# An analysis of home ranges, movements, foods, and breeding of kereru (*Hemiphaga novaeseelandiae*) in a rural-urban landscape on Banks Peninsula, New Zealand

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By
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# Frontispiece

Kereru regularly ate plums (*Prunus* spp.) in residential gardens during the first half of the breeding season.

# Abstract

Aspects of kereru (*Hemiphaga novaeseelandiae*) ecology were studied on Banks Peninsula, New Zealand, from February 2004 until March 2005 (13 months). Telemetry equipment was used to locate 15 radio-tagged kereru. Characteristic of the human-modified landscape where this study took place is a mosaic of farmland, peri-urban areas, townships, native forest patches, and conifer plantations. Main study sites were at Church Bay and Orton Bradley Park.

This study is part of the Kaupapa Kereru Programme which aims to enhance the kereru population on Banks Peninsula, and also contributes to national efforts to enhance kereru populations in human-modified landscapes. Before this study, little was known of kereru ecology in landscapes such as on Banks Peninsula.

The breeding season extended from mid-July 2004 to at least March 2005. Sixty-seven percent of tagged kereru bred and seven chicks fledged from 20 nesting attempts (35% success rate). Breeding success was higher compared with kereru populations on mainland New Zealand, but not as successful as a relatively predator-free population or for populations in areas where predators were controlled. Kereru nested in native forest patches and in areas frequently occupied by humans.

Kereru ate 11 native and 12 introduced plant species. Two to eight species were eaten each field week. Introduced species were eaten solely during parts of summer and autumn, and made up at least 50% of the diet during these periods. Native species were eaten during winter but made up less than 50% of diet. During mid to late summer, kereru ate solely native species. Native species provided leaves, flowers, and fruit. Introduced species provided leaves and flowers, except plum trees (*Prunus* spp.) which also provided fruit. Before and during the first part of the breeding season, kereru were recorded eating leaves and flowers, mostly of introduced deciduous species and kowhai. The crop content of one brooding female found dead suggested that a chick was at least partly raised on plum tree and willow (*Salix* spp.) leaves. The kereru population did not appear to be limited by food. However, planting of additional food sources could enhance food variety and ensure availability of sufficient foods for an increased population.

Home ranges, estimated using cluster analysis, were significantly smaller during the breeding season than during the non-breeding season. Home ranges (1.8-22.2 ha) and core areas (0.01-0.28 ha) were significantly smaller than those found in the Whirinaki Forest Park (13.9-704.2 ha, and 1.1-26.7 ha respectively). Home range overlap was less at Orton Bradley Park than at Church Bay. Home range overlap was generally less during the breeding season than during the non-breeding season at both study sites. During the non-breeding season, six of 10 kereru moved away from Orton Bradley Park for about two months perhaps as a result of insufficient food. Daily movements were mostly less than 500 m at both study sites. Presence of kereru was regulated by food availability, except during the breeding season when kereru also required suitable nesting sites.

The Church Bay and Orton Bradley Park study sites appeared to contain all required resources as home ranges were within these sites. However, more predation events occurred at Orton Bradley Park reducing its quality.

Increased food availability across Banks Peninsula should allow kereru to colonise new areas. Additional (native) fruiting food species should improve carrying capacity of areas, diet choice of kereru, and indirectly improve species composition in forest patches through improved seed dispersal by kereru. Seed dispersal of native plant species occurred only during mid to late summer, and mostly within 500 m from foraging locations.

Management efforts to enhance the kereru population on Banks Peninsula should first focus on predator control. Adult survival should be prioritised above reproductive output. Adult kereru were especially vulnerable to predation during summer and the breeding season when foraging on low scrub and while incubating or brooding. Five of 20 nests were preyed upon; four eggs and one chick were preyed upon. Kereru in human-modified landscapes elsewhere in New Zealand could be exposed to similar threats. Secondly, management should focus on providing suitable nesting sites and increasing the food availability before and during the breeding season for future, increased populations (i.e., following predator control). Suggestions for future research of kereru in human-modified landscapes are made.

# Acknowledgements

**This thesis was sponsored with assistance and funding from the Kaupapa Kereru Programme, a collaborative effort between Ngai Tahu, Lincoln University, the Department of Conservation, and Landcare Research.**

To my parents who suggested I travel to New Zealand to trace the footsteps of Tante Bolletje and Oom Walter!

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# Chapter 1

# Introduction

## 1.1 Thesis justification and knowledge gap

Populations of the endemic kereru or New Zealand pigeon (*Hemiphaga novaeseelandiae*) have declined drastically throughout New Zealand since the start of European settlement. Over the last two centuries, settlers have destroyed large tracts of native forest habitat and hunted kereru extensively (Clout, 1988; Wilson, 1998). Kereru populations were further reduced through predation of adult kereru and nests and competition for food by introduced mammals such as brush-tailed possums (*Trichosorus vulpecula*), rats (*Rattus* spp.) and stoats (*Mustela erminea*) (Clout, 1988; Pierce, 1993; Clout *et al.*, 1995; Pierce & Graham, 1995; Mander *et al.*, 1998).

On Banks Peninsula, European settlers deforested 700,000 ha of native forest in less than a century and, by 1920, only 800 ha of old-growth forest remained (Wilson, 1998). Since then, native forest started to regenerate in pockets and at the end of the 20th century the total area of regenerated native forest patches and other areas with native vegetation was approximately 28,000 ha (Wilson, 1998). The current rural-urban landscape on Banks Peninsula, similar to rural-urban landscapes elsewhere in New Zealand, is characterised by a mosaic of farmland, peri-urban areas, townships, regenerating native forest patches and conifer plantations. The native remnant and regenerating forest fragments range in size from a few hectares to about 1000 ha.

In the first half of the 20th century, published information on kereru was restricted to records of sightings (Dawson, 1950; Taylor, 1950). Research, conducted in the latter half of the 20th century, focussed on kereru biology and ecology including studies of food sources in native forests, kereru's role as seed disperser of native trees, main causes of population decline, breeding biology in native forests, and seasonal changes in abundance (Beveridge, 1964; Dawson *et al.*, 1978; McEwan, 1978; Clout, 1988, 1990; Atkinson, 1993; Pierce *et al.*, 1993; Clout *et al.*, 1995; Pierce & Graham, 1995; Mander *et al.*, 1998). Most of these studies were conducted in areas with large tracts of native forest, within a relatively intact landscape.

Consequently, little is known of kereru ecology in highly fragmented, human-modified landscapes (Clout *et al.*, 1995; Mander *et al.*, 1998); no information was available on the home ranges, or daily distances travelled, reproductive success, timing of the breeding cycle, or population size. The apparent abundance of kereru on Banks Peninsula suggests these birds have adapted to modifications of the landscape in the last two centuries.

Kereru remain culturally important to New Zealanders (Clout *et al.*, 1995; Wright *et al.*, 1995; Young, 1995; Higgins & Davies, 1996). On Banks Peninsula, kereru are culturally important to Te Runanga o Ngai Tahu and the local community. In 2000, the Banks Peninsula Runanga approached the Department of Conservation to assess the status of the kereru population on Banks Peninsula; the collaborative Kaupapa Kereru Programme (KKP) was initiated by Te Runanga o Ngai Tahu in collaboration with the Department of Conservation, Landcare Research and Lincoln University. The aims of KKP are to increase kereru numbers on Banks Peninsula by: 1) enhancing the landscape for kereru, 2) sustaining and/or improving the seed dispersing role of kereru, 3) working within a timeframe of 5 to 10 years so that changes in the kereru population can be detected, 4) promoting the KKP within the community, and 5) focussing on peri-urban areas so the community can experience the results of KKP.

There is a national demand for knowledge on how kereru utilise resources available to them in a human-modified landscape with a high deciduous component (Mander *et al.*, 1998; Wilson, 1998). This study, initiated by the Kaupapa Kereru Programme, provides essential information on aspects of kereru ecology specifically for the Banks Peninsula population, supplements national research efforts on kereru ecology, and provides management advice for kereru populations in rural-urban landscape such as on Banks Peninsula.

## 1.2 Aim and objectives

The overall aim of this study in the rural-urban landscape on Banks Peninsula was: 'To determine seasonal changes in home ranges, movements, use of food species, and number of kereru present within study sites, and to describe aspects of nesting sites'.

The objectives as identified for this study were to:

1. Determine annual and seasonal home ranges and movement patterns of individual kereru, and identify changes between seasons for the study population.
2. Describe seasonal changes in the use of food species and food type.
3. Describe the timing of the reproductive cycle for kereru on Banks Peninsula.
4. Determine seasonal changes in the use of study sites.
5. Describe the proximity of nest sites to areas frequently used by humans.
6. Estimate the population baseline for population trend monitoring.

## 1.3 Summary of present knowledge

### *1.3.1 Status*

Kereru inhabit lowland native forests throughout New Zealand (Higgins & Davies, 1996). The species is currently listed as 'endangered bird species in gradual decline' (Hitchmough, 2002).

### *1.3.2 Diet*

Kereru are generalist feeders and traditional in their use of food sources (Beveridge, 1964; McEwan, 1978; Clout, 1990; Pierce & Graham, 1995; Mander *et al.*, 1998; Ridley, 1998). Kereru diet consists of a combination of plant parts (i.e., leaves, flowers, buds, young shoots, and fruits) from different plants, to a single plant part from one individual plant, depending on the seasonal availability (Beveridge, 1964; Clout *et al.*, 1986; Clout & Hay, 1989; Clout *et al.*, 1991; Clout & Tilley, 1992; Mander *et al.*, 1998; Ridley, 1998). They consume whole podocarp seeds plus the fibrous parts of fruits of tree species such as kahikatea (*Dacrycarpus dacrydioides*), matai (*Podocarpus spicatus*), miro (*Podocarpus ferrugineus*), and tawa (*Beilschmiedia tawa*) (Beveridge, 1964). Studies suggest kereru switch to flowers, buds, and fruit when these become available, possibly due to their higher nutrient content.

The presence of exotic tree species with edible parts appeared to benefit kereru in areas where native trees are not abundant or supply insufficient amounts of food (Clout & Gaze, 1984). Kereru are attracted to suburban gardens by exotic species such as tree lucerne *(Chamaecytisus palmensis)*, guava (*Psidium cattleyanum*), plum trees (*Prunus* spp.), and other fruiting trees (McEwan, 1978). Numerous records are available of kereru feeding on fruit from plum and cherry trees *(Prunus* spp.), and leaves from apple trees (*Malus* spp.) (Dawson, 1950; Taylor, 1950; Gibb, 1970). Kereru browsing on foliage of exotic trees can remove significant amounts of leaves (Clout & Hay, 1989). Exotic conifer plantations are used by kereru only when native forest is adjacent or when certain food types (e.g., of introduced plant species such as *Leycesteria formosa* and *Rubus fructicosus* or native species such as *Fuchsia excorticata)* are available within the plantation (Clout & Gaze, 1984). Kereru, in landscapes without sufficient native food species, might rely on introduced species for survival.

Locations of food sources, whether native or introduced species, directly regulate movements and home ranges (Clout & Gaze, 1984; Clout *et al.*, 1986; Clout *et al.*, 1991; Pierce *et al.*, 1993).

### *1.3.3 Home ranges and movements*

In the past 30 years, radio tracking studies throughout New Zealand, mainly conducted in landscapes with native forests, suggest kereru occupy home ranges which vary in size according to the location of seasonally available food sources (Clout & Gaze, 1984; Wilson *et al.*, 1988; Clout, 1990; Pierce & Graham, 1995; Bell, 1996; Mander *et al.*, 1998; Hill, 2003). Home ranges may shift during the year or between seasons, may be as small as 1-2 ha, and may be a circuit of seasonal home ranges spread out over distances of up to 18-20 km (Clout *et al.*, 1991; Bell, 1996; Mander *et al.*, 1998). Telemetry studies show kereru are capable of travelling over 100 km in approximately seven weeks (*unpublished Kereru News, August 2005, R. Powlesland, Department of Conservation Wellington).* During colder parts of the year, kereru move to lower altitudes (Mander *et al.*, 1998). Previous studies reported kereru move to gardens in rural and urban areas to forage on introduced plant species in spring (Dawson, 1950; Taylor, 1950; Day, 1995; Ridley, 1998).

### *1.3.4 Aspects of breeding ecology*

The timing of the reproductive cycle of kereru appears to be strongly related to availability and quality of food (Clout *et al.*, 1995; Pierce & Graham, 1995; Powlesland *et al.*, 2003). During periods of nutritional stress, breeding attempts might be delayed (e.g., due to poor fruiting seasons of native trees or food competition with possum), or kereru may not attempt to nest at all (Pierce & Graham, 1995). The number of re-nesting attempts is thought to be affected by food availability (Mander 1998).

The onset of the breeding season (or reproductive cycle; display flights, egg-laying, and chick hatching and fledging) is associated with an influx of male kereru performing display flights to defend territories and nest sites, although display flights can be recorded throughout the breeding season (Mander *et al.*, 1998). The timing of the breeding season varies with latitude: Northland kereru are known to breed year-round with a peak in summer (Pierce & Graham, 1995); kereru at Pelorus Bridge breed only during the summer months (Clout *et al.*, 1995). Food quality affects the length of the chick rearing stage and the duration chicks are fed after fledging (Clout *et al.*, 1995; Mander *et al.*, 1998).

Kereru lay only one egg for every nesting attempt, but might attempt to nest up to four times in one breeding season when the food supply is plentiful (Clout *et al.*, 1988; Clout *et al.*, 1995; Pierce & Graham, 1995; Mander *et al.*, 1998). Studies show survival of adult kereru and nests is currently limited mainly by predation (Pierce, 1993; Clout *et al.*, 1995; Powlesland *et al.*, 2003). Predator control efforts have resulted in an increase in nesting success on mainland New Zealand (Burns *et al.*, 2000; Powlesland *et al.*, 2003). Graham and Pierce (1995) and Powlesland *et al.* (2003) found success rates (i.e., chicks fledging) of approximately 19 to 25% in areas where predators were not controlled. In areas where predators were controlled and on an off-shore island (i.e., both areas relatively predator-free), the success rates were 75 and 63% respectively (Pierce & Graham, 1995; Powlesland *et al.*, 2003).

### *1.3.5 Kereru: seed dispersers of native tree species*

Much of the regeneration within New Zealand's native forests relies on birds as seed dispersers. A number of native tree species are known to benefit from seed dispersal by kereru, for example: miro, karaka (*Corynocarpus laevigatus*), kahikatea, puriri (*Vitex lucens*), tawa, and taraire (*B. taraire)* (Clout & Hay, 1989; Ridley, 1998). Due to local extinctions of seed dispersing birds such as kokako (*Callaeas cinerea)* and tui (*Prosthemadera novaeseelandiae*), and total extinction of species such as the piopio (*Turnagra capensis)*, various native forest ecosystems rely entirely on kereru as seed dispersal vectors (Clout, 1990). Kereru are also the only widespread bird species capable of dispersing the seeds of tree species whose fruits are too large (> 12 mm) for other native birds species to swallow (i.e., tui and bellbird (*Anthornis melanura*) (Gibb, 1970; Clout & Hay, 1989; Clout, 1990; Mander *et al.*, 1998). In addition, tui and bellbird are primarily nectar feeders, supplementing their diet with invertebrates and fruits.

Little knowledge is available of the extent to which kereru disperse seeds in fragmented landscapes (Mander *et al.*, 1998), seed dispersal distances, which native and introduced species benefit, and if potential weed species are being dispersed (Burrows, 1994a, b). From an ecological viewpoint, maintenance and/ or enhancement of kereru populations is necessary to ensure ongoing seed dispersal and to maintain natural regeneration processes of native forests.

## 1.4 Outline of this thesis

This thesis is written as separate papers. There will inevitably be some overlap between chapters.

In the following chapter, the methodology used to radio tag kereru and collect data are outlined (Chapter 2). More detailed descriptions of the rural-urban landscape on Banks Peninsula and the study sites are given in Chapter 3. Chapter 4 describes the timing of the breeding season as recorded for tagged kereru during this study. Chapter 5 illustrates which food species and food types were eaten by kereru, followed by Chapter 6 which analyses home ranges and movements of kereru. In Chapter 7, the kereru population at two study sites is estimated, as well as a record of mortality of tagged kereru. Finally, Chapter 8 discusses kereru ecology in relation to local and national efforts to enhance kereru populations, seed and weed dispersal in the rural-urban landscape, key results for management, management recommendations, suggestions for future research, and achievements of this study.

# Chapter 2

## Capture and radio-tagging of kereru (*Hemiphaga novaeseelandiae*)

### 2.1 Introduction

To investigate kereru (*Hemiphaga novaeseelandiae*) ecology in the rural-urban landscapes on Banks Peninsula, the movement and behaviour of 15 radio-tagged kereru were recorded between February 2004 and March 2005 (13 months). This Chapter outlines the capture and radio-tagging procedures and data collection methodology.

### 2.2 Capture procedure

*2.2.1 Permits*

Capture of kereru, collection of feather samples, and radio tagging was conducted with the approval of the Department of Conservation (DOC; Low Impact, Collecting and Research Application Permit, CA13957FAU, Hitchmough 2002 classifications; www.doc.govt.nz) and the Lincoln University Animal Ethics Committee (permit no. 30). A kereru banding permit was obtained (R. O. Cossee, Manager, New Zealand National Banding Scheme, DOC, Head Office, Wellington) under K-J. Wilson's (Bio-Protection and Ecology Division, Lincoln University) existing permit (no. 0298).

*2.2.2 Constructing mist net rigs*

Two 7-m high mist net rigs were constructed at Lincoln University (Figure 2.1). Each rig consisted of two poles made of three joined 2.5 m sections of aluminium tubing. On site, each pole was held in place by guy lines attached to the top and was equipped with a vertical rope mounting system; a combination of pullies, karabiners, and eye bolts were used to guide a cord along each of the poles which was used to pull the nets to a vertical position. When the rig was assembled, the vertical position of the mist nets could be adjusted according to site parameters. The mist nets were 210 denier / 4-ply 100 mm mesh 3 m x 6 m and 3 m x 12 m.

The name 'mist net' refers to the fact that the nets become almost invisible to the eye while used against a dark background. Where possible, rigs were placed on opposite sides of a tree or bush utilised by kereru. On several occasions two mist nets of the same size were attached, one beneath the other on one net rig, to create a larger catching surface.

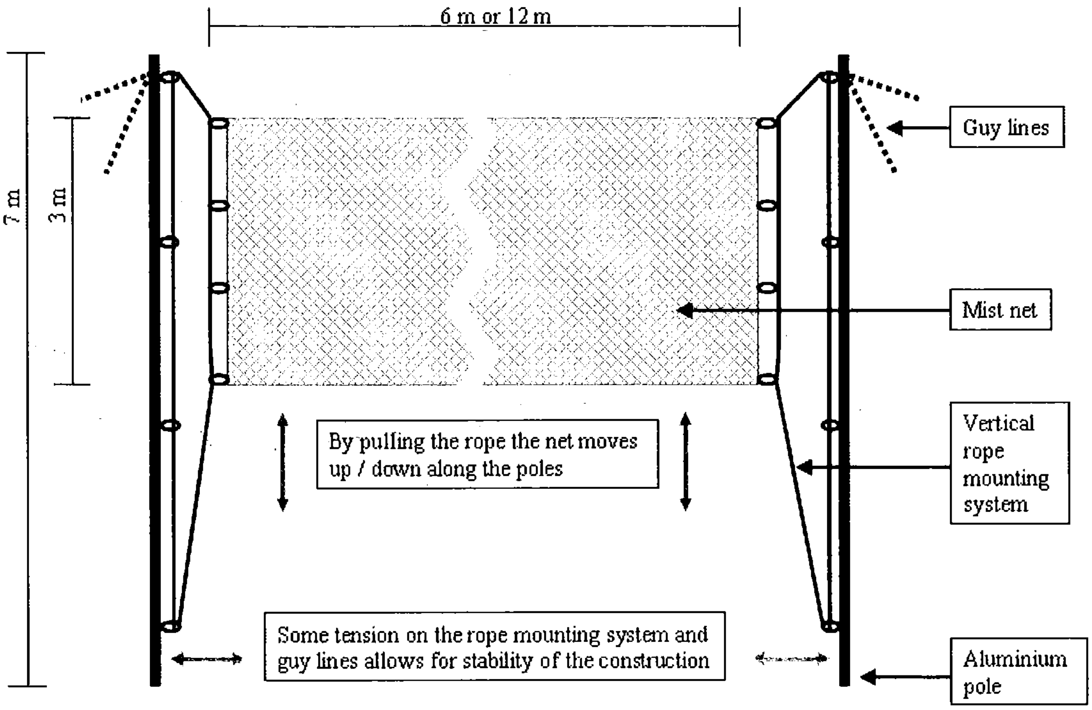



**Figure 2.1. Design of the mist net construction. Not drawn to scale.**

*2.2.3 Capture sites*

Capture of kereru took place at two sites in Charteris Bay and one site in Church Bay, in the Lyttelton Harbour basin on Banks Peninsula (Figure 2.2). Requirements for capture sites were a tree or bush that: 1) was used by several kereru on a daily basis, 2) was below a height of 7 m, and 3) was located in a site suitable for mist netting (Figure 2.3a). In the weeks before the capture (January 2004), direct observations and information from local residents revealed that several kereru were foraging in fruit trees (mostly plums trees; *Prunus* spp.) and poroporo bushes (*Solanum aviculare* and *S. laciniatum).* Capture sites were located near these food sources. Appendix 1 summarises the capture data. The rural-urban landscape on Banks

Peninsula, the study sites and the vegetation types at each study site, are described in Chapter 3 and Appendix 2.

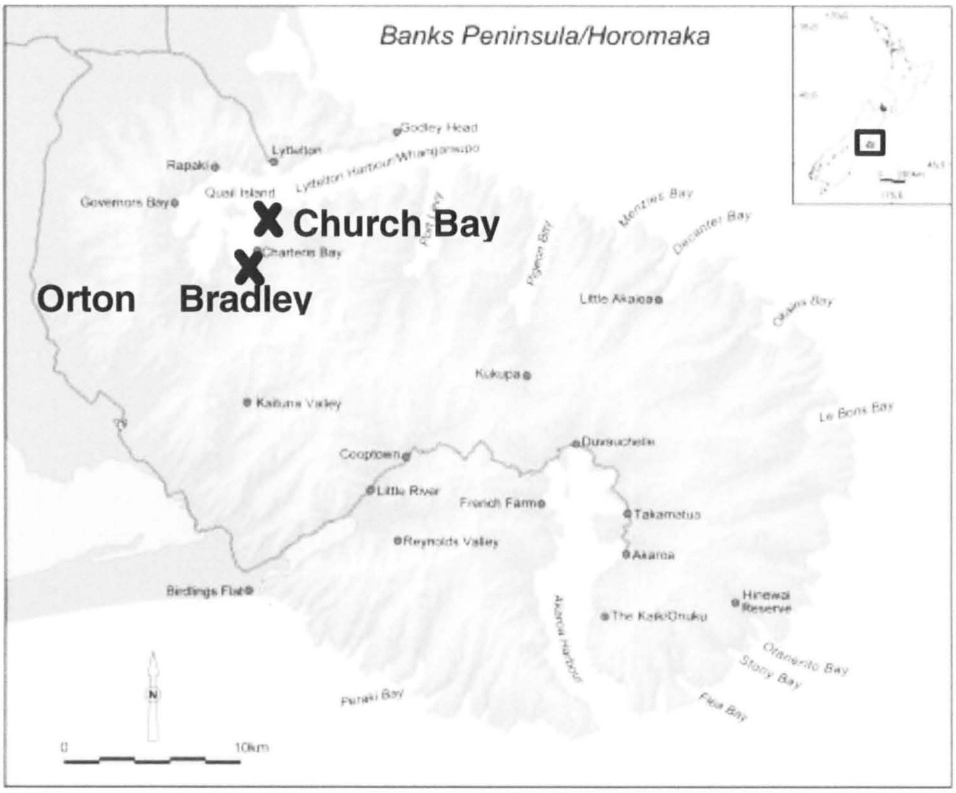



**Figure 2.2. Banks Peninsula with the location of the catch sites in Church Bay and Orton Bradley Park.**

## *2.2.4 Removal of kereru from the mist nets*

At least two experienced DOC staff and/or Lincoln University personnel were present at the capture sites at all times to supervise bird handling. Captured kereru were extracted from the net as quickly as possible to avoid unnecessary stress; one person extracted a bird from the net, while another held onto it to prevent the bird flapping its wings and injuring itself. No captured kereru were harmed during the process. Kereru were placed in a soft, lightweight cotton bag for transportation to a nearby site where the bird was processed (Figure 2.3b).

## *2.2.5 Measurements*

While in the soft cotton bag, the captured kereru were weighed to the nearest five grams, using a handheld pesola (1000 g). For each kereru, the following data were recorded to the nearest millimetre: length of the bill, longest tail feather, and longest primary wing feather (O'Donnel & Dilks, 1988) (Appendix 1). Callipers were used to measure the length of the bill (upper mandible) from the base of the feathers to the tip to the nearest 0.1 mm. A metric ruler was used to measure the tail and primary feathers to the nearest 1 mm.

