Vegetation composition and phenology of Mokoia Island, and implications for the reintroduced hihi population

John K. Perrott and Doug P. Armstrong
Institute of Natural Resources, Ecology Group, Massey University, Private Bag 11222, Palmerston North, New Zealand (E-mail: jkperrott@xtra.co.nz)

Abstract: Hihi (or stitchbird, *Notiomystis cincta*) is a rare honeyeater endemic to the North Island of New Zealand. Hihi were translocated from Little Barrier Island to Mokoia Island, Lake Rotorua, in 1994. Mokoia is a small (135 ha) island with secondary vegetation, so there was some doubt as to whether the island had sufficient diversity of fruit and nectar sources to support a hihi population. This paper reports data collected in the year after the translocation on the density, distribution and phenology of plants likely to be used by hihi. We address the following questions. (1) How many hihi food plant species are on Mokoia? (2) How are the food plant species distributed over the island? (3) Are there periods when flower and fruit sources are scarce and/or spatially confined? (4) How might the availability of fruit and nectar change with succession or additional planting?
There was always a minimum of 2-3 species providing nectar or fruit used by hihi. Most (16/21) of the species providing nectar flowered during the hihi breeding period, from October-February, and most (9/16) of these were canopy tree species. The greatest diversity of fruit sources was from March-May. August-September stood out as the period with the lowest diversity of fruit and flower sources, followed by June-July. While there was no time of year when hihi clearly suffered from shortage of fruit and nectar, we suggest that they may be susceptible to shortages in future years at times when diversity of food sources is low. We recommend further planting that could make the island more suitable for hihi in the long term.

Keywords: Food availability; hihi; Mokoia Island; New Zealand; *Notiomystis cincta*; phenology; vegetation.

Introduction

Hihi (*Notiomystis cincta*[1]) were originally found throughout the North Island of New Zealand, and on at least the larger offshore islands. However, hihi vanished from the North Island following European colonisation, and survived only on Little Barrier Island (Oliver, 1955). There were several translocations of hihi to Hen, Cuvier, and Kapiti islands from 1980-92, but these failed to establish self-sustaining populations (Rasch et al., 1996). The main hypothesis for these failures was insufficient year round supply of nectar and fruit, in conjunction with competition from other more dominant honeyeaters, bellbirds (*Anthornis melanura*) and tui (*Prosthemadera novaeseelandiae*).

Mokoia is in Lake Rotorua in the North Island (38°06'S, 174°55'E). With an area of 135 ha, it is the largest island in a lake in New Zealand. However, it is the smallest island where hihi have been released. It has secondary forest, which has been regenerating for about 50 years. Given the small size of the island, and the youth of the vegetation, there was particular concern about whether Mokoia had a sufficient diversity of fruit and nectar sources to support a hihi population. Mokoia has a long history of Maori occupation. Maori grew crops in the fertile soil for hundreds of years, and most of the island was fired, cleared and terraced (Andrews, 1992). Cultivation had stopped on Mokoia by about 1950, and the island was made a Wildlife Refuge under the Wildlife Act (1953).

Maori also modified Mokoia by deliberate introduction of many native trees such as karaka (*Cordynocarpus laevigatus*[2]), whau (*Entelea arborescens*), totara (*Podocarpus totara*), puriri (*Vitex lucens*), kowhai (*Sophora* spp.) and southern beech (*Nothofagus* spp.).

[1]Nomenclature of birds follows Turbott (1990).
[2]Nomenclature of plants follows Allan (1961), Moore and Edgar (1970), Connor and Edgar (1987), and Webb, Sykes and Garnock-Jones (1988).

Europeans arrived on Mokoia not long after 1830 (Andrews, 1992). European missionaries planted exotic tree species like pine (*Pinus radiata*), poplar (*Populus* spp.) and a variety of fruit trees. Europeans also introduced cattle (*Bos taurus*[3]), goats (*Capra hircus*), sheep (*Ovis aries*), horses (*Equus calballus*), pigs (*Sus scrofa*), and cats (*Felis catus*). Norway rats (*Rattus norvegicus*) and mice (*Mus musculus*) were introduced accidentally, and were abundant on Mokoia by 1840 (King, 1984). There are no reports of possums (*Trichosurus vulpecula*) or mustelids ever being present on Mokoia. Pheasants (*Phusianus colchicus*) were farmed as a commercial venture from 1952-56, and grain fed to pheasants probably encouraged irruptions of the rat and mouse populations (Beveridge and Daniel, 1965). Weka (*Gallirallus australis*) were translocated to Mokoia sometime in the 1950s, and are still there. It is not clear when the Australian crested wattle trees (*Albizia lophantha*) were planted. These are not abundant, but provide an important nectar source for hihi in winter.

Goats were introduced in 1985 to control blackberry (*Rubus fruticosus*) on the eastern flat, which was fenced off. However, the goats escaped into the bush and began browsing the regenerating forest. By 1989 the understory was open with no further regeneration of canopy species taking place. During 1989-90 the Department of Conservation successfully eradicated rats and goats from Mokoia. An attempt to eradicate mice in September 1996 was unsuccessful.

Since the rats and goats were eradicated, toutouwai or North Island robin, (*Petroica australis*), and tieke or saddleback, (*Philesturnus carunculatus*), and hihi have all been introduced to Mokoia. Nine other native bird species are present, having either survived human occupation or naturally re-colonised the island. Lizards were thought to be absent, but speckled skinks (*Oligosoma infrapunctatum*[4]) were discovered on the island in 1993.

