Notornis, 2008, Vol. 55: 173-183
0029-4470 © The Ornithological Society of New Zealand, Inc.

Diet of kereru (*Hemiphaga novaeseelandiae*) in a rural-urban landscape, Banks Peninsula, New Zealand

KIRSTEN L. CAMPBELL*
Bio-Protection and Ecology Division, Lincoln University, P.O. Box 84, Lincoln 7647, New Zealand

H. MAAIKE SCHOTBORGH**
Bio-Protection and Ecology Division, Lincoln University, P.O. Box 84, Lincoln 7647, New Zealand

KERRY-JAYNE WILSON
SHAUN C. OGILVIE
Bio-Protection and Ecology Division, Lincoln University, P.O. Box 84, Lincoln 7647, New Zealand

Abstract The diet of 30 radio-tagged kereru (*Hemiphaga novaeseelandiae*) was studied at 4 sites on Banks Peninsula, New Zealand, from Feb 2004 to Feb 2006, in 2 main habitat types: 1) highly modified rural-urban habitats where introduced plant species were common and remnants of native forest small, and 2) a habitat containing relatively few introduced species with a large area of regenerating native forest (Hinewai Reserve). Kereru at Hinewai had the most varied diet and ate a higher proportion of native plant species (82%) than those at rural-urban sites where only half the diet comprised native species. At all sites, native fruits were the most frequently eaten foods during mid-summer and autumn. Foliage and flowers of introduced plants - tree lucerne (*Chamaecytisus palmensis*) and fruit trees (*Prunus* and *Malus* spp.) at rural-urban sites, and broom (*Cytisus scoparius*) at Hinewai - were most frequently eaten prior to the breeding season. Kereru at all sites made multiple breeding attempts. This suggested that food was not limiting and foliage of introduced species can allow kereru to breed successfully. Food sources for kereru on Banks Peninsula, and potentially in similar habitats throughout New Zealand, could be improved based on the list of food species compiled during this study. Advantages and disadvantages of using introduced plant species for enhancement of food sources are discussed.

Campbell, K.L.; Schotborgh, H.M.; Wilson, K.-J.; Ogilvie, S.C. 2008. Diet of kereru (*Hemiphaga novaeseelandiae*) in a rural-urban landscape, Banks Peninsula, New Zealand. *Notornis 55(4):* 173-183.

Keywords: kereru, *Hemiphaga novaeseelandiae;* diet; Banks Peninsula; rural-urban landscape

INTRODUCTION

The kereru (*Hemiphaga novaeseelandiae*) is a large (550-850 g) fruit-eating pigeon, endemic to New Zealand (Clout 1990). Kereru inhabit a wide range of habitats including native and exotic forest, rural, and urban areas. Kereru are a taonga (treasure) of cultural and spiritual significance to Maori (Waitangi Tribunal 2006) and an iconic species to all New Zealanders. Kereru are declining in many areas due to destruction of native forest, predation, food competition, and poaching (Mander *et al*. 1998).

Received 21 Mar 2008; accepted 18 May 2009
*Current address: Department of Conservation, PO Box 1146, Rotorua 3040
kcampbell@doc.govt.nz
**Current address: 354 E. Cambridge Drive, Tucson, Arizona 85704, USA
maaike@pamelakeyes.com

Kereru are generalist herbivores, eating fruit, foliage and flowers of native and introduced plants. Feeding studies throughout New Zealand have shown that the diet of kereru is flexible and varies between habitat types (Bell 1996; Clout *et al*. 1986; Clout *et al*. 1991; Dunn 1981; Hill, 2003; Pierce & Graham 1995; Ridley 1998).

The timing and duration of the breeding season of kereru is thought to be linked to the availability of foods that meet the nutritional requirements of breeding adults and fledglings (Clout 1990, Clout *et al*. 1995, Powlesland *et al*. 2003). This appears to be the case for other wholly or partly frugivorous birds. Powlesland *et al*. (1997) discovered that the reproductive cycle of parea (Chatham Island pigeon, *H. chathamensis*) was strongly influenced by the abundance of hoho (*Pseudopanax chathamicus*) and matipo (*Myrsine chathamica*) fruit. During times of fruit abundance, a higher proportion of parea pairs bred and made multiple nesting attempts

(Powlesland *et al.* 1997). Crome (1975) found that the breeding seasons of several species of fruit pigeon in northern Queensland coincided with maximum fruit abundance and diversity.

Studies in areas where fruit was unavailable or scarce prior to and during the breeding season, have found that kereru eat the foliage of native and introduced legumes and budding leaves of introduced deciduous species (Hill 2003; Pierce & Graham 1995). Kereru at these sites switched to fruit when it became readily available.

With the destruction of >90% of Banks Peninsula's native forest during the 19th century, there was a decline in food availability for forest-dwelling birds such as kereru (Wilson 2004). However, previous studies have shown that kereru can include introduced plants in their diet (Dunn 1981; Ridley 1998; R. Powlesland *pers. comm.*). It is probable that this adaptability enabled kereru to persist on Banks Peninsula despite extensive modification of habitat. Currently, little is known about the availability and quality of food for kereru in such highly modified rural-urban landscapes where there are few, usually small, patches of regenerating native forest, and how such habitat changes affect diet, survival, home ranges and reproductive output of kereru (Campbell 2006; Schotborgh 2005).

In this paper we compare and contrast foods used by 30 radio tagged kereru in 4 study sites, and 2 main habitat types, on Banks Peninsula: 1) a highly human-modified rural-urban habitat where introduced plant species were common and remnants of native forest small (study sites Church Bay, Orton Bradley Park and Akaroa); and 2) a habitat containing relatively few introduced species with a large area of regenerating native forest (Hinewai study site).

METHODS

Study Areas

The rural-urban habitat consisted of 3 geographically discrete sites described below. The predominantly native habitat comprised a single site (Hinewai). In this paper, pooled results from all rural-urban sites were compared with the Hinewai site. However, differences among the rural-urban sites were also examined.