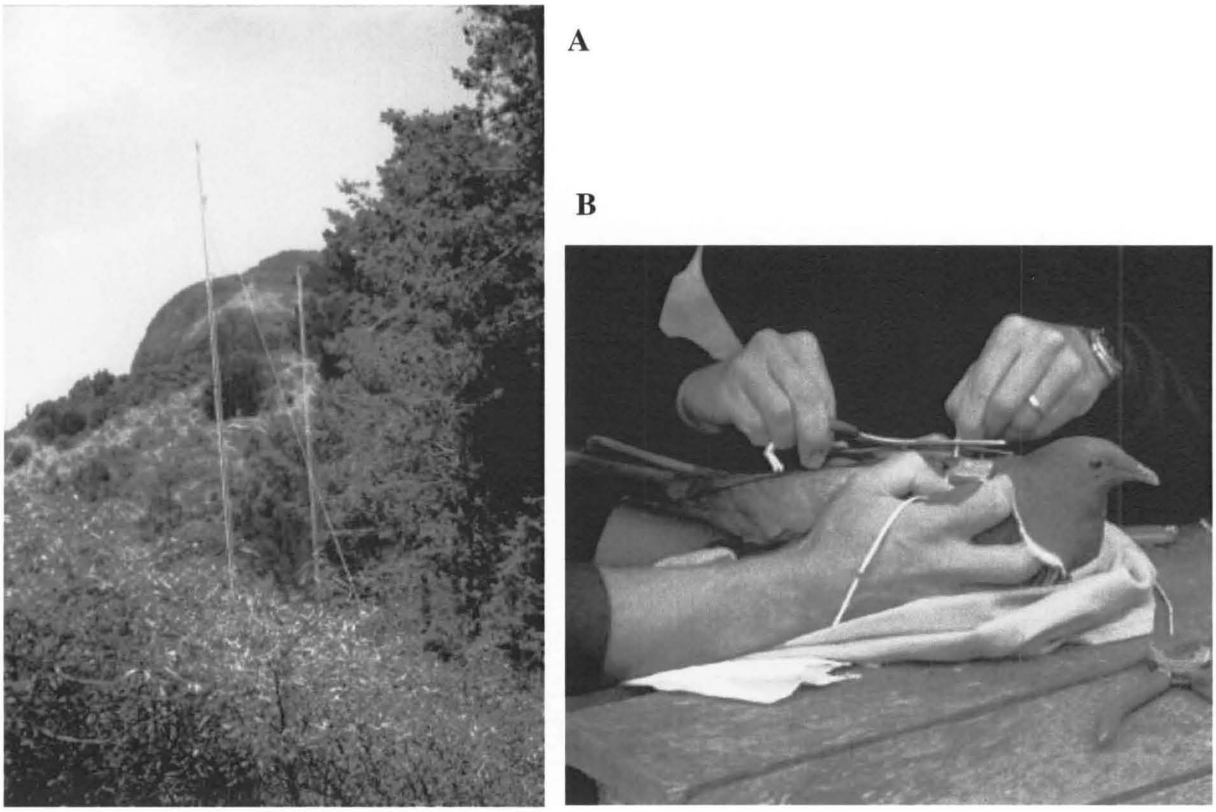



**Figure 2.3. A) At a catch site in Orton Bradley Park, the mist net was placed between conifer trees used for roosting and poroporo bushes used for foraging at the time; B) handling was a two-person effort where one held the kereru while the other attached the backpack-like transmitter to the bird.**

*2.2.6 Attachment of radio transmitters, aluminium bands, and coloured leg jesse(s)*

The radio transmitters used were Sirtrack Ltd® transmitters (Private Bag 1403, Goddard Lane, Havelock North, New Zealand). The transmitter design allowed it to be mounted on the back of the kereru, held in place with a nylon cord harness with a built-in weak link release mechanism of biodegradable cotton. This backpack-like design (Karl & Clout, 1987) has been used in previous kereru studies (Clout & Tilley, 1992; Powlesland *et al.*, 1992) (Figure 2.4).

Each transmitter weighed 18 grams; less than 4% of the bird's body mass (Kenward, 2001; Millspaugh & Marzluff, 2001). The 2/3 AA lithium cell batteries had an estimated average life of 18 months (± 4 months). The transmitters had an antenna of approximately 20 cm to amplify the pulsed signal. Each transmitter was tested before it was attached to the kereru, and the frequency channel and fine tuning recorded (Figure 2.3b; Appendix 1). The transmitters were programmed to deliver pulsed signals on a unique frequency, 40 pulses per minute, for 12 hours per day (the start of the 12 hour interval commenced when the transmitter was turned on manually with a magnet switch at 7 a.m. each capture day; New Zealand summer time). The VHF (very high frequency; 160 mHz) receivers used to receive the signal were a Regal 1000 VHF receiver and a TR-4 receiver (manufactured by Telonics Telemetry-Electronics Consultants (932 E. Impala Ave, Mesa, Arizona 85204-6699, USA)). The transmitted signal was received via handheld, collapsible, three element yagi antennas (Kenward, 2001; Millspaugh & Marzluff, 2001).

Each captured kereru was initially banded on one leg with a 'K' size band (Appendix 1). However, as these bands seemed slightly tight around some of the kereru's legs, 'S' size bands were used on the remainder of the birds. No specific leg was used to band each kereru but the band was placed on the tarsus (*tarso-metatarsus*). When the bird was to receive only one leg jess, the band was placed on the same leg as the bird's leg jess (see below).

A unique colour combination of one or two coloured jesses (red, blue, yellow, green, and orange) was attached to one or both leg(s) of each kereru in; only one per leg (Figure 2.5, Appendix 1). When attached around the kereru's leg, the jess protrudes about 4 cm, like a flag. Jesses were made of PVC-coated nylon (2 mm thick x 2 cm x 10 cm). Leg jesses are not known to influence kereru behaviour or mortality rate and have been used in previous studies (Powlesland *et al.*, 1992).

Following processing, kereru were released away from the capture site. Radio-tagged kereru resumed normal behaviour within two hours (i.e., flying and foraging near the capture site). Tagged kereru were checked every second day until the start of the radio tracking study to ensure their well-being.

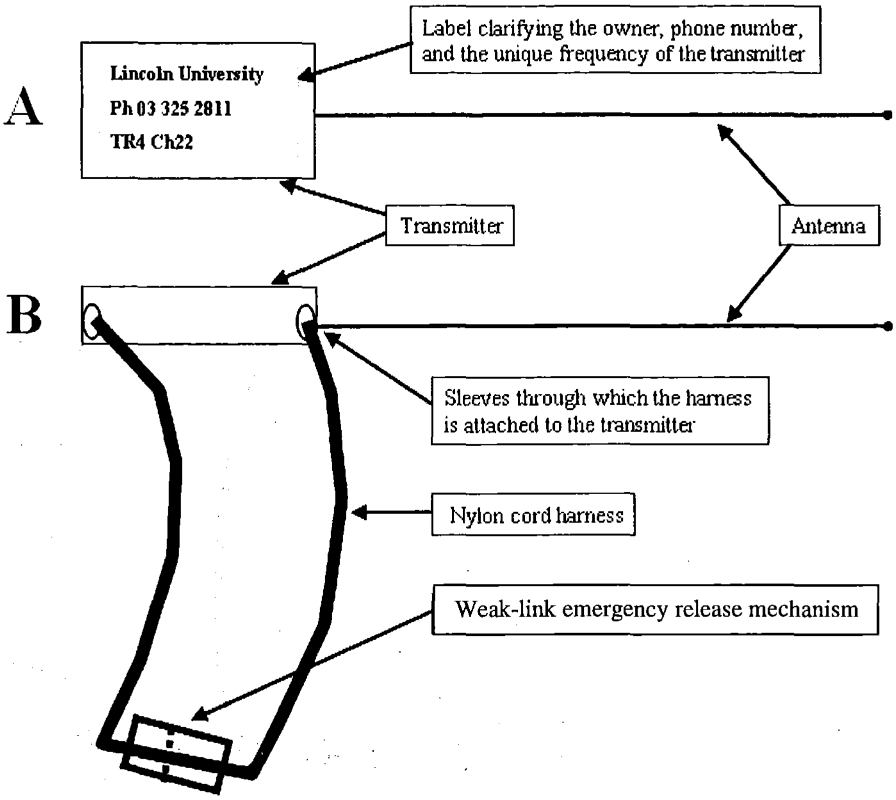



**Figure 2.4. A) top view of radio transmitter with the label and antenna; B) side view of radio transmitter as it was attached to kereru, including the design of the nylon cord with the weak link emergency release mechanism. Not drawn to scale.**

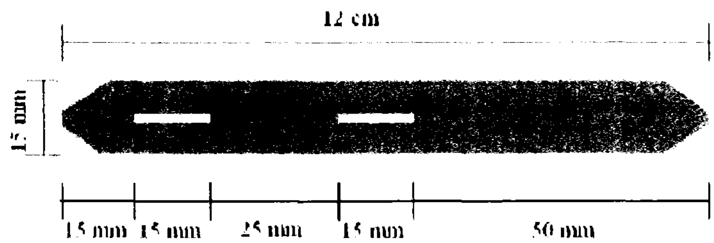


**Figure 2.5. View of jess with slits. When attached to the bird's leg it protruded about 4 cm like a flag. Not drawn to scale.**

### *2.2.7 DNA samples*

About five contour feathers from the breast area were collected from each captured kereru. These samples have been stored for potential DNA extraction.

### 2.2.8 *Radio tracking methodology and data collection*

Telemetry equipment was used to locate the 15 tagged kereru during fortnightly field trips, 4 to 5 days each, from February 2004 to March 2005 (13 months). An attempt was made to locate tagged kereru visually at least once on each field day (White & Garrott, 1990; Kenward, 2001; Millspaugh & Marzluff, 2001). The physical location of tagged kereru in the field and distances between tagged kereru determined which birds were tracked more regularly. Priority was given to collect data from kereru with known locations. A handheld global positioning unit (GPS) was used to record locations as close to any kereru as possible. When it was obvious a kereru was in a defined area but not visible, the location was estimated using triangulation (White & Garrott, 1990; Kenward, 2001; Millspaugh & Marzluff, 2001). Data in each of the following chapters were collected while radio tracking kereru as described in here. See Appendix 3 for the data sheet used.

In addition to the collection of location data for the purpose of home range and movement analysis, records were obtained of behaviour using the following terms:

- Roost: to perch or settle for sleep
- Fly: to travel through the air
- Feed/ eat: to take food or to swallow food
- Preen: to smooth feathers with bill
- Brooding: to incubate eggs or nestlings
- Twigging: to move small branches for nest making.

Records were also obtained of the food species and food types when kereru were feeding. The number of untagged kereru encountered while tracking and observing tagged kereru was recorded to estimate the population (see Chapter 7). Additional data collected during the breeding season included the sex of each breeding kereru, the number of display flights performed by male kereru, the number of nesting attempts for each breeding pair, hatching records, fledging records, and nest fates (see Chapter 4).

### 2.2.9 *Pilot study*

A pilot study was executed from mid February 2004 to early March 2005 to identify patterns in diurnal activity/behaviour of kereru to estimate the time necessary for statistical independence of location data (e.g., to avoid autocorrelation which is a basic assumption for most home range estimation techniques and statistical analysis) (Kenward, 2001; Millspaugh & Marzluff, 2001). During the pilot study, the error of location data was also assessed.

#### *2.2.9.1 Autocorrelation*

Auto-correlated data sets are created when: 1) the animal has too little time to move between two observations, 2) the animal simply does not move between consecutive observations, or 3) the animal periodically returns to a previously used portion of its range (Millspaugh & Marzluff, 2001). Data collected without autocorrelation should reflect the importance of areas within home ranges. In addition, auto-correlated data generally underestimates the home range size (Millspaugh & Marzluff, 2001). Location data collected for individual kereru during this study are most likely auto-correlated due to the following biological characteristics of kereru, because they: 1) were observed to remain in the same location for up to 1.5 hours (*pers. obs.)*, and 2) frequently returned to previously used locations within their home range.

#### *2.2.9.2 Time for independent sampling*

During the first and second field week of the pilot study, the most appropriate time for independent samples was established at 1.5 hours using field observations of the time between foraging activities. It was assumed that kereru moved within this timeframe. Locations of each tagged kereru were collected at regular intervals with a minimum of two hours between observations, similar to the interval used in the study on kereru home ranges at Wenderholm Regional Park (Bell, 1996). Also, the time of day during which each individual kereru was searched for was randomised whenever possible, taking into consideration the time for independent sampling. Field days were divided into two-hourly intervals (i.e., 0700-0900, 0900-1100, 1100-1300, 1300-1500, 1500-1700, 1700-1900) and kereru were located so that records were equally spread out over these intervals. When encountering kereru in the field, each bird was observed for 10 to 30 minutes depending on time of day, weather conditions, and behaviour at the time.

### *2.2.9.3 Error*

Location data were collected using a GPS whenever tagged kereru were within 10 m of the observer. Whenever the error was 10 m or less, it was ignored. Terrain and weather circumstances limited the accuracy of triangulation when kereru could not be approached. In these situations, the location of tagged kereru was estimated using triangulation.

The unique channel number of transmitters was used to refer to tagged kereru throughout this thesis. Whenever a reference is made to 'tagged kereru', 'kereru' will be used unless stated otherwise (e.g., untagged kereru).

# Chapter 3

## Description of study sites

### 3.1 Banks Peninsula: geography and history

Banks Peninsula was shaped by a history of volcanic eruptions and subsequent erosion (Wilson, 1998). The three main volcanoes (Lyttelton, Herbert, and Akaroa), although inactive, are still recognisable in the landscape. Characteristic for Banks Peninsula are the numerous harbours and inlets around its perimeter. Before human settlement, the landscape was mostly covered in native forests at lower elevations, and sub-alpine vegetation and scrub in the higher valleys and ridges above 800 m a.s.l. (Wilson, 1998). Maori had cleared one-third of the forest on the Peninsula when the Europeans arrived from 1840 onwards (Wilson, 1998). The Settlers deforested 700,000 ha of the original native forest for farming, in less than a century. They also introduced mammals such as cattle, sheep, goats, and possums to New Zealand which caused damage to forests via browsing. By 1920, only about 800 ha of old-growth forest remained. Clearing of the native forests destroyed habitats suitable for New Zealand's native birds such as kereru (*Hemiphaga novaeseelandiae*).

Areas with native remnant forest patches that were of no economic use for agriculture (e.g., steep slopes and river beds that were not cleared of native forest) started to regenerate and forest cover increased in size despite browsing of the forest understorey by stock (Wilson, 1998). At the end of the 20$^{th}$ century, the total area of regenerated native forest and other native vegetation was about 28,000 ha (Wilson, 1998). Conifer plantations cover an additional 2,000 ha.

The Department of Conservation is attempting to manage regenerating native forest fragments on Banks Peninsula. Conservation goals are to allow these native forest fragments to regenerate and restore as much land as possible to its original flora and fauna (Wilson, 1998). A growing number of private owners and community members are also actively involved to achieve this conservation goal (Wilson, 1998). Other initiatives allow the growth of native forest and/ or conduct research on the local native flora and fauna (e.g., Hinewai Reserve, Banks Peninsula) (Wilson, 1998).

This chapter describes the study sites used by the tagged kereru.

## 3.2 Study sites

### *3.2.1 Methodology*

Limited information on kereru home ranges and movements in rural-urban landscapes made it difficult to estimate in advance the area over which kereru would move (see Chapter 1). I attempted to estimate the study area using the location data collected of all kereru as described in Chapter 2. This approach would include areas visited by kereru while excluding areas where kereru were not located (i.e., distinguish discrete areas used by kereru).

The term 'vegetation type' was used to distinguish the boundary of three-dimensional compositions of plant species. At least one tagged kereru had to use all or part of each vegetation type for it to be included in this study. The location data were plotted onto an aerial photograph of Banks Peninsula (obtained from the Department of Conservation, Christchurch) using ArcGIS (ESRI, 2004); topographic map references 260-M36, M37, N36, N37, 1985; 1980). Contour lines were drawn around each vegetation type and borders were distinguished using the aerial photograph and field observations. When vegetation types were geographically adjacent, they were grouped to form study sites.

### *3.2.2 Results*

Five different study sites were distinguished: Church Bay, Orton Bradley Park, Mount Herbert Reserve, Port Levy, and Puaha (Figure 3.1). A description of each study site follows below. A description of vegetation types at study sites Church Bay and Orton Bradley Park is presented in Appendix 2.

#### *3.2.2.1 Study site: Church Bay*

Five vegetation types were distinguished at Church Bay (43° 37' S - 172° 43' E) (Figure 3.1 and 3.2, Appendix 2). Church Bay is a relatively small, steep-sided bay located in the

Diamond Harbour area on the south side of Lyttelton Harbour Basin, Banks Peninsula (Figure 3.1 and 3.2). The Bay's aspect is north-northwest with land outcrops outward to sea on either side. The distance between the outcrops is approximately 500 m. For about 650 m, the Church Gully Stream flows from the upper margins of the study site (150 m a.s.l.) along the centre of the Bay to the beach. Relatively steep slopes in places (i.e., cliffs and rock faces) make access difficult in the higher areas. Towards the beach, accessibility improves (e.g., residential area). Marine Drive follows the contour of the Bay at about 50 m above sea level. Power and telephone lines and poles are present along the road and between residences.

Approximately half of the area consists of residential houses with gardens. These residential gardens contain native and introduced plant species, with only small (< 0.5 ha) areas with pasture. The eastern side contains a conifer-eucalypt block (Appendix 2). The remaining middle-part of the Bay is the Hunter Scenic Reserve, which was planted with native trees around 1970 (K-J. Wilson, *pers. comm.*). Public access in the Church Gully Stream area is limited (Appendix 2).

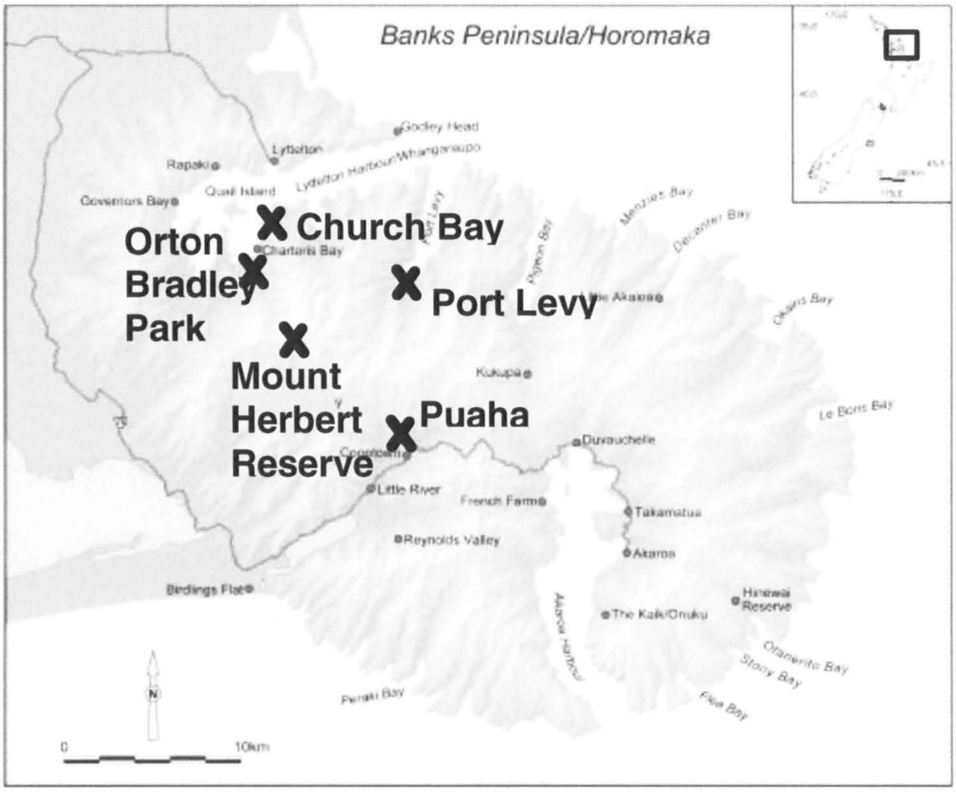



**Figure 3.1. Banks Peninsula with the location of the study sites Church Bay, Orton Bradley Park, Mount Herbert Reserve, Port Levy, and Puaha. Map source: Oral History Project, Kaupapa Kereru Programme, 2005**

**Vegetation types in Church Bay**

1. Residential gardens
2. Hillside
   (Above Marine Drive)
3. Hunters Scenic Reserve
4. Tree Lucerne-conifer stand
5. Tree Lucerne-eucalypt stand

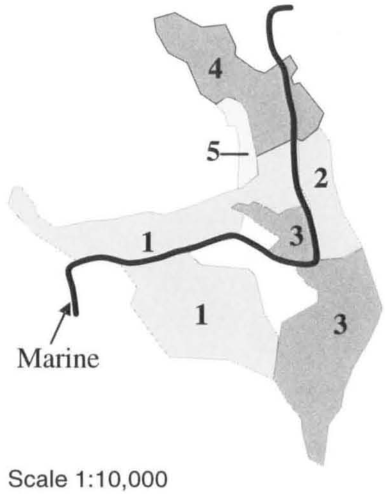



**Figure 3.2. The Church Bay study site with the vegetation types.**

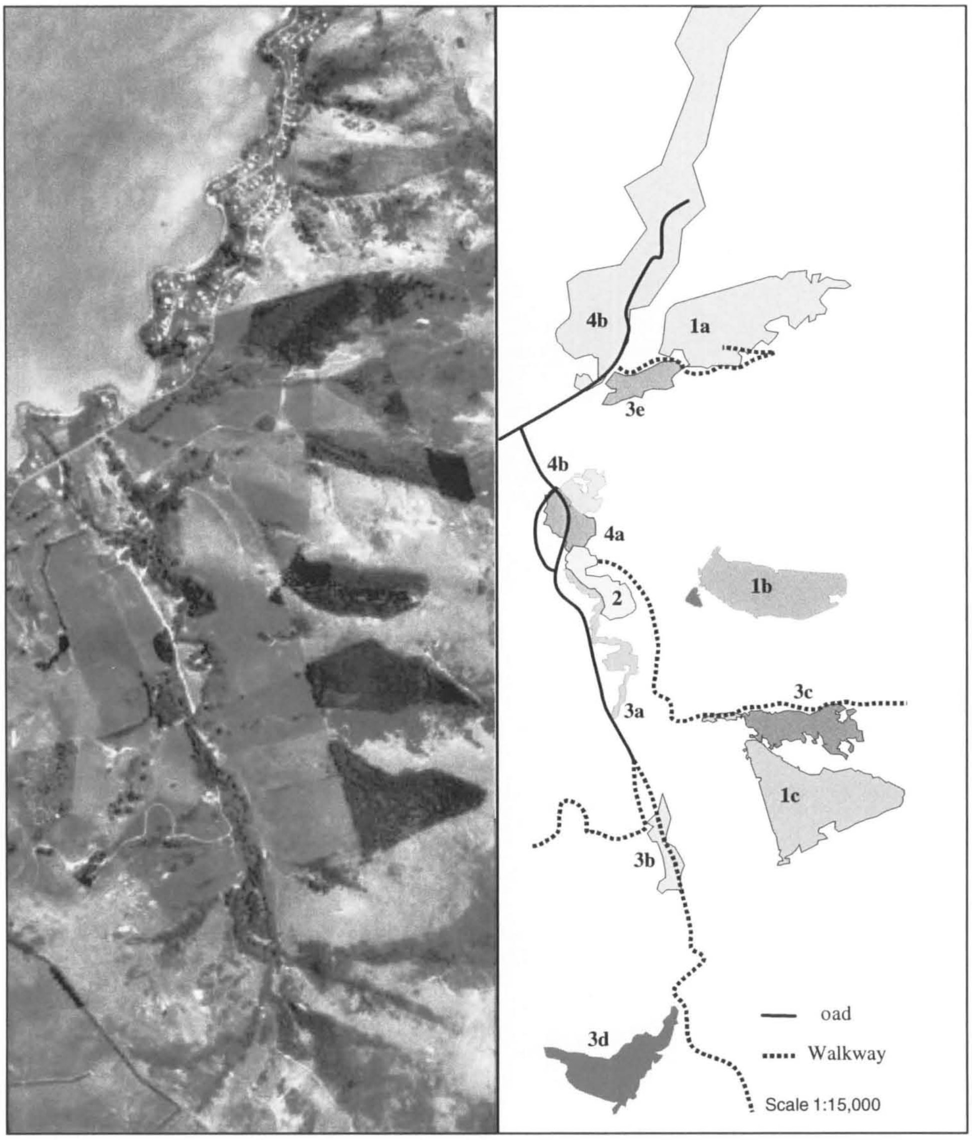
### *3.2.2.2 Orton Bradley Park*

Orton Bradley Park is located in Charteris Bay ($43^o$ 39' S - $172^o$ 43' E), on the south side of Lyttelton Harbour, Banks Peninsula (Figure 3.1 and 3.3), and contains 12 vegetation types used by tagged kereru (Appendix 2). The Park is within the catchment of the Te Wharau Stream and has relatively flat areas closer to the coast on the northern side, with rolling and steep hillsides towards Mount Herbert (919 m a.s.l.) and Mount Bradley (855 m a.s.l.) where the Park's boundaries end. The distance from the coastal area to the Park's southern boundaries on the mountain ridge is approximately five km; the width is approximately two km. The total surface area is approximately 640 ha (Wilson, 1992). In 1981, the Park became protected (Wilson, 1992). The Park is open to the public and facilities available are walkways, horse tracks, and recreational areas (i.e., camp, picnic, and play sites). During lambing season and periods with high fire risk, public access is limited.