The first restoration attempts, in the mid 1960s, involved planting thousands of native tree saplings and ferns. Most of these were probably eaten by rats, and the planting had negligible effect on the present vegetation (Wallace, 1993). The island's vegetation is now composed largely of understory species such as five-finger (*Pseudopanax arboreus*), kawakawa (*Macropiper excelsum*), mahoe (*Melicytus ramiflorus*) and rangiora (*Brachyglottis repanda*). The vegetation is low and scrubby on the ridges, particularly near the summit, but there is a closed canopy with an open forest floor in gullies and near the lake shore. The canopy species are largest in gullies and bush edges, where mahoe, kohuhu (*Pittosporum tenuifolium*) and treefern (*Cyathea* spp.) dominate. On the south-facing slopes mamaku (*Cyathea medullaris*) is the dominant canopy species. Amongst the patches of bracken (*Pteridium aquilinum*) and blackberry on the north-facing slopes the dominant species are cabbage tree (*Cordyline australis*) and five-finger.

When hihi were translocated to Mokoia Island in 1994 (Armstrong *et al.,* 1999), we developed a programme to directly test whether this new population was limited by nectar and fruit availability, and if so, whether this was due to competition from tui (there are no bellbirds on Mokoia). We collected data in three categories during each of the first 14 months after hihi were released. (1) We did supplementation experiments to determine what times of year, if any, that condition, survival or reproduction of hihi was limited by carbohydrate availability (Perrott 1997; Armstrong *et al.*, 1997). (2) We collected data on vegetation composition, fruiting phenology and flowering phenology to determine if times of food limitation were correlated with abundance or diversity of fruits and flowers (reported in this paper). (3) We collected data on energetic quality of fruits and flowers, foraging by hihi, and interactions with tui, to determine if the energy intake rates achieved by hihi closely matched seasonal changes in abundance and diversity of flowers and fruits.

As well as addressing the question of food shortage in the year after release, the data in this paper also allow us to predict how seasonal patterns of nectar and fruit availability may change with succession. These data provide a detailed case study of the vegetation composition and phenology of an island undergoing natural revegetation, and provide a comparison for future vegetation studies on Mokoia.

Methods

Vegetation Surveys

We surveyed the distribution and density of all plant species likely to be used by hihi. Initially we surveyed 24 target species by noting all species hihi had been seen using on Little Barrier and Kapiti Islands (Godley, 1979; Angehr, 1984; Castro 1995), and comparing this to the list of plant species recorded on Mokoia (Beadle and Ecroyd, 1990). We recorded the phenology of these 24 species throughout the study. During the project we also saw hihi feeding on kawakawa fruits, deadly knightshade (*Solanum nigrum*) fruits, and akeake (*Dodonaea viscosa*) flowers. We added these to our target species, making 27 in total.

The island was divided into 28 grid squares (200 m x 200 m each). Grid points were determined with a

[3]Nomenclature of mammals follows King (1990)
[4]Nomenclature of lizards follows Gill and Whitaker (1996)

Table 1. Plant species known or likely to be used by hihi (from Godley, 1979; Angehr, 1984; Castro, 1995, and observations during this study). Species found on Mokoia and species included in the vegetation survey are indicated. The species not included in surveys were either discovered to be used by hihi late in the project, or or are so rare that flowering and/or fruiting individuals were not found.

(a) Nectar taken	Found	Surveyed
Albizia lophantha	X	X
Alectryon excelsus		
Alseuosmia macrophylla		
Aristotelia serrata	X	X
Astelia spp.	X	X
Beilschmiedia tawa		
Carpodetus serratus		
Chamaecytisus palmensis		
Clematis vitalba	X	
Clianthus spp.		
Cordyline australis	X	X
Coriaria arborea	X	X
Corynocarpus laevigatus	X	X
Cyathodes spp.		
Dodonaea vicosa	X	X
Dracophyllum spp.		
Dysoxylum spectabile	*X*	*X*
Earina autumnalis	*X*	*X*
Elaeocarpus dentatus		
Entelea arborescens	*X*	
Fuchsia excorticata	X	X
Geniostoma rupestre	X	X
Griselinea littoralis		
Hebe spp.	X	
Hedycarya arborea		
Hoheria populnea		
Knightia excelsa	X	X
Laurelia novaezelandiae		
Melicytus ramiflorus	X	X
Metrosideros excelsa	X	X
Metrosideros fulgens		
Metrosideros perforata		
Metrosideros robusta	X	X
Metrosideros white flower	X	X
Metrosideros umbellata		
Mida salicifolia		
Myoporum laetum		
Myrsine australis	X	X
Myrsine salicina		
Nestegis lanceolata		
Pseudopanax arboreus	X	X
Passiflora tetrandra		
Peraxilia spp.		
Toronis toru		
Phormium tenax	*X*	*X*
Pittosporum crassifolium		
Pittosporum eugenioides		
Pittosporum tenuifolium	*X*	*X*
Pittosporum umbellatum		
Prumnopitys ferruginea		
Pseudopanax crassifolius		
Rhabdothamhus solandri		
Rhopalostylis sapida		
Ripogonum scandens	X	
Rubus cissoides	X	X
Schefflera digitata	X	X
Sophora spp.		
Syzgium maire		
Vitex lucens		
Weinmannia racemosa	X	X
Lupinus luteus	X	

(b) Fruits taken	Found	Surveyed
Alseuosmia macrophylla		
Aristotelia serrata	X	X
Ascarina lucida		
Astelia spp.	X	X
Coprosma dodonaeifolia		
Coprosma grandifolia	X	X
Coprosma lucida.		
Coprosma macrocarpa		
Coprosma repens		
Coprosma rhamnoides		
Coprosma robusta	X	X
Coriaria arborea	X	X
Cyathodes fasciculata		
Cyathodes juniperina		
Freycinetia baueriana		
Fuchsia excoticata	X	X
Gahnia setifolia		
Geniostoma rupestre	X	X
Griselineia littoralis	X	
Ixerba brexioides		
Macropiper excelsum	X	
Melicytus ramiflorus	X	X
Muehlenbeckia australis	X	X
Myoporum laetum		
Myrsine australis	X	X
Myrsine salicina		
Nestegis lanceolata		
Passiflora tetrandra		
Pennantia corymbosa		
Phytolacca octandra		
Pseudopanax arboreus	X	X
Pseudopanax crassifolius		
Pseudopanax discolor		
Pseudopanax edgerleyi		
Pseudopanax lessonii		
Pseudowintera axillaris		
Ripogonum scandens		
Rubus cissoides	X	X
Schefflera digitata	X	X
Solanum nigrum	X	X

compass and measuring tape, and the centre of each grid marked with flagging tape. Some grids were partially in the lake. If the central point was in the lake the flagging tape was placed on the nearest point on the shoreline. Each month, from September 1994 (when hihi were released) until November 1995, we selected a random sample point within each grid. The sample point in each grid was determined by measuring a specific distance from the central grid point at a specific compass bearing. If the random point was in the lake, we disregarded that sample. Therefore, there was no bias for or against lake-edge habitat.