Church Bay study site

Church Bay is a small (approximately 520 m × 480 m at the widest points), steep-sided bay on the south side of Lyttelton Harbour (43° 37′ S, 172° 43′ E) (Fig. 1). Approximately half of the area consisted of houses and holiday homes with rough gardens. These gardens contained a range of plant species, including introduced tree lucerne (*Chamaecytisus palmensis*) and fruit trees (*Prunus* spp.), and native trees such as kowhai (*Sophora microphylla*),

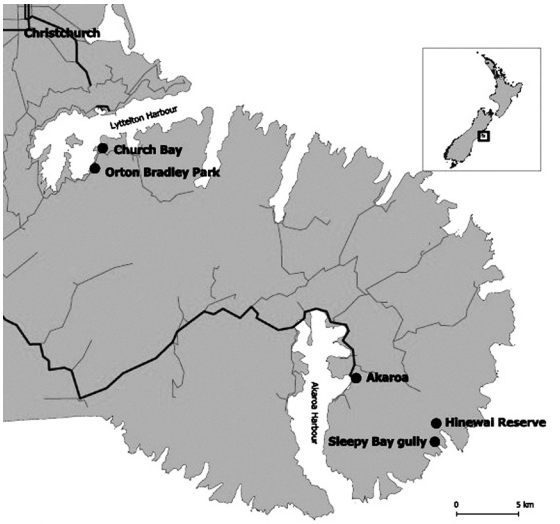


Figure 1. Map of Banks Peninsula showing locations of study sites at Church Bay, Orton Bradley Park, Akaroa and Hinewai (includes Sleepy Bay gully). Study sites are indicated by solid dots. Lines are major roads.

ngaio (*Myoporum lateum*) and poroporo (*Solanum aviculare; S. laciniatum*). The central-part of the Bay is the Hunter Nature Reserve, which consisted mainly of second-growth kanuka (*Kunzea ericoides*) and mixed hardwood forest, including some native trees not naturally found on Banks Peninsula that were planted around 1970 (Kelly 1972). Vegetation bordering the reserve was mainly kanuka, kowhai, *Coprosma* spp, cabbage tree (*Cordyline australis*) and tree lucerne.

Orton Bradley Park study site

Orton Bradley Park (approximately 640 ha) is located in Charteris Bay (43° 39′ S, 172° 43′ E), on the south side of Lyttelton Harbour, and is 2.5 km from Church Bay (Fig. 1). Altitude ranges from sea level to Mount Herbert (919 m ASL) and Mount Bradley (855 m ASL) on the southern boundaries. Vegetation in the park consists of open pasture, exotic conifer and hardwood plantations, second-growth native forest, including both kanuka and mixed hardwood canopies, scattered plants on rock outcrops, and small areas of second-growth native hardwoods regenerating through bracken (*Pteridium esculentum*) (Wilson 1992). Native scrub and forest are found in locations with limited access or low intensity farming activities. Common introduced species in and around the park were eucalypt (*Eucalyptus* spp.), alder (*Alnus glutinosa*), willow (*Salix* spp.), tree lucerne, fruit trees (*Malus* and *Prunus* spp.), oak (*Quercus robur*), walnut (*Juglans regia*), chestnut (*Aesculus hippocastanum*), *Rhododendron* spp., exotic conifer species and poplar (*Populus* spp.). Common native species were kanuka, pate (*Schefflera digitata*),

kamahi (*Weimannia racemosa*), mahoe (*Melycitus ramiflorus*), fuchsia (*Fuchsia exorticata*), cabbage tree, pohuehue (*Muehlenbeckia australis*), kawakawa (*Macropiper excelsum*), kowhai, five-finger (*Pseudopanax arboreus*), *Coprosma* spp., poroporo and ngaio.

Akaroa study site

Akaroa is a coastal town on the north-eastern side of Akaroa Harbour (43° 48′ S, 172° 57′ E) (Fig. 1). The landscape is a mosaic of residential properties, farmland and small native forest fragments. A wide range of native and introduced plant species was available in gardens and on roadsides. Introduced species such as willow, tree lucerne, poplar, walnut and hawthorn (*Crataegus oxycantha*) were common on farmland. Tree lucerne was more common in Akaroa than in the Hinewai study site. Broom was less common with patches tending to be small and scattered. The range of native plant species present in forest remnants in Akaroa was similar to native forest at the Hinewai study site. However, there was little well-developed coastal forest or scrub and many native forest fragments were grazed by stock. Many native forest fragments also contained introduced tree and weed species such as oak and hawthorn.

Hinewai study site

The Hinewai study site comprised Otanerito Valley and adjacent Sleepy Bay gully in the southeast sector of Banks Peninsula (43° 49′ S, 173° 2′ E) and is 5 km from Akaroa (Fig. 1). There is a steep gradient from Stony Bay Peak at 806 m to sea level at the mouth of Otanerito Valley. Hinewai Reserve, 1050 ha, covered most of Otanerito Valley. Approximately 4% of the reserve is covered by old growth forest (Wilson 1993). A large proportion of this forest is dominated by red beech (*Nothofagus fusca*) and Hall's totara (*Podocarpus hallii*) (Wilson 1994). Much of Hinewai Reserve was dominated by introduced gorse (*Ulex europaeus*) and broom (*Cytisus scoparius*). The 2nd most common vegetation types were native 2nd-growth hardwood forest and scrub consisting of kanuka, mahoe, fuchsia, pate, *Pseudopanax* spp., *Coprosma* spp., kowhai, wineberry (*Aristotelia serrata*) and lemonwood (*Pittosporum eugenioides*). At high altitudes (>300 m) horopito (*Pseudowintera colorata*) was common in the sub-canopy and in open areas. Kawakawa was an abundant sub-canopy species at low altitudes. Poroporo was found in large patches in open areas at low altitudes.

Kereru, tagged in Hinewai Reserve, also used lower Otanerito Valley and adjacent Sleepy Bay gully, which were outside the reserve boundary. This part of the Hinewai study site comprised farmland, small patches of exotic forest and small fragments of regenerating native forest and scrub. The dominant native species in coastal gullies were rohutu (*Lophomyrtus obcordata*), mahoe, kawakawa and pigeonwood (*Hedycarya arborea*). Mahoe and kanuka were predominant in Sleepy Bay gully. There was a limited number of introduced plant species in lower Otanerito Valley including tree lucerne, willow, eucalypt and walnut.

Capture and radio tagging of kereru

Capture of 15 kereru took place at 2 sites in Orton Bradley Park and 1 site in Church Bay in Jan and Feb 2004 (Fig. 1). A further 15 kereru were captured at 2 sites in Hinewai Reserve in Feb and Mar 2005 (Fig. 1). After the week of their capture, 3 kereru captured in Hinewai Reserve were observed only in Akaroa for the remainder of the study; this resulted in Akaroa becoming a distinct study site. Kereru were captured in mist nets with a mesh size of 10 cm on 7-m high rigs. Mist nets were located on flight paths near favoured food sources.

