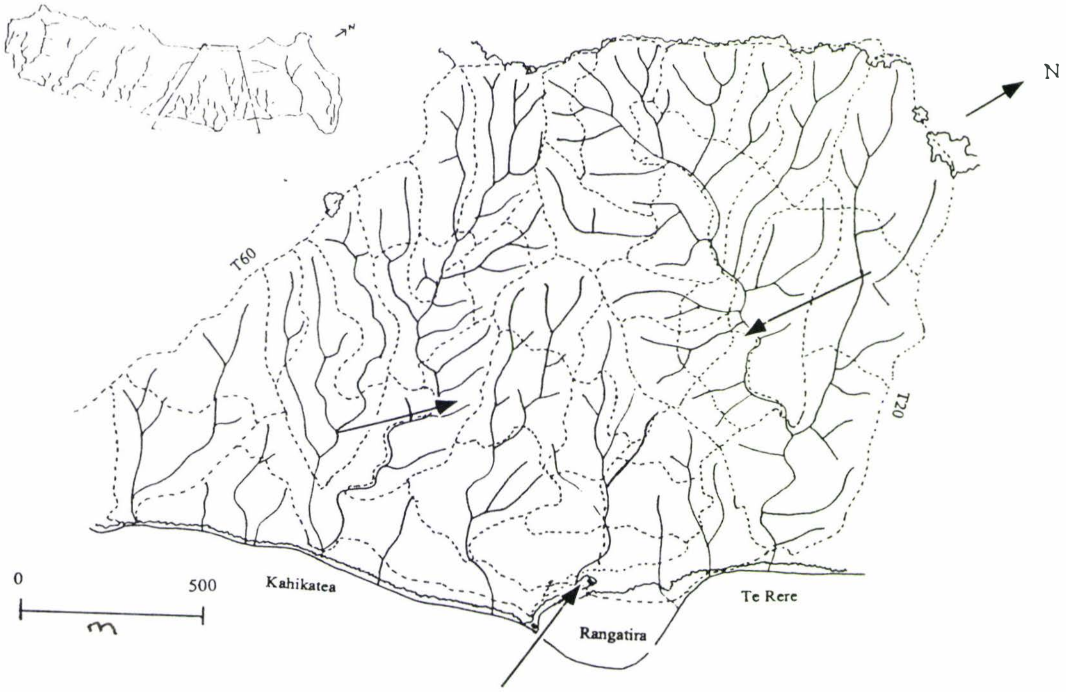

Figure 6.10. Map showing the location of the feeders on Kapiti Island. Arrows point at the location of feeders. Dotted line = tracks. Solid Line = streams.

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Chapter 7

Chapter 7

Concluding Remarks

This thesis grew out of a basic problem in the management of a rare New Zealand species. After seven unsuccessful translocations, a total of 192 hihi, and thousands of dollars, the managers (New Zealand Department of Conservation) were eager to know "Why are hihi failing to establish self-sustaining populations after translocations?".

The answer to a question of such magnitude can be found only by first listing all possible causes of failure and then evaluating each one. Separate causes, however, can have synergistic effects. I went about answering this question in two ways. The first was to evaluate how translocations were done to find out if the failures were a consequence of the methodology. The second was to study the behavioural ecology of hihi to see if the failures reflected a conflict in the relationship between hihi and their new environment.

Little was known about hihi when I started research for this thesis. On the way to answering some basic management questions I discovered a bird with unique behaviour and ecology that make it an ideal subject for advancing several topical areas of evolutionary ecology and conservation biology.

7.1 Management

The basic translocation technique involves the capture of individuals and their release in an area where they are absent. To achieve success when translocating organisms, however, it is necessary to develop techniques to ensure their survival during the transportation process. It is necessary to know that the area where translocation is taking place is free of whatever caused the organism to disappear in the first place. It is indispensable to have a way of measuring the success of the translocation. It is not easy to meet these requirements because many of the species translocated in New Zealand are endangered. We can not be certain that sites presently occupied represent the best habitat for the species. Moreover, the reasons why species disappear are often unknown. Until recently, translocations were done uncritically, often as a result of near crisis situations. Information gathered through translocations was rarely published. The outcomes of translocations were impossible to analyse because of the lack of experimental design and post-release monitoring. It was difficult to rationalise an experimental design when, because of their rarity, the loss of a single individual could represent the loss of the species. As a consequence, the procedures that seemed to work for some species became standard practice for all species without real data to support them.

My project with hihi is one rare example where translocations are being carried out before the species is at real risk. Particular attention was given to the way the birds were treated during the translocation process and the methodology was carefully recorded. Releases were carried out as designed experiments. After release the hihi were followed to observe the effect of the release techniques and to determine the birds' use of the environment. Most important of all, descriptions of the techniques and the results from monitoring the translocation were published and are available to managers. The techniques developed during my research and the results of the experimental translocations now determine the way hihi are translocated to other islands (Stitchbird Recovery Group, pers. comm.). Moreover, the project itself has become an example of the way the study of translocations should proceed. Hihi translocations have set a precedent as the first translocations carried out as designed experiments, having been monitored for several years, and having been published.