Once the sample point was established, a sample area of 3 m radius was measured out using measuring tape and a telescopic pointer. During this study 157 points were sampled, each 28.3 m^2, giving a total sampled area of 4443 m^2. In each sample area we counted the number of individuals of each plant species on the target list. A ramet was considered to define an individual plant, i.e., we counted the number of trunks not joined above the ground. Plants were counted only if the trunk was within the sample area at ground level. Plants too small to be flowering were not counted (below about 2 m height for most species).

Sample areas were classified into one of five habitat types based on topography: (1) gully, (2) slope, (3) ridge top, (4) within 5 m of track, and (5) within 12 m of the shore. This allowed us to compare species composition and densities among these habitat types.

Measuring fruiting and flowering phenologies

The number of fruits or flowers was estimated for each target plant in the sample area every two weeks, and data was pooled on a monthly basis. Different estimation methods were used, depending on the species and situation:

If the plant had less than about 300 flowers or fruits, then all were counted. If the plant had abundant flowers and/or fruits distributed around the periphery of the plant, a 16 cm x 16 cm sampling quadrat was used. All fruits or flowers were counted in one quadrat, and the surface area of the plant estimated from its height and width. To estimate the total number of fruits and/or flowers, we multiplied the count by the plant's total surface area divided by the surface area of the quadrats sampled. Species in this category included *Muehlenbeckia australis* and white rata (*Metrosideros* white flower spp.).

If fruits and flowers were not confined to the periphery, the plant was divided into branches of equivalent area, and five branches selected at random. The fruits or flowers were counted for each selected branch unit or estimated with the quadrat. The average per branch was calculated, and multiplied by the total number of branches. Species in this category included mahoe, *Coprosma* spp., and wineberry (*Aristotelia serrata*).

If the species had fruits or flowers in inflorescences, we counted the number of inflorescences per tree. Individual flowers or fruits were counted on five randomly chosen inflorescences. The mean number of flowers or fruits per inflorescence was then multiplied by the total inflorescence count to estimate the number of flowers or fruits on the tree. Species in this category included pohutukawa (*Metrosideros excelsa*), five-finger and, pate (*Schefflera digitata*).

Only open flowers were counted, and not buds. Old flowers not producing nectar were not counted, and were removed by shaking the branch. All fruits were recorded, ripe fruit being given as a proportion of the total count. For dioecious species such as mahoe and five-finger, we recorded genders of all individuals whenever possible. Sexing was not possible for plants without flowers or fruits.

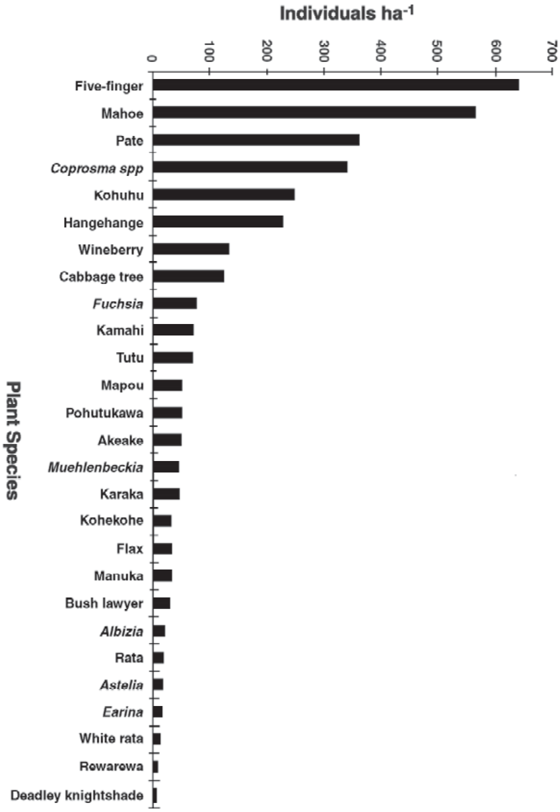

Figure 1. Number of individuals per hectare for plant species producing fruit or nectar likely to be used by hihi on Mokoia. Calculations are from 157 random sample areas of 28.3 m^2.

Table 2. Plant species used by hihi on Mokoia, divided into successional and size categories. The percentages show the overall relative abundances of each species in terms of individuals per hectare (see Figure 1). The totals give the combined percent abundance for all species in each category.