Each kereru was fitted with a SIRTrack Ltd® radio transmitter with a unique frequency (Havelock North, New Zealand). Transmitters were mounted on the back using a harness that incorporated a weak-link designed to free the bird if it became entangled (Karl & Clout 1987). Transmitter plus harness weighed approximately 20 g. Kereru were individually banded using numbered S or K size bands. A uniquely colour-coded leg jess (colour tag made of nylon-reinforced PVC) or combination of 2 jesses were attached to the leg(s) of each kereru to allow visual identification. Kereru were released at the capture site. Capture and radio tagging was approved by the Department of Conservation and by the Lincoln University Animal Ethics Committee.

Radio tracking and feeding observations

Radio tagged kereru were tracked on foot using a hand-held Yagi antennae and Telonics® receiver. Field trips were 4 or 5 consecutive days in length and took place fortnightly in alternate weeks. Field trips are referred to as 'field weeks' or 'weeks' in this paper. An attempt was made to visually locate each kereru at least once a day during each field week. Efforts to locate tagged kereru were randomised as much as possible, taking into consideration the time of day and locations of different tagged kereru. Observations of individual birds were at least 2 hours apart.

Feeding observations were made while kereru were being tracked from Feb 2004 to Mar 2005 at the Orton Bradley Park and Church Bay study sites, from Feb 2005 to Feb 2006 at the Hinewai study site, and from Mar 2005 to Feb 2006 at the Akaroa study site. The number of feeding observations gathered from each site is shown in Table 1.

Food species and food types eaten were recorded whenever a radio tagged kereru was observed feeding. A food species was defined as a plant on

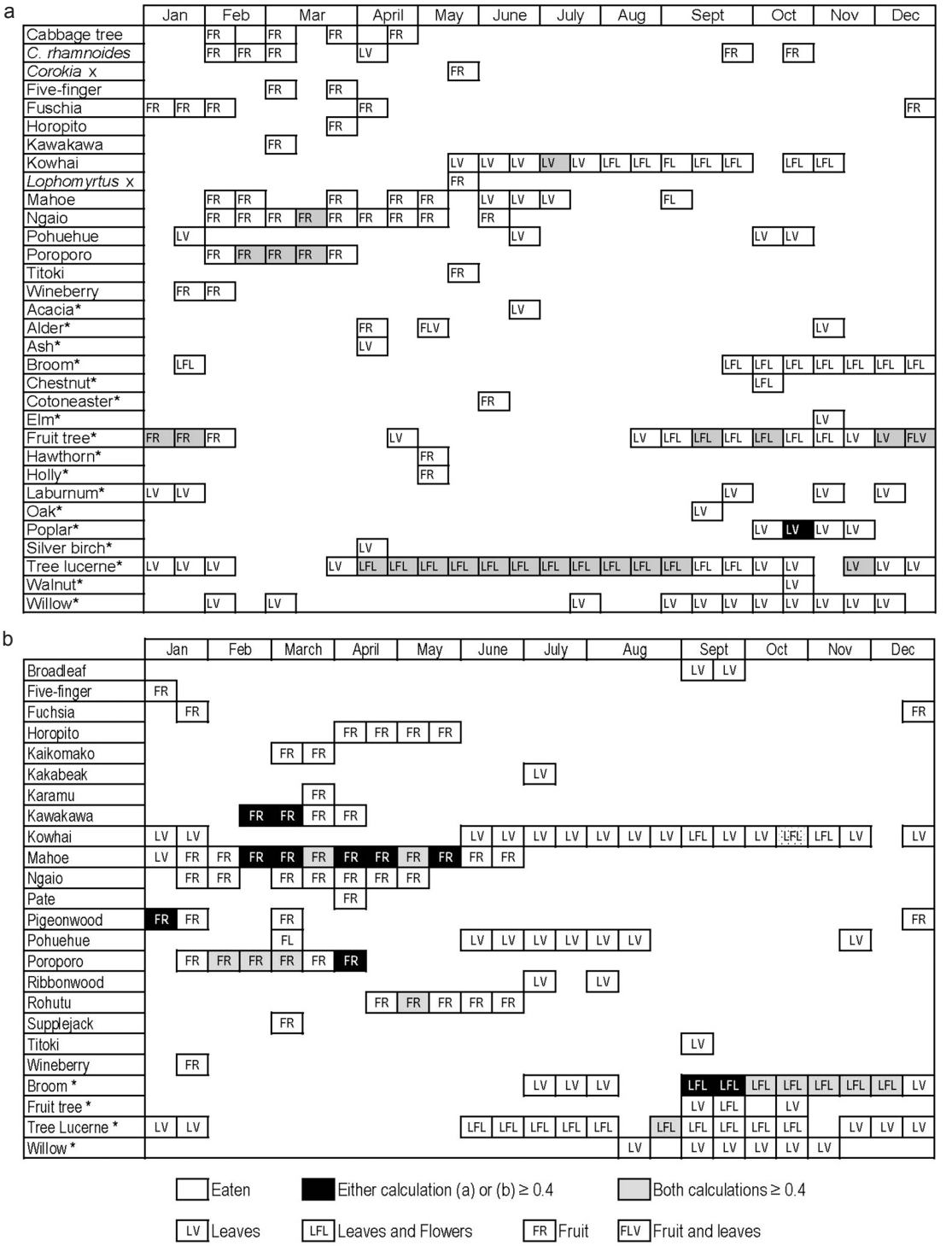


Fig. 2. Food species and food types eaten by kereru at the rural-urban (a) and Hinewai (b) study sites. Use of each species is indicated by the extent of the shading (see text for description of calculations). Introduced fruit trees have been grouped under 'fruit tree.' For full list of common and scientific names see Appendix 1. *Introduced plant species.

which 1 or more tagged kereru were observed feeding; food types were flowers, leaves and fruit. Food species were identified using standard reference books (Poole & Adams 1994; Webb *et al.* 1988) or were identified by experienced botanists (Hugh Wilson, Hinewai Reserve and Jon Sullivan, Lincoln University). The food species recorded was the 1st species eaten during each observation (McGrath & Lill 1983). Because kereru may eat more than 1 food type of a single food species in a single observation, one change was made to the methods used by MaGrath and Lill (1983): during a single observation, all food types eaten of the 1st food species were recorded (any combination of leaves, flowers, and fruit of the same plant). Kereru were observed for no more than 30 minutes (e.g. observer would wait 30 minutes if bird was not feeding when found; if a feeding session lasted <30 minutes the observer would not continue to watch that bird). A feeding session was judged to end when the bird stopped eating to perform other activities such as preening or roosting.