As a result of my experiments it has even been necessary to reverse the terminology applied to releases. The former designation of "hard" and "soft" release are not descriptions of the process but rather of the presumed outcomes. Soft releases, where the birds are kept in captivity for some time prior to release, were thought to help the animals by providing a buffer period between the stress of the translocation and the hardships of adapting to a new area. Hard releases were those where birds were liberated directly on arrival at the release sites. Soft releases proved to be relatively stressful for hihi, and birds released hard survived better (Chapter 1). This shows the benefit of more objective terminology. It is necessary, therefore, to rename "hard" and "soft" releases as "immediate" and "delayed" respectively. Immediate releases were made less stressful by providing food for the released birds. The results of monitoring hihi showed that disease, interspecific and intraspecific competition for nesting sites, and food availability, were all factors affecting the survival of the birds on Kapiti Island. I learned this by careful monitoring of hihi after the releases. The results show that management measures can improve the birds' survival and establishment. Such management must be trialed and monitored to observe the effects on hihi. In Chapter 6 I provide a monitoring scheme that will allow managers to evaluate the management alternatives based on my research.

7.2 **Breeding biology**

During my research I found in hihi a breeding system unusual amongst birds. Hihi have a highly variable mating system including *monogamy* (one male and one female), *polygyny* (one male and several females), *polyandry* (one female and several males), and *polygynandry* (several males and several females). This finding opens the possibility for the study of the evolution of mating systems.

Based on the knowledge of hihi's breeding and feeding ecology acquired on

Kapiti I have developed a testable model to explain the variability of mating systems in hihi. The model suggests that hihi choose their breeding system on the basis of the distribution of food and nest sites in relation to one another. Emlen and Oring (1977) first suggested that environmental conditions determine the degree to which mates can be defended or monopolised, and determine the temporal availability of receptive mates giving rise to the different mating systems. For instance, monogamy occurs when food is evenly distributed spatially and males can defend areas only large enough to support a single pair of individuals. Polygyny occurs when food is spatially aggregated. Davies (1983, 1992) convincingly demonstrated that for dunnocks *Prunella modularis,* another passerine with a variable mating system. His experimental manipulation of the spatial distribution of food resulted in the predicted change in mating system. Specifically, an increase in food availability increased polygynandry.

Hihi provide a unique opportunity to test these hypotheses about mating systems because they are restricted to islands, breed in nest boxes, and readily take food from feeders providing the opportunity to experimentally manipulate nesting sites and food availability. Furthermore, I have also proposed that manipulation of hihi breeding system through altering resource availability could be used as a management tool. Some mating systems might prove less stressful than others, decreasing the incidence of stress related diseases and increasing survival and reproductive success. Polygyny could be desirable in some circumstances (with more females than males, chick production would be greater), while monogamy could be useful in some others (greater genetic diversity).

Testing this model in the wild is the next step. It will put hihi in the international scene by testing some general concepts about the evolution of mating systems. However, on the way to obtaining the results, there will be other contributions specifically regarding sperm competition, female sperm choice and parental investment.

7.3 **Honeyeaters and pollination**

New Zealand honeyeaters feed on nectar from flowers that are very different from those honeyeaters use elsewhere. Very few New Zealand flowers have characteristics usually associated with bird pollination. New Zealand flowers are renowned for being small, rather than large, and mostly yellow or white, rather than brightly coloured. They are also quite simple in their structure, and are often scented. All those characteristics are closer to those known from flowers pollinated by insects in other parts of the world. For that reason, until now it was believed that the New Zealand honeyeaters used those small flowers only incidentally. Pollination by New Zealand birds was thought to be restricted to those species with flowers that resembled those pollinated by birds in other parts of the world.

From my work on hihi I knew that visitation to some of the very small flowers was anything but incidental. Hihi, tui and bellbird visited small flowers consistently. They spent most of their foraging activity time on them, and visited the flowers every year. I was interested to know the calorific value of the nectar in the flowers the birds were using, to relate it to the rate of visitation to flowers, and obtain an idea of the availability of food on Kapiti I.. When I obtained those values it became apparent that the birds were using the flowers because they could get enough energy from the nectar to sustain their metabolism. Some of the small flowers could provide as many calories as some of the larger flowers.

I proposed in Chapter 4 that New Zealand flowers might have evolved to accept pollination from a number of pollinators, including birds. This idea arises from two observations. First, the New Zealand insect fauna is poorly developed when compared to other parts of the world, even lacking some of the commonest insect pollinators. Second, I found the honeyeaters visiting *Pseudopanax arboreus* female flowers (they also visit the male flowers). Unlike the male *Pseudopanax arboreus* flowers, the female flowers are very small and for most of their lives do not have petals. Closer observation showed me that the birds were licking the flower body, which resembled a fruit and which had nectar all over it. I described this as a "lolly-pop" syndrome. It is possible that New Zealand flowers have evolved other ways to ensure pollination by birds different from those known from other parts of the world. It takes a few seconds for a honeyeater to remove the nectar from the "lolly-pop". During this time it can contact the reproductive parts of the flower and deposit pollen from the male flowers.