Category	Species	%	Part used
Canopy trees	*Melicytus ramiflorus*	13.0	Fruit
	Pittosporum tenuifolium	5.8	Flowers
	Cordyline australis	3.6	Flowers
	Weinmannia racemosa	1.3	Flowers
	Meterosideros excelsa	1.1	Flowers
	Corynocarpus laevigatus	1.0	Flowers
	Dysoxylum spectabile	0.5	Flowers
	Meterosideros robusta	0.2	Flowers
	Knightia excelsa	0.1	Flowers
	Total	26.6	
Sub-canopy hardwood trees/shrubs	*Aristotelia serrata*	3.0	Flowers, Fruit
	Fuchsia excorticata	1.8	Flowers
	Myrsine australis	0.9	Flowers, Fruit
	Albizia lophantha	0.4	Flowers
	Leptospermum ericoides	0.1	Flowers
	Total	6.2	
Sub-canopy softwood trees/shrubs	*Macropiper excelsum*	27.4	Fruit
	Pseudopanax arboreus	15.0	Flowers, Fruit
	Schefflera digitata	8.1	Fruit
	Coprosma spp.	8.0	Fruit
	Geniostoma rupestre	5.0	Flowers, Fruit
	Dodonaea viscosa	1.0	Flowers
	Coriaria arborea	0.9	Fruit
	Total	65.4	
Monocots and epiphytes	*Muehlenbeckia australis*	1.0	Fruit
	Phormium tenax	0.4	Flowers
	Rubus cissoides	0.2	Flowers, Fruit
	Astelia spp.	0.2	Flowers, Fruit
	Earina autumnalis	0.1	Flowers
	Meterosideros white flower	0.1	Flowers
	Total	1.8	

Results

Vegetation density, distribution and successional effects

Most species used by hihi are trees or shrubs, which can be divided into three successional categories: canopy trees, sub-canopy hardwood trees/shrubs, and sub-canopy softwood trees/shrubs (Tables 1, 2). Hihi also used some epiphytes, which occur only under closed canopy, and flax, which only occurs in open areas in a few patches on Mokoia. However, almost all hihi foraging observed on Mokoia was on the trees and shrubs (Perrott, 1997). Of the 27 species surveyed, sub-canopy species such as mahoe, kawakawa, five finger, pate, and *Coprosma* spp. are clearly the most abundant species (Fig. 1). The distributions and relative proportions of plant species in the three successional categories are described below.

Canopy trees

Canopy trees are larger than sub-canopy trees/shrubs, and this partially accounts for their lower abundance (Table 2, Fig. 2). Most of the fruiting and flowering individuals of these species were quite large. There are also abundant seedlings and saplings of most of these species, but few of intermediate size, i.e., 2-3 m tall. Most provide nectar used by hihi.

Mahoe is not normally thought of as a canopy species. However, it is a common canopy species on all parts of Mokoia and is therefore considered a canopy species here. Mahoe makes up 49% of all canopy trees counted. Without mahoe in this category, the canopy species make up only 13.6 % of all plants counted during this study. The large mahoe trees are found in gullies, track areas and near the shoreline, and produce relatively few flowers and fruits (Fig. 2).