Data analysis

Kereru were radio tagged primarily for the purpose of obtaining home range data (Campbell 2006, Schotborgh 2005). Therefore, feeding observations were incidental and biased towards radio tagged birds. The number of times each tagged kereru was observed feeding fluctuated from week to week, as did the total number of kereru observed feeding. In addition, the duration of feeding and amount of food eaten were not recorded. As a result of the variability of sample sizes at study sites, there were limitations to the analyses we could carry out. Feeding data from individual birds were pooled for each study site. Each kereru was associated with 1 study site only (e.g. for Akaroa kereru, the few observations collected while the birds were in Hinewai Reserve were pooled with data collected in Akaroa).

Relative importance of food species

As we were unable to determine species composition at each site, we could not assess whether kereru targeted certain plant species or food types using selection indices. Instead we used a method that measured the importance of each species relative to all other species eaten during each field week. Data from the rural-urban study sites were pooled for comparison with the Hinewai site.

Two calculations were used to measure the importance of each species in each field week. First, (a) the proportion of kereru observed eating each food species was defined as the total *number of kereru* observed feeding on each food species, divided by the total number of kereru observed feeding that week. Second, (b) the proportion of feeding observations on each food species was defined as the total *number of occasions* on which kereru were observed eating each food species, divided by the sum of all feeding observations that week.

Table 1. Number of feeding observations collected at each study site and the number of kereru observed.

	No. of feeding observations	No. of kereru observed
Church Bay	175	5
Orton Bradley Park	258	10
Akaroa	128	3
Hinewai	484	12

An arbitrary threshold of 0.4 was chosen for both calculations to indicate species that were being used more frequently or by a higher proportion of kereru, relative to other species each week (Schotborgh 2005). When a species reaches the threshold in both calculations (a *and* b), this indicates that a high proportion of kereru were using the species heavily. When a species reaches the threshold in only one calculation (a *or* b), this indicates that either a high proportion of kereru were eating that species, or that a large number of feeding observations was made on that species.

Differences in the number of species eaten each week

Kruskal–Wallis tests were used to determine if there was a significant difference in number of species eaten each week, between seasons or between separate study sites. Seasons were defined as: summer (Dec – Feb), autumn (Mar – May), winter (Jun – Aug) and spring (Sep – Nov). Calculations were done manually using the method given by Fowler *et al*. (2004).

RESULTS

Importance of food species

Both native and introduced plant species were important in the diet of kereru at all study sites. One or 2 species were found be to favoured in either 1 or both calculations in most weeks during the year at the rural-urban sites (Fig. 2, 3 & 4). At all sites, there were weeks where no species reached the threshold in either calculation. This occurred most frequently at the Hinewai site during winter. The threshold for both calculations was met for at least 1 species in most weeks of the year at the rural-urban sites but was met consistently only in spring and early summer at the Hinewai site.

Increasing amounts of foliage and flowers of introduced plant species were eaten at all sites as winter progressed (Fig. 2, 3 & 4). Tree lucerne and fruit trees were the most frequently eaten introduced species at the rural-urban sites. In contrast to the rural-urban sites, broom was heavily used during

a

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Cabbage tree		0.04	0.04	0.2								
C. rhamnoides		0.1 0.1	0.2	0.2						0.1	0.1	
Five-finger			0.04	0.2								
Fuschia				0.1								
Kawakawa			0.1									
Kowhai					0.1	0.1	0.1	0.5	0.1	0.4 0.4	0.1 0.1 0.1	0.1	0.2
Mahoe		0.1 0.1								0.1		
Ngaio		0.0 0.3	0.3	0.4	0.2							
Pohuehue	0.1									0.1	0.1	
Poroporo		0.3	0.5	0.4 0.6	0.1							
Titoki					0.1							
Acacia*							0.1					
Alder*				0.2	0.1						0.2	
Broom*	0.1									0.1	0.04 0.1	0.2 0.1 0.1 0.3
Chestnut*										0.04		
Elm*											0.1	
Fruit tree*	0.9 0.7	0.3			0.1				0.1 0.1	0.4	0.3 0.4	0.1	0.2 0.3	0.5 0.5
Laburnum*	0.1 0.1										0.1		0.1	0.1
Oak*									0.1					
Poplar*												0.1		
Tree lucerne*		0.04		0.2	0.5 0.9	0.9 0.8	0.9 0.8	0.5 0.8	0.6 0.4	0.6 0.4	0.3	0.2	0.2	0.4 0.1 0.2
Walnut*												0.1		
Willow*		0.1	0.04					0.1			0.3	0.2	0.1	0.1 0.1 0.1

b

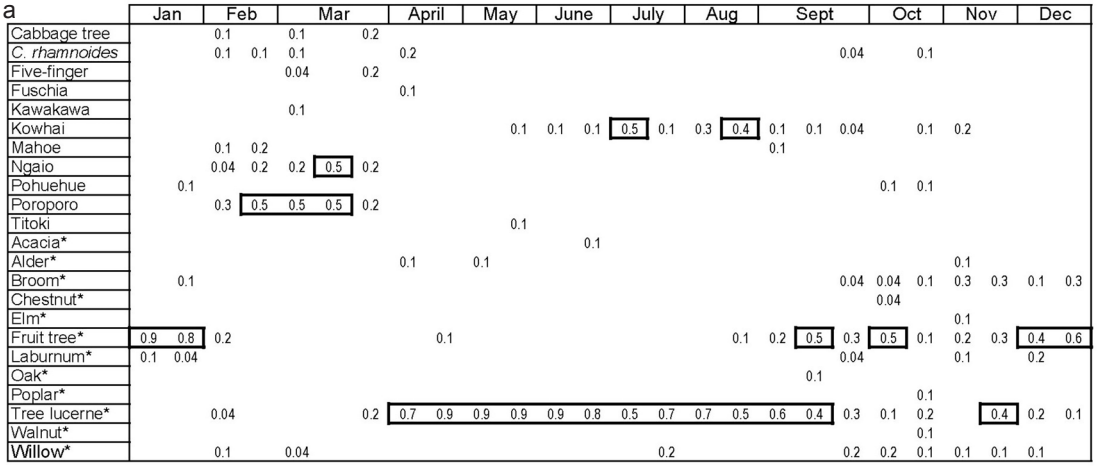
	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Broadleaf									0.03 0.1			
Karamu			0.1									
Five-finger	0.1											
Fuchsia	0.1 0.2	0.1										0.3
Horopito				0.2 0.2	0.1 0.1							
Kaikamako			0.1 0.1									
Kakabeak							0.03					
Kawakawa		0.3	0.1 0.1	0.05								
Kowhai	0.1 0.1					0.2 0.5	0.3	0.4 0.7 0.4 0.4	0.1	0.2	0.2 0.2 0.2	0.1
Mahoe	0.1 0.1	0.2 0.2	0.2 0.5	0.3 0.5 0.6	0.3	0.1 0.1						
Ngaio	0.1	0.2	0.1 0.2	0.1 0.1 0.1								
Pate				0.05								
Pigeonwood	0.5 0.2		0.1									0.3
Pohuehue						0.2 0.05	0.1 0.1	0.2 0.2			0.1	
Poroporo	0.2	0.5 0.5 0.5	0.1	0.3								
Ribbonwood							0.1	0.1				
Rohutu				0.3	0.3 0.6 0.4	0.2						
Supplejack			0.1									
Titoki									0.03			
Wineberry	0.1											
Broom *					0.03	0.04	0.1	0.2 0.1	0.3	0.4 0.6 0.6 0.7 0.7 0.9		0.3
Fruit tree *									0.1 0.03	0.04		
Tree Lucerne *	0.1 0.1					0.1	0.1 0.3	0.3 0.1	0.6 0.1	0.1 0.1	0.04	0.1	0.1	0.1
Willow *								0.4	0.4	0.3 0.1	0.1 0.1			