If the New Zealand honeyeaters have an important pollinating role, the effects of their decrease in numbers on the mainland could be detrimental to the reproduction of plants. New Zealand honeyeaters not only feed on the nectar of flowers, but often eat the fruits as well. Reduction on honeyeater numbers might cause a decrease in fruit set and in turn a decrease in the dispersal of seeds.

The use of small flowers by the New Zealand honeyeaters challenge the current views on evolution of flowers and pollinators. I propose research projects that clarify the role of birds as pollinators and their effect on the plants they pollinate.

The different topics presented in this thesis provide the basis for building a hihi management program. Moreover, they make a significant contribution to several theoretical problems. Finally, my work has provided ideas and base line data for addressing further critical questions.

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Appendixes

Appendix 1. Comparison between the plants in flower at each month of the year and hihi flower use.

Date	Plants Available	Plants used	
		Male hihi	Female hihi
April 1992	*Dysoxylum spectabile*	√	√
	Melicitus ramiflorus	√	√
	Metrosideros fulgens		
	Pseudopanax crassifolius		
May 1992	*Dysoxylum spectabile*	√	
	Melicitus ramiflorus		
	Metrosideros fulgens		
	Pseudopanax arboreus	√	
	Pseudopanax crassifolius		
	Vitex lucens	√	
June 1992	*Dysoxylum spectabile*	√	√
	Fuchsia excorticata		
	Melicitus ramiflorus		
	Metrosideros fulgens	√	√
	Pseudopanax arboreus	√	√
	Pseudopanax crassifolius		
	Vitex lucens	√	
July 1992	*Fuchsia excorticata*		
	Pseudopanax arboreus		
	Pseudopanax crassifolius		
	Weinmannia racemosa		
August 1992	*Fuchsia excorticata*		
	Geniostoma rupestre		
	Pittosporum crassifolium		
	Pittosporum eugenioides	√	√
	Pittosporum tenuifolium		
	Pseudopanax arboreus	√	√
	Pseudopanax crassifolius		
	Vitex lucens	√	√
	Weinmannia racemosa		
September 1992	*Fuchsia excorticata*		
	Geniostoma rupestre	√	√
	Metrosideros fulgens		
	Pittosporum crassifolium		
	Pittosporum eugenioides		
	Pittosporum tenuifolium	√	√
	Pseudopanax arboreus	√	√
	Vitex lucens		
	Weinmannia racemosa		
October 1992	*Fuchsia excorticata*		
	Geniostoma rupestre	√	√
	Metrosideros fulgens		
	Myoporum laetum		
	Pittosporum eugenioides	√	√
	Pittosporum tenuifolium		
	Pseudopanax arboreus	√	
	Pseudopanax crassifolius		
	Vitex lucens		
	Weinmannia racemosa		
November 1992	*Elaeocarpus dentatus*	√	√
	Geniostoma rupestre	√	√
	Knightia excelsa		
	Metrosideros robusta		
	Myoporum laetum		

	Pittosporum eugenioides	√	
	Vitex lucens		√
	Weinmannia racemosa	√	√
December 1992	*Elaeocarpus dentatus*	√	√
	Knightia excelsa	√	
	Melicitus ramiflorus		
	Metrosideros robusta	√	
	Myoporum laetum		
	Weinmannia racemosa	√	√
January 1993	*Melicitus ramiflorus*		
	Metrosideros excelsa	√	
	Metrosideros robusta	√	√
	Myoporum laetum		√
	Weinmannia racemosa	√	
February 1993	*Metrosideros excelsa*		
	Vitex lucens		√
	Weinmannia racemosa		
March 1993	*Melicitus ramiflorus*		
	Metrosideros fulgens	√	√
	Vitex lucens		√
	Weinmannia racemosa	√	
April 1993	*Dysoxylum spectabile*	√	√
	Metrosideros fulgens		
May 1993	*Dysoxylum spectabile*	√	√
	Metrosideros fulgens	√	√
	Vitex lucens		
June 1993	*Dysoxilum spectabile*	√	√
	Fuchsia excorticata		
	Geniostoma rupestre	√	√
	Pittosporum crassifolium		
	Pseudopanax arboreus	√	√
	Vitex lucens		
July 1993	*Fuchsia excorticata*	√	
	Geniostoma rupestre	√	√
	Metrosideros fulgens		√
	Pittosporum crassifolium		
	Pseudopanax arboreus	√	√
	Vitex lucens		
August 1993	*Fuchsia excorticata*		
	Geniostoma rupestre	√	
	Metrosideros fulgens		√
	Pittosporum crassifolium	√	√
	Pseudopanax arboreus	√	√
	Vitex lucens		
September 1993	*Fuchsia excorticata*		
	Geniostoma rupestre	√	√
	Pittosporum crassifolium		
	Pittosporum teniufolium		
	Pseudopanax arboreus	√	√
	Vitex lucens		
	Weinmannia racemosa		
October 1993	*Fuchsia excorticata*		
	Geniostoma rupestre	√	√
	Metrosideros excelsa		
	Pittosporum eugenioides	√	
	Pittosporum teniufolium		
	Pseudopanax arboreus	√	
	Pseudopanax crassifolius		
	Vitex lucens		
	Weinmannia racemosa		
November 1993	*Elaeocarpus dentatus*		
	Geniostoma rupestre	√	√