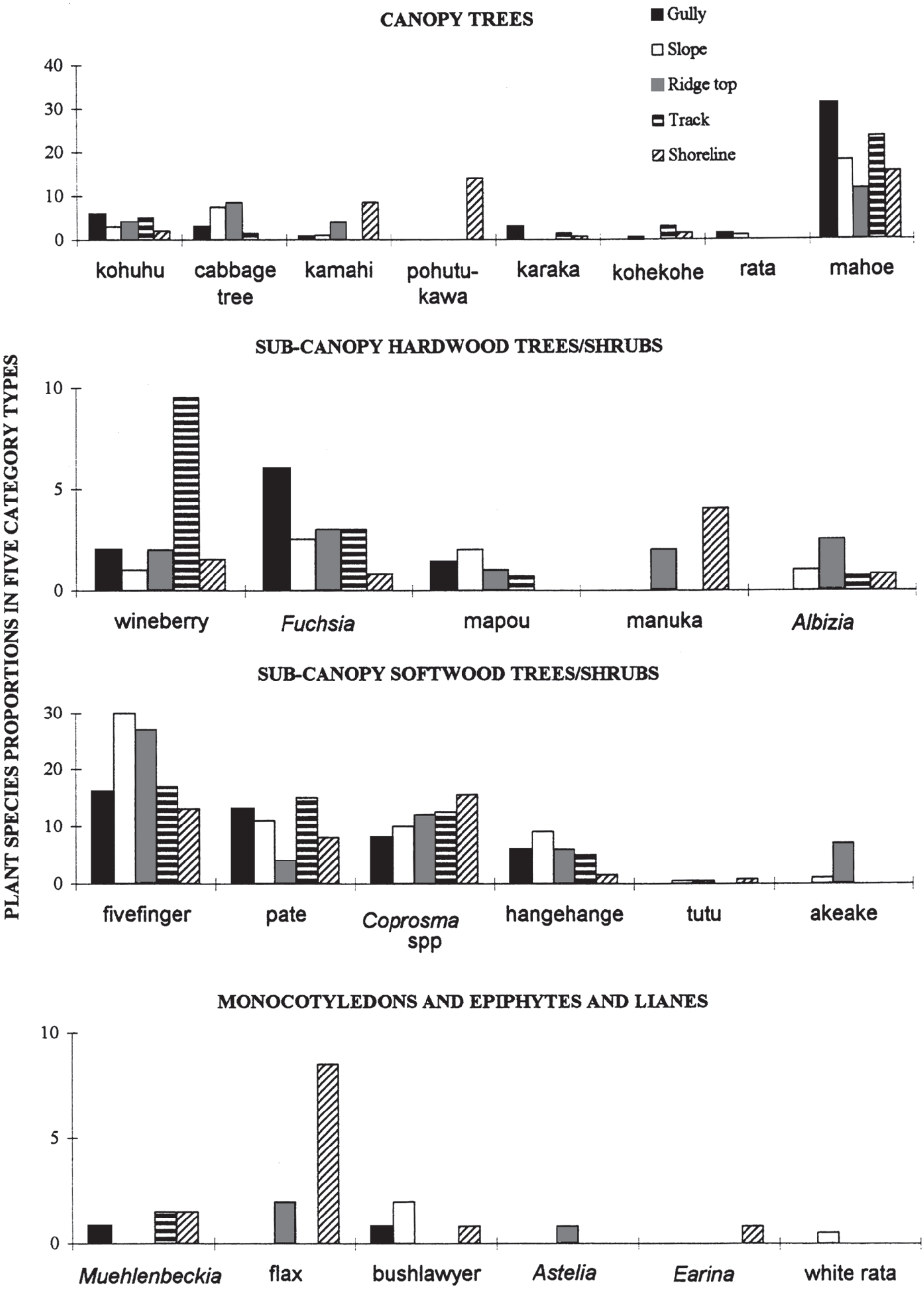

Figure 2. Distribution and the proportional abundance of 25 plant species shown in Table 2. Kawakawa and rewarewa are excluded to make the graphs easier to read. Kawakawa is a superabundant species found in all localities, while rewarewa is rare with only two individuals recorded. Plant species have been grouped into five successional categories, canopy trees, sub-canopy hardwood tree/shrubs, sub-canopy softwood tree/shrubs, and monocotyledons, epiphytes and lianes. Plant species proportions within these categories are compared among five habitat types. Cabbage tree and mahoe are placed in the canopy tree category because these are major emergent tree species on Mokoia.

Table 3. Comparison of the number of recorded hihi food plant species in flower and fruit each month on Kapiti Island (Castro, 1995) and Mokoia Island (this study).

	Kapiti Island			Mokoia Island		
Month	Flowers	Fruits	Total	Flowers	Fruits	Total
January	5	15	20	15	9	24
February	5	12	17	12	11	23
March	3	6	9	6	12	18
April	2	6	8	6	13	19
May	3	2	5	2	10	12
June	4	3	7	3	8	11
July	6	3	9	3	6	9
August	6	2	8	2	5	7
September	6	6	12	6	4	10
October	7	11	18	12	1	12
November	9	13	22	13	3	16
December	10	16	26	16	5	21
Total	33	17	50	21	13	34

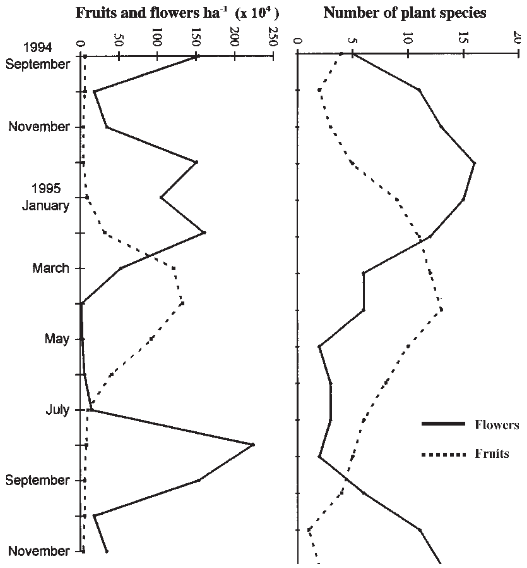

Figure 3. Number of hihi food plant species in fruit and flower each month on okoia (top), and total number of flowers and fruits per hectare for those species (bottom).

Kohuhu is the second most abundant canopy tree species on Mokoia, and is an important nectar source in spring. Kohuhu is found all over Mokoia, but especially in gullies, particularly in the west and northwest portions of the island. However, many large kohuhu have died and fallen over.

Pohutukawa is a key nectar source in summer. It is confined to a narrow strip around the shore, particularly in the northwest, west and southwest where the shore is rocky and steep. Most trees are 10-12 m and have over 100,000 flowers at their peak. However, because pohutukawa are few and far between, the total flower counts for December and January are lower than February (Figs. 1, 3).

Kohekohe is confined to an area of about 5 ha at the south of the island, and may be a key nectar source in winter. The 'kohekohe-karaka forest' in this area is probably the most mature vegetation type on the island (Wallace, 1993). There are many seedlings and saplings, but most of the flowering kohekohe are 8-10 m tall. Cabbage trees are found mainly on the north-facing slopes. However, the larger trees are found away from the north-facing slopes, around the lower gully areas. There are many dead trees, but recruitment of cabbage tree juveniles appears quite high. Rewarewa are rare, and only one was counted in the vegetation surveys. There are trees on the upper slopes and the south side of the island, and some seedlings and juveniles.

Sub-canopy hardwood trees/shrubs

This category contains the lowest number of species, but has species that may be important for both nectar and fruit. Wineberry is the most abundant, and its fruits provide the richest packets of energy on Mokoia (Perrott, 1997). However, the fruits are not abundant because most trees produce few fruits. Most are spindly juveniles, and these are found all over much of the island. There are a few very large trees, some of which had thousands of fruit.

Fuchsia is a widespread species on Mokoia, and is an important nectar source in spring. Most are small trees or shrubs. There are mature trees exceeding 12 m in some gullies, but these large trees tend to have few branches and produce few flowers. *Fuchsia* is found in all five habitat types, but are most common in gullies and least common on the shoreline. *Fuchsia* is possibly dying off in some locations along with kohuhu. *Albizia* is not abundant, but is a key nectar source in winter. *Albizia* trees are scattered in small patches around the island from shore to ridge top. The largest trees (6-9 m) are found along the west side and in the south-eastern portion.

Sub-canopy softwood trees/shrubs

These are early successional species, and are clearly the most widespread and abundant hihi food plants. These are important fruit species, and all except akeake provide fruit that hihi eat. Five finger and pate also provide flowers. Five-finger is the most widespread and abundant species, and is a key source of both flowers and fruit. It is particularly dense around the midline, especially on northern slopes and ridge areas. Five-finger flowers have little nectar per flower, but

Table 4. Plant species that could be planted on Mokoia to increase the diversity of nectar and fruit sources.