Fig. 3. Proportion of kereru observed eating each species throughout the year at rural-urban (a) and Hinewai (b) study sites. Values ≥ 0.4 are outlined in black. *Introduced species.

spring and early summer at the Hinewai site. At all sites, native fruits were the most frequently eaten foods during mid-summer and autumn.

Proportion of native and introduced species eaten

Kereru at the Hinewai site ate more native plant species than those in the rural-urban sites where only half of the total number of feeding observations comprised of native plant species (Table 2). At the rural-urban study sites, the highest proportion of native species was eaten from mid-summer to autumn (Fig. 5). Kereru at the Hinewai site ate a diet comprised of >85% native species until the end of Jun. More native species were eaten at this study site throughout winter than at the rural-urban study sites. During spring, kereru at all study sites fed almost entirely on introduced species (Fig. 5). At the Hinewai site, kereru resumed feeding on native species in Dec and by Jan most of the diet comprised native fruit (Fig. 5). Kereru at the rural-urban sites continued feeding mostly on fruit and foliage of introduced species until late summer when native fruit made up a large proportion of the diet (Fig. 5).



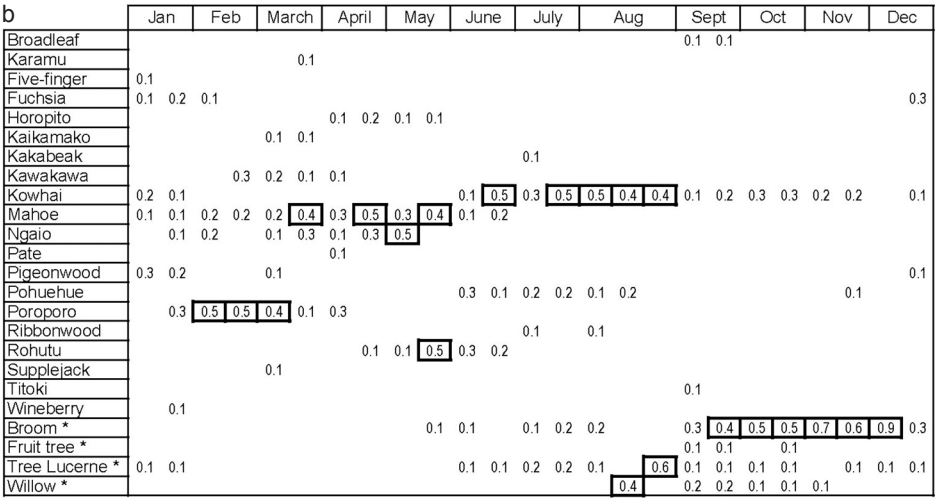


Fig. 4. Proportion of feeding observations on each food species throughout the year at the rural-urban (a) and Hinewai (b) study sites. Values ≥ 0.4 are outlined in black. *Introduced species

Differences in number of species eaten each week
There was no significant difference in number of plant species eaten between seasons except at Orton Bradley Park where there was a higher number of species eaten in spring and summer than in autumn and winter ($K=0.866$, $p<0.01$). Between study sites, there was a significant difference in number of plant species eaten in all seasons except summer. In autumn and winter, kereru at the Hinewai site ate a significantly higher number of species than those at the urban rural sites ($K=12.5$, $p<0.01$; $K=11.4$, $p<0.01$). In spring, kereru at the Orton Bradley Park and Hinewai sites ate significantly more species than kereru at Church Bay or Akaroa ($K=12.8$, $p<0.01$).

DISSCUSION

Our study highlighted differences and similarities between the diets of kereru in 2 different landscapes on Banks Peninsula. The extent of landscape modification, and therefore the availability and distribution of food species, appears to have influenced the number and types of species eaten by kereru at each study site.

It appears that availability of native plant species at each site was reflected by the proportion of native species eaten by kereru throughout the

Table 2. Total number of plant species eaten by kereru at each study site and the percentage of native species included.

	Total no. of plant species	Percent plant species native
Church Bay	11	55
Orton Bradley Park	19	47
Akaroa	19	47
Hinewai	24	83