The vegetation in the Park consists of open pasture, exotic conifer and hardwood plantations, second-growth native hardwood forest, including both kanuka (*Kunzea ericoides*) and mixed hardwood canopies, scattered plants on rock outcrops, and small areas of second-growth hardwoods regenerating through bracken (Wilson, 1992). The conifer plantations are present along the eastern side bordered by pasture as well as stands of regenerating native vegetation (Figure 3.3). Native scrub and forest are found in locations with limited access or low intensity of farming activities: stream beds, steep and inaccessible hillsides and in and amongst growths of introduced scrub and tree species. The Park contains a group of historic buildings, the manager's house and garden, and farm buildings (i.e., woolshed, and garage; Figure 3.3). From the entrance of the Park, a one km public access road runs past the historic and farming buildings, to give access to recreational areas. Where the Park borders Charteris Bay Road, residential gardens with native and introduced plant species are present (see Appendix 2).

#### *3.2.2.3 Mount Herbert Reserve, Kaituna Valley*

The Mount Herbert Reserve (240 ha; 43° 70' S - 172° 75' E) (Figure 3.1) is one of the few patches of original forest which has not been burned since European settlement. It has been grazed periodically by stock in the last 120 years but was reserved in 1915 (Kelly, 1972; Wilson, 1992). Most of the native forest vegetation is re-growth, except on the steep sites. The broadleaved mixture of the upper bush is similar throughout (i.e., broadleaf being dominant), but with characteristic species increasing at the wet (i.e., pate (*Schefflera digitata*), fuchsia (*Fuchsia excorticata*)) and dry ends (i.e., akiraho (*Olearia paniculata*), red matipo (*Myrsine australis*)) (Kelly, 1972). In areas above 500 m, Hall's totara (*Podocarpus totara*) is abundant and locally dominant. In the lower areas, matai (*Podocarpus spicatus*), totara, and in some areas kahikatea (*Podocarpus (Dacrycarpus) dacrydioides*), are characteristic. Mahoe (*Melicytus ramiflorus*) increases below 500 m. The second-growth regeneration is tending to the original vegetation except for cedar (*Juniperus* spp.). Most of the cedars died within the recent decades (Kelly, 1972).




**Vegetation types in Orton Bradley Park:**

| | | | |
|---|---|---|---|
| 1a-c | Poroporo – Conifer | 3a-d | Native and introduced tree stands |
| 2 | Tree lucerne – eucalypt | 4a-b | Residential gardens |

**Figure 3.3. Orton Bradley Park with the borders of the vegetation types within the study site (only patches of vegetation used by tagged kereru are shown on the right-hand side of the figure).**

### *3.2.2.4 Whites Road, Puaha (near Little River)*

The Hikuika Stream runs along Whites Road in Puaha, near Little River (43° 74' S - 172° 83' E) (Figure 3.1). The Stream has a zone (10 to 30 m) with scrub and trees on either side before bordering several residences and open pasture. The length of this study site is about 200 m. Tree species growing here are tree lucerne *(Chamaecytisus palmensis)*, willow (*Salix* spp.), kamahi (*Weimannia racemosa)*, kowhai (*Sophora microphylla*), conifer species (*Pinus* spp./ *Macrocarpa* spp.), and kanuka (*Kunzea ericoides*). Maximum height of the trees is about 15 m. Presence of stock resulted in little re-growth and open grassy areas. This study site is on private land.

### *3.2.2.5 Port Levy*

Along Wharf Road is a block of farmland (about 6 ha of pasture) (43$^{o}$ 66' S - 172$^{o}$ 81' E) with a stand of mostly native tree species, including kowhai and cabbage trees (*Cordyline* spp.) (Figure 3.1). The vegetation has an open structure with trees (e.g., kowhai, kanuka, and cabbage trees) growing in low densities or solitary in the paddock. The height of the trees is up to 15 m. Stock has access to this area, which is bordered by open pasture, and a conifer plantation. This study site is on private land.

# Chapter 4

# Timing of the reproductive cycle of kereru (*Hemiphaga novaeseelandiae*) in the Lyttelton Harbour Basin, Banks Peninsula

## 4.1 Introduction

The onset of breeding in kereru starts with male kereru (*Hemiphaga novaeseelandiae*) performing display flights about a month before egg-laying (Mander *et al.*, 1998). The timing of the breeding season is related to adequate food availability (Clout *et al.*, 1995; Mander *et al.*, 1998). Incubation time is 28 to 30 days (Mander *et al.*, 1998). During the egg-phase, male kereru incubate from mid morning until late afternoon; the female takes over from late afternoon until mid morning. Chicks are brooded for the first days after hatching and then left unattended while being fed up to three times a day by both parents until fledging. Food quality and quantity affects the length of the chick rearing stage which was previously recorded to be four to seven weeks (Clout *et al.*, 1995; Mander *et al.*, 1998). Chicks fledge when weighing approximately 400 g, and are fed for at least a week after fledging, mostly by the male parent (Mander *et al.*, 1998).

The timing of the reproductive cycle of kereru in the rural-urban landscape on Banks Peninsula was assessed to compare it with the timing of the reproductive cycle elsewhere in New Zealand, to supplement current knowledge, and to help determine the importance of food species and food types eaten before and during the breeding season (see Chapter 5). The timing of the breeding season was also used to analyse differences in home ranges and movements of kereru between the non-breeding and breeding seasons (see Chapter 6).

This chapter describes the timing of the reproductive cycle and the locations of nesting sites in relation to vegetation types and areas used by humans. Reference will be made to the independent but supplementary study by T.A. Prendergast on the effects of predation on kereru reproductive success.

## 4.2 Methodology

Kereru were radio tracked as described in Chapter 2 and data regarding the reproductive cycle were collected while tracking (i.e., number of display flights performed by make kereru, start of egg-laying, chick hatching and fledging, and nest fate). When a breeding pair laid an egg, or when a chick was present in a nest, it was regarded as a nesting attempt.

The identical plumage and similar behaviour of male and female kereru outside the breeding season made it difficult to sex birds before the breeding season (Mander *et al.*, 1998). The sex of tagged kereru was determined by records of display flights performed by male kereru and the incubation roster of male/female kereru (Mander *et al.*, 1998).

### *4.2.1 Timing of the reproductive cycle*

The non-breeding season was from the start of this study until male kereru began performing display flights. The start of the reproductive cycle for the 2004-2005 breeding season was defined as the period when male kereru first performed display flights, until the end of the final nesting attempts (see section 4.2.2). The date at which eggs were laid and chicks hatched and fledged, were recorded whenever possible.

### *4.2.2 Breeding pairs and nesting attempts*

Nesting attempts could be located only while tagged kereru were incubating. Because the sex of tagged kereru was unknown before the breeding season, it was therefore unknown when each breeding kereru would be incubating (see section 4.1). Kereru were regularly tracked during times both males and females were incubating; early in the morning (7-10 am), during mid-day (12-3 pm), and late during afternoon (4-7 pm) on a weekly basis from September 2004 to March 2005. Once the sex of kereru was determined and nest locations known, daily checks of the nests were conducted to confirm nesting activity each field week and to record nest fate.

### *4.2.3 Nest height and tree species preference*

To analyse the height range at which kereru nested and tree species used, the number of nesting attempts in each vegetation type (see Chapter 3) was recorded, as well as the tree species' origin (i.e., native or introduced) in which each nest was built, and the nests' approximate height above the ground.

### *4.2.4 Nest sites and areas of human occupancy*

Disturbance of nesting sites by humans during the early stages of the reproductive cycle was thought to cause nest abandonment (Mander *et al.*, 1998). The distance of nesting sites to the following categories of areas with human activity, was measured: 1) walkway, 2) recreational area, 3) road, 4) beach front, and 5) residential garden. ArcGIS 9.0 was used to create a map representing the nest sites and areas of human occupancy.

## 4.3 Results

Two tagged male and two tagged female kereru bred at Church Bay. At Orton Bradley Park, three tagged males and three tagged females bred (see Table 4.1). At each study site, one of the breeding pairs had both the male and female tagged (kereru 18 and 38 at Church Bay; kereru 20 and 30 at Orton Bradley Park) while the remaining tagged kereru paired up with untagged kereru.

**Table 4.1. Sex of kereru breeding in Church Bay and Orton Bradley Park**

| Study site where kereru was breeding | Kereru no. | Sex (male / female) |
|---|---|---|
| Church Bay | 10 | m |
| | 18 | m |
| | 36 | f |
| | 38 | f |
| Orton Bradley Park | 20 | f |
| | 22 | f |
| | 24 | f |
| | 28 | m |
| | 30 | m |
| | 32 | m |

### *4.3.1 Timing of the reproductive cycle*

The timing of the reproductive cycle is summarised in Figure 4.1. The breeding season (or reproductive cycle) began in mid July 2004 and continued until at least the end of March 2005. The peak of male kereru performing display flights was in the first month of the breeding season in July and August, before the first nesting attempts were recorded. Males continued to perform display flights throughout the breeding season. At least one breeding pair attempted to nest in each field week from early September onwards. Chicks began hatching and fledging in October and November. The reproductive cycle was still underway in the final field week in March with at least one kereru incubating.

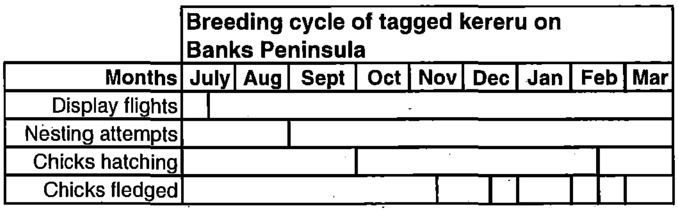
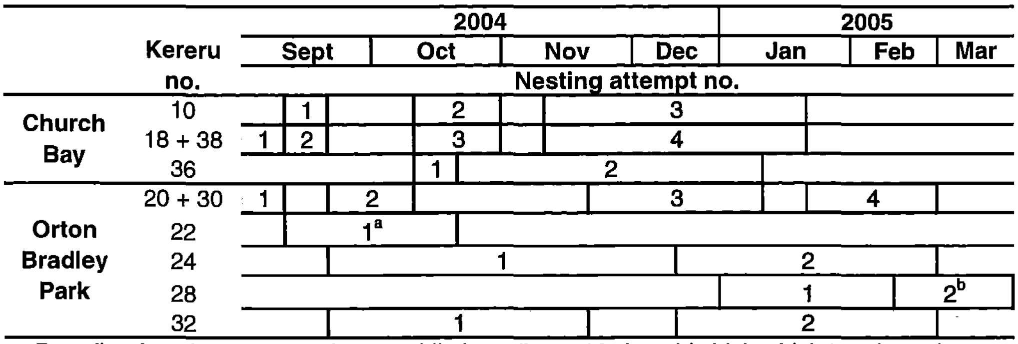



**Figure 4.1. Timing of the reproductive cycle as recorded for kereru on Banks Peninsula.**

### *4.3.2 Breeding pairs and timing of nesting attempts*

Ten out of fifteen (67 %) kereru were observed frequently enough to confirm breeding, forming eight breeding pairs; the remaining kereru were not observed regularly enough to determine if they bred. Of two breeding pairs, both female and male kereru were radio-tagged (kereru 18-38 and 20-30); of six other pairs, either the male or female was radio-tagged (Table 4.1, Figure 4.2). All known pairs re-nested (except one female (kereru 22) that died due to predation; Figure 4.2) and a total of 20 nesting attempts was recorded (average of 2.5 nests for each pair).

Of all 20 nesting attempts, seven fledged chicks (35% success rate). The other nesting attempts failed either at egg stage (12) or chick stage (1) due to abandonment, predation, or the egg falling through the nest (T.A. Prendergast, *pers. comm.*). These nest failures caused a gap in the period during which chicks were hatching, from mid-February onwards, and in the period chicks were fledging in parts of December, February, and from March onwards (T.A. Prendergast, *pers. comm.*) (Figure 4.2 and Table 4.2).




a: Breeding female was preyed upon while brooding a 10-day old chick which terminated the nesting attempt.
b: Kereru continued to incubate beyond final field day.

**Figure 4.2. The kereru recorded nesting with the number and timing of nesting attempts for each pair.**

**Table 4.2. Records of kereru nests at Church Bay and Orton Bradley Park with the fate and the stage of failure of each nest**

| | Tagged kereru no. + sex | Nesting attempt no. | Nest fate | Stage at which nest failed |
|---|---|---|---|---|
| Church Bay | 10 m | 1 | Preyed on | Egg |
| | | 2 | Abandoned | Egg |
| | | 3 | Chick fledged | N/A |
| | 18/38 m/f | 1 | Egg fell through nest | Egg |
| | | 2 | Egg fell through nest | Egg |
| | | 3 | Preyed on | Egg |
| | | 4 | Chick fledged | N/A |
| | 36 f | 1 | Unknown | Egg |
| | | 2 | Chick fledged | N/A |
| Orton Bradley Park | 20/30 m/f | 1 | Preyed on | Egg |
| | | 2 | Preyed on | Egg |
| | | 3 | Abandoned | Egg |
| | | 4 | Abandoned | Egg |
| | 22 f | 1 | Preyed on | Chick |
| | 24 f | 1 | Chick fledged | N/A |
| | | 2 | Chick fledged | N/A |
| | 28 m | 1 | Abandoned | Egg |
| | | 2 | underway (egg stage) | N/A |
| | 32 m | 1 | Chick fledged | N/A |
| | | 2 | Chick fledged | N/A |

*4.3.3 Nest height and tree species used for nest building*

Of 20 nesting attempts, 13 nests were built in native trees and seven in introduced tree species (Table 4.3). Nine nests were built in native vegetation types, and 11 nests were built in vegetation types with introduced species but four of these 11 were in native trees (Table 4.3).

Nest heights varied between 2-15 m with a mean of 7.4 m; mean nest height was 6.2 m in Church Bay and 9.4 m in Orton Bradley Park. The lowest nest was in native tree species (2 m) and highest were two nests in introduced tree species (15 m).

**Table 4.3. Nest sites, vegetation types, and origin of tree species used for nesting.**

| Vegetation types* used for nest building at each study site | No. of nesting attempts | Nest height (m.) in the tree species: Native | Nest height (m.) in the tree species: Introduced |
|---|---|---|---|
| **Church Bay*** | | | |
| Hunter Native Reserve (Scenic Reserve) | 5 | 10, 10, 4, 4, 2 | |
| Tree lucerne - eucalypt stand | 2 | | 10, 15 |
| Residential gardens | 1 | | 5 |
| Tree lucerne - conifer stand | 1 | | 5 |
| **Orton Bradley Park*** | | | |
| Te Wharau Stream (play/ campgrounds) | 4 | 5 | 8, 15, 8 |
| Regenerating natives (kowhai stand) | 4 | 8, 4, 10, 10 | |
| Andersons' Road park | 2 | 7, 4 | |
| Tree lucerne - eucalypt block | 1 | 3 | |
| Total no. of nests | 20 | 13 | 7 |

*: see Chapter 3 for a desctiption of the study sites and vegetation types

*4.3.4 Nest sites and areas of human occupancy*

Kereru attempted to nest within <1 to 1250 m of road sides, walkways and recreational areas where human use was frequent (Figure 4.3a, b).

**Legend on right side of figure:** Tagged kereru numbers with the next number shown after the full stop (e.g., 10.2 is kereru number 10, nest two).

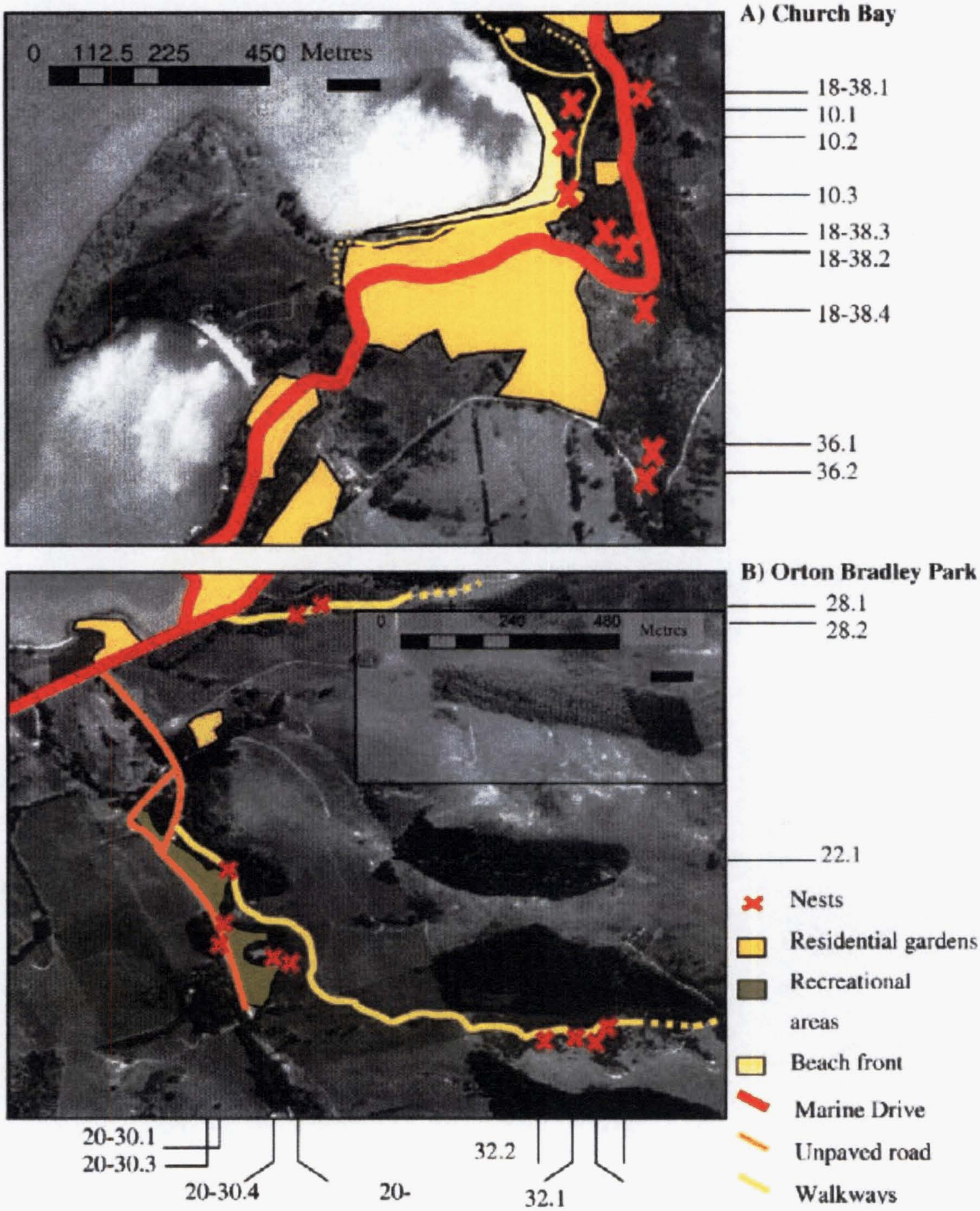



**Figure 4.3. Maps of A) Church Bay and B) Orton Bradley Park showing locations of nests and areas occupied by humans.**

## 4.4 Discussion

The timing of the reproductive cycle in this study was comparable to the timing reported in previous studies where kereru attempted to nest over summer, although timing of breeding encompassed a larger part of the year in other (warmer) parts of New Zealand (Clout *et al.*, 1988; Clout, 1990; Clout *et al.*, 1995; Pierce & Graham, 1995). The timing of the reproductive cycle appears strongly affected by food availability and predicting the exact timing of the cycle is difficult in any kereru population. These studies, conducted over multiple breeding seasons, found that the start and length of breeding seasons differed between years within the same population. While this study recorded the timing of the reproductive cycle from mid-July 2004 to at least March 2005, additional studies would supply information on variation between years and how the number of nesting attempts is affected by factors such as food availability.

The proportion of kereru involved in nesting during this study (67%) and the breeding success rate (35%) suggest that kereru at the study sites had a reasonably successful breeding season compared with other study populations on mainland New Zealand (Clout *et al.*, 1995; Pierce & Graham, 1995; Powlesland *et al.*, 2003) (Table 4.4). Several observations made during this study suggested the successful breeding season and the number of nesting attempts was not limited by availability of factors such as food and presence of suitable nesting sites:

- During this study, eight breeding pairs attempted to nest, and seven attempted to re-nest with an average of 2.5 nests for each pair; one breeding tagged kereru was preyed upon and could not re-nest (Table 4.2; also see Chapter 7). Other studies recorded up to four attempts in one season, but the number of pairs that re-nested was lower than those recorded in this study: Clout *et al.* (1995) found 50% of pairs to re-nest; Powlesland (2003) recorded one and two re-nesting attempts (in two breeding seasons) out of seven and 12 first nests.
- At least two pairs attempted at least four nests (Table 4.2). One of these pairs did not fledge a chick; the other one did on the final nesting attempt.
- Two pairs attempted to nest again after successfully fledging a chick, and both these pairs successfully fledged chicks on the second attempt (Table 4.2).
- Two pairs, of which nests were preyed upon, attempted to nest up to two or three times. One of these two pairs fledged a chick on the third attempt (Table 4.2).

The reproductive success of a study on the Chickens Islands and one in Whirinaki Forest Park suggest the reproductive output can be higher when fewer predatory mammals are present (Pierce & Graham, 1995; Powlesland *et al.*, 2003) (Table 4.4).

**Table 4.4. Summary of fledge rates of three studies conducted on reproductive success of kereru, including the present study.**

| Studies conducted on reproductive success | Study area | Total no. of nests observed | Fletch rate (%) |
|---|---|---|---|
| Pierce & Graham (1995) | Maungatapere[a] | 31 | 19 |
| | Chickens Islands[b] | 16 | 63 |
| Clout *et al.* (1995) | Pelorus Bridge[a] | 45 | 22 |
| | Mohi Bush[a] | 9 | 0 |
| | Wenderholm Regional Park[a] | 20 | 0 |
| Powlesland *et al.* (2003) | Whirinaki Forest Park (1998/99)[a] | 8 | 25 |
| | Whirinaki Forest Park (2001/02)[b] | 14 | 75 |
| Present study | Banks Peninsula[a] | 20 | 35 |

[a]: Study on mainland New Zealand; predatory mammals and birds present

[b]: Population with relatively few predatory mammals (i.e., off-short island or mainland island with predator control)

Predation was the definite cause of failure of 25% of nesting attempts recorded in this study (T.A. Prendergast, *pers. comm.*). Compared with other studies conducted on mainland New Zealand, predation rates were low and approached those of pairs in relatively predator free areas (i.e., Chickens Islands and Whirinaki Forest Park) (Table 4.5). One study on mainland New Zealand showed nesting success increases after predator control (Powlesland *et al.*, 2003).

Kereru were not limited to nesting in native forest patches, and have successfully nested in patches of forest with mainly introduced tree species and in residential gardens. Nests were recorded to be closer to the ground in native forest patches. However, nest height appeared to be unaffected by the presence of humans since nests were between 2 and 8 m high in areas occupied by humans. Nests in more distant locations were within the same height range (Table 4.3). However, the extent to which humans disturb nesting kereru should be investigated in future research.

**Table 4.5. Summary of predation rates of three studies conducted on reproductive success of kereru, including the present study.**

| Studies conducted on reproductive success | Study area | Proportion of nests preyed upon* (%) | Success rate* (%) |
|---|---|---|---|
| Pierce & Graham (1995) | Maungatapere[a] | 42 | 19 |
| | Chickens Islands[b] | 19 | 63 |
| Clout *et al.* (1995) | Pelorus Bridge[a] | 58 | 24[e] |
| | Mohi Bush[a] | 44 | 0 |
| | Wenderholm Regional Park[a] | 60 | 0 |
| Powlesland *et al.* (2003) | Whirinaki Forest Park (1998/99)[a] | 75** | 25 |
| | Whirinaki Forest Park (2001/02)[b] | 25** | 75 |
| Present study | Banks Peninsula[a] | 25 | 35 |

*: Reproduced from the studies

**: Proportion of unsuccessfull nests, possibly including causes other than predation

[a]: Study on mainland New Zealand; predatory mammals and bird present

[b]: Population with relatively few predatory mammals (i.e., off-short island or mainland island with predator control)

[e]: 24% ± 0-0.6 over seven breeding seasons

Previous studies suggest that chicks fledging by four weeks indicates good food quality and quantity; chicks fledging after four weeks indicates poorer food quality (Clout *et al.*, 1995; Mander *et al.*, 1998). In this study, seven chicks fledged between four and nine weeks after hatching. This observation does not confirm or exclude the presence of good or poor food quality in the study sites as no previous studies reported on the length of chick rearing phases in rural-urban landscapes. Rather, this suggests that kereru in rural-urban landscapes have adjusted the length of the chick rearing stage to the food species available to them and are capable of raising chicks (at least partly) on a diet of introduced food species (see section 5.4.3).