	Knightia excelsa		
	Melicitus ramiflorus		
	Metrosideros robusta		
	Myoporum laetum		
	Pittosporum eugenioides	√	
	Pseudopanax arboreus		
	Weinmannia racemosa		
December 1993	*Elaeocarpus dentatus*	√	
	Knightia excelsa		
	Metrosideros fulgens		
	Metrosideros robusta	√	√
	Myoporum laetum		
	Pseudopanax arboreus		
	Weinmannia racemosa		
January 1994	*Elaeocarpus dentatus*		
	Melicitus ramiflorus	√	√
	Metrosideros excelsa		√
	Metrosideros fulgens		
	Metrosideros robusta	√	
	Myoporum laetum	√	
	Vitex lucens		
	Weinmannia racemosa		
February 1994	*Melicitus ramiflorus*		
	Metrosideros fulgens	√	
	Pseudopanax crassifolius		
	Vitex lucens		
March 1994	*Metrosideros fulgens*		
	Vitex lucens		
April 1994	*Dysoxilum spectabile*	√	√
	Metrosideros fulgens		
	Vitex lucens		
May 1994	*Dysoxilum spectabile*	√	√
	Metrosideros fulgens		
	Vitex lucens		
June 1994	*Dysoxilum spectabile*	No data	
	Fuchsia excorticata		
	Geniostoma rupestre		
	Metrosideros fulgens		
	Pseudopanax arboreus		
	Vitex lucens		
July 1994	*Dysoxilum spectabile*	No data	
	Fuchsia excorticata		
	Metrosideros fulgens		
	Pseudopanax arboreus		
	Vitex lucens		

Appendix 2: Flower phenology for 17 plant species selected from hihi preferred nectar sources on Kapiti Island - 1992-1994.

Flowered later in 1993-94 than in 1992-93

```
Myoporum laetum               A M J J A S O N D J F M
1992-93                                   --------
1993-94                                     ------
1994
Pittosporum crassifolium      A M J J A S O N D J F M
1992-93                               ------
1993-94                                 ---
1994
Pittosporum eugenioides       A M J J A S O N D J F M
1992                                    ------
1993                                      -----
1994
Pittosporum tenuifolium       A M J J A S O N D J F M
1992                                  ------
1993                                    ----
1994
Pseudopanax arboreus          A M J J A S O N D J F M
1992                            -----------
1993                              --------------
1994                              ----
Pseudopanax crassifolius      A M J J A S O N D J F M
1992                          -------------
1993                                     --
1994
Weinmannia racemosa           A M J J A S O N D J F M
1992-93                             ------------------
1993-94                                 ---------
1994
```

Flowered earlier in 1993-94 than in 1992-93

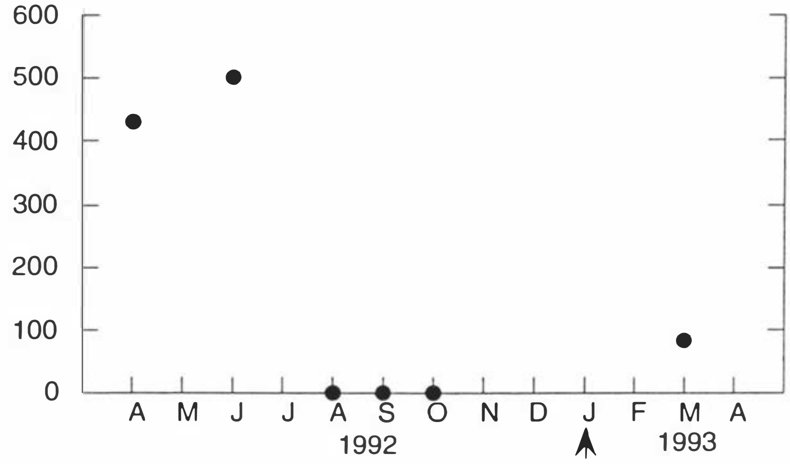
```
Geniostoma rupestre           A M J J A S O N D J F M
1992-93                               --------
1993-94                           ------------
1994                                --
Melicitus ramiflorus          A M J J A S O N D J F M
1992-93                       ------        ------  --
1993-94                                     --  ---
1994
```