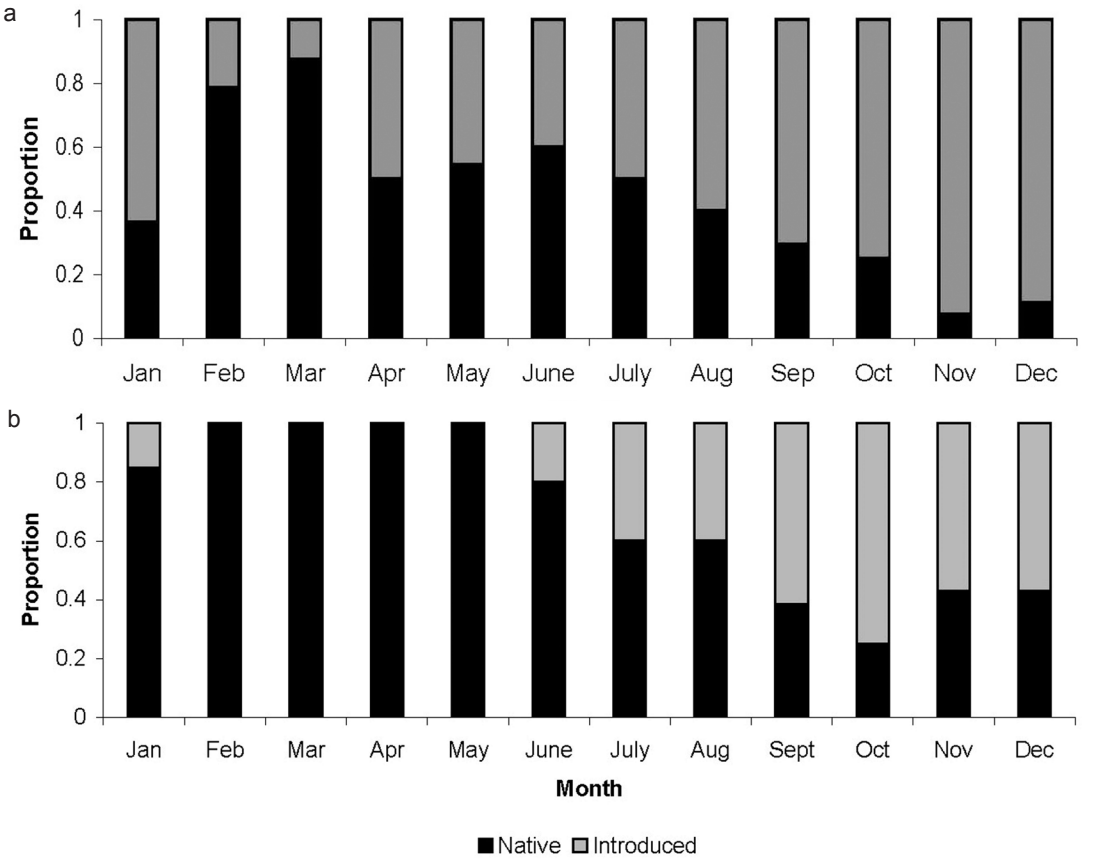


Fig. 5. Proportion of native and introduced plant species eaten by kereru at the rural-urban (a) and Hinewai (b) study sites. Graphs are descriptive due to the small sample sizes. Data for all rural-urban sites are pooled.

year. This is particularly apparent when our data is compared with feeding data from a study in Whirinaki Forest Park, a large tract of native forest in the central North Island (Hill 2003). At Hinewai, 83% of food species used throughout the year were native compared with 47% in Akaroa and Orton Bradley Park, 55% in Church Bay and 95% in Whirinaki Forest (Hill 2003). There was minimal use of introduced plant species in Whirinaki and greatest use in the highly modified sites on Banks Peninsula. Kereru at the Hinewai site ate a higher proportion of native species throughout the year compared with the more modified rural-urban sites. The phenology study at Hinewai Reserve showed that tree lucerne and broom continued to produce new leaves throughout the year, but kereru barely fed on these species while native fruit was abundant (Campbell 2006). Native fruit was not available on Banks Peninsula during late winter, spring and early summer. Studies in the North Island where fruit is available for a greater part of the year, found that foliage and introduced fruits were used only when native fruit was scarce (Hill 2003; Pierce and Graham 1995). Introduced fruit was available at the rural-urban sites in early summer, before native fruit ripened. Kereru switched from eating solely foliage to a large proportion of introduced fruit, suggesting that fruit, whether native or introduced, was the preferred food.

Kereru at the rural-urban sites ate very similar proportions of native species throughout the year because they used the same sub-sets of habitat even though the broader landscape was quite different. Church Bay and Akaroa contained a relatively large amount of native vegetation relative to their size but much of this appeared to be young regenerating scrub with few foods available. This may be why kereru in these areas used gardens and roadside vegetation for much of the year, and used similar vegetation types to those used in Orton Bradley Park.

Kereru at the Hinewai site were found to eat more species during autumn and winter than those in the rural-urban sites. This might be explained

by the greater local variation in native food species at Hinewai where large areas of native vegetation ranges from coastal to sub-montane. For example, in autumn, kereru at high altitude (c. 600 m) fed on horopito while another group of kereru fed almost exclusively on rohutu in coastal gullies, while others in lower Otanerito Valley fed on ngaio, poroporo and mahoe (Campbell 2006). In addition, the Hinewai site contained a number of native species that were absent or uncommon at the rural-urban sites (Campbell 2006, Schotborgh 2005). Some of these species were autumn or winter fruiters which allowed kereru at Hinewai to continue eating fruit when kereru at the rural-urban sites had switched to a largely foliage diet. Consequently, food species reached the proportional threshold in our analysis less often at the Hinewai site.

There was little seasonal difference in number of species eaten at any study site except Orton Bradley Park where kereru ate a larger range of species during spring and summer than in winter, suggesting this site may have had a restricted number of foods available in winter. Given that the Akaroa site contained almost all of the species that were eaten at Orton Bradley Park, it would be expected that a similar range of species would have been eaten at the same times during the year. Instead, tagged kereru at the Akaroa site ate a fairly limited number of species throughout the year. In addition, residents from Akaroa have reported that un-tagged kereru were eating a number of unrecorded species (Campbell 2006). We believe that the small number of radio tagged kereru may have resulted in an unrepresentative sample of recorded food species, although without information on the total population size on Banks Peninsula we cannot be sure.

Despite the larger range of plant species available at the rural-urban sites (i.e., present in plantings in gardens and parks) compared with the Hinewai site, kereru ate a relatively small proportion of introduced species: only tree lucerne, fruit trees, broom, poplar and willow were eaten consistently by kereru at all study sites. Without information about the number, density or palatability of introduced species, we do not know if this small range reflects selectivity or a lack of palatable species.

Broom appeared to be preferred over native species such as mahoe and kowhai at the Hinewai site (Campbell 2006). A phenology study showed that new growth of both broom and kowhai were abundant and readily accessible in Hinewai Reserve (Campbell 2006). Kowhai was eaten only in small amounts while broom was used heavily. Observations showed that kereru were flying from roosting sites with numerous kowhai trees less than 50 m away, to patches of broom up to 1 km away. In contrast, studies at Whirinaki Forest Park and Waihi Bush, south Canterbury showed that new growth of kowhai was an important seasonal food (Hill 2003; Ridley 1998). Broom was not shown to be frequently used at the rural-urban sites, but there were only small patches available at these sites. A comparison of the nutritional characteristics of introduced plant species such as broom and tree lucerne and native plant species such as kowhai is needed to properly assess the nutritional selectivity of kereru.