# Chapter 5

## Foods eaten by kereru (*Hemiphaga novaeseelandiae*) in the Lyttelton Harbour Basin, Banks Peninsula

### 5.1 Introduction

The rapid destruction of the original native forests on Banks Peninsula in the past 150 years has caused a decline in native food availability for forest-dwelling birds such as kereru (*Hemiphaga novaeseelandiae*) (Wilson, 1998) (see Chapter 3). During European settlement, plant species foreign to New Zealand were introduced and these now dominate in most urban and rural landscapes throughout New Zealand, including Banks Peninsula (Wilson, 1998). Despite the recent modifications of the landscape, kereru appear to have remained on Banks Peninsula but few data are available to support this statement (Clout, 1988; Crossland, 1996).

In the past 30 years, studies investigating kereru diet were conducted at several locations throughout New Zealand, mostly in tracts of native forest (Beveridge, 1964; McEwan, 1978; Clout, 1990; Pierce & Graham, 1995; Mander *et al.*, 1998; Ridley, 1998). These studies suggest kereru movement is regulated by food availability, and also suggest that the timing of the reproductive cycle is triggered by native fruit availability, where the quality and quantity regulates the number of nesting attempts (Clout *et al.*, 1991; Pierce *et al.*, 1993; Clout *et al.*, 1995) (see Chapter 4). Also, these studies suggest that exotic plant species may benefit kereru by providing food (Ridley, 1998).

In spite of previous research, it remains unclear if certain foods bring kereru into breeding condition (Mander *et al.*, 1998). Ongoing studies in Invercargill and New Plymouth investigate methods to enhance kereru populations and to retain kereru's role as a seed disperser of native tree species in forest fragments (R. Powlesland, *pers. comm.*). These studies also investigate kereru diet and food availability in urban and rural environments. There remains limited knowledge of food availability and quality in rural-urban landscapes such as on Banks Peninsula with patches of regenerating native forest, and how this affects survival and reproductive output.

Researchers had thought that kereru in rural-urban landscapes would require (native) fruiting food species to trigger the reproductive cycle (T.C. Greene, K-J. Wilson, *pers. comm.*). Researchers expected that the quality of food in the rural-urban landscapes on Banks Peninsula to be lower compared to original native forests, and they had suggested an increase in food availability and quality might well contribute to a population increase through improved breeding success (P. Dilks, T. C. Greene, S. Ogilvie, K-J. Wilson *pers. comm.*).

This chapter describes the food species and food types eaten by kereru during this study, including a description of seasonal changes. The focus was especially on food species and types eaten during winter, and before and during the breeding season.

## 5.2 Methodology

A study of food species and food types eaten by kereru was carried out simultaneously with the analysis of home ranges and movements (see Chapter 6) from February 2004 to March 2005 (13 months).

Data regarding food species and food types eaten were collected whenever a kereru was observed feeding. A food species is defined as a plant on which tagged kereru were feeding; food types included were flowers, leaves, fruit. The food species and type recorded was the first species and item eaten (Magrath & Lill, 1983; Hill, 2003). Because kereru eat multiple food types of single food species in a single observation, one change was made to the methods used by Magrath and Lill (1983) and Hill (2003): when a kereru ate multiple types of one species during one observation, all food types eaten of the first food species were recorded (e.g., combination of leaves and flowers of the same plant). Kereru were observed for no more than 30 minutes and observations were at least two hours apart (see Chapter 2).

Initially, all data were pooled across all kereru to describe food species and food types. To investigate differences between study sites, data were also pooled according to the geography of the study sites (see Chapter 3). Statistical analysis of data sets was not viable due to inconsistency in the number of kereru observed eating and the number of eating observations of each kereru each week. Analyses of food species and types were therefore descriptive.

For the purpose of this chapter plant species will be referred to by their common name (where possible), species names are given in Appendix 4.

*5.2.1 Number of kereru available for observation*

A record was kept of the number of kereru available for behavioural observation each week (i.e., kereru which could be visually observed). The proportion of kereru observed eating was calculated from the total number of kereru available.

*5.2.2 Food species eaten*

A score of '1' was given to a food species whenever at least one kereru was recorded eating a food species on at least one occasion each week. To illustrate the food species eaten over time, a pivot table was created from these data. The total number of food species eaten during each week was determined from the pivot table. The proportion of native versus introduced species eaten each week was calculated from the pivot table, and presented in a bar chart.

*5.2.3 Relative importance of food species*

With one exception, food species data were obtained from visual observations; the relative importance of different species is therefore based on frequency of observation, not volume. Only one kereru was found dead with sufficient food in its crop to provide relative food species importance by weight (see section 5.4.3.).

A test to assess whether kereru targeted particular species in their diet (i.e., a comparison of species composition with the data pooled across all kereru) was not feasible as detailed information on vegetation composition in the study sites was not obtainable, and data were not statistically consistent (see section 5.1). Nonetheless, two calculations were used to determine which food species were relatively more important each week:

a) Proportion of kereru observed eating each food species; the number of kereru observed eating on each food species were added, and the sum divided by the total number of kereru observed eating each week.

b) Proportion of feeding observations on each food species; the number of occasions on which kereru were observed eating each food species was recorded each week, and divided by the sum of all feeding observations recorded that week.

The food species were referred to as 'relatively more important' when the proportion score was =0.4 for both calculations. The choice of this threshold is subjective, and was selected to identify one or two relatively more important species in most weeks. Individual kereru were often recorded eating more than one food species during any given week. The proportions were calculated for each species independently and proportions therefore do not add to 1.

### *5.2.4 Food types eaten*

Food types eaten were categorised as leaves, flowers, fruits, or a combination of these (see section 5.1). A score of '1' was given whenever a kereru was recorded eating a food type each week. To illustrate the food types eaten on each species, a pivot table was created from these data. A second table was created showing when leaves, flowers, and fruits, were eaten over time.

### *5.2.5 Importance of food species eaten at different study sites*

Kereru were divided into groups according to the geographical location of their home ranges (see Chapter 6). Only data from kereru which were present at Church Bay and Orton Bradley Park were included in this analysis, in a similar manner to sections 5.2.2 and 5.2.3. Data collected at Puaha and Port Levy were used to confirm use of species in locations other than the main study sites Church Bay and Orton Bradley Park.

## 5.3 Results

### *5.3.1 Number of kereru available for observation*

The number of kereru available for behavioural observation (i.e., kereru that were visible within the vegetation) each week ranged from nine to 15 (Figure 5.1). The number of kereru observed feeding each week ranged from four to thirteen (Figure 5.1).

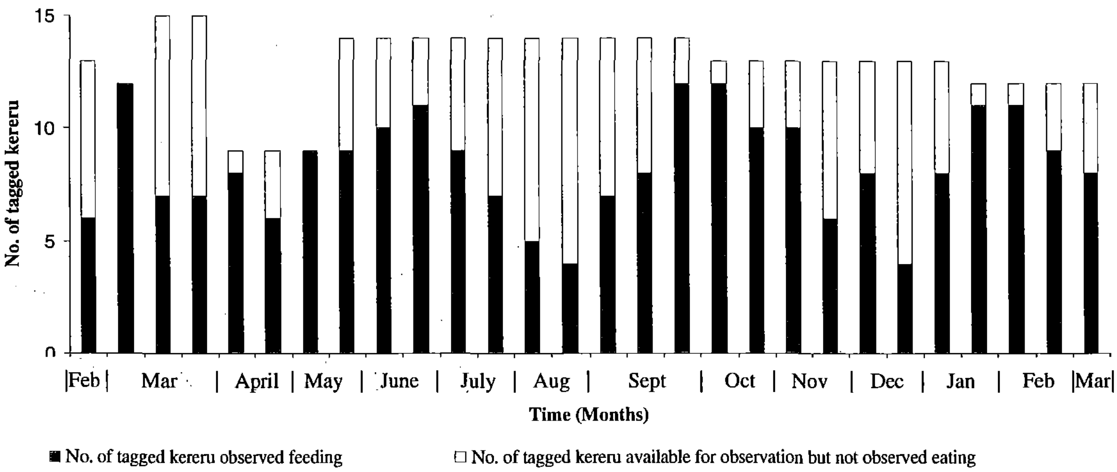



**Figure 5.1. The number of kereru available for behavioural observation and the number of kereru observed eating each week.**

### *5.3.2 Food species eaten*

In total, 23 different food species were eaten over the entire study period: 11 native species (*Coprosma rhamnoides*, cabbage tree *(Cordyline* spp.*)*, poroporo (*Solanum aviculare, S. lacinaiatum),* ngaio (*Myoporum laetum)*, kawakawa *(Macropiper excelsum)*, five-finger (*Pseudopanax arboreus)*, fuchsia *(Fuchsia excorticata)*, titoki (*Alectryon excelsus)*, kowhai (*Sophora* spp.), pohuehue (*Muehlenbeckia* spp.*)*, and mahoe (*Melicytus ramiflorus*)) and 12 introduced species (tree lucerne *(Chamaecytisus palmensis)*, willow (*Salix* spp.*)*, alder (*Alnus glutinosa*), fruit trees (*Prunus spp.*; plum, apricot, and cherry), acacia (*Racosperma* spp.*)*, elm (*Ulmus xhollandica)*, chestnut *(Aesculus hippocastanum)*, walnut (*Juglans* spp.*)*, oak (*Quercus* spp.), broom (*Cytisus scoparius*), poplar (*Populus* spp.), and *Laburnum anagyroides* (Figure 5.2).

Kereru ate two to eight different species each week (Figure 5.2). The number of species eaten was lower during the latter half of autumn, from late April to August (two to three), than during the rest of the year (four to nine), except during mid-March, late-December, and early January, when few species were eaten as well (two to three).

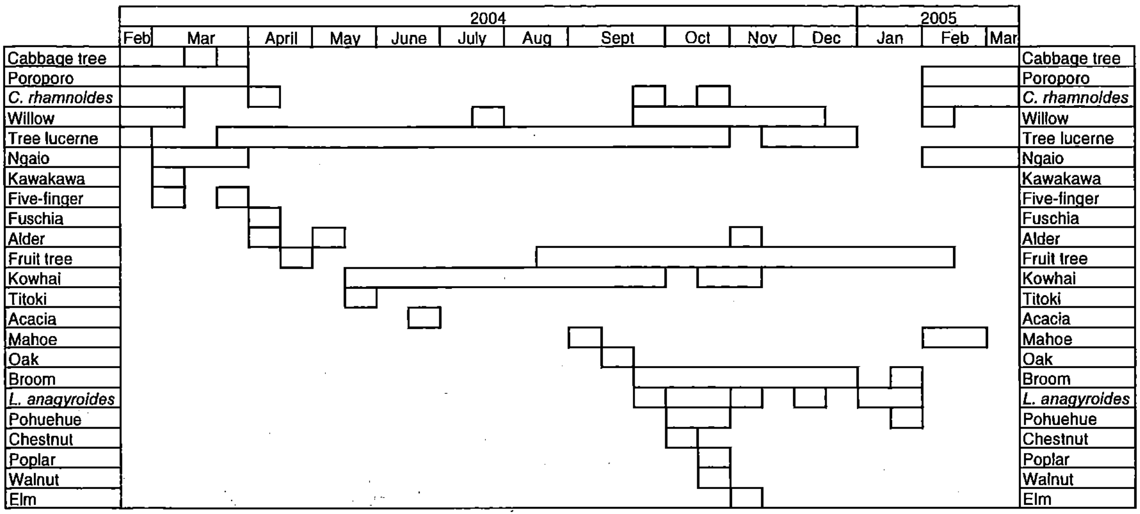



**Figure 5.2. The food species eaten by kereru each week, during the study period from February 2004 to March 2005.**

The diet of kereru consisted of at least 50% introduced food species from April to January, except during late May (Figure 5.3). Tagged kereru ate solely introduced species in late April, early May, and between late November and mid-January. At least 50% native food species were eaten from February to March 2004, late May 2004, and February to March 2005. In March 2004, and late February to early March 2005, kereru ate at least 80% native species (Figure 5.3).

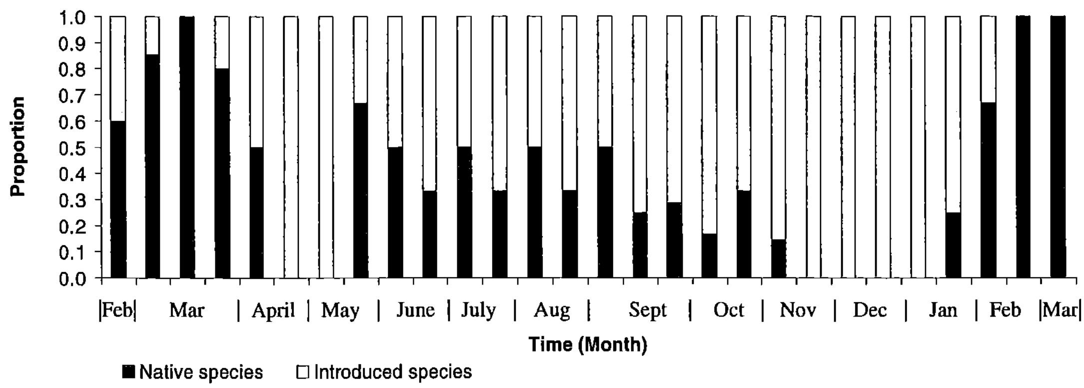



**Figure 5.3. Proportion of native versus introduced species eaten by kereru**

### 5.3.3 *Relative importance of food species*

The proportion of kereru eating each food species and the proportion of feeding observations for each food species varied from 0.1 to 0.9 (Tables 5.1a and b). Only four species were scored as relatively more important (i.e., =0.4) (Tables 5.1a and b) by both methods used to calculate importance: two native species (poroporo and kowhai), and several introduced species (tree lucerne and fruit trees). Tables 5.1a and b also show that:

- During most weeks, only one species had a proportion of =0.4, except in early July, late August, and mid-September.
- During late-March, late-September, and late-October to early November, no food species eaten were relatively more important.
- Ngaio, *Coprosma rhamnoides*, willow, and broom were the only species with a relative importance of =0.4 in only one of the two calculations used to determine importance.

The number of kereru recorded eating more than one food species each week ranged from zero to six. In other words, one species was relatively more important in the diet of each kereru each week.

**Table 5.1a. Proportion of kereru feeding on each food species. Proportions of =0.4 (considered relatively more used) are highlighted.**

| | 2004 | | | | | | | | | | | | | | | | | | | | | | | 2005 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feb | Mar | | | April | | May | | June | | July | | Aug | | Sept | | | Oct | | Nov | | Dec | | Jan | | Feb | | Mar | |
| Cabbage tree | 0.2 | 0.1 | | 0.3 | | | | | | | | | | | | | | | | | | | | | | | | | Cabbage tree |
| Poroporo | 0.8 | 0.4 | 0.7 | 0.1 | | | | | | | | | | | | | | | | | | | | | | 0.2 | 0.7 | 0.5 | Poroporo |
| *C. rhamnoides* | 0.2 | 0.2 | | | 0.4 | | | | | | | | | | | | 0.1 | | 0.1 | | | | | | | 0.1 | 0.1 | 0.3 | *C. rhamnoides* |
| Willow | 0.3 | 0.1 | | | | | | | | | | 0.1 | | | | | 0.4 | 0.4 | 0.1 | 0.1 | 0.2 | 0.1 | | | | 0.1 | | | Willow |
| Tree lucerne | 0.2 | | | 0.3 | 0.9 | 1.0 | 1.0 | 0.9 | 0.9 | 0.9 | 0.6 | 0.9 | 0.6 | 0.8 | 0.7 | 0.6 | 0.4 | 0.3 | 0.3 | | 0.5 | 0.1 | 0.3 | | | | | | Tree lucerne |
| Ngaio | | 0.3 | 0.4 | 0.3 | | | | | | | | | | | | | | | | | | | | | | 0.1 | 0.3 | 0.4 | Ngaio |
| Kawakawa | | 0.2 | | | | | | | | | | | | | | | | | | | | | | | | | | | Kawakawa |
| Five-finger | | 0.1 | | 0.3 | | | | | | | | | | | | | | | | | | | | | | | | | Five-finger |
| Fuschia | | | | | 0.1 | | | | | | | | | | | | | | | | | | | | | | | | Fuschia |
| Alder | | | | | 0.3 | | 0.1 | | | | | | | | | | | | | 0.2 | | | | | | | | | Alder |
| Fruit tree | | | | | | 0.2 | | | | | | | | 0.3 | 0.1 | 0.6 | 0.4 | 0.8 | 0.2 | 0.3 | 0.3 | 0.5 | 0.8 | 0.9 | 0.9 | 0.5 | | | Fruit tree |
| Kowhai | | | | | | | | 0.1 | 0.1 | 0.1 | 0.7 | 0.1 | 0.4 | 0.8 | 0.1 | 0.1 | 0.1 | | 0.2 | 0.3 | | | | | | | | | Kowhai |
| Titoki | | | | | | | | 0.1 | | | | | | | | | | | | | | | | | | | | | Titoki |
| Acacia | | | | | | | | | | 0.1 | | | | | | | | | | | | | | | | | | | Acacia |
| Mahoe | | | | | | | | | | | | | | | 0.1 | | | | | | | | | | | 0.2 | 0.1 | | Mahoe |
| Oak | | | | | | | | | | | | | | | | 0.1 | | | | | | | | | | | | | Oak |
| Broom | | | | | | | | | | | | | | | | | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.1 | 0.5 | | 0.2 | | | | Broom |
| *L. anagyroides* | | | | | | | | | | | | | | | | | 0.1 | | | 0.1 | | 0.1 | | 0.1 | 0.1 | | | | *L. anagyroides* |
| Pohuehue | | | | | | | | | | | | | | | | | | 0.2 | 0.1 | | | | | | 0.2 | | | | Pohuehue |
| Chestnut | | | | | | | | | | | | | | | | | | 0.1 | | | | | | | | | | | Chestnut |
| Poplar | | | | | | | | | | | | | | | | | | | 0.2 | | | | | | | | | | Poplar |
| Walnut | | | | | | | | | | | | | | | | | | | 0.1 | | | | | | | | | | Walnut |
| Elm | | | | | | | | | | | | | | | | | | | | 0.1 | | | | | | | | | Elm |

**Table 5.1b. Proportion of feeding observations on each food species. Proportions of =0.4 (considered relatively more used) are highlighted.**

| | 2004 | | | | | | | | | | | | | | | | | | | | | | 2005 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feb | Mar | | | April | | May | | June | | July | | Aug | | Sept | | | Oct | | Nov | | Dec | | Jan | | Feb | | Mar | |
| Cabbage tree | 0.1 | 0.1 | | 0.2 | | | | | | | | | | | | | | | | | | | | | | | | | Cabbage tree |
| Poroporo | 0.5 | 0.4 | 0.7 | 0.2 | | | | | | | | | | | | | | | | | | | | | | 0.2 | 0.5 | 0.4 | Poroporo |
| *C. rhamnoides* | 0.1 | 0.1 | | | 0.2 | | | | | | | | | | | | 0.0 | | 0.1 | | | | | | | 0.1 | 0.1 | 0.2 | *C. rhamnoides* |
| Willow | 0.2 | 0.1 | | | | | | | | | | 0.2 | | | | | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | | | | 0.1 | | | Willow |
| Tree lucerne | 0.1 | | | 0.2 | 0.7 | 0.9 | 0.9 | 0.9 | 0.9 | 0.8 | 0.5 | 0.7 | 0.7 | 0.5 | 0.6 | 0.4 | 0.3 | 0.1 | 0.2 | | 0.4 | 0.2 | 0.1 | | | | | | Tree lucerne |
| Ngaio | | 0.2 | 0.3 | 0.2 | | | | | | | | | | | | | | | | | | | | | | 0.1 | 0.2 | 0.3 | Ngaio |
| Kawakawa | | 0.1 | | | | | | | | | | | | | | | | | | | | | | | | | | | Kawakawa |
| Five-finger | | 0.1 | | 0.2 | | | | | | | | | | | | | | | | | | | | | | | | | Five-finger |
| Fuschia | | | | | 0.1 | | | | | | | | | | | | | | | | | | | | | | | | Fuschia |
| Alder | | | | | 0.1 | | 0.1 | | | | | | | | | | | | | 0.1 | | | | | | | | | Alder |
| Fruit tree | | | | | | 0.1 | | | | | | | | 0.1 | 0.2 | 0.5 | 0.3 | 0.5 | 0.1 | 0.2 | 0.3 | 0.4 | 0.6 | 0.9 | 0.8 | 0.5 | | | Fruit tree |
| Kowhai | | | | | | | | 0.1 | 0.1 | 0.1 | 0.5 | 0.1 | 0.3 | 0.4 | 0.1 | 0.1 | 0.0 | | 0.1 | 0.2 | | | | | | | | | Kowhai |
| Titoki | | | | | | | | 0.1 | | | | | | | | | | | | | | | | | | | | | Titoki |
| Acacia | | | | | | | | | | 0.0 | | | | | | | | | | | | | | | | | | | Acacia |
| Mahoe | | | | | | | | | | | | | | | 0.1 | | | | | | | | | | | 0.2 | 0.2 | | Mahoe |
| Oak | | | | | | | | | | | | | | | | 0.1 | | | | | | | | | | | | | Oak |
| Broom | | | | | | | | | | | | | | | | | 0.0 | 0.0 | 0.1 | 0.3 | 0.3 | 0.1 | 0.3 | | 0.1 | | | | Broom |
| *L. anagyroides* | | | | | | | | | | | | | | | | | 0.0 | | | 0.1 | | 0.2 | | 0.1 | 0.0 | | | | *L. anagyroides* |
| Pohuehue | | | | | | | | | | | | | | | | | | 0.1 | 0.1 | | | | | | 0.1 | | | | Pohuehue |
| Chestnut | | | | | | | | | | | | | | | | | | 0.0 | | | | | | | | | | | Chestnut |
| Poplar | | | | | | | | | | | | | | | | | | | 0.1 | | | | | | | | | | Poplar |
| Walnut | | | | | | | | | | | | | | | | | | | 0.1 | | | | | | | | | | Walnut |
| Elm | | | | | | | | | | | | | | | | | | | | 0.1 | | | | | | | | | Elm |

### *5.3.4 Food types eaten*

Kereru ate leaves of at least one species each week throughout the entire study period, except mid-March 2004 and late-February to March 2005 when kereru ate solely fruits of native species (Figure 5.4). Fruits of *C. rhamnoides* were eaten during parts of September and October; introduced plums were eaten from mid-December until native fruits became available. Kereru ate flowers in combination with leaves and/or fruits of at least one species from mid-May until late-January, except during early January (Figure 5.5).

#### *5.3.4.1 Crop content of a dead kereru*

On 20 October 2004, a female kereru (no. 22) was found dead below her nest in which a ten-day old chick was present. The crop content consisted of 12.2 grams of plum and willow leaves (measurement taken within 24 hours after death).

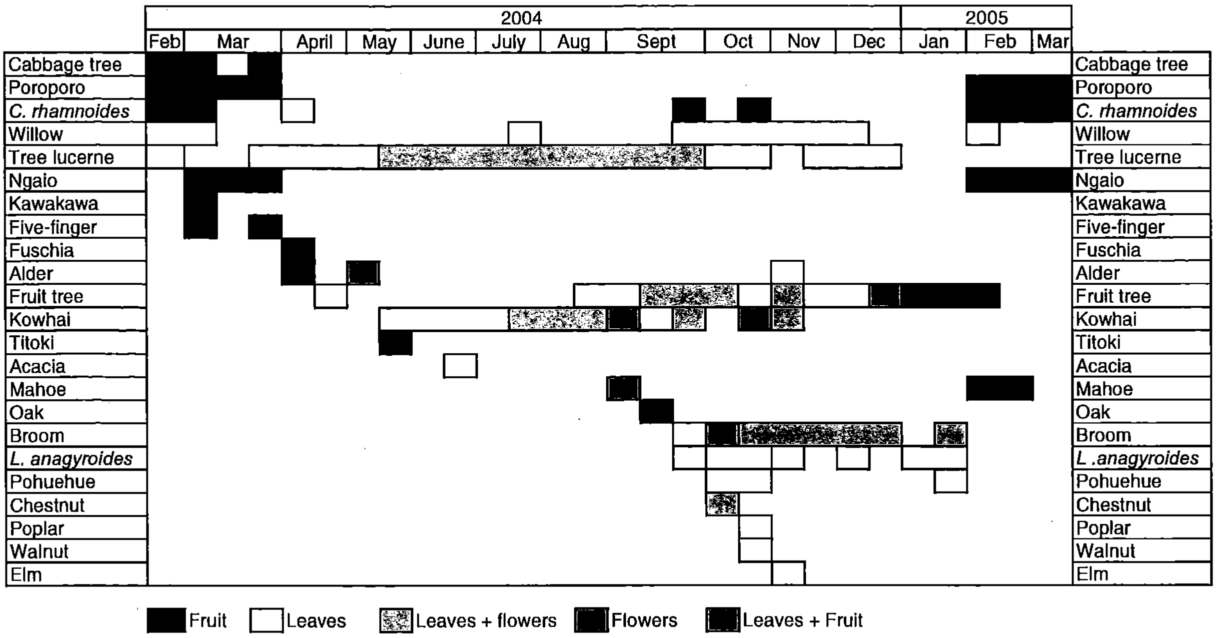



**Figure 5.4. The food species and parts eaten by kereru over time**

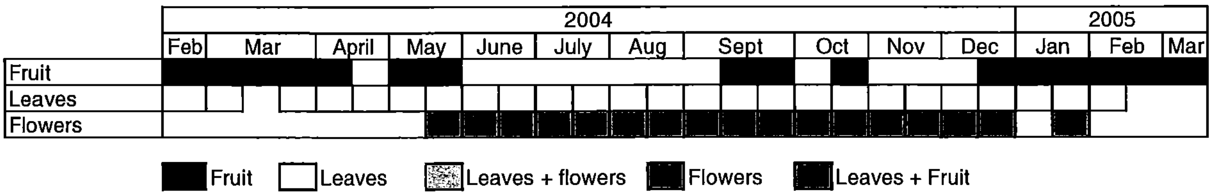



**Figure 5.5. Summary of the food types eaten over time.**

### *5.3.5 Importance of food species eaten at different study sites*

The number of food species eaten at each study site varied: 11 species were eaten in Church Bay, 19 in Orton Bradley Park, five in Puaha, and three species in Port Levy (Table 5.2, Figure 5.6). Fruit trees and kowhai were eaten at all locations while tree lucerne and willow were eaten at three of four locations (Figure 5.6). The number of food species recorded eaten by kereru in Puaha and Port Levy was lower than in Church Bay and Orton Bradley Park, possibly due to there being only one individual at these sites for only part of the year (Table 5.2).