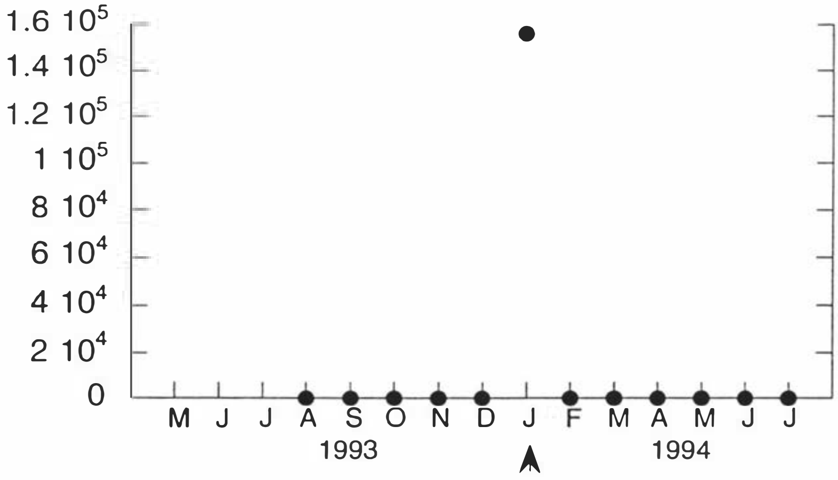
Flowered at the same time in 1993-94 and in 1992-93

```
Dysoxylum spectabile          A M J J A S O N D J F M
1992-93                       ------
1993-94                       ------
1994                          ------
Elaeocarpus dentatus          A M J J A S O N D J F M
1992-93                                     ----
1993-94                                     ------
1994
Fuchsia excorticata           A M J J A S O N D J F M
1992-93                           ----------
1993-94                           ----------
1994                              ----
Knightia excelsa              A M J J A S O N D J F M
1992-93                                     ----
1993-94                                     ----
1994
Metrosideros excelsa          A M J J A S O N D J F M
1992-93                                         ----
1993-94                                   -     --
1994
Metrosideros robusta          A M J J A S O N D J F M
1992-93                                     ------
1993-94                                     ------
1994
Metrosideros fulgens          A M J J A S O N D J F M
1992-93                       -----     ---         -
1993-94                       ----  ----      -------
1994                          --------
Vitex lucens                  A M J J A S O N D J F M
1992-93                         ----  --------   ----
1993-94                         -----------       -----
1994                          --------
```

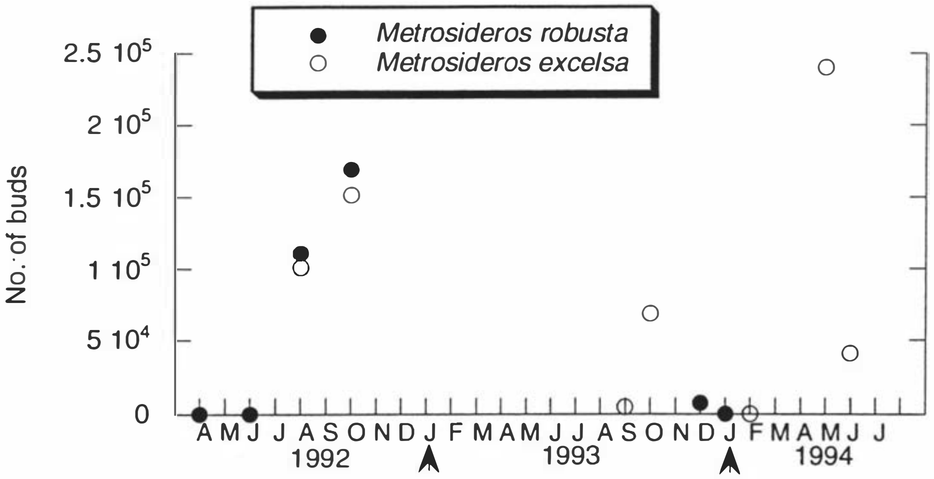
Appendix 3. Number of fruits and flowers for a selection of forest plants on Kapiti Island, 1992-1994.

M. ramiflorus flowers twice yearly with about a month separation between the flowering episodes. Notice the difference in scale between 1992, 1993, and 1994.