Key results regarding the reproductive cycle

An abundance of quality food is required within a kereru's breeding season home range to support breeding (Clout 1990, Powlesland *et al.* 2003). This is also the case for parea (Flux *et al.* 2001). Results from previous studies have suggested that native fruit is required to trigger breeding (Clout 1990; Clout *et al.* 1995; Mander *et al.* 1998). Abundant food is also required during chick rearing to sustain nestlings and newly fledged chicks. During this study, 67% of radio-tagged kereru bred, with most pairs attempting to nest at least twice. The mean number of nesting attempts was higher at the Church Bay and Orton Bradley Park sites with 2 pairs attempting to nest 4 times (Schotborgh 2005). The high number of nesting attempts suggests food supply was not a limiting factor. However, no pair of kereru was observed to overlap clutches, as has occasionally been observed at previous study sites where fruit was readily available throughout the nesting season (Mander *et al.* 1998).

Prior to and during the 1st part of the breeding season, the foliage and flowers of tree lucerne and introduced fruit trees at the rural-urban sites, and broom at the Hinewai site, were the most frequently used foods. At the Church Bay and Orton Bradley Park sites, the 1st clutches fledged before kereru were observed eating fruit and at the Hinewai and Akaroa sites nesting began early in spring well before fruit became available in Hinewai Reserve (Campbell 2006). These observations indicate that a foliage diet does contain sufficient nutritional value to rear chicks. Previous research recorded kereru eating kowhai leaves before breeding while not eating available fruits (Hill 2003). Hill (2003) found that new leaves of kowhai and mahoe had more than 4 times the protein content than the fruits that were analysed (i.e. mahoe, tawa (*Beilschmiedia tawa*), miro (*Prumnopitys ferruginea*), fuchsia, wineberry and karamu). We suggest that the high protein levels of leaves of legumes and deciduous plant species triggered breeding and enabled kereru to breed successfully at Banks Peninsula.

Additional research is required to assess what is required nutritionally to trigger the reproductive cycle in kereru in rural-urban landscapes and if this is different in native forests where the diet likely contains a higher proportion of native species

(Clout *et al.* 1995; Pierce & Graham 1995; Bell 1996; Hill 2003).

Management Implications

Our study confirms the suggestion made by Ridley (1998) that introduced food species could be important to kereru in human-modified landscapes, at least during parts of the year. We confirmed that introduced species such as broom, tree lucerne, willow and fruit trees were important foods during winter, spring and early summer, and for breeding on Banks Peninsula. A straightforward and fast way to enhance kereru populations would be to plant selected introduced plant species (see Appendix 1). However, we must also recognise our responsibility to protect and enhance New Zealand's native biodiversity. Fleshy fruits of some introduced species such as hawthorn, cherry species (*Prunus campanulata*, *P. laurocerasus* and *P. serrulata*), cotoneaster (*Cotoneaster* spp.) and holly (*Ilex* spp.), are easily dispersed into native forest fragments by birds such as kereru and are known to be invasive (Department of Conservation 2005; Webb *et al.* 1988; Williams 2006). Crack willow (*Salix fragilis*), grey willow (*S. cinerea*) and broom are on the National Plant Pest Accord and therefore should not be planted (Biosecurity New Zealand 2007). We suggest that emphasis be placed on using native plant species for habitat restoration. It is also possible to promote certain non-invasive introduced species for kereru and other native birds such as tui (*Prosthemadera novaeseelandiae*) (R. Powlesland, *pers. comm.*) and bellbird (*Anthornis melanura*) (Ridley 1998).

Use of certain introduced plant species may be necessary to boost kereru productivity in areas where food is currently limiting population growth. As tree lucerne and broom appear to be valuable to kereru as primary and supplementary food sources, we suggest that existing patches of these species could be temporarily allowed to remain while native plantings are made available to replace these food sources in the future. Neither broom or tree lucerne is invasive in native forest, but they are classed as weeds in some areas and should be contained to avoid spread.

Large scale removal of introduced species in rural-urban landscapes could have a detrimental influence on the survival of kereru and on the timing and productivity of the kereru breeding season. Removal should be mitigated by planting alternative foods.

Acknowledgements

This study was carried out as part of the Kaupapa Kereru Programme (KKP), established in 2000 after a Ngāi Tahu kaumātua (Maori elder chosen by the people to teach younger generations about customs, traditions, history and Maori language) expressed a desire to increase kereru numbers on Banks Peninsula. The KKP is a collaboration between Te Rūnanga o Ngāi Tahu (the main South Island Maori iwi (tribe)), Lincoln University; Manaaki Whenua Landcare Research and the Department of Conservation. KKP uses research and community education to accomplish their goal of increasing kereru numbers on Banks Peninsula. We thank all members of that group for their support and funding. Peter Dilks, Terry Greene and Moira Pryde kindly assisted with catching and radio tagging of kereru. Thanks also to Hugh Wilson and the Hinewai Reserve board of trustees for the use of the Reserve and accommodation on site. Thanks to Orton Bradley Park for allowing us access. We are grateful to Church Bay, Otanerito Valley and Akaroa residents for allowing us access to their properties to observe kereru. Leon Fife did great work studying the kereru at Church Bay and his enthusiasm and efforts were and are greatly appreciated. Myles Macintosh assisted with fieldwork and Alison Lister and James Ross helped with data analysis.

References

Bell, R. 1996. *Seed Dispersal by kereru (Hemiphaga novaeseelandiae) at Wenderholm Regional Park*, MSc, University of Auckland, Auckland, New Zealand.

Biosecurity New Zealand 2006. *National pest plant accord*. Manual printed by the Ministry of Agriculture and Fisheries, Wellington, New Zealand.

Campbell, K. L. 2006. *A study of home ranges, movements, diet and habitat use of kereru (Hemiphaga novaeseelandiae) in the southeastern sector of Banks Peninsula, New Zealand*, MSc, Lincoln University, Christchurch, New Zealand.

Clout, M.N.; Gaze, P.D.; Hay, J.R.; Karl, B.J. 1986. Habitat use and spring movements of New Zealand pigeons at Lake Rotorua, Nelson lakes National Park. *Notornis 33*: 37-44.

Clout, M. 1990. The kereru and its forest. *Birds International 2:* 10-19.

Clout, M.N.; Karl, B.J.; Gaze, P.D. 1991. Seasonal movements of New Zealand pigeons from a lowland forest reserve. *Notornis 38:* 37-47.

Clout, M.N.; Karl, B.J.; Pierce, R.J.; Robertson, H.A. 1995. Breeding and survival of New Zealand pigeons *Hemiphaga novaeseelandiae*. *Ibis 137:* 264-271.