**Table 5.2. The number of native and introduced food species eaten at the study sites Church Bay, Orton Bradley Park, Puaha, and Port Levy.**

| Study site | Total no. of species | No. of introduced species | No. of native species |
|---|---|---|---|
| Church Bay | 11 | 5 | 6 |
| Orton Bradley Park | 19 | 10 | 9 |
| Puaha | 5 | 4 | 1 |
| Port Levy | 3 | 2 | 1 |
| Total species overall sites | 23 | 12 | 11 |

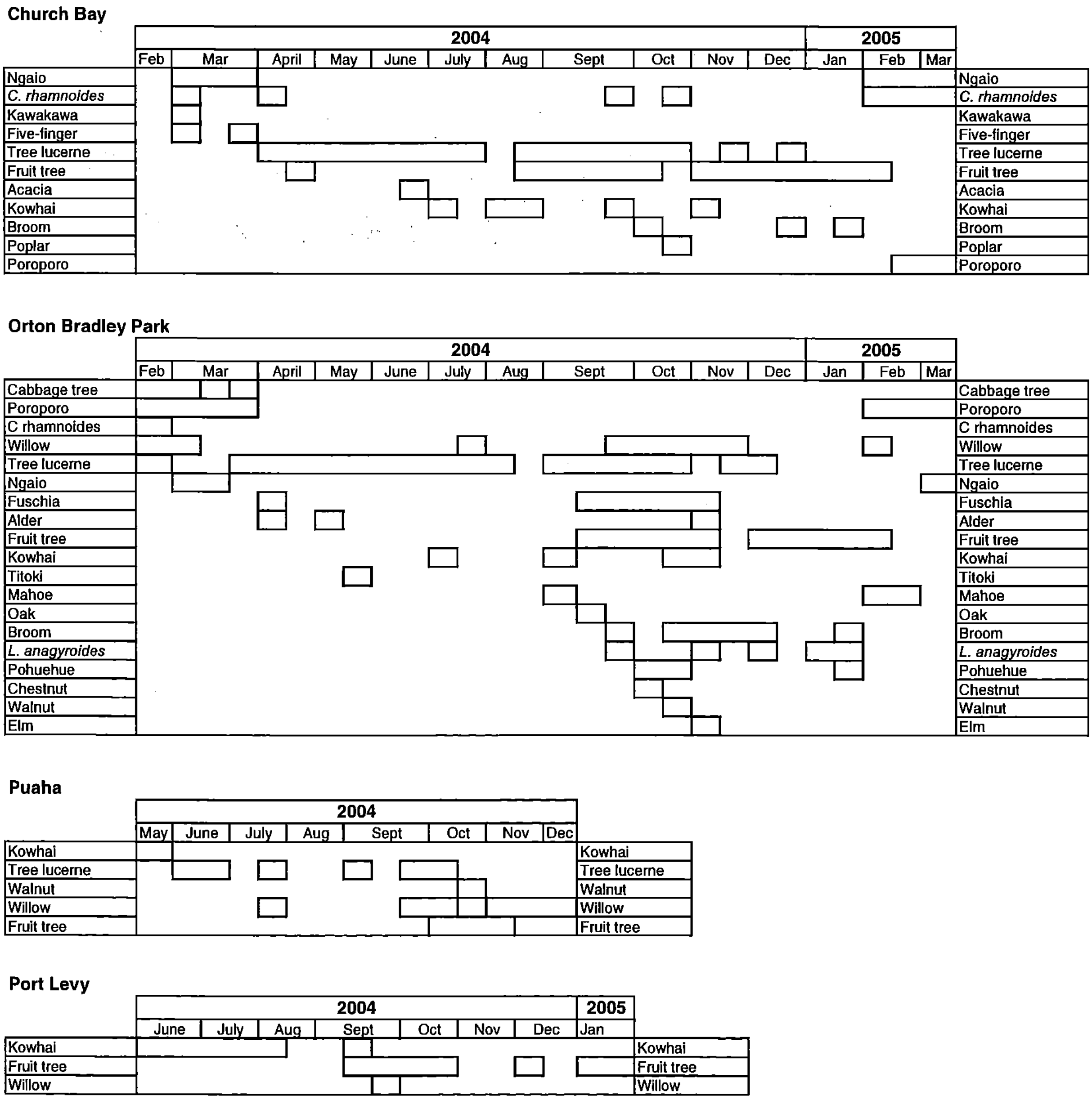



**Figure 5.6. The food species eaten by kereru over time at different study sites**

The relative importance of food species was calculated for Church Bay and Orton Bradley Park (Appendix 5) because kereru were consistently present throughout the study period at these two locations. Species categorised as relatively more important at both study sites were tree lucerne, fruit tree, and kowhai. Species categorised as more important in only one site were:

- Church Bay: ngaio, *C. rhamnoides*, five-finger, and poplar (kawakawa and poroporo were categorised as important in only one of the Figures in Appendix 5).
- Orton Bradley Park: cabbage tree, poroporo, mahoe, and broom (alder and pohuehue were categorised as important in only one of the Figures in Appendix 5)

## 5.4 Discussion

As much of kereru ecology is thought to be related to food availability and quality (see Chapter 1, 4, and section 5.1), knowledge of the food species eaten by kereru could be used to improve food availability and quality at the study sites, in the rural-urban landscape of the greater Banks Peninsula, and in rural-urban landscapes elsewhere in New Zealand (see Chapter 1 and 8). The descriptive list of food species eaten by kereru during this study provides a baseline and will be supplemented in the future by ongoing research of the Kaupapa Kereru Programme (see Chapter 8)

### *5.4.1 Key results regarding the list of food species*

Data gathered during this study ranks the importance of food species eaten by kereru over time. Species categorised as 'relatively more important' were subject to the arbitrary classification of the =0.4 threshold. However, this seemed most appropriate as only one species fell into this category during most weeks. The 'relatively more important' species from Church Bay and Orton Bradley Park suggest the following:

1) Species that were on the list at both locations were eaten during the same times, suggesting they could be preferred food species at that time.
2) Several species are not present on the lists from one location, suggesting that these species are either absent or other food species are preferred.

3) A continuous food supply is available at both locations since there is always at least one species categorised as relatively more important (i.e., in one of the two calculations used to determine relative importance).

Leaves, buds, flowers, and fruits might follow each other successively on the same food species, or are available on different species during the same time (Dijkgraaf, 2002; Hill, 2003). When available, kereru might eat edible parts of species such as tree lucerne, plum tree, broom, and *Laburnum anagyroides*. These species, with multiple edible parts available throughout the year, had a higher chance of being added to the list of food species because kereru spent more time feeding on them. In contrast, when a species had only one part that was edible for a short time period (i.e., kereru eating only the fruit of kawakawa, titoki, fuchsia and ngaio) the chance of such species being added to the list was smaller. The list of food species (see section 5.3.2 and Figure 5.2) shows which species were eaten during this study.

Both native and introduced species were relatively more important during different times of this study. The observations of kereru eating solely introduced food species during parts of the study period suggest they have adjusted to the change in vegetation composition and food source availability; the results of human-modifications of the landscape (Crossland, 1996). Suggested causes for this adjustment could be:

1) Parts of Banks Peninsula lack native food species during parts of the year due to the human-modifications; kereru were forced to eat introduced species or instead were lost from some areas.
2) Native food species are present in low numbers which results in a reduced availability of native food types; kereru feed on introduced species instead.
3) Food types of introduced species are preferred by kereru at times (Dijkgraaf, 2002; Hill, 2003).

In contrast, consumption of solely native fruits during mid to late summer suggests these food species were preferred or introduced species have no food available during that time.

Information from previous research (Clout *et al.*, 1986; Clout *et al.*, 1991; Pierce & Graham, 1995), and from research currently underway in Hinewai Reserve (Campbell, *in progress)*, suggest that additional food species present on Banks Peninsula are: rowan (*Sorbus* *aucuparia*), *Coprosma* spp., broadleaf (*Griselinia littoralis*), horopito (*Pseudowintera colorata*), kahikatea (*Dacrycarpus dacrydioides*), kaikomako (*Pennantia corymbosa*), lancewood (*Pseudopanax* spp.), matai (*Podocarpus spicatus*), red matipo (*Myrsine australis*), pate (*Schefflera digitata*), pigeonwood (*Hedycarya arborea*), supplejack (*Ripogonum scandens*), Hall's totara (*Podocarpus hallii*), wineberry (*Aristotelia serrata*). Landowners looking to improve food availability for kereru (and other fruit eating birds such as bellbird and tui) might consider planting species of this list. It has been recommended to retain introduced deciduous species as a food source for kereru until native food species can supplement their role (Clout *et al.*, 1991).

When kereru were foraging close to the ground (i.e., poroporo), especially during mid to late summer, predation increased (T.A. Prendergast, *pers. comm.*) (see Chapters 7 and 8). Food species with similar physical structure may cause kereru to be potentially more vulnerable to predation, which should be considered. However, predator control in areas where kereru use such food species could reduce the problem.

### *5.4.2 Key results regarding the reproductive cycle*

An abundance of food sources is especially required within breeding season home ranges to support breeding kereru (so they do not have to move long distances between nest and foraging sites). Abundant food is also required during the brooding period through to fledging to sustain nestlings and newly fledged chicks. During this study, 67% of kereru were involved in breeding, and each pair attempted to nest at least twice with at least two pairs attempting to nest at least four times (see Chapter 3). The high number of nesting attempts suggests food supply was not limiting kereru during the breeding season in my study. However, additional research is required to assess what exactly triggers the reproductive cycle in kereru in rural-urban landscapes where the food species and types eaten before and during the breeding season were unlike those recorded in native forests (Clout *et al.*, 1995; Pierce & Graham, 1995; Bell, 1996; Hill, 2003) (see Chapter 4 and 8). Additional research should also assess whether sufficient foods are available to sustain increased population in the future (i.e., following predator control).

A significant finding in my study was that breeding kereru were recorded to eat a leaf-only diet (mostly young leaves of deciduous trees; see section 5.4.3) before switching to a fruit-only diet in February after the first chicks had fledged. I theorise that the availability of leaves and flowers of deciduous and native species (i.e., tree lucerne, willow, fruit trees, *Laburnum anagyriodes*, and kowhai) trigger the reproductive cycle of kereru in the rural-urban landscape on Banks Peninsula. This is based on the following observations:

1) The first nesting attempts were recorded when the first deciduous tree species produced young leaves. The kereru continued to eat leaves and flowers from native and introduced species while brooding chicks to fledging. A relatively higher number of food species were eaten during chick rearing: up to 9 species. Notable was the high proportion (0.7-1.0) of introduced species' leaves eaten.
2) Several chicks had fledged before kereru commenced eating fruit.

I also found that all kereru (breeding and non-breeding) stopped eating leaves, flowers, and fruit of introduced species when native fruits became available. The proportion of native species eaten during the breeding season changed from zero to one within two weeks (Figure 5.3).

Hill (2003) suggested that during some periods of the year, certain foliage might be preferred as a result of lack of food availability, and food types might be carefully selected to meet nutritional needs of kereru. Previous research recorded kereru eating kowhai (Family Fabaceae (or Leguminosae)) leaves before the start of the reproductive cycle, while excluding available fruits from their diet (Hill, 2003). Ridley (1998) also found kereru positively selected kowhai, suggesting it is an important seasonal food source. Kowhai leaves are known to contain protein; a characteristic for this family is the ability to fix atmospheric nitrogen in their leaves (Webb *et al.*, 1988). Protein is important for all forms of growth, including development of eggs, growth of young birds, and growth of new feathers (Hill, 2003). Hill (2003) also suggested that fruits of some species appear to be a preferred food source, but during part of the kereru lifecycle, leaves are a favoured food type.

Observations from this study show that kowhai and tree lucerne (Family Fabaceae (or Leguminosae) (Webb *et al.*, 1988) were eaten before, and during, the breeding season. *Laburnum anagyroides* (Family Fabaceae (or Leguminosae) was eaten by one kereru (no. 28) before breeding. Assuming kereru carefully select food sources during parts of their seasonal cycle, these observations suggest that these three species (and possibly other species of which young leaves were eaten) perform an important role in the rural-urban landscape by providing kereru with protein required for breeding.

Assuming kereru require protein before breeding, the consumption of introduced species' leaves (as opposed to solely kowhai leaves being eaten in native forest, (Hill, 2003) suggested available introduced species may have similar nutritional values to kowhai, or these species were preferred given that kowhai was present within home ranges. Additional research is required to be definite about the nutritional requirements before and during the breeding season, and if introduced species have similar nutritional values as native species such as kowhai.

The observation that breeding kereru ate young leaves of introduced food species (and most likely fed these to their chicks; see Chapter 4) suggests kereru in rural-urban landscapes have adjusted their diet to food sources available to them and are capable of raising chicks at least partly on leaves of introduced food species. This confirms the suggestion made by Ridley (1998) that introduced food species could well be important to kereru in human-modified landscapes during parts of the year; loss of essential food species could well be critical to the survival of kereru especially during winter, to the timing and output of the breeding season, and for an increased population.

Chapter 8 will discuss findings of this chapter in relation to the quality of the main study sites (Chapter 3), management of the local kereru population and landscape on Banks Peninsula, seed and potential weed dispersal, and suggestions for future research.

# Chapter 6

## Home range and movement analysis of kereru (*Hemiphaga novaeseelandiae)* in the Lyttelton Harbour Basin, Banks Peninsula

### 6.1 Introduction

Information about and analyses of home ranges and movements of animals is needed to guide many active species management programmes (van Winkle, 1975; Harris *et al.*, 1990; Kenward, 2001; Millspaugh & Marzluff, 2001). Knowledge of kereru (*Hemiphaga novaeseelandiae)* home ranges and movements within the rural-urban landscape on Banks Peninsula will assist conservation of the local kereru population because it indicates which parts of study sites are used more intensively relative to others, how far kereru move between resources, and the distances over which seeds are dispersed.

Previous studies on kereru addressed the length and timing of seasonal movements in landscapes with mainly native forests and relatively little human-modification (Dawson *et al.*, 1978; Clout & Gaze, 1984; Clout *et al.*, 1986; Wilson *et al.*, 1988; Clout *et al.*, 1991; Pierce & Graham, 1995; Bell, 1996; Hill, 2003). Kereru home ranges have previously been addressed specifically in three of these studies which took place at Maugatapere (Pierce & Graham, 1995), Wenderholm Regional Park (Bell, 1996), and Whirinaki Forest Park (Hill, 2003). These three studies took place in less human-modified areas compared with the rural-urban landscape on Banks Peninsula; the landscape was less fragmented and the size of forest fragments was larger, and there was a higher presence of native food species. Results from those studies suggested that kereru home ranges and movements are associated with locations of food sources and that these shift with changing food availability. There remains little knowledge on how home range and movements are affected in human-modified landscapes such as on Banks Peninsula where the fragmentation of native forest and presence of humans has altered food availability.

The aims of the home range and movement analysis for kereru in the rural-urban landscapes on Banks Peninsula were to:

1. Determine the home ranges and core areas of each tagged kereru to:

a. Determine if there is correlation between the size of the home ranges and core areas, and between the numbers of discrete areas included in each home range and core area;
b. Determine if there is difference in home range size between the non-breeding and breeding seasons; and
c. Assess the difference in home range overlap between the non-breeding and breeding seasons;

2. Determine if there are differences in the distance travelled and timing of movements between the non-breeding and breeding seasons.
3. Assess which sections of the study sites are important to kereru and if this changes over time.

## 6.2 Methodology

Kereru were radio-tracked as described in Chapter 2, and location data were collected while tracking the tagged kereru from February 2004 until March 2005 (13 months). The time between consecutive observations was at least two hours to avoid autocorrelation of data. The error of location data were ignored as described in section 2.2.10.3.

### *6.2.1 Home range and core area estimation*

For the purpose of this study, *home range* is defined as 'the extent of area with a defined probability of occurrence of the study animal during a specified time period' (Millspaugh & Marzluff, 2001). Two levels of the probability of occurrence within a home range define its boundaries: 1) areas within which the animal usually occurs (i.e., all locations except outlying locations; see below) defines the outer home range boundary; 2) high-use areas within the home range referred to as '*core areas*' (Kenward, 2001; Millspaugh & Marzluff, 2001; Kenward *et al.*, 2003). '*Outlying locations*' (or outliers) occur when an animal uses areas outside its home range. These locations should technically not be included in the home range estimation because the animal's probability of occurrence in these areas is too low (Millspaugh & Marzluff, 2001).

Location data of individual kereru were used to estimate individual home ranges and core areas over the entire study period.

Several estimation techniques are available for home range analysis (Millspaugh & Marzluff, 2001). The unique algorithms and outputs of each technique determine which one was most appropriate to answer the research questions of this study (Millspaugh & Marzluff, 2001). A review of home range estimation techniques used in previous studies on kereru ecology suggested the minimum convex polygon (MCP) method (Pierce & Graham, 1995; Bell, 1996) and cluster analysis (Hill, 2003) should be used for the home range and movement analysis. Ranges 6 software (Kenward *et al.*, 2003) was used to estimate home ranges in this study.

### 6.2.1.1 *Minimum convex polygon method*

The minimum convex polygon (MCP) method had been used to identify the area within which an animal moves, and within which the animal chooses its home range. All data from each kereru (100% of location data) were used to estimate the MCPs. I assume that kereru are familiar with the resources available to them within their MCP area (i.e., area within which kereru moved during this study period).

The MCP method plots location data on a grid and creates convex polygons with external angles all greater than $180^{\circ}$ (Kenward *et al.*, 2003). The smallest of such polygons forms the minimum convex polygon. The MCP method is not sensitive to autocorrelation of data (see Chapter 2) and is based on non-parametric assumptions (Millspaugh & Marzluff, 2001). This method has been criticised because of its inability to take into consideration high-use areas and because it does not exclude outlying locations (Kenward *et al.*, 2003). In patchy rural-urban landscapes, the MCP method was likely to include large areas that were not used by the kereru (e.g., areas between discrete seasonal ranges in which kereru were not located). Technically, these areas should not be included in the home range (Harris *et al.*, 1990; Kenward, 2001; Millspaugh & Marzluff, 2001; Hill, 2003). Appendix 6 shows a home range estimation using the MCP method and how this included areas that were not included in the cluster analysis (see below).

#### 6.2.1.2 *Cluster analysis*

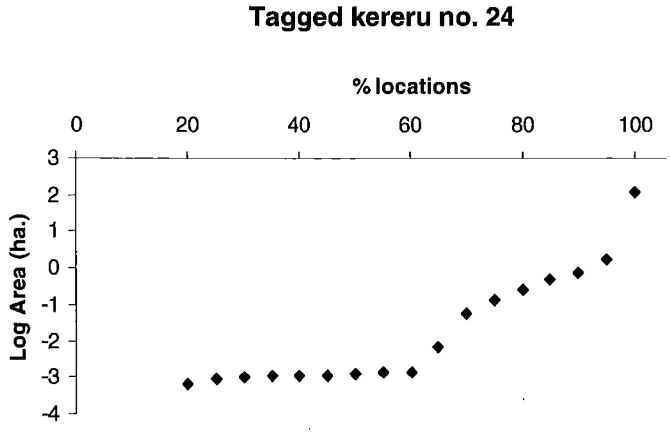
Cluster analysis is thought to be the best index to identify an animal's home range and core area (Kenward, 2001; Hill, 2003; Kenward *et al.*, 2003). The advantage of cluster analysis is the ability of the algorithm to differentiate discrete areas where kereru were located, and separate those from areas with no occurrence of tagged kereru. This is due to the clustering of location data based on linking distances between data points and linking nearest neighbours. Appendix 6 shows a home range estimation using cluster analysis with the different nuclei that, combined, form the home range and core area (e.g., this shows four home range nuclei and 10 core area nuclei). The cluster analysis technique is more fully described in Kenward (2001) and Kenward *et al.* (2003). This method is not sensitive to autocorrelation of data (Millspaugh & Marzluff, 2001) (see Chapter 2). Ranges 6 software was used to create nuclei of the clustered data where appropriate (Kenward *et al.*, 2003); the cumulative area values of nuclei form the total size of each home range and core area (Appendix 6).

To determine what percentage of location data were required to define outer home range boundaries, the 'objective cores' option was used using Ranges 6 software (outlier exclusion rate >5% of the distance distribution) (Kenward *et al.*, 2003).

To determine the percentage of data points that defined the core areas, 'utilisation plots' were created using Ranges 6 for each data set in a similar manner to Hill (2003). The point of inflection in each graph determined the percentage of location data included in the estimation of core areas. Figure 6.1 shows a utilisation plot for kereru 24 where the point of inflection was estimated at 60%. To estimate core areas, cluster analyses were conducted using the percentage of data specified from the utilisation plots of individual kereru data sets.

#### 6.2.1.3 *Reliability of estimated MCP areas and home range sizes*

Before the MCP areas (MCP method) and the home ranges (cluster analysis) were estimated, it was determined if sufficient location data were collected from each kereru to estimate these areas and ranges reliably. This was conducted using the area-location curve analysis in Ranges 6. The estimated MCP area or home range was plotted against the number




| % of location used to calculate the area | Area (ha.) |
|---|---|
| 100 | 117.1 |
| 95 | 1.80 |
| 90 | 0.73 |
| 85 | 0.47 |
| 80 | 0.26 |
| 75 | 0.14 |
| 70 | 0.06 |
| 65 | 0.01 |
| 60 | 0.0014 |
| 55 | 0.0014 |
| 50 | 0.0013 |
| 45 | 0.0012 |
| 40 | 0.0012 |
| 35 | 0.0011 |
| 30 | 0.0010 |
| 25 | 0.0009 |
| 20 | 0.0007 |

**Figure 6.1. Utilisation plot used to determine the percentage of data included in the core area estimation of the cluster analysis**

of locations used to generate that estimate initially using the first three locations (the minimum number required to estimate an area) (Voight & Tinline, 1980; Kenward, 2001; Millspaugh & Marzluff, 2001). The MCP area or home range was then re-calculated after adding each new location in the data set. When 100% of the MCP area or home range was estimated by a given number of locations, and additional location data did not improve the area estimate, the area-location curve approached zero. At this point, the MCP area or home range could be estimated reliably. Unstable area-location curves suggested that more location data were required, and estimations of MCP areas/ home ranges were likely underestimated (i.e., the area estimate in these cases was interpreted as the minimum area traversed by the kereru).

*6.2.2 Correlation between home ranges and core areas (cluster analysis)*

The size of each core area was expressed as a proportion of the home range of each kereru (both estimated using cluster analysis). To indicate the intensity with which kereru used the core areas, it was investigated if there was a correlation between the size of the home range and core areas. An attempt was made to fit a regression to the data.

To determine if there was a correlation between the number of nuclei in the home range and the core area for each kereru, a scatter plot was created. An attempt was made to fit a regression to the data.

### 6.2.3 Seasonal differences in home range size

To investigate differences in home ranges between the non-breeding and breeding seasons, data were pooled according to the division of these seasons: the non-breeding season went from February to July 2004; and the breeding season from August 2004 to March 2005 Chapter 4). The seasonal home ranges were estimated for individual kereru using cluster analysis while taking into consideration the stability of the area-location curves (see section 6.2.1.2). Differences in the home range sizes between seasons were tested using a Wilcoxon's signed ranks test.

### 6.2.4 Home range overlap between seasons

To determine if kereru used similar parts of the study sites, the home range overlap (static interaction) between pairs of kereru was measured separately for the non-breeding and breeding season using the 'Intersect tool' in ArcGIS 9.0 (ESRI, 2004) to intersect home range files created in Ranges 6 (i.e., static interaction where the time factor was not taken into account) (Kenward, 2001; Millspaugh & Marzluff, 2001). Due to geographical location of kereru home ranges, overlap was measured separately for pairs of kereru in Church Bay and Orton Bradley Park. Overlap proportions of less than 10% were not included in this analysis. Appendix 7 shows the home range overlap between kereru A and B; overlap was relatively smaller for kereru A (approximately 15%) compared with kereru B (approximately 80%).