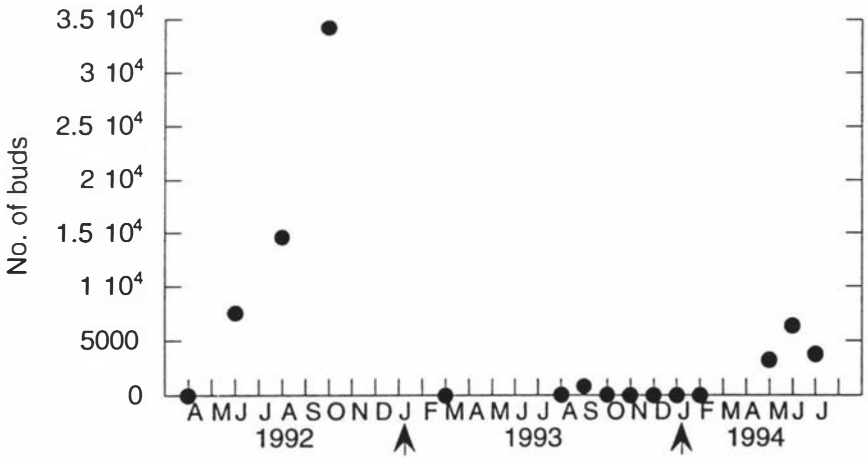




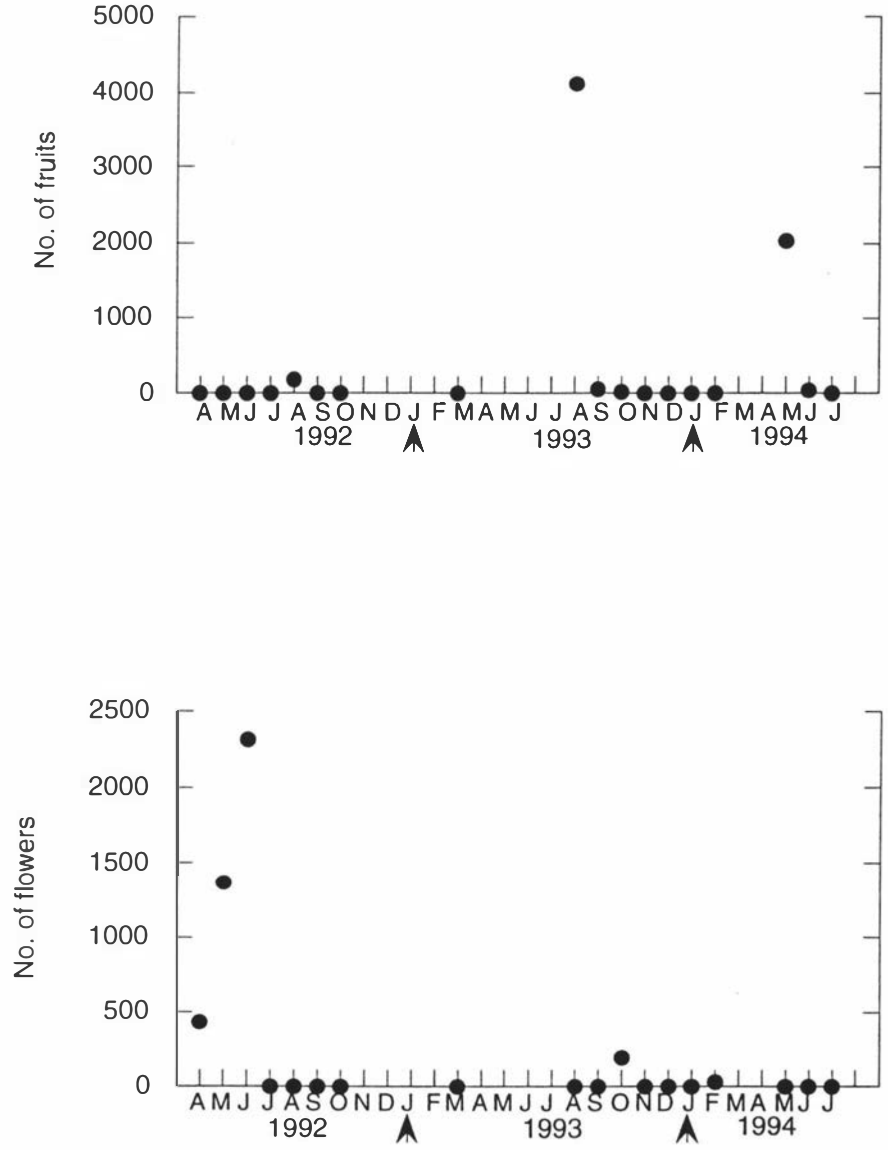
Number of buds (as a representation of flower numbers) for *Metrosideros robusta* and *M. excelsa.*



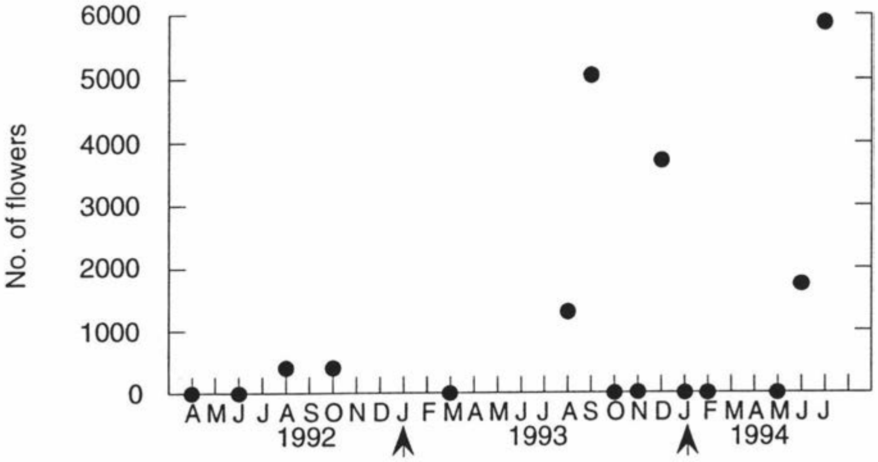
Number of buds produced by *Knightia excelsa*