Crome, F.H.J. 1975. The ecology of fruit pigeons in tropical northern Queensland. *Australian Wildlife Research 2:* 155-185.

Crossland, A. 1996. *Port Hills birdlife, inventory, analysis and restoration potential*. Parks Unit Christchurch City Council, New Zealand.

Department of Conservation 2005. *Plant me instead: plants to use in place of common and invasive environmental weeds in the lower North Island.* Department of Conservation, Wellington, New Zealand.

Dunn, P.L. 1981. *The feeding ecology of the New Zealand Pigeon (Hemiphaga novaeseelandiae)*, MSc Thesis, University of Otago, Dunedin, New Zealand.

Fowler, J.; Cohen, L.; Jarvis, P. 2004. *Practical statistics for field biology* (2nd edn). John Wiley & Sons Ltd, West Sussex, England.

Karl, B.J.; Clout, M. 1987. An improved radio transmitter harness with a weak link to prevent snagging. *Journal of Field Ornithology 58:* 75-77.

Kelly, G.C. 1972. *Scenic reserves of Canterbury. Rep. No. 2*. Botany Division, Department of Scientific and Industrial Research, New Zealand.

Hill, M.T. 2003. *Diet, dispersal and distribution of kereru (Hemiphaga novaeseelandiae) in a lowland podocarp-hardwood forest*, MSc Thesis, Massey University, Palmerston North, New Zealand.

Mander, C., Hay, R.; Powlesland, R. 1998. *Monitoring and management of kereru (Hemiphaga novaeseelandiae), Rep. No. 15.* Department of Conservation, Wellington, New Zealand.

McGrath, R.; Lill, A. 1983. The use of time and energy by the crimson rosella in a temperate wet forest in winter. *Australian Journal of Zoology 31:* 903-912.

Pierce, R.J.; Graham, P.J. 1995. *Ecology and breeding biology of kukupa (Hemiphaga novaeseelandiae) in Northland.* Science and Research Series 91, Department of Conservation, Wellington, New Zealand.

Poole, A L; Adams, N 1994. *Trees and shrubs of New Zealand* Landcare Research, Wellington, New Zealand.

Powlesland, R.G.; Dilks, P.J.; Flux, I.A.; Grant, A.D.; Tisdall, C.J. 1997. Impact of food abundance, diet and food quality on the breeding of the fruit pigeon, Parea *Hemiphaga novaeseelandiae chathamensis*, on Chatham Island, New Zealand. *Ibis 139*: 353-365.

Powlesland, R.G.; Wills, D.E.; August, A.C.L.; August, C.K. 2003. Effects of a 1080 operation on kaka and kereru survival and nesting success, Whirinaki Forest Park. *New Zealand Journal of Ecology 27:* 125-137.

Ridley, A.R. 1998. *The feeding ecology and habitat use of kereru and bellbird in a modified forest remnant, South Canterbury, New Zealand*. BSc (Honours) Thesis, Lincoln University, Christchurch, New Zealand.

Schotborgh, H.M. 2005. *An analysis of home ranges movements, foods and breeding of kereru (Hemiphaga novaeseelandiae) in a rural-urban landscape on Banks Peninsula, New Zealand*, MSc Thesis, Lincoln University, Christchurch, New Zealand.

Waitangi Tribunal 2006. *WAI 262: The flora and fauna and cultural intellectual property claim*. Te Ropu Whakamana i te Tiriti o Waitangi/Waitangi Tribunal, Wellington, New Zealand

Webb, C.J.; Sykers, W.R.; Garnock-Jones, P.J. 1988. *Flora of New Zealand* Botany Division, DSIR, Christchurch, New Zealand.

Williams, P.A. 2006. The role of blackbirds (*Turdus merula*) in weed invasion in New Zealand. *New Zealand Journal of Ecology 30 (2)*: 285-291

Wilson, H.D. 1992. *Banks Peninsula region 'Survey report for New Zealand's protected natural areas programme'. Rep. No. 21.* Department of Conservation, Wellington, New Zealand

Wilson, H.D. 1993. *Banks ecological region*. Department of Conservation, Wellington, New Zealand.

Wilson, H.D. 1994. Regeneration of native forest on Hinewai Reserve, Banks Peninsula. *New Zealand Journal of Botany 32:* 373-383.

Wilson, K-J. 2004. *Flight of the Huia. Ecology and conservation of New Zealand's frogs, reptiles birds and mammals*. Canterbury University Press, Christchurch. 204 pages.

Appendix 1. List of species eaten by kereru at Church Bay, Orton Bradley Park, Akaroa and Hinewai study sites.

Native plant species

broadleaf (*Griselinia littoralis*),
cabbage tree (*Cordyline australis*)
Coprosma rhamnoides
Corokia buddleioides x C. cotoneaster
five-finger (*Pseudopanax aboreus*)
fuchsia (*Fuchsia excorticata*)
horopito (*Pseudowintera colorata*)
kakabeak (*Clianthus puniceus*)
kaikomako (*Pennantia corymbosa*)
karamu (*Coprosma robusta*)
kawakawa (*Macropiper excelsum*)
kowhai (*Sophora microphylla*)
Lophomyrtus obcordata x L. bullata
mahoe (*Melicytus ramiflorus*)
ngaio (*Myoporum laetum*)
pate (*Schefflera digitata*)
pigeonwood (*Hedycarya arborea*)
pohuehue (*Muehlenbeckia australis*)
poroporo (*Solanum aviculare; S. laciniatum*)
ribbonwood (*Plagianthus regius*)
rohutu (*Lophomyrtus obcordata*)
supplejack (*Ripogonum scandens*)
titoki (*Alectryon excelsus*)

Introduced plant species

acacia (*Racosperma* spp.)
alder (*Alnus glutinosa*)
apple (*Malus* spp.)
apricot (*Prunus* sp.)
ash (*Fraxinus excelsior*)
broom (*Cytisus scoparius*)
cherry (*Prunus* spp.)
cherry plum (*Prunus xblireiana; P. cerasifera*)
chestnut (*Aesculus hippocastanum*)
cotoneaster (*Cotoneaster lacteus*)
elm (*Ulmus xhollandica*)
hawthorn (*Crataegus oxycantha*)
holly (*Ilex aquifolium*)
laburnum (*Laburnum anagyroides*)
oak (*Quercus robur*)
plum (*Prunus* spp.)
poplar (*Populus nigra italica*)
silver birch (*Betula pendula*)
tree lucerne (*Chamaecytisus palmensis*)
walnut (*Juglans regia*)
willow (*Salix fragilis*)
wineberry (*Aristotelia serrata*)