### 6.2.5 Travel distance and timing of movement

Movements were analysed to give an insight into the timing and distances travelled between resources within and between seasons. Three types of movement were defined in a similar manner to Clout *et al.* (1991) and Hill (2003): 1) long-distance movements (>1.5 km) where individuals made a one-way or round-trip movement between two or more areas or seasonal home ranges, including a period when the animal resided in a new area, 2) long-distance movements (>1.5 km) where individuals move within a seasonal home range within a short time (e.g., daily), 3) short-distance (<1.5 km) where individuals moved often within a home range (White & Garrott, 1990; Millspaugh & Marzluff, 2001).

The distance between consecutive locations was analysed using Pythagoras' formula. The records were scored in categories: 0-250 m, 251-500 m, 501-750 m, 751-1000 m, 1001-1500 m. The proportion of movements in each category was determined for each kereru during the non-breeding and breeding seasons. Differences in the proportions of distances travelled in all categories were tested between seasons using Wilcoxon's signed ranks test. Differences in the proportion of short-distances < 500 m were tested between seasons using a Chi-squared test.

### *6.2.6 Use of areas within study sites*

Sections of the study sites at Church Bay and Orton Bradley Park were categorised according to the presence of plant species and/or the type of utilisation by humans (see also Chapter 3): residential gardens, areas containing tree lucerne *(Chamaecytisus palmensis)*, recreational areas, patches of regenerating native vegetation/forest, areas containing poroporo (*Solanum aviculare, S. laciniatum*), and native forest reserves at higher altitudes. Use of the study sites by kereru was determined by: 1) the time during which at least one kereru used the category; 2) the percentage of location data recorded within each category; 3) the number of kereru using each category. ArcGIS 9.0 was used to overlay location data (pooled across each category) with the map of the vegetation types distinguished in Chapter 3.

To identify what percentage of the MCP area individual kereru used for their home range (estimated using cluster analysis), and to determine the areas they are familiar with but choose not to use (i.e., area included in the MCP areas but excluded in the home range), the percentage of MCP area that contains the home range is determined.

## 6.3 Results

### *6.3.1 Home range and core area estimation*

Fifteen kereru were fitted with transmitters. Fourteen kereru were re-located regularly during each of the 28 fortnightly field weeks from February 2004 to March 2005 (see Chapter 2). Home ranges could be reliably estimated for eight of the 14 kereru using the MCP method and nine of the 14 kereru using cluster analysis (Appendix 8).

Areas estimated using the MCP method ranged from 26 to 10,638 ha (Table 6.1). Kereru used between 0.1 and 11.6 percent of the areas familiar to them (MCP area) as their home range (Table 6.2). Therefore, at least 90% of the area with which kereru were familiar, was not included in the home range.

**Table 6.1. Estimates of the home ranges and core areas using MCP and cluster analysis.**

| Kereru | Home range | | Core area (ha.) | | No. nuclei | |
|---|---|---|---|---|---|---|
| | MCP (ha) | Cluster analysis (ha) | Cluster analysis (ha) | Core area % of home range | Core area | Home range |
| 10 | 886 | 7.9 | 0.03 | 0.4 | 15 | 2 |
| 14** | 3858 | 21.8 | 0.10 | 0.5 | 12 | 7 |
| 16* | 27 | 3.1 | 0.04 | 1.3 | 17 | 3 |
| 18* | 43 | 4.5 | 0.12 | 2.7 | 16 | 2 |
| 20* | 26 | 2.3 | 0.06 | 2.6 | 20 | 4 |
| 22 | 433 | 2.4 | 0.02 | 0.9 | 9 | 4 |
| 24 | 611 | 22.2 | 0.01 | 0.1 | 14 | 6 |
| 26** | 10638 | 5.4 | 0.04 | 0.7 | 4 | 3 |
| 28* | 258 | 12.1 | 0.07 | 0.6 | 22 | 2 |
| 30* | 71 | 1.8 | 0.03 | 2.0 | 20 | 5 |
| 32 | 364 | 6.4 | 0.21 | 3.3 | 13 | 4 |
| 34 | 383 | 7.4 | 0.28 | 3.8 | 16 | 5 |
| 36 | 50 | 3.6 | 0.05 | 1.3 | 12 | 5 |
| 38* | 1326 | 5.6 | 0.04 | 0.8 | 12 | 3 |

*: The area-location curve of these kereru did not show stability when plotting the curve using MCP method and cluster analysis, except for 16 which showed stability for the cluster analysis. Home range estimation is likely to be inaccurate and was treated as minimum area traversed.

**: These kereru were captured in Orton Bradley Park and then they moved to Port Levy (14) and Puaha (26)

**Table 6.2. Percentage of MCP area that is included in the home range (estimated using cluster analysis).**

| Kereru no. | % of MCP area included in the home range estimated using cluster analysis |
|---|---|
| 10 | 0.9 |
| 14 | 0.6 |
| 16 | 11.6 |
| 18 | 10.4 |
| 20 | 8.7 |
| 22 | 0.6 |
| 24 | 3.6 |
| 26 | 0.1 |
| 28 | 4.7 |
| 30 | 2.5 |
| 32 | 1.8 |
| 34 | 1.9 |
| 36 | 7.3 |
| 38 | 0.4 |

Home ranges estimated using cluster analysis ranged between 3.6 and 22.2 ha (Table 6.1). Between 2 and 11% of location data of each kereru were regarded as outliers (Appendix 9). The estimated core areas ranged from 0.01 to 0.28 ha (Table 6.1). Between 45 and 70% of location data were included in the estimation of the core areas (Appendix 9).

### *6.3.2 Correlation between home ranges and core areas (cluster analysis)*

Between 0.1 and 3.8% of the home range area was included in the core area (Table 6.1). Statistical correlation between home range and core area sizes was not strong ($r^2$ <0.001, P = 0.96). Although a relationship is not statistically significant, it may be biologically significant as all core areas were less than 0.28 ha (average of 1.4%), less than 4% of the home range area across all kereru (Table 6.1).

The number of nuclei included in the home ranges and core areas ranged from 2 to 7 and 4 to 22, respectively (Table 6.1). A correlation between the number of nuclei in the home ranges and core areas was not apparent ($r^2$ = 0.018, P = 0.65).

### *6.3.3 Seasonal difference in home range sizes*

The home ranges of seven breeding kereru could be reliably estimated for both breeding and non-breeding seasons; the home ranges of three breeding kereru could not be reliably estimated during either one or both of the seasons (Table 6.3). Breeding season home ranges were significantly smaller than non-breeding season ones (means 1.8 and 5.2 ha, respectively) (Wilcoxon's signed = 2.666; P = 0.008). There appeared to be little difference in range size between sexes (Table 6.3).

### *6.3.4 Home range overlap between seasons*

For each kereru breeding pair, the non-breeding and breeding season home range overlap (static interaction) was expressed as a proportion. There was a higher proportion of home range overlap in Church Bay than in Orton Bradley Park (Table 6.4); during the non-

**Table 6.3. Breeding and non-breeding season home range estimated for breeding kereru.**

| Kereru | | Non-breeding season | | | Breeding season | | |
|---|---|---|---|---|---|---|---|
| no. | Sex | n | Area (ha) | Nuclei | n | Area (ha) | Nuclei |
| 10 | m | 81 | 6.1 | 2 | 107 | 1.5 | 2 |
| 18 | m | 93 | 0.9** | 2 | 100 | 1.5** | 2 |
| 28 | m | 82 | 3 | 2 | 82 | 1.2 | 4 |
| 30 | m | 90 | 2.7 | 1 | 95 | 2.2 | 3 |
| 32 | m | 55 | 1.8 | 4 | 97 | 3.3 | 3 |
| 20 | f | 99 | 2.7 | 3 | 101 | 0.8** | 3 |
| 22* | f | 60 | 2.0 | 4 | 37 | 0.1 | 3 |
| 24 | f | 52 | 21.9 | 3 | 104 | 1.4 | 9 |
| 36 | f | 95 | 1.1 | 4 | 103 | 3.2 | 6 |
| 38 | f | 95 | 2.6 | 4 | 108 | 2.6** | 2 |

Sex: m = male, f = female
n: number of locatons used for the home range estimation
* : Due to predation the breeding season for this kereru ended mid October
**: The area-location curve showed no stability. Therefore the home range of this kereru is likely to be underestimated

breeding season, overlap at Church Bay ranged from 11 to 97%, and overlap in Orton Bradley Park ranged from 10 to 42%. Breeding season overlap was higher in Church Bay where most home ranges overlapped (ranging from 11 to 90%). In Orton Bradley Park, only three of the seven home ranges overlapped during the breeding season (ranging from 14 to 96%). Breeding pairs at both study sites (kereru 18-38 and 20-30) had a relatively high overlap compared with non-breeding kereru that, except for the combination 10-34 (34 is thought to be 10's chick from the 2003-2004 breeding season as 10 was recorded feeding 34 in February 2004).

### *6.3.5 Travel distance and timing of movements*

Long-distance movements (>1.5 km) occurred between March and July 2004 (non-breeding season) and January and March 2005 (breeding season) (see Chapter 4) and made up 1% of all movements. The total number of long-distance movements made by individual kereru ranged between 0 and 12 (Figure 6.2). During the non-breeding season, kereru moved mainly between two areas and resided in the new area before either returning to the starting home range (i.e., kereru 10, 22, 24, and 32), or moving to a third new area (i.e., kereru 14 and 26; Figure 6.2). Two kereru made long-distance movements within their home range during the non-breeding season (i.e., kereru 28 and 38). With two exceptions, the long-distance movements made were within breeding season home ranges (Figure 6.2).

**Table 6.4. Proportions of home range overlap of kereru in Church Bay and Orton Bradley Park during the non-breeding and the breeding seasons.**

| Site | The home range of kereru no. ... | ... overlaps with kereru no. ... | Overlap percentage >0.1** Non-breeding season (%) | Breeding Season (%) |
|---|---|---|---|---|
| Church Bay | 10 | 34 | 15 | 90 |
| | | 36 | 13 | ~ |
| | 18 | 34 | ~ | 22 |
| | | 36 | ~ | 24 |
| | | 38 | 84 | 62 |
| | 34 | 10 | 97 | 27 |
| | | 36 | 13 | 21 |
| | | 38 | 29 | ~ |
| | 36 | 10 | 71 | ~ |
| | | 18 | ~ | 11 |
| | | 34 | 11 | 33 |
| | | 38 | 32 | ~ |
| | 38 | 10 | 15 | ~ |
| | | 18 | 29 | 36 |
| | | 34 | 11 | ~ |
| | | 36 | 14 | ~ |
| Orton Bradley Park | 20 | 30 | 25 | 96 |
| | | 32 | ~ | 14 |
| | 22* | 20 | 10 | ~ |
| | | 32 | 18 | ~ |
| | 30 | 20 | 25 | 87 |
| | | 22* | 42 | ~ |
| | | 24 | 10 | ~ |
| | | 32 | 17 | ~ |
| | 32 | 20 | 14 | ~ |
| | | 22* | 19 | ~ |
| | | 24 | 31 | ~ |
| | | 30 | 25 | ~ |

*: Kereru 22 was preyed upon part way through the breeding season so no home range overlap was estimated for the breeding season.
**: Home range overlaps smaller than 0.10 in either season were not reported in this table (~)

Short-distance movements (<1.5 km) comprised 90% of all movements. With one exception, 60-100% of short-distances were within the 0-250 m and 251-500 m categories respectively during the non-breeding and breeding seasons (Table 6.5; Appendix 10). Proportions of movements in these categories were not significantly different between the non-breeding and the breeding seasons (Wilcoxon's signed = 0.949, P = 0.343) (Table 6.5). The proportions of short-distance movements less than 500 m, during the non-breeding season and the breeding season were not significantly different ($?^2 < 0.1$, df = 1, P = 0.83) (Table 6.5). However, there was a non-significant difference in the percentage of movements in the categories of 251 to 1000 m between seasons.

| Kereru no. | Non-breeding season | | | | | | | | | | | | Breeding season | | | | | | | | | | | | | | | | Total movements |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2004 | | | | | | | | | | | | | | | | | | | | | | 2005 | | | | | | |
| | Feb | Mar | | | April | | May | | June | | July | | Aug | | Sept | | | Oct | | Nov | | Dec | | Jan | | Feb | | Mar | |
| 10 | | | | 1 | | 1 | | | | | | | | | | | | | | | | | | | | | | 2 | 4 |
| 14 | | | | 1 | | | | | 1 | 1 | 1 | | | | | | | | | | | | | | 1 | 3 | 3 | | 11 |
| 16 | - | - | | | | | | | | | | | | | | | | | | | | | | | | | | | 0 |
| 18 | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 1 |
| 20 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0 |
| 22 | | | | 1 | | | | | 1 | | | | | | | | | | - | - | - | - | - | - | - | - | - | - | 2 |
| 24 | | | 1 | | | | | | | 1 | | | | | | | | | | | | | | 3 | | 4 | 3 | | 12 |
| 26 | - | - | | x | | | 1 | 2 | | 1 | | 1 | 1 | | | 1 | 1 | | | | | | x | 1 | x | x | x | x | 9 |
| 28 | - | - | | 2 | | | | | | | | | | | | | | | | | | | | | | | | | 2 |
| 30 | 1 | 1 | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | 3 |
| 32 | | | 1 | | | | | 1 | | | | | | | | | | | | | | | | | | 1 | 1 | | 4 |
| 34 | | | | | | | | | | | | | | | | | | | | | | | | | | | 4 | | 4 |
| 36 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0 |
| 38 | | | 2 | | | | | | | | | | | | | | | | | | | | | 1 | 1 | | | 2 | 6 |
| Total | 1 | 1 | 4 | 6 | 0 | 1 | 1 | 3 | 2 | 3 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 2 | 8 | 11 | 5 | 58 |

- Kereru not not available for data collection
x Kereru at unknown location
1, 2, 3, 4 Number of long-distance movements made at that time

**Figure 6.2. The number of long-distance movements (>1.5 km between two consecutive locations) made by each kereru.**

**Table 6.5. Proportion in each distance category of distances travelled by kereru during the non-breeding and the breeding seasons.**

| | Distance categories (m) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0-250 | 251-500 | 501-750 | 751-1000 | 1001-1250 | 1251-1500 | >1500 |
| Non-Breeding season | 0.84 | 0.08 | 0.01 | 0.02 | 0.01 | 0.001 | 0.03 |
| Breeding season | 0.75 | 0.11 | 0.04 | 0.03 | 0.03 | 0 | 0.04 |

### *6.3.6 Use of areas within study sites*

Most location data were collected in residential gardens (34%), followed by areas containing poroporo (24%) (Figure 6.3). Only 2% of location data were recorded in recreational areas. Up to four kereru used areas containing regenerating native forest or poroporo for foraging, but these were not consistently used throughout the study period because poroporo fruit are available only in late summer (Figure 6.3).

Some categories of areas used by kereru were not used during parts of the study, but have a relatively high percentage of location data (e.g., areas with regenerating natives (17%)

and poroporo (24%)) (Figure 6.3). During the times these areas were used, they were used intensively relative to other areas during the same time (e.g., recreational areas). For example, up to four kereru (out of 10 present in Orton Bradley Park) used the areas containing poroporo during the relatively short time poroporo fruits were available.

A different situation occurred in the higher altitude reserves on Banks Peninsula, which were used only during some months of this study; only 5% of location data were collected in these areas (Figure 6.3). Here, logistical constrains permitted fewer opportunities to collect data at these areas, ultimately resulting in seemingly lesser importance. However, these reserve areas were thought to be important to kereru between March and June 2004 since up to six of 15 kereru were recorded there (Figure 6.3). The same principle should be applied to areas containing poroporo during the times when these areas were used.

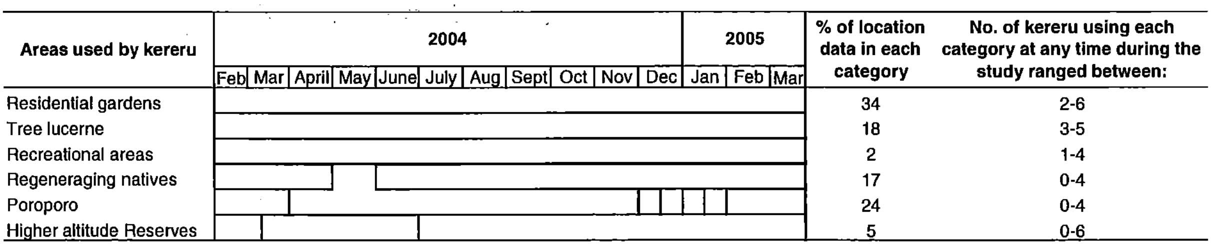



**Figure 6.3. Areas used by at least one kereru during the study period, with the percentage of location data in check category and the number of kereru which used each category.**

## 6.4 Discussion

### *6.4.1 Home ranges and core areas*

Only three previous studies reported specifically on kereru home ranges (Pierce & Graham, 1995; Bell, 1996; Hill, 2003). The study by Bell (1996) is the most similar to this study with regard to the sampling interval (minimum of two hours between observations) and presence of fragmented forest patches near the study area (see Chapter 2). However, the fragmentation of the landscape in Bell's (1996) study was less modified by humans compared with the rural-urban landscape of this study; Bell's study area also had a higher proportion of native food species available. To analyse home ranges, Bell (1996), as well as Pierce and

Graham (1995), used the MCP method. However, of these two studies, only Bell (1996) reported the statistics related to the analysis. The only previous study that used cluster analysis to analyse both home ranges and core areas was conducted in a large tract of native forest (Hill, 2003).

The home ranges estimated using cluster analysis in my study ranged between 1.8 and 22.2 ha. This was significantly smaller than those estimated by Hill (2003), which ranged from 13.9 to 704.2 ha (non-parametric Mann Whitney U test, $P < 0.001$). Core areas estimated in my study ranged between 0.01 and 0.28 ha, which was also significantly smaller than those estimated by Hill (2003) that ranged from 1.1 to 26.7 ha (non-parametric Mann Whitney U test, $P < 0.001$). Smaller home ranges and core areas suggest a more intensive use of fewer sites (i.e., data from this study are more clustered). This is also shown by the relationship between home range and core area sizes which suggests that core areas were used more intensively than those found in Hill (2003): core areas in this study were 1.4% on average (smaller than the 4% of total home ranges across all kereru); in Hill (2003) core areas covered 6% of home range on average).

The fact that home ranges and core areas were significantly smaller during this study may also suggest the quality of the study sites in the rural-urban landscape is better than that found by Hill (2003). On the other hand, since there is a difference in food species eaten between Hill (2003) and my study (see Chapter 5), the reduced size of home ranges could be the result of kereru adjusting to different food species which are distributed differently in the rural-urban landscape than those present in native forests. Nevertheless, it should be noted that a comparison between my home range analysis and Hill's (2003) study could be biased due to differences in the time interval of data collection, and division of seasons as a result of differences in landscape layout.

In this study, kereru used less than 12% of the areas with which they were familiar within their home range suggest either one of the following:

1) Kereru were forced to use small discrete areas for their home ranges because the remaining areas did not contain the required resources (e.g., pasture).
2) Kereru did not need to use large areas but could suffice with small discrete areas because each contained one or more required resources; however, kereru did move

outside their home range to either explore new areas or to use discrete traditional seasonal ranges.

What also needs to be considered is that even though home ranges did not necessarily overlap, MCP areas of individual kereru did overlap, especially during the breeding season. Therefore, areas which fall within the home range of some kereru maybe an area familiar to another one even though the latter one doesn't use it as part of its home range.

Home range estimations conducted during my study (using the MCP method and cluster analysis) are relatively easy to replicate. Especially when using the same software package, the results of the analyses could be used as a baseline for comparison (Kenward, 2001; Millspaugh & Marzluff, 2001).

To determine whether study sites were of good quality for kereru variations in home ranges between the non-breeding and breeding seasons, home range overlap, and kereru movements between seasons were analysed. Lack of previous studies in rural-urban landscapes make it difficult to determine if correlation between size (and number of nuclei) of home ranges and core areas could be used as an indicator for the quality of an area for kereru.

*6.4.3 Difference in home ranges between the non-breeding and breeding seasons*

Kereru occupied significantly smaller home ranges during the breeding season compared with the non-breeding season, but no consistent trends were observed, nor between seasons. During the breeding season, home ranges of breeding kereru were found to either increase because those individuals utilized roosting and foraging areas away from nest sites, or decrease, likely because those individuals roosted and foraged relatively close to their nest sites.

Breeding kereru usually moved away from the nesting area while their mate was incubating (see Chapter 4), resulting in a non-significant increase in daily movements within home ranges during the breeding season. Lack of other studies that investigated daily movements of kereru made it difficult to determine if kereru in the rural-urban landscape were forced to travel further between resources, between seasons or in general, compared with the native forest situation.

### *6.4.4 Home ranges overlap between seasons*

Measuring the home range overlap between pairs of kereru provided information about how kereru were using resources located in different parts of the study sites. In Church Bay, the proportion of home range overlap was larger than in Orton Bradley Park. During the breeding season, Church Bay kereru utilised the same sites for foraging and roosting as during the non-breeding season but nested in areas away from these sites. Also, overlap during the breeding season in Church Bay was greater relative to the non-breeding season overlap. In Orton Bradley Park, kereru nested in separate forest patches perhaps because of the higher patchiness of the landscape had reduced food density, forcing kereru to use different foraging areas. This resulted in a decreased home range overlap during the breeding season (Table 6.3).

Home range overlap, as analysed in this study, did not measure whether kereru utilised overlapping parts of their home range at the same time (i.e., dynamic interaction). The amount of home range overlap could be used as an index of the amount of resources available at specific locations relative to other sites (e.g., between Church Bay and Orton Bradley Park). An attempt was made to investigate dynamic interaction between pairs of kereru. But due to software problems (i.e., the algorithm used in Ranges 6 to calculate the Jacob's index (Kenward *et al.*, 2003)), it was not achievable. Future research could attempt to describe dynamic interaction between kereru in the rural-urban landscape to investigate if kereru utilise the same sites at the same time.

### *6.4.5 Travel distances and timing of movements*

Kereru were observed relatively frequently during this study compared with previous studies; the tracking frequency was up to several times each day, similar to Bell (1996), but different from the single weekly or fortnightly observation of Pierce and Graham (1995) and Hill (2003). This higher frequency allowed the collection of relatively detailed data on daily movements.

Short-distance movements (< 500 m) made by kereru during this study comprised approximately 90% of daily movements (Table 6.5). As kereru retain seeds in their gut for approximately two hours, seed dispersal distances were thought to be mainly less than 500 m of foraging sites (Clout & Tilley, 1992; Bell, 1996). No other studies on kereru have reported daily movements, so seed dispersal distances could not be compared with those from other landscapes within New Zealand. A study on pacific pigeons (*Ducula pacifica*) in Tonga reported that most seeds were dispersed within 50 m of the parent tree, but that distances of up to 100 m may be common and distances of three km are also regularly possible (McConkey *et al.*, 2004). When comparing these findings with the short-distance movements made by kereru, it appears that seed dispersal distances, especially in the category < 250 m are regularly possible. However, seed dispersal distances in the rural-urban landscape could well be different from those in native forests in both New Zealand and Tonga due to differences in the spread of resources. Additional research on seed dispersal distances in other landscapes (e.g., tracts of native forest) should supply more detailed information on this subject.

Long-distance movements (>1.5 km) were less than 10% of recorded movements (Table 6.5). With one exception, no kereru were recorded to have moved more than approximately 15 km without returning to the study site; six kereru moved 6 km away from capture sites during the non-breeding season. Eight kereru did not move outside the study sites at Church Bay and Orton Bradley Park except for occasional daily movements. With two exceptions, no movements to new areas occurred during the breeding season. One kereru, which was lost, was assumed to have moved further than 15 km but no data were collected on exact distance. Studies currently underway in Invercargill and New Plymouth have recorded a kereru travelling over 200 km within two months. This is noticeably further than movements recorded during this study (*unpublished Kereru News, Department of Conservation, Wellington*). Other studies found kereru moved an average of 3 km on a daily basis, or around 24 km between seasonal home ranges (Clout *et al.*, 1986; Clout *et al.*, 1991; Pierce & Graham, 1995; Hill, 2003). Comparison with previous studies shows that maximum distances travelled by kereru were not as great as previously recorded.

Timing of movements, in combination with distances travelled, might be used as an indicator of resource availability, assuming the reason kereru move to other areas is that insufficient resources are present. Between the non-breeding season and the breeding season, the number of long-distance movements between areas decreased and the number of long-distances travelled within home ranges increased (Figure 6.2). Since, with two exceptions, all kereru home ranges were within study sites during the breeding season, it could be concluded that Church Bay and Orton Bradley Park contained all required resources: food sources and suitable nesting sites.

### *6.4.6 Importance of landscape features over time*

The most obvious and relevant differences in landscape features and vegetation composition between pre-human settlement native forests and the rural-urban landscape on Banks Peninsula are the lack of large tracts of native forest and the presence of introduced plant species in gardens and in regenerating native forest patches (Wilson, 1992, 1998). Also, residential gardens were included in or relatively close to the home ranges of kereru in this study (approximately 6 km away) compared with previous studies. Kereru used areas with native species during the parts of summer when these areas provide native fruits (Figure 6.3). The movements to and from Mount Herbert and Mount Sinclair Reserves during autumn suggest part of the population finds a required resource in these reserves at that time; it is likely that the resources found there are native food species. I conclude that kereru presence in the rural-urban landscape is regulated by food availability and presence of suitable nesting sites, rather than species composition. This conclusion is consistent with those made in studies conducted in native forest (Beveridge, 1964; McEwan, 1978; Clout, 1990; Pierce & Graham, 1995; Mander *et al.*, 1998; Ridley, 1998).