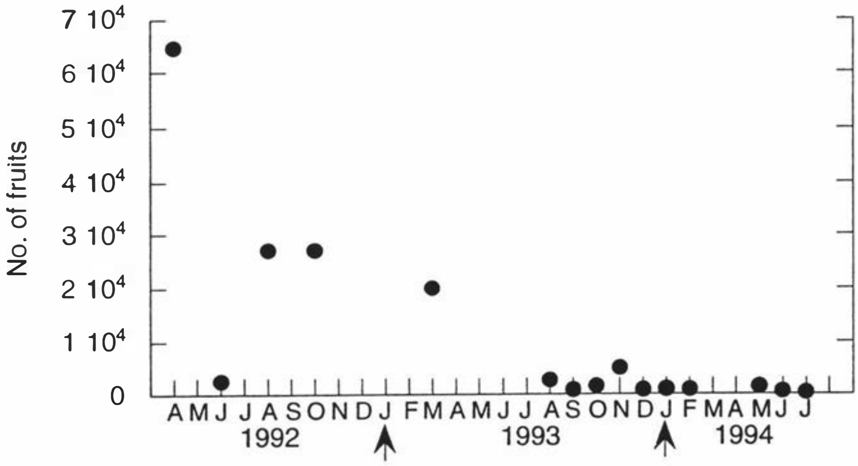


Number of fruits and flowers produced by *Pseudopanax crassifolius*

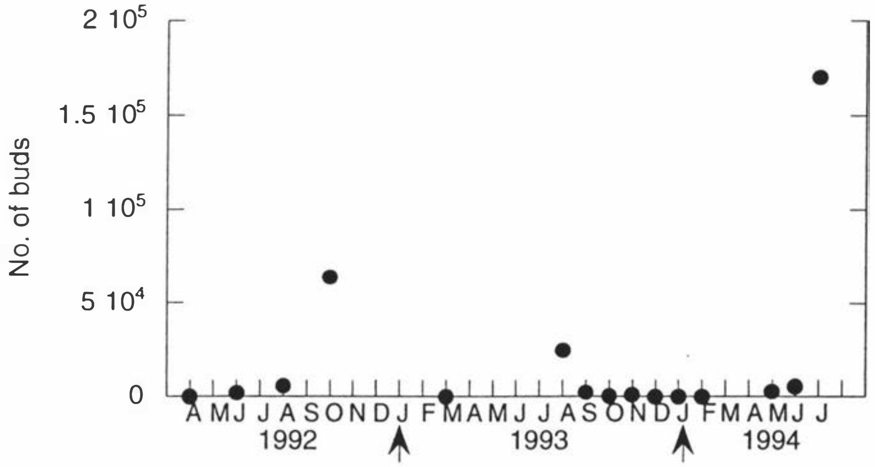


Number of flowers and fruits produced by *Pseudopanax arboreus*

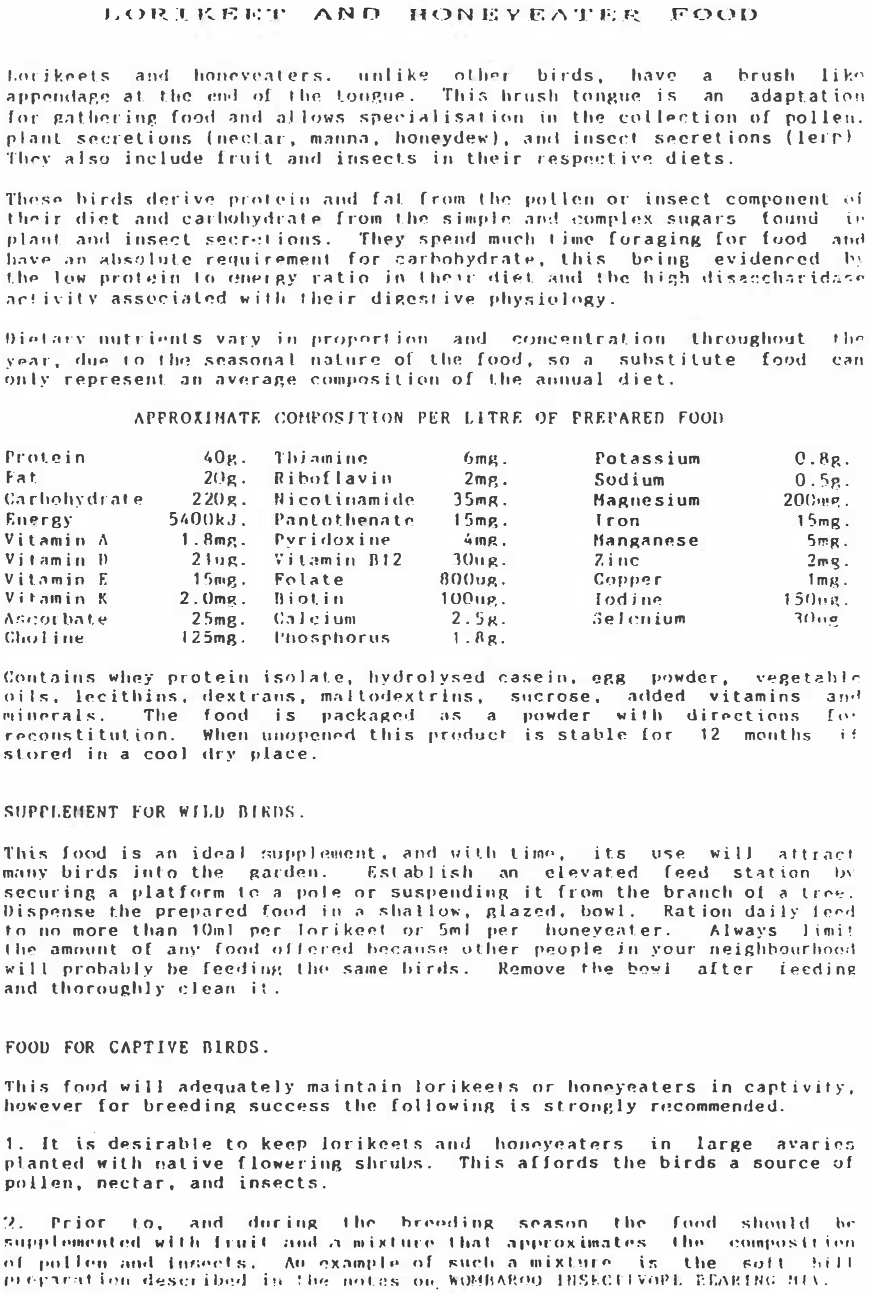




Comparison between 1992-93 and 1993-94 in the number of *Elaeocarpus dentatus* buds.



Appendix 4: Information about Womberoo® nectar mix.



LORIKEET AND HONEYEATER FOOD

Lorikeets and honeyeaters, unlike other birds, have a brush like appendage at the end of the tongue. This brush tongue is an adaptation for gathering food and allows specialisation in the collection of pollen, plant secretions (nectar, manna, honeydew), and insect secretions (lerp) They also include fruit and insects in their respective diets.

These birds derive protein and fat from the pollen or insect component of their diet and carbohydrate from the simple and complex sugars found in plant and insect secretions. They spend much time foraging for food and have an absolute requirement for carbohydrate, this being evidenced by the low protein to energy ratio in their diet and the high disaccharidase activity associated with their digestive physiology.

Dietary nutrients vary in proportion and concentration throughout the year, due to the seasonal nature of the food, so a substitute food can only represent an average composition of the annual diet.

APPROXIMATE COMPOSITION PER LITRE OF PREPARED FOOD

Protein	40g.	Thiamine	6mg.	Potassium	0.8g.
Fat	20g.	Riboflavin	2mg.	Sodium	0.5g.
Carbohydrate	220g.	Nicotinamide	35mg.	Magnesium	200mg.
Energy	5400kJ.	Pantothenate	15mg.	Iron	15mg.
Vitamin A	1.8mg.	Pyridoxine	4mg.	Manganese	5mg.
Vitamin D	21ug.	Vitamin B12	30ug.	Zinc	2mg.
Vitamin E	15mg.	Folate	800ug.	Copper	1mg.
Vitamin K	2.0mg.	Biotin	100ug.	Iodine	150ug.
Ascorbate	25mg.	Calcium	2.5g.	Selenium	30ug
Choline	125mg.	Phosphorus	1.8g.		