Species providing nectar in spring and summer	Species providing nectar in autumn and winter	Species providing fruit in spring and summer
Knightia excelsa[1]	*Vitex lucens*	*Myrsine salicina*
Pennantia corymbosa	*Syzygium maire*	*Passiflora tetrandra*
Elaeocarpus dentatus	*Dysoxylum spectabile* [1]	*Hedycarya arborea*
Sophora microphylla	*Metrosideros spp.* [1]	*Pseudopanax edgerleyi*
Pittosporum crassifolium		*Coprosma lucida*
Dodonaea viscosa [1]		
Mida salicifolia		
Toronia toru		
Alectryon excelsus [2]		
Alseuosmia macrophylla [3]		
Pittosporum umbellatum		

[1]Found on Mokoia, but neither common nor widespread
[2]Currently one tree near the hotpool
[3]A small number were planted in one part of Mokoia in 1994

compensate through abundance and high flower densities (Castro and Robertson, 1997).

Pate is abundant, and an important fruit source. It is most commonly found as an understory plant in gullies and southern slopes dominated by mamaku, and is least abundant in open areas like ridge tops (Fig. 2). Some large individuals (6-7 m) are found in the lower regions of the island where the canopy is highest. *Coprosma* spp. are also abundant, and are an important fruit source. *Coprosm*a are evenly distributed throughout all habitat types, but are most abundant away from gullies. Like wineberry, most *Coprosma* plants sampled were young individuals (under 1.5 m) that have probably grown since the goats were eradicated in 1989-90.

Other species

There are several epiphytes and lianes on Mokoia that are sometimes used by hihi (Table 1), but the only one likely to be important to hihi is *Muehlenbeckia australis*. *M. australis* is always an edge species, but is common in several parts of Mokoia. Flax (*Phormium tenax*) is scattered over a few locations, mostly on ridge tops and along the shoreline (Fig. 2).

Fruiting and flowering phenology

The number of species in flower was highest between October and the end of February (Fig. 3), which coincided with the hihi breeding season. All but one of the 21 nectar-providing species surveyed flowered during this period (Fig. 4). The number of species in fruit was highest from March-May. Wineberry, pate, kawakawa, five-finger, cabbage tree, hangehange (*Geniostoma rupestre*), *Muehlenbeckia*, tutu (*Coriaria arborea*), and most *Coprosma* had fruit during this period. August and September were the months with the fewest species in fruit or flower.

While the number of species flowering peaked in December-January, the total number of flowers did not peak until February. There are two reasons for this. First, during summer most flowering species provide many flowers per tree, but occur in low density and/or are confined to particular habitats such as gullies or the lakeshore (Fig. 1). These species include karaka, pohutukawa, kamahi (*Weinmannia racemosa*) and rewarewa (*Knightia excelsa*). Secondly, widely distributed sub-canopy species such as mahoe and pate reached peak flowering in February.

Flower counts dropped dramatically after summer, and most species stopped flowering in March or April. There were twice as many species providing fruits than flowers in March and April, and five times as many by May. There were more species fruiting than flowering for most of the hihi non-breeding season (March-August). However, fruit and flower counts were both relatively low in June and July (Fig. 3).

In early winter, only kohekohe (*Dysoxylum spectabile*) and *Albizia* were providing useful nectar sources, and neither is abundant on Mokoia. *Fuchsia excorticata* and five-finger start flowering in July, with male five finger starting before female five finger. During July and August birds had few flowers available other than five-finger, *Albizia* and *Fuchsia*. However, total flower counts were high in August due to five finger, which had a high density of flowers all over Mokoia during August-September.

The *Albizia*/five-finger flowering period finished in spring. *Fuchsi*a and kohuhu then provided most of the available nectar, but their flowers were less abundant than five-finger. While the number of species in flower increased in October and November, there was a large drop in the total number of both flowers and fruits (Fig. 3).