I conclude that kereru move and choose their home ranges according to food source availability, a conclusion similar to the one made in previous research (Clout *et al.*, 1986; Clout *et al.*, 1991; Pierce & Graham, 1995; Ridley, 1998). I conclude also that kereru are highly adaptable, that they can include areas within their home ranges that are very modified by humans, and that the current landscape does not appear to limit the current kereru population from a home range perspective (as home ranges were smaller than those of kereru in native forests). The lack of detailed vegetation records and resource constraints prevented a comparison of the effect of resource availability on kereru home ranges and movements between the rural-urban landscape and landscapes with tracts of native forest. Home range and movement analyses were therefore described as a baseline for future studies. Future studies should investigate the effect of resource availability on kereru home ranges and movements in different landscapes (e.g., tracts of native forest versus human-modified landscapes) in combination with phenology studies.

Chapter 8 will discuss the findings from this chapter in relation to differences between the study sites (Chapter 3), timing of the breeding cycle (Chapter 4), plant species eaten (Chapter 5), population estimate (Chapter 7), and management of the local kereru population and landscape on Banks Peninsula.

# Chapter 7

# A population estimate for kereru (*Hemiphaga novaeseelandiae*) at Church Bay and Orton Bradley Park in the Lyttelton Harbour Basin, Banks Peninsula

## 7.1 Introduction

The kereru population on Banks Peninsula has not previously been estimated, although the species was most likely common before European settlement. The population is thought to have declined considerably following native forest destruction and hunting activities by European settlers on the Peninsula (see Chapters 1 and 3) (Wilson, 1998). In recent decades there has been public speculation that kereru numbers have increased (*Oral History Project; Programme (2005), in progress*), but no data are available to support this observation.

Studies of kereru abundance, conducted in native forest landscapes, have utilised five-minute bird counts as an index of abundance (Dawson *et al.*, 1978; Clout & Gaze, 1984; Clout *et al.*, 1986; Clout *et al.*, 1991; Pierce *et al.*, 1993; Greene, 2004) but this method has not been used to estimate kereru numbers on Banks Peninsula. Other methods to estimate the number of animals within a predefined area are mark-recapture techniques. Recently developed mark-resight techniques utilise radio-tagged animals to collect data in a similar manner to mark-recapture techniques, except that radio-tagged animals are resighted rather than recaptured (Millspaugh & Marzluff, 2001). Mark-resight methods using tagged kereru have not previously been used to estimate the size of kereru populations (R. Powlesland and T.C. Greene, *pers. comm.*).

The aim of this Chapter was to report the kereru population at Church Bay and Orton Bradley Park as a baseline for future population trend monitoring at these study sites. Mortality records of tagged kereru encountered during this study were also included.

## 7.2 Methodology

*7.2.1 Estimation of the kereru population*

Telemetry equipment was used to locate the 15 tagged kereru from February 2004 until March 2005 (13 months) (see Chapter 2). While radio-tracking and observing tagged kereru at Church Bay and Orton Bradley Park, the number of untagged kereru encountered was also recorded.

Sampling of the number of untagged kereru present within the study sites did not occur using the grid that is usually used to collect mark-resight data (White & Garrott, 1990; Millspaugh & Marzluff, 2001); data on the number of untagged kereru encountered were collected while tracking and observing tagged kereru. These data were treated as mark-recapture data. The extended Lincoln-Petersen estimator was used to estimate the kereru population (N) (Millspaugh & Marzluff, 2001):

$$N = \frac{(n1+1)\ (n2+1)}{(m2+1)} - 1$$

Where:

N is the population estimated

n1 is the number of radio-tagged animals present in the population;

m2 is the number of radio-tagged animals resighted during the resighting intervals;

n2 is the number of animals (tagged and untagged) counted on a resighting survey (see Millspaugh & Marzluff (2001) for a full description of the equation/method).

The extended Lincoln-Petersen estimator used here relies on two assumptions:

1. Radio-tagged animals have the same sightability as untagged animals (White & Garrott, 1990; Millspaugh & Marzluff, 2001). I assumed the sightability of tagged kereru and untagged kereru were equal; while radio-tracking and observing tagged kereru, the number of tagged kereru was recorded as was the number of untagged kereru encountered. When I had to thoroughly search for a tagged kereru in dense vegetation, the non-sighting record of the tagged kereru was not included in the data. Untagged kereru sighted while searching for tagged kereru were included.

2. The population is geographically and demographically closed during the time the estimate is made (Millspaugh & Marzluff, 2001). Radio-tagged animals in the population were used to confirm this assumption.

### *7.2.2 Mortality records*

Whenever a tagged kereru was found dead, data were obtained about the cause of death when possible.

## 7.3 Results

### *7.3.1 Estimation of the number of kereru*

The kereru populations at Church Bay and Orton Bradley Park were estimated separately during three resighting intervals (see assumption 2; section 7.2) in 2004: 1) February, 2) June to July, and 3) September to October. In addition, the population at Church Bay was estimated from April to May and from October to December. At Orton Bradley Park, one additional estimate was made during February and March 2005.

The five kereru tagged at Church Bay in January 2004 were available for resighting during all resight intervals (Table 7.1; n1; see Chapter 2). Ten individuals were initially tagged at Orton Bradley Park in January and February 2004, however, due to death and movement away from the Park, only between eight and six tagged kereru remained available for resights between February 2004 and March 2005 (Table 7.1; n1; see Chapter 2). Tagged kereru were resighted multiple times during resighting intervals (Table 7.1; m2), and the total number of kereru encountered during resighting intervals varied over time (Table 7.1; n2).

The estimated kereru population was greater at Orton Bradley Park than at Church Bay (Table 7.1; N). At Orton Bradley Park, kereru numbers varied from nine in June-July (winter) to 34 in February 2004 (peak breeding season). At Church Bay, the estimated number of kereru varied less; between six and 11 from February to December 2004.

**Table 7.1. Estimation of kereru numbers at Church Bay and Orton Bradley Park during resight intervals using the Lincoln-Petersen estimator.**

| | Re-sighting interval | Tagged kereru present at study site during re-sighting interval (n1) | No. of re-sightings of tagged kereru during re-sighting interval (m2) | Total kereru (tagged and untagged) sighted during re-sighting interval (n2) | Estimated no. of kereru present at study site during re-sighting interval (N) |
|---|---|---|---|---|---|
| Church Bay | | | | | |
| | Feb. | 5 | 24 | 50 | 11 |
| | April - May | 5 | 128 | 147 | 6 |
| 2004 | Jun. - Jul. | 5 | 82 | 102 | 6 |
| | Sept. - Oct. | 5 | 103 | 146 | 7 |
| | Oct. - Dec. | 5 | 73 | 96 | 7 |
| Orton Bradley Park | | | | | |
| | Feb. | 8 | 40 | 157 | 34 |
| 2004 | Jun - Jul | 7 | 121 | 151 | 9 |
| | Sept. - Oct. | 7 | 95 | 169 | 13 |
| 2005 | Feb. - Mrch. | 6 | 62 | 161 | 17 |

### *7.3.2 Mortality records*

Three tagged kereru were lost within the first two weeks after they were radio-tagged (Appendix 1): two were taken by a predator while foraging on poroporo (possible predators were cat (*Felis cattus*) and stoat (*Mustela erminea*)), and a third kereru died after breaking its collar bone, perhaps as a result of a collision with a window or a branch (T.A. Prendergast, *pers. comm.*). It was found in a residential area underneath a conifer. The transmitters of these three mortalities were placed on new kereru (Appendix 1).

Two additional mortalities (the transmitters were not replaced) that occurred during the remainder of the study were:

1. Kereru 12 which did not move again after it moved from Orton Bradley Park to Mount Herbert Reserve in April 2004 (see Chapter 6);
2. Kereru 22 was found dead below the nest on which she was brooding a 10-day old chick at Orton Bradley Park on 20 October 2004. The remains of the adult female consisted of two wings, tail and contour feathers, a foot, the crop and the transmitter with harness cord (T.A. Prendergast, *pers. comm.*).

## 7.4 Discussion

Kereru numbers at Church Bay and Orton Bradley Park appeared to respond to food availability, with the population estimate at its lowest when fewer food species were eaten (see Chapter 5) and during times when some of the kereru tagged at Orton Bradley Park had moved away to other areas (see Chapter 6); numbers were higher when relatively more food species were eaten from summer to early autumn and breeding kereru stayed within study sites. Kereru numbers were also relatively higher when kereru foraged on food sources within or close to conifer plantations, especially in Orton Bradley Park. During these times, kereru were also eating similar food species in native forest patches and residential gardens but the numbers at the latter locations did not appear to fluctuate as much as those near conifer plantations (*pers. obs.)*. Studies suggest kereru abundance is directly related to food availability (Dawson *et al.*, 1978; Clout & Gaze, 1984; Clout *et al.*, 1986; Clout *et al.*, 1991; Pierce, 1993; Day, 1995). Kereru numbers were previously found to increase in conifer plantations when food species were available within or close to conifer plantations (*Pinus* spp.*)*, and only during spring, summer, or autumn (Clout & Gaze, 1984). During winter (June to July), kereru numbers at Church Bay were half of the number estimated during summer; at Orton Bradley Park, the number estimated during winter was approximately one quarter of that estimated during summer.

Previous studies had not estimated local population size, but compared relative abundance at specific points in time and space (Dawson *et al.*, 1978; Clout & Gaze, 1984; Clout *et al.*, 1986; Clout *et al.*, 1991; Pierce, 1993; Day, 1995). Due to differences in the data collection method used between this study and those that conducted five-minute bird counts (Clout & Gaze, 1984; Pierce *et al.*, 1993), a comparison between these studies was not feasible unless calibration is carried out. However, during this study, encounters with untagged kereru followed a trend similar to the change in the number of encounters with tagged kereru at specific points in time and space (*pers. obs.*).

Management success at Church Bay and Orton Bradley Park should be measured using population trend monitoring. Future data collection should be a replicate of this study's method, and the numbers estimated during this study would form the baseline for the trend monitoring. Alternatively, monitoring population trends of kereru at the study sites is possible without the use of radio transmitters or marked kereru. The Department of Conservation has suggested two alternative methods for population trend monitoring (Mander *et al.*, 1998): 1) five-minute counts along transects (an index of abundance); and 2) display flight monitoring from vantage points (an index of the number of breeding pairs). It should be noted that when a method (other than the one used in this study) is used for population trend monitoring, the results of this study are no longer appropriate for comparison unless calibration is carried out.

Future population estimates at Church Bay and Orton Bradley Park, using the method used in this study, could best be carried out during the time interval June – July. It appears that, during this time, only resident kereru were present at the study sites. Trends in numbers during winter could be indicative of changes in food availability. A disadvantage of the September – October time interval is that kereru are likely to be breeding and therefore the results may be biased as birds are less likely to use the same sites during this season (e.g., low home range overlap; see Table 6.4). Estimation during summer would be biased because more kereru from outside the study area would be present. Even though this would show a trend in numbers among years, it could be biased by changes in resources outside of the study areas.

The population estimate was conducted for two study sites on Banks Peninsula. Results of this study cannot be extrapolated over the greater Banks Peninsula area because the distribution of kereru is currently unknown and because there is too little quantitative information of areas similar to Church Bay and Orton Bradley Park. This information is required before kereru numbers can be estimated elsewhere on Banks Peninsula. In regards to information on the distribution of kereru, this could be obtained through five-minute counts along transects or from vantage points at specific times (Mander *et al.*, 1998). Alternatively, local residents could be interviewed to obtain this information. The records should include the time of year during which kereru are present/absent as kereru have been recorded to include multiple discrete seasonal home ranges (Clout *et al.*, 1991).

# Chapter 8

# General discussion

The preceding chapters examined different aspects of kereru ecology on Banks Peninsula. This chapter discusses the significance of this study to the Kaupapa Kereru Programme and efforts to enhance kereru populations in rural-urban landscapes throughout New Zealand. Recommendations for management and suggestions for future research are presented.

## 8.1 How does this study fit into the long-term vision of the Kaupapa Kereru Programme and national research on kereru ecology?

The Kaupapa Kereru Programme aspires to increase kereru populations because of the kereru's cultural importance to New Zealanders, and the kereru's role in seed dispersal of native tree species. My study is the first to examine kereru ecology in a rural-urban landscape. The results and management recommendations from this study complement those of other studies on kereru ecology, coordinated by the Department of Conservation (Mander *et al.*, 1998), in a wider range of landscapes throughout New Zealand, including both rural and urban landscapes (e.g., (McEwan, 1978; Clout *et al.*, 1986; Clout *et al.*, 1988; Clout *et al.*, 1991; Clout *et al.*, 1995; Pierce & Graham, 1995; Worton, 1995; Bell, 1996; Ridley, 1998; Powlesland *et al.*, 2003).

## 8.2 Quality of study sites for kereru

The quality of the study sites at Church Bay and Orton Bradley Park for kereru was assessed based on food availability, number of nesting attempts for each breeding pair, seasonality and distance movements, and differences in the spatial arrangement of resources. Two assumptions were made to assess the quality of the sites:

1) Fluctuations in the number of kereru at each study site were an indicator for quality. As kereru are known to occupy multiple seasonal home ranges (Clout *et al.*, 1991), long-distance movements between areas (such as between Orton Bradley Park and

Mount Herbert Reserve) cannot be assumed to be driven solely by food availability or quality. However, I assumed that movements of kereru away from their summer home ranges or capture sites indicated a decrease in food availability.

2) Predation of nests by introduced mammals is known to terminate birds nesting attempts (Innes, 1995; Sadlier, 2000), and specifically kereru nests (Powlesland *et al.*, 2003). Predation of nests perhaps stimulates kereru to again attempt to nest, however, studies suggest that if insufficient foods are available (quality and quantity), kereru may not attempt to nest at all or may not attempt to re-nest (Clout *et al.*, 1988; Clout *et al.*, 1995; Pierce & Graham, 1995). Therefore, the number of nesting and re-nesting attempts of each breeding pair was used to evaluate whether sufficient foods were available at study sites.

The Church Bay study site consisted of a residential area, a native forest reserve, with relatively few areas (e.g., pasture) with little of no value to kereru. At this site, all but one kereru nested, each of the three pairs fledged a chick, no adult kereru died or moved away without returning, and kereru were absent for shorter periods compared with kereru tagged at Orton Bradley Park. The Orton Bradley Park site consisted of relatively large areas of pasture. The native forest patches that were smaller than those at Church Bay. At the Park, most kereru bred but only two of four pairs were successful in fledging chicks. Six tagged kereru moved out of the Orton Bradley Park site and two did not return. Four of the 13 kereru, tagged at this site died during the study.

Kereru numbers at Church Bay fluctuated less during winter than at Orton Bradley Park suggesting there was a more constant food availability throughout the study period (Table 7.1). Home ranges of tagged kereru stayed within the boundaries of each of the study sites during the breeding season, demonstrating that all resources required for nesting and foraging were available. Kereru, present at both study sites, travelled similar distances (mostly < 500 m) between resources (e.g., food sources and nesting sites) suggesting the spatial layout of the landscape did not appear to limit movement (i.e., the presence of pasture between resources). Observations by K-J. Wilson show that, with one exception, kereru remained in Church Bay for approximately 98% of observations during the non-breeding season; during the breeding season, three kereru remained within Church Bay (absence records between 94-99% of observations), and two kereru left this study site but returned on a daily basis (absence 50 and 34% of observations). Continuation of observations after my study ended showed that kereru increase their amount of time spent outside Church Bay (absence between 10 and 71% of observations), but all kereru, except one, return on a regular basis.

Judging by the number of nesting attempts, mortality, seasonality and lengths of movements, and fluctuation of the number of kereru, Church Bay appears to be of better quality for kereru than Orton Bradley Park; food was not available to some individuals at some stages of the year at Orton Bradley Park. However, all but one kereru returned after moving away and, with one exception, all breeding pairs attempted to nest at least twice. The quality of study sites for kereru is defined by continuous food availability rather than presence of native forest patches within home ranges.

### 8.3 How can the kereru population be increased on Banks Peninsula?

Predator control efforts should increase survival of adult kereru and nests; predation of adult kereru and nests was significant during this study (T.A. Prendergast, *pers. comm.*). Results of previous studies suggest that predator control should be a crucial component of management of the kereru population in Banks Peninsula; in the Whirinaki Forest Park, Powlesland *et al.* (2003) found nesting success to triple after predator control, and in Te Urewera, kereru populations increased 2.6 fold after predator control (Burns *et al.*, 2000).

Management efforts, following predator control, should focus on providing sufficient food sources for an increased kereru population (i.e., following predator control); a special focus on increasing native food availability before and during the breeding season, and increasing the number of locations where food species are available (see sections 5.3.1 and 5.4.1 for food species that could be planted). Management efforts should also make provision for suitable nesting sites.

### 8.4 How well does the current kereru population disperse seeds?

Factors affecting seed dispersal are: plant species which supply fruit, sites of seed deposition, and distances travelled between consumption and defaecation (Burrows, 1994a; McConkey *et al.*, 2004). Seed dispersal of native plant species occurred only during mid to late summer when fruits were eaten of cabbage tree (*Cordyline australis*), poroporo (*Solanum aviculare*), *Coprosma rhamnoides*, ngaio (*Myoporum laetum*), kawakawa (*Macropiper excelsum*), five-finger (*Pseudopanax arboreus*), fuchsia (*Fuchsia excorticata*), titoki (*Alectryon excelsus*) and mahoe (*Melicytus ramiflorus*) (Figures 5.4 and 5.5). Introduced fruit trees (*Prunus* spp.; especially plum trees), eaten during late spring and early summer, were the only introduced food species whose fruits were eaten during this study that could benefit from dispersal by kereru. Other plant species occurring on Banks Peninsula that could benefit from seed dispersal by kereru are: rowan (*Sorbus aucuparia*), *Coprosma* spp., broadleaf (*Griselinia littoralis)*, horopito (*Pseudowintera colorata*), kahikatea (*Dacrycarpus dacrydioides)*, kaikomako (*Pennantia corymbosa)*, lancewood (*Pseudopanax* spp.), matai (*Podocarpus spicatus)*, red matipo (*Myrsine australis*), pate (*Schefflera digitata*), pigeonwood (*Hedycarya arborea),* supplejack (*Ripogonum scandens*), Hall's totara (*Podocarpus hallii)*, wineberry (*Aristotelia serrata*) (see also section 5.4.1). Fruits eaten and dispersed by kereru were consistent with those observed on Banks Peninsula by Burrows (1994b).

As seeds take approximately two hours to traverse the gut of kereru (Clout & Tilley, 1992; Bell, 1996), daily movements between sites determine the locations where seeds would be dispersed. With one exception, 61 to 100% of movements made by kereru between consecutive observations throughout this study, were mostly less than 500 m (see section 6.4.5 and Appendix 10). Therefore, effective dispersal distances are assumed to be within 500 m of a foraging site. Because previous studies on kereru within New Zealand have not described seed dispersal distances, it is not possible to compare dispersal distances found in, this study with dispersal distances found in native forests. However, seed dispersal distances found during this study were similar to those found for fruit eating pigeons in Tonga (McConkey *et al., 2004)* (see section 6.4.5).

A larger kereru population would potentially visit more locations (i.e., forest patches and other areas) and disperse seeds to and from a greater number of locations. However, this may not automatically improve regeneration of native plants because kereru could also disperse seeds of introduced species into native forest fragments. Home range analyses showed that kereru in the rural-urban landscape were not confined to native forest patches and regularly visited areas of predominantly introduced species. This confirms the observations of Clout (1991) and Ridley (1998) that kereru use introduced food species in human-modified areas. Seed dispersal of native and introduced food species by kereru will enhance species variety. Areas currently lacking food species and which are not used for nesting (e.g., sites not regularly visited by kereru), have minimal potential to benefit from seed dispersal. Seed dispersal of native species could be enhanced if an increased variety of native fruiting species is planted at multiple locations. A greater variety of species may also increase the period during which fruits are available and the period during which seeds are dispersed.

## 8.5 What is essential to allow kereru to expand their range on Banks Peninsula?

Kereru are absent from parts of Banks Peninsula for three reasons: 1) lack of food throughout part or all of the year; 2) absence of suitable nesting sites; and 3) predation. In areas where kereru are absent during part or all of the year, planting additional food species should facilitate colonisation of new areas (see section 8.3). It is also essential to control predators in areas currently occupied by kereru (during parts of the year) to increase survival of adult kereru and nests, and also in areas not currently occupied year-round to increase survival when these areas are eventually colonised.

Areas where kereru currently occur are 'source areas' for the establishment of new populations; once carrying capacity in those areas is reached, kereru will disperse to new sites. In source areas, priority should firstly be given to increasing adult kereru and nest survival through predator control, and secondly to increasing food availability.

## 8.6 Key results for kereru management on Banks Peninsula

1. Breeding did not appear to be limited by food availability during this study, but nesting failure due to predation was one of the reasons fledging success was limited. The importance of suitable nesting sites (a potential limiting factor for breeding kereru) should not be neglected because kereru made greater use of native forest patches for foraging as well as nesting during the breeding season.
2. To facilitate an increase in the kereru population, adult survival should be prioritised above reproductive output. Predator control of cats during summer would enhance adult kereru survival; predator control of rats and possums, before and during the breeding season, would enhance reproductive success.

3. The number of nesting attempts is regulated by food quality and quantity. Maintaining and/or increasing the availability of essential food species is important for reproductive activity before and during the breeding season, and also adult survival during winter. The available volume of native and introduced food species should continue to be monitored, and the volume of young deciduous leaves available from introduced plant species should be maintained until native species replace them (if the policy becomes promotion of the planting of natives and reducing introduced species).

4. The current amount of resources available (e.g., foods and suitable nesting sites) could become a limiting factor in the future (i.e., following predator control when the population increases).

5. Increasing the variety of fruiting native food species could improve food choice for kereru, lengthen the period during which native fruits are being eaten and dispersed by kereru, and enhance regeneration of native forest patches through improved seed dispersal.

6. To increase food availability within specific areas, so that these areas can sustain an increased kereru population throughout the year, it would be most effective to plant a variety of food species within approximately 500 m between two areas, because kereru moved most often less than 500 m on a daily basis. Each planting area should contain a year-round food supply.

7. Priority should be given to planting food species to provide food year-round to allow kereru to colonise new areas, and areas where kereru are present during part of the year. The Kaupapa Kereru Programme aims to improve food sources especially in the more urban areas of Banks Peninsula where it is hoped the community can experience the increase of kereru numbers in 5-10 years.

8. Consumption of fruit bearing introduced species by kereru, such as plums, could potentially result in an invasion of introduced species within areas used by kereru. It is unclear to what extent introduced species currently benefit from seed dispersal and/or if dispersal by kereru enhances their weed potential (Burrows, 1994b). Establishment of

native food species as an alternative food source to kereru might reduce the potential spread of undesirable species.

9. Human presence does not appear to have an adverse effect on kereru behaviour at foraging or nesting sites.

10. Kereru populations in similar rural-urban landscapes elsewhere in New Zealand could be exposed to limiting factors similar to these reported in this study, primarily predator impacts and uncertainty regarding the quality and quantity of available native food supplies.

## 8.7 Management recommendations

Management recommendations in order to increase the local kereru population on Banks Peninsula are:

1. Control of predators such as cats, rats, possums, and stoats to reduce predation of adult kereru and enhance reproductive output. Control of cats should have priority to increase adult kereru survival; rats and possums should be prioritised to enhance reproductive output (T.A. Prendergast, *pers. comm.*).

2. Cultivate additional food species to increase year-round food availability (i.e., variety, quantity, and quality of foods).

3. Initiate a cooperative programme with individual landowners to plant essential food species and control predators.

4. Enhance regeneration of food species by reducing browsing of seedlings by stock in forest patches and fencing off these patches from stock.

To increase native food availability in the future, I recommend the planting of the following native species (recorded eaten by kereru during this study): cabbage tree, poroporo, *C. rhamnoides*, ngaio, kawakawa, five-finger, fuchsia, kowhai, titoki, mahoe, and pohuehue. Increasing the food availability of introduced species is possible, although most governmental and other organisations prefer plantings of native species. Additional species that were recorded to be eaten by kereru on Banks Peninsula are: *Coprosma* spp., broadleaf (*Griselinia littoralis)*, horopito (*Pseudowintera colorata*), kahikatea (*Dacrycarpus dacrydioides)*, kaikomako (*Pennantia corymbosa)*, lancewood (*Pseudopanax* spp.), matai (*Podocarpus spicatus)*, red matipo (*Myrsine australis*), pate (*Schefflera digitata*), pigeonwood (*Hedycarya arborea),* supplejack (*Ripogonum scandens*), Hall's totara (*Podocarpus hallii)*, wineberry (*Aristotelia serrata*).