Contains whey protein isolate, hydrolysed casein, egg powder, vegetable oils, lecithins, dextrans, maltodextrins, sucrose, added vitamins and minerals. The food is packaged as a powder with directions for reconstitution. When unopened this product is stable for 12 months if stored in a cool dry place.

SUPPLEMENT FOR WILD BIRDS.

This food is an ideal supplement, and with time, its use will attract many birds into the garden. Establish an elevated feed station by securing a platform to a pole or suspending it from the branch of a tree. Dispense the prepared food in a shallow, glazed, bowl. Ration daily feed to no more than 10ml per lorikeet or 5ml per honeyeater. Always limit the amount of any food offered because other people in your neighbourhood will probably be feeding the same birds. Remove the bowl after feeding and thoroughly clean it.

FOOD FOR CAPTIVE BIRDS.

This food will adequately maintain lorikeets or honeyeaters in captivity, however for breeding success the following is strongly recommended.

1. It is desirable to keep lorikeets and honeyeaters in large avaries planted with native flowering shrubs. This affords the birds a source of pollen, nectar, and insects.

2. Prior to, and during the breeding season the food should be supplemented with fruit and a mixture that approximates the composition of pollen and insects. An example of such a mixture is the soft bill preparation described in the notes on WOMBAROO INSECTIVORE REARING MIX.

Appendix 5: Work sheets used in the Monitoring of hihi

Data Sheet 1

Name of Observer:

Date	Place	Bird	Activity	Comments

Data Sheet 2

Name of Observer:

Nest Site	Date	Male(s)	Female(s)	Activity*	Nest Box	Comments

---

* Ex. mating, chasing, calling, incubating (female enters nest for 20 + minutes and is out for 5 min), brooding (male and female enter nest for 1 to 10 minutes and stay out for 15 to 30), feeding fledglings, etc.

Data Sheet 3

Name of Observer:

Feeder:　　　　　　　　　　　　Date:

Bird bands	Comments