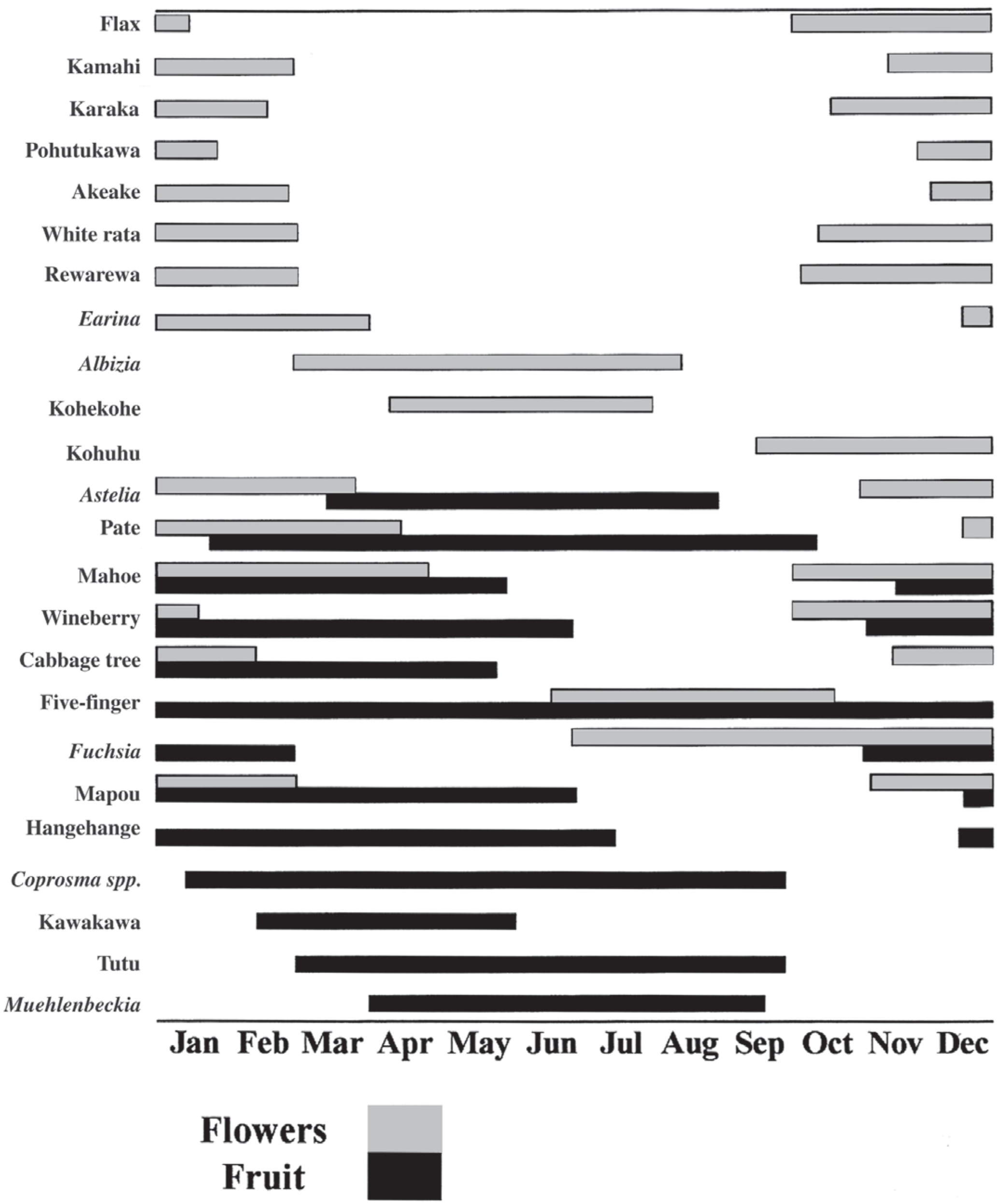

Figure 4. Fruiting and flowering phenologies for most plant species likely to used by hihi on Mokoia. Four plant species in the vegetation survey were excluded from the phenology study: manuka, bushlawyer, rata, and deadly knightshade. These species were either discovered to be used by hihi after the start of the phenology study, or are so rare that flowering and/or fruiting individuals were not found.

In October five finger was the only remaining species in fruit, while there were 11 species flowering. October was a crossover period, when most species either started flowering (e.g., karaka, kohuhu, rewarewa, hangehange *Geniostoma rupestre*) or finished fruiting (e.g., pate, *Coprosma*, tutu, and *Muehlenbeckia*). After October the flower count per hectare increased sharply.

Discussion

Our supplementary food experiment showed that the condition and survival of hihi were not limited by carbohydrate availability from January-October (Armstrong and Perrott, 2000). It is possible that reproduction (from October-February) was limited by carbohydrate availability, but the results are variable and unclear. While there is no clear evidence of carbohydrate shortage in the period studied, there were times when hihi probably relied on one or two plant species. August-September was the period with the lowest diversity of nectar and fruit sources, suggesting that five-finger (which has peak flowering in August-September) is a key species. Kohekohe and *Albizia* were also important nectar sources, being the only two available in early winter. *Fuchsia* may also have been important during October, when most species were just starting to produce flowers. Pate and *Coprosma* spp. provided fruit through winter and early spring, and were key fruit sources.

There can be great variation in phenology from year-to-year (Castro, 1995). The timing of flowering, abundance of flowers, and degree of synchrony among species will be different on Mokoia in subsequent years, and it is likely that there will be some years with "crunch" periods when food is particularly scarce. Such crunches may be relatively rare, but can be key events in the ecology of honeyeater populations (Ford, 1991). By identifying periods when hihi may be dependent on one or a few species, we can predict the periods when crunch periods are most likely to happen.

Crunch periods may be more common and/or pronounced on small islands such as Mokoia. In comparison to Mokoia, Little Barrier Island (3076 ha) has a much wider range of habitats. Due to the higher altitude on Little Barrier, there may also be some seasonal variation between low-altitude and high-altitude habitats that birds can exploit.

Of the 102 plant species used by hihi on Little Barrier, hihi take nectar from 27 species and fruit from 34 species (Angehr, 1984; 1986). Kapiti Island has 75 of these species, with hihi taking nectar from 33 species and fruit from 17 (Castro, 1995). This is more than twice the species available on Mokoia (27), but like Kapiti hihi, Mokoia hihi take nectar from more species (21) than fruit (14) (Perrott, 1997). Castro (1995) noted that preferred fruiting species may be rare or absent on Kapiti, forcing hihi to forage more on invertebrates and low-grade nectar sources. In comparison to Kapiti, Mokoia has about twice the number of fruit sources from March-July, the months when hihi mostly take fruit on Little Barrier (Table 3) (Angehr, 1984; Rasch and Craig, 1988). Kapiti shows a drop in fruiting species during these months, but has more fruit sources available in spring and summer compared to Mokoia.

Castro (1995) noted that 13 flowering species were available on Kapiti during the hihi breeding period, but that most were rare, confined or of low quality, e.g., pohutukawa and *Fuchsia*. On Mokoia there were a total of 16 nectar sources available during this time. While half of these species are rare, eight of them are reasonably abundant including pohutukawa and *Fuchsia*.

The vegetation on Mokoia Island is regenerating, another contrast between it and Little Barrier is that seasonal patterns of fruit and nectar availability will change with succession. At present, most of the nectar sources for hihi are canopy species or hardwood sub-canopy species. In contrast, most of the fruit sources are softwood subcanopy species which are the earliest successional species. A shift toward later successional stages may decrease fruit availability. However, this is complex and will certainly not happen in the near future.

The immediate future will mainly see a maturation of subcanopy species, rather than a shift to canopy species. In addition, fruit production of some species will change with succession. Both pate and mahoe mostly produce fruit in closed-canopy environments. Therefore, the total fruit production of these species is likely to increase even if their abundance decreases. In contrast, most *Coprosma* spp. produce more fruit in high light environments, so may decrease their total fruit production with succession.

Table 4 lists 20 species that could be planted, some of which are already found on Mokoia in low numbers. These species are all found in the Rotorua area, and they are all suitable for lowland forest.

Planting recommendations

It is possible that Mokoia may be less suitable for hihi if it were a climax habitat. This would occur if the already existing canopy species, such as seral mahoe, were to succeed much of the area presently occupied by subcanopy species such as five-finger.