In Church Bay, food species could be planted in areas where the current vegetation contains tree lucerne, conifer species and eucalypts, and in areas which already contain native species used by kereru (see Chapter 3 and Appendix 2). In Orton Bradley Park, the potential to increase food sources should be focussed at the edges of forest patches (especially conifer plantations), which would increase their value to kereru (see Chapter 3 and Appendix 2). Not only are kereru likely to increase their use of forest patches when their value increases, more seeds are likely to be dispersed between patches. Other potential locations for enhancing the food supply are recreational areas where visitors to the Park would encounter kereru. Residential gardens also have the potential to attract more kereru if the above-named species are present.

Native forest patches could benefit from plantings, although enhancement of natural regeneration is likely to occur as a result of increased seed dispersal by kereru from other locations to these patches.

## 8.8 Strengths and weaknesses of this study

The lack of previous studies on kereru ecology in rural-urban landscapes suggest that the results of this study should be used as a baseline for future studies. A comparison with studies conducted in relatively little human-modified forests showed significant differences; I suggest this is the result of the variations in landscape features. It should be noted that differences in data collection methods between this study and previous ones could also have affected the results. Therefore, a comparison with previous studies did not tell me if kereru in the rural-urban landscape of Banks Peninsula have to survive in a poorer quality landscape. In addition, I could not determine whether this study was conducted during a good, average, or poor year regarding food availability because this study was conducted over a 13-month period and because no previous data were available.

The primary strength of this study is that it supplies previously unreported information on kereru ecology in a rural-urban landscape, which contributes to conservation of this species on a local (i.e., Banks Peninsula; Kaupapa Kereru Programme) and national level (i.e., rural-urban landscapes throughout New Zealand; Department of Conservation). A second strength of my study was that kereru were located multiple times a day which allowed for an assessment of home range size and seed dispersal distances (see section 6.4.5 and Table 6.6). Thirdly, in my study, at least 44% of the kereru population was tagged at Church Bay and a minimum of 24% at Orton Bradley Park. As it has been suggested that at least 20% of animals from a population need to be monitored to draw reliable inferences on home ranges and movements (Millspaugh & Marzluff, 2001), inferences drawn from the results from this study should therefore be reliable. This allowed for a description of daily movements, behaviour, fate of nesting attempts, and food species eaten.

## 8.9 Enthusiasm of the community

The Banks Peninsula Runanga, as well as the local community, have shown interest to initiate this study. Community involvement could well be the key to successful management of the local population; the Kaupapa Kereru Programme's effective management area could exceed the area of conservation land if private properties are managed to favour kereru. Landowners could assist by increasing the food supply and implementing predator control. An example of this is the release of research findings (the list of plant species eaten by kereru during this study; section 8.7) to the community which was received very positively.

## 8.10 Future research

These suggestions for further research have been formulated specifically to supplement and extend current research efforts for the Banks Peninsula kereru population as well as enhancing the knowledge base of kereru ecology in rural-urban landscapes elsewhere in New Zealand. My recommendations are:

1. Replicate this radio-tracking study in 5-10 years to measure management success.

2. Measure management success through monitoring population trends. Either by replicating the methods used to estimate the kereru numbers as described in this study, or alternatively, one of two methods suggested by the Department of Conservation (Mander *et al.*, 1998): five-minute bird counts or display flight counts. Careful consideration of the strengths and weaknesses of any method should be considered before its application in rural-urban landscapes. It should be noted that these alternative methods have previously been conducted in landscapes quite different from the rural-urban landscape on Banks Peninsula (e.g., large tracts of native forest).

3. Assess of vegetation composition in forest patches visited by kereru to test whether kereru target specific food species and to determine if seedlings establish.

4. Assess of the relationship between food abundance and breeding in kereru (Clout *et al.*, 1995) would give a further insight into the role of introduced food species in regards to the timing of the reproductive cycle of kereru in landscapes modified by humans.

5. Assess of predator impacts on the (increased) kereru population and evaluation of the success of predator control efforts.

6. Obtain a more complete list of food species eaten by kereru on other parts of Banks Peninsula (this is partially satisfied by the current study of kereru ecology in and around Hinewai Reserve near Akaroa; Campbell, *pers. comm.*).

7. Determine if kereru forage, nest, and/or roost at the same locations at the same time (dynamic interaction) as an index for resource availability.

8. Assess of seed dispersal distances of native food species to investigate which species and locations benefit.

9. Investigate the extent to which humans disturb nesting kereru.

10. Assessment of seed germination was outside of the scope of this study but should be addressed in future research. It is unclear to what extent natural forest regeneration currently benefits from seed dispersal by kereru. Establishment of native seedlings was previously noted to be limited due to the browsing of the forest understorey by livestock on Banks Peninsula (Burrows, 1994a).

11. Evaluation of the effectiveness of stock exclosures for the establishment of seedlings within forest fragments.

### 8.11 Achievements of this study

This study provided a baseline for future kereru research in the rural-urban landscape of Banks Peninsula by describing seasonal changes in home ranges, movements, use of food species, and the number of kereru present at two sites, and describing aspects of the breeding season. This study also supports previous research because it found kereru adjusted their home ranges and movements according to food species availability.

The home range analysis (estimated using cluster analysis) showed significant differences in the size of home ranges and core areas compared to those reported in a study conducted in native forests. I concluded that the layout of the landscape caused these differences, as the spread of resources (especially food species) is different, and much of kereru ecology depends on this (see Chapters 5 and 6). I regard the adjustment of kereru to introduced food species as positive from a species conservation point, because the small home ranges and core areas indicate good quality of sites for kereru, and because kereru were recorded to reproduce successively and raised chicks on a diet which (at least partly) consisted of introduced plant species' leaves.

The results of my research are further enhanced by the fact that this study was conducted as part of the Kaupapa Kereru Programme. Not only will future research initiated by the Kaupapa Kereru Programme supply more information regarding kereru diet and home ranges on Banks Peninsula and in similar landscapes, the predation study (carried out simultaneously with my study) supplied us with a more complete picture of the dynamics of the local kereru population. For example, we now know that food availability was not a limiting factor for kereru in the study sites, while predator impacts play a significant role in survival of adult kereru and nests.

Results of this study demonstrate the effectiveness of radio telemetry as a tool for assessing home ranges and movements in kereru and estimating population size.

The Kaupapa Kereru Programme motivated the Banks Peninsula community through regular press releases of the different studies being initiated by the Programme, and presentations of research findings. The Kaupapa Kereru Programme should continue to communicate with the community as this would continue to enhance research and management efforts.

## References


Atkinson, R. (1993) Killing the Kereru. *Forest & Bird*, 267, 18-23.

Bell, R. (1996) Seed dispersal by kereru (*Hemiphaga novaeseelandiae*) at Wenderholm Regional Park. Masters thesis, University of Auckland.

Beveridge, A.E. (1964) Dispersal and destruction of seed in central North Island podocarp forests. *Proceedings of the New Zealand Ecological Society*, 11, 48-55.

Burns, R., Harrison, A., Hudson, J., Jones, G., Rudolf, P., Shaw, P., Ward, C., Wilson, D., & Wilson, L. (2000) Northern Te Urewera Ecosystem Restoration Project, Summary Annual Report July 1999 to June 2000. East Coast Hawke's Bay Conservancy, Department of Conservation, Gisborne.

Burrows, C.J. (1994a) Fruit types and seed dispersal modes of woody plants in Ahuriri Summit Bush, Port Hills, Western Banks Peninsula, Canterbury, New Zealand. *New Zealand Journal of Botany*, 32, 169-181.

Burrows, C.J. (1994b) Fruit, seeds, birds and the forests of Banks Peninsula. *New Zealand Natural Sciences*, 21, 87-108.

Clout, M.N. & Gaze, P.D. (1984) Effects of plantation forestry on birds in New Zealand. *Journal of Applied Ecology*, 21, 795-815.

Clout, M.N., Gaze, P.D., Hay, J.R., & Karl, B.J. (1986) Habitat use and spring movements of New Zealand pigeons at Lake Rotoroa, Nelson Lakes National Park. *Notornis*, 33, 37-44.

Clout, M.N. (1988) Kereru hunting. *Forest & Bird*, 19, 9.

Clout, M.N., Gaze, P.D., & Hay, J.R. (1988) Clutch overlap by a New Zealand pigeon. *Notornis*, 35, 59-62.

Clout, M.N. & Hay, J.R. (1989) The importance of birds as browsers, pollinators and seed dispersers in New Zealand forests. *New Zealand Journal of Ecology*, 12, 27-33.

Clout, M.N. (1990) The kereru and its forests. *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. & Tilley, J.A.V. (1992) Germination of miro (*Prumnopitys ferruginea)* seeds after consumption by New Zealand pigeons (*Hemiphaga novaeseelandiae*). *New Zealand Journal of Botany*, 30, 25-28.

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.

Crossland, A. (1996) Port Hills Birdlife Inventory, Analysis & Restoration Potential. Christchurch City Council, Christchurch.

Dawson, D.G., Dilks, P.J., Gaze, P.D., McBurney, J.G.R., & Wilson, P.R. (1978) Seasonal differences in bird counts in forests near Reefton, South Island, New Zealand. *Notornis*, 25, 257-278.

Dawson, E.W. (1950) Bird notes from Little Barrier. *Notornis*, 4, 27-31.

Day, T.D. (1995) Bird species composition and abundance in relation to native plants in urban gardens, Hamilton, New Zealand. *Notornis*, 42, 175-186.

Dijkgraaf, A.C. (2002) Phenology and frugivory of large-fruited species in northern New Zealand and the impacts of introduced mammals. PhD. Thesis, University of Auckland.

ESRI (2004) ArcGIS 9. Environmental Systems Research Institute (ESRI), Redlands, California, USA.

Gibb, J.A. (1970) A pigeon's choice of plums. *Notornis*, 17, 239.

Greene, T.C. (2004) Distance sampling populations of New Zealand birds: estimating kaka and kereru abundance. (ed Poster). Department of Conservation, Christchurch.

Harris, S., Cresswell, W.J., Forde, P.G., Trewhella, W.J., Woolard, T., & Wray, S. (1990) Home-range analysis using radio-tracking data - a review of problems and techniques particularly as applied to the study of mammals. *Mammal Review*, 20, 97-123.

Higgins, P.J. & Davies, S.J.J.F. (1996). *Hemiphaga novaeseelandiae* New Zealand Pigeon. In: *Handbook for Australian, New Zealand & Antarctic birds*, Vol. 3: Snipe to Pigeons, pp. 1012-1018. Oxford Universiry Press, Melbourne.

Hill, M.T. (2003) Diet, dispersal, and distribution of kereru (*Hemiphaga novaeseelandiae novaeseelandiae)* in a lowland podocarp-hardwood forest. Masters thesis, Massey University.

Hitchmough R., (2002) *New Zealand Threat Classification System lists, 2002*. Biodiversity Recovery Unit, Dept. of Conservation Wellington, New Zealand.

Innes, J. (1995). Impacts of possums in native fauna. In: *Possums as conservation pests* (ed C.F.J.C. O'Donnel), pp. 11-15. Department of Conservation, Wellington, New Zealand.

Karl, B.J. & Clout, M.N. (1987) An improved radio transmitter harness with a weak link to prevent snagging. *Journal of Ornithology*, 73-77.

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

Kenward, R. (2001) *A manual for wildlife radio tagging*. Academic Press, San Diego ; London.

Kenward, R.E., South, A.B., & Walls, S.S. (2003) *Ranges 6 Manual - Software for the analysing animal location data (www.anatrack.com)*. Institute of Terrestrial Ecology, Wareham, United Kingdom.

Magrath, R. & Lill, A. (1983) The use of time and energy by the crimson rosella in a temporate wet forest in winter. *Australian Journal of Zoology*, 31, 903-12.

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

McConkey, K.R., Meehan, H.J., & Drake, D.R. (2004) Seed dispersal by Pacific pigeons (*Ducula pacifica*) in Tonga, Western Polynesia. *Emu*, 104, 369-376.

McEwan, W.M. (1978) The food of the New Zealand pigeon *(Hemiphaga novaseelandiae novaseelandiae). New Zealand Journal of Ecology*, 1, 99-108.

Millspaugh, J.J. & Marzluff, J.M. (eds) (2001) *Radio Tracking and Animal Populations*. Academic Press, San Diego, California, USA.

O'Donnel, C.F.J. & Dilks, P.J. (1988) A method for quantifying habitat use by forest birds. Rep. No. No.4. Science & Research Directorate, Department of Conservation, Wellington.

Pierce, R. (1993) Ecology of the kukupa in Taitokerau: problems and some solutions. *Ecological Management*, 1, 44-48.

Pierce, R.J., Atkinson, R., & Smith, E. (1993) Changes in bird numbers in six Northland forests 1979-1993. *Notornis*, 40, 285-293.

Pierce, R.J. & Graham, P.J. (1995) Ecological breeding biology of kukupa (*Hemiphaga novaeseelandiae*) in Northland. Rep. No. 91. Department of Conservation, Wellington.

Powlesland, R., Grant, A., Tisdal, C., Dilks, P., & Flux, I. (1992) Ecology and breeding biology of Parea (Chatham Island pigeon) on Southern Chatham Island, July 1991-1992. Rep. No. No. 134. Department of Conservation, Wellington.

Powlesland, R., 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.

Programme, K.K. (2005) The kereru Oral Histories Project, Christchurch, New Zealand.

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

Sadlier, R. (2000). Evidence of possums as predators of native animals. In: *The brushtail possum: biology, impact and management of an introduced marsupial* (ed T.L. Montague), pp. 126-131. Manaaki Whenua Press, Lincoln, New Zealand.

Taylor, M.M. (1950) Wood pigeon eating shoots and leaves. *Notornis*, 4, 33.

van Winkle, W. (1975) Comparison of several probabilistic home-range models. *Journal of Wildlife Management*, 39.

Voight, D.R. & Tinline, R.R. (1980). Strategies for analysing radio tracking data. In: *A handbook in biometry and radio tracking* (eds C.J. Amlaner & D.W. MacDonald), pp. 387-404. Pergamon Press, Oxford.

Webb, C.J., Sykers, W.R., & Garnock-Jones, P.J. (1988) *Flora of New Zealand volume IV, Naturalised pteridophytes, gymnosperms, dicoltyledons*. Botany Division, DSIR, Christchurch, New Zealand.

White, G.C. & Garrott, R.A. (1990) *Analysis of wildlife radio-tracking data*. Academic Press, San Diego.

Wilson, H.D. (1992) Banks Peninsula Region 'Survey report for New Zealand's Protected Natural Areas Programme'. Rep. No. 21. Department of Conservation.

Wilson, H.D. (1998). Living in Raoul country: the changing flora and vegetation of Banks Peninsula. In: *Etienne Raoul and Canterbury Botany 1840-1996* (ed C.J. Burrows), pp. 101-121. Canterbury Botanical Society, Manuka Press 1998.

Wilson, P.R., Taylor, R.H., & Thomas, B.W. (1988) Effects of topography on seasonal distribution of forest birds in the Ohikanui, Lower Buller and Inangahua Valleys, North Westland. *Notornis*, 35, 217-243.

Worton, B.J. (1995) Using Monte Carlo simulation to evaluate kernel-based home range estimators. *Journal of Wildlife Management*, 59, 794-800.

Wright, S.D., Nugent, G., & Parata, H.G. (1995) Customary management of indegenous species: a Maori perspective. *New Zealand Journal of Ecology*, 19, 83-86.

Young, E. (1995) Maori customary use of native birds, plants and other traditional materials. Submission to the New Zealand Conservation Authority on their discussion paper on Maori customary use. *New Zealand Journal of Ecology*, 19, 77-82.

# Appendix 1.

## Capture information, measurements, and sex of the radio-tagged kereru

| Kereru no. | Frequency Channel | Capture date | Catch site [c] | Band no. [d] | Jesse code [e] | Weight (g) | Tail (mm) | Wing (mm) | Beak (mm) | Sex |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 10 +1.0 | 1/22/2004 | CB | K 13859 | R-yellow | 653 | 193 | 252 | 18.2 | male |
| 12 | 12+0.9 | 1/28/2004 | OBP1 | S 80595 | L-green R-yellow | 613 | 198 | 255 | 16.8 | ~ |
| 14 | 14+0.9 | 1/20/2004 | OBP1 | K 13851 | R-blue | 568 | 184 | 258 | 14.9 | ~ |
| 16 [a] | 16+0.3 | 1/20/2004 | OBP1 | K 13856 | L-red | 723 | 186 | 262 | 23.4 | ~ |
| 18 | 18+0.5 | 1/28/2004 | CB | S 80592 | L-yellow R-red | 654 | 200 | 261 | 16.1 | male |
| 20 | 20+1.0 | 1/20/2004 | OBP1 | K 13853 | R-green | 648 | 186 | 249 | 16.9 | female |
| 22 | 22+0.1 | 1/20/2004 | OBP1 | K 13852 | L-yellow | 663 | 200 | 265 | 15.3 | female |
| 24 | 24+0.9 | 1/20/2004 | OBP1 | K 13854 | R-red | 718 | 187 | 255 | 17.9 | female |
| 26 [a] | 26+1.0 | 1/28/2004 | OBP1 | S 80596 | L-green | 624 | 203 | 257 | 12.3 | ~ |
| 28 [a] | 28+0.5 | 1/20/2004 | OBP1 | K 13855 | L-blue | 603 | 198 | 246 | 23.2 | ~ |
| 30 | 30+1.0 | 1/21/2004 | OBP1 | K 13857 | L-blue R-red | 708 | 200 | 257 | 16.9 | male |
| 32 | 32+0.3 | 1/21/2004 | OBP1 | K 13858 | L-red R-blue | 687 | 192 | 260 | 18 | male |
| 34 | 34 -1.0 | 1/28/2004 | CB | S 80594 | L-yellow R-green | 524 | 170 | 227 | 14.2 | ~ |
| 36 | 36+0.9 | 1/25/2004 | CB | S 80591 | green-green | 603 | 175 | 249 | 18.4 | female |
| 38 | 38+0.5 | 1/28/2004 | CB | S 80593 | L-blue R-yellow | 794 | 188 | 260 | 19.9 | female |
| 16 [b] | 16+0.5 | 3/9/2004 | OBP2 | S 80598 | L-red | 643 | 206 | 260 | 18 | male |
| 26 [b] | 26+1.0 | 3/9/2004 | OBP2 | S 80599 | Orange-Orange | 594 | 163 | 259 | 16.1 | ~ |
| 28 [b] | 28+0.5 | 3/9/2004 | OBP2 | S 80597 | L-blue | 705 | 191 | 259 | 18.4 | male |
| | | | | | Mean: | 781.7 | 228 | 306.1 | 20.99 | |

[a]: bird found dead; transmitter was placed on an other bird on 09/03/04

[b]: transmitter was recycled from one of the kereru found dead

| [c]: Catch sites: | | | |
|---|---|---|---|
| | OBP1 = Orton Bradley Park site 1 | 43o 39' S – 172o 42' E | 7 kereru captured on 20, 21, 28 January 2004 |
| | OBP2 = Orton Bradley Park site 2 | 43o 38' S – 172o 42' E | 3 kereru captured on 9 March 2004 |
| | CB = Church Bay | 43o 37' S – 172o 43' E | 5 kereru captured on 22, 25, 28 January 2004 |

[d]: Bandsize:K and S

[e]: Jesse code: L = jesse on left leg; R = jesse on right leg

~: sex was not determined for these kereru

# Appendix 2.

## Detailed description of study site vegetation types

## Church Bay

### Residential gardens

The gardens had a relatively high density of trees and scrubs with few open areas with low, non-woody vegetation. Most trees had a height of about 10 m, except for several tall eucalypt and macrocarpa spread throughout the area (up to 25 m). Tagged kereru used a variety of roosting locations (i.e., trees, roofs, power lines and lamp posts). Native and introduced food sources were present within the gardens (e.g., tree lucerne *(Chamaecytisus palmensis)*, acacia (*Racosperma* spp.*)*, fruit trees (*Prunus* spp.), kowhai (*Sophora microphylla*), ngaio (*Myoporum laetum)*, poroporo (*Solanum aviculare, S. laciniatum)*; see Chapter 3).

### Hillside vegetation (above Marine Drive)

The vegetation on the hillsides on the east of Church Bay, above Marine Drive, was a mixture of mainly kowhai, cabbage tree, and tree lucerne with a maximum height of 10 m. Caprosma spp. And kowhai were present on steep cliffs and rock faces. The hillside is inaccessible due to its steepness and borders with Hunters Native Forest (see below). Several eucalypt and conifer species (15 m) protrude above the other trees.

### Hunter Native Forest (Scenic Reserve)

This is a 8.2 ha Scenic Reserve, currently management by the Department of Conservation, was declared Protected Private Land in 1983 and Reserved in 1985. The Church Gully Stream flows within the Reserve which is characterised by steep cliffs above the Marine Drive. Along the length of the Church Gully Stream are rock faces and waterfalls but these change into less steep slopes towards the beach. The vegetation in the Reserve is second growth kanuka and mixed hardwood forest, dry bluffs, scrub, some silver tussock, and a lot of planted New Zealand native trees and scrubs foreign to the Canterbury district (Kelly, 1972). The vegetation is dense in places (e.g., saplings, supple jack, weeds). The maximum height of the trees is about 10 m but most of the canopy is within 6-8 m. Tall trees, suitable for roosting by kereru, are absent but such trees are present within close proximity. Access to the Reserve is closed for the public. For the purpose of this research access was permitted by DOC.

**Tree lucerne - conifer stand**

This low-density conifer stand (12 to 25 m), had an undergrowth of tree lucerne (up to 4m). Kereru used the conifer trees for roosting while foraging on the tree lucerne. The site is sunny later in the day as it is on a hillside facing west.

**Tree lucerne – eucalypt stand**

This tree lucerne-eucalypt stand along the beachfront has tree lucerne (up to 6 m.) growing in between the tall eucalypts and conifers (up to 25 m). Kereru used the eucalypts for roosting while foraging on the tree lucerne. The area is sunny and relatively flat but the lower parts are largely shaded by the tall eucalypts.

**Orton Bradley Park**

**1. Poroporo - Conifer blocks**

These conifer plantations had patches of poroporo bushes along the edges, beyond which was farmland. Characteristic was the presence of poroporo (up to 3 m) within close proximity of roosting locations (i.e., conifer trees, up to 25 m). Some tagged kereru used roosting locations further away but returned to the poroporo-conifer blocks on a daily basis.

Below is a description of three poroporo-conifer blocks used by tagged kereru:

**(1a) Andersons Road**

The conifer stand (up to 25 m) bordered the poroporo (3 m) over its full length (500 m x 20 m). The conifer block borders a kanuka stand (6-8m high) on the opposite side. The site is sunny during the day as it is on the top of a hill.

**(1b) Gum gully**

The conifer stand (up to 20 m) bordered the poroporo (3 m) on the east and south sides, with a sharp change in vegetation height. Other roosting locations in close proximity were kanuka (4-8 m) and eucalypt (about 25 m). The site is sunny during the day as the gully's aspect is northwest.

### (1c) Cemetery

The poroporo (3 m) bordered with a conifer block (25 m) on the south side and a narrow kanuka stand on the east side. A sharp change in vegetation height was present between the poroporo, conifer species, and kanuka (8 m). Other roosting locations within proximity of the poroporo were solitary eucalypts (25 m), several willows (6 m), and solitary pear trees (10 m). The site is sunny during the day as the hillside faces northwest.

## 2. Tree Lucerne-Eucalypt

The Rhododendron walkway is along a small, steep hill of about 75 m a.s.l. A walkway runs from the north side over the hilltop, to the bottom of the south side where it is connected to the Rhododendron walkway. Off-trail access of the hillsides is difficult due to the steepness of the slope, the dense vegetation, and loose rock and leaf litter. The vegetation on the hillsides consists of eucalypt (up to 25 m), tree lucerne (up to 6 m), and conifer species (up to 20 m). On the lower areas along the walkway, the vegetation is a landscaped mix of introduced plant species (i.e., rhododendron species, eucalypts, conifers species, and other aesthetic plants) and native tree, scrub, and fern species. The habitat borders with pasture to the north and east, and with the Te Wharau Stream to the south and west side.

## 3. Native and introduced tree stands

### (3a) Te Wharau Stream (along play and campgrounds)

Te Wharau Stream meanders through the Park's playground and campgrounds over a distance of 900 m.

Either side of the Stream was zoned by trees (width is about 10 m.) beyond which was open pasture and recreational areas. The maximum height of the trees was about 15 m with the exception of one eucalypt (30 m high). Tree species that grow in this zone were mainly alder (*Alnus glutinosa*) and willow (*Salix* spp.), kanuka (*Kunzea ericoides*), pate (*Schefflera digitata*), kamahi (*Weimannia racemosa)*, tree lucerne, plum tree, eucalypt (*Eucalyptus* spp.), poroporo were present as single trees or a small group. The introduced species (alder and willow) loose their foliage during winter. Public use in this area is intensive especially during nice weather and summer: recreational areas and unimpeded access to the streambed. During summer school groups make use of the camping and playground facilities and children were led free to explore the stream and play along was likely to causing disturbance (i.e., destruction of vegetation, noise).

**(3b) Te Wharau Stream (along walkway)**

Te Wharau Stream runs along a public walkway for about 400 m. On either side of the Stream is a zone with trees (width: 30-150 m) bordering with open farmland. Canopy species that grow here are mainly introduced species with heights up to 30 m (i.e., eucalypt, alder, willow, conifer species