Without additional planting, species abundance and/or diversity on Mokoia may decrease with time as the forest matures. If the early successional species (e.g., *Albizia* and five-finger) are replaced by species that fruit or flower at different times then crunch periods could become more pronounced for the birds.

The diversity of habitats may also decrease. Therefore, problems associated with small islands may become more pronounced with succession to climax forest. This could partly explain why hihi were only recorded historically on the mainland and larger offshore islands.

Unlike Tiritiri Matangi, Mana, and Motutapu islands, there is currently no planting programme for Mokoia. However, planting is being considered as part of the management plan for the island being developed. Like planting programmes on the other islands, planting on Mokoia is likely to be oriented towards providing fruits and flowers for birds. Further research would be needed to confirm if species were previously found on Mokoia, and to select genetic stock for planting.

The species selected would diversify the supply of fruit and nectar sources on Mokoia to prevent a natural decrease in diversity with succession. It may also be important to monitor key species that are rare or spatially confined, such as kohekohe. *Albizia* also falls in this category. However, it is being removed from the island because it is an exotic, and this is probably reducing the quality of the island for hihi. If the main goal of planting were to conserve hihi, the best strategy would probably be to conserve *Albizia* and plant more exotics such as *Eucalyptus* spp. and *Acacia* spp. However, any planting must fit the overall cultural and restoration objectives for Mokoia. The objectives are being developed by the Mokoia Island Trust Board, which represents the traditional Maori land owners.

Acknowledgements

We are grateful to Ed Minot, Alastair Robertson, Isabel Castro, Alan Perrott and Kimberley Perrott for their advice and instruction. Thank you to Peter Koole, Jon Roygard, Ben Hagglund, John Ewen, Martin Aldridge, Ian Watson, Halema Flannagan, Jay Jury, Bill Hansby, Brooklyn and Carolyn Povy, and Dino and Weavil for help in the field. Ngaroto Cruises helped by storing our vehicles and running several errands for us. Our research was done with permission from the Mokoia Island Trust Board and the Department of Conservation. Financial support was provided by the World Wide Fund for Nature and the Todd Foundation.

References

Allen, H.H. 1961. *Flora of New Zealand, Volume I.* Government Printer, Wellington, N.Z.

Andrews, P. 1992. *Mokoia: a brief history*. Bibliophil, Rotorua, N.Z.

Angehr, G.R. 1984. *Ecology and behaviour of the Stitchbird: with recommendations for management and future research.* Internal report to the New Zealand Wildlife Services, Department of Internal Affairs, Wellington, N.Z.

Angehr, G.R. 1986. Ecology of honeyeaters on Little Barrier Island: a preliminary survey. In: Wright, A.E. and Beaver, R.E. (Editors), *The offshore islands of northern New Zealand*, pp. 1-11. New Zealand Department of Lands and Survey Information Series No. 16, Wellington, N.Z.

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

Armstrong, D.P.; Perrott, J.K. (2000). An experiment testing whether condition and survival are limited by food supply in a translocated hihi population. *Conservation Biology* (in press).

Armstrong, D.P.; Perrott, J.K.; Castro, I. 1997. *The effect of food supply on the viability of hihi populations: an experimental study on Mokoia.* Report to World Wide Fund for Nature, Wellington, N.Z.

Beadle, S.M.; Ecroyd, C.E. 1990. Checklist of vascular plants of Mokoia Island. *Rotorua Botanical Society Newsletter 20*: 18-24.

Beveridge, A.E.; Daniel, M.J. 1965. Observations on a high population of brown rats (*Rattus norvegicus*) on Mokoia Island, Lake Rotorua. *New Zealand Journal of Science 8*: 174-189.

Castro, I. 1995. *Behavioural ecology and management of hihi* (Notiomystis cincta) *an endemic New Zealand honeyeater*. Ph.D. Thesis, Massey University, Palmerston North, N.Z.

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

Connor, H.E.; Edgar, E. 1987. Name changes in the indigenous New Zealand flora, 1960- 1986 and Nomina Nova IV, 1983- 1986. N*ew Zealand Journal of Botany 25*: 115-170.

Ford, H.A. 1991. Coping with an erratic nectar source- Eastern Spinebills (*Acanthorhynchus tenuirostris*) at New England National Park. *Emu 91*: 53-56.

Gill, B,; Whitaker, T. 1996. *New Zealand frogs and reptiles*. David Bateman Ltd., Auckland, N.Z.

Godley, E.J. 1979. Flower Biology in New Zealand. *New Zealand Journal of Botany 17*: 441-466.

King, C. 1984. *Immigrant killers: introduced predators and the conservation of birds in New Zealand.* Oxford University Press, Auckland, N.Z.

King, C. (Editor). 1990. *The handbook of New Zealand mammals*. Oxford University Press, Auckland, N.Z.

Moore, L.B.; Edgar, E. 1970. F*lora of New Zealand, Volume II*. Government Printer, Wellington, N.Z.

Oliver, W.R.B. 1955. *New Zealand birds, 2nd edition*. A.H. and A.W. Reed, Wellington, N.Z.

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

Rasch, G.; Boyd, S.; Clegg, S. 1996. *Stitchbird* (hihi, Notiomystis cincta) *recovery plan*. Department of Conservation, Wellington, N.Z.

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

Turbott, E.G. (Convener). 1990. *Checklist of the birds of New Zealand and the Ross Dependency, Antarctica. Third Edition*. Ornithological Society of New Zealand Inc., Wellington, N.Z.

Wallace, S.W. 1993. *Establishment of four permanent vegetation plots on Mokoia Island, Lake Rotorua*. Report for the Bay of Plenty Conservancy, Department of Conservation, Rotorua, N.Z.

Webb, C.J.; Sykes, W.R.; Garnock-Jones, P.J. 1988. *Flora of New Zealand, Volume* IV. Botany Division, Department of Scientific and Industrial Research, Christchurch, N.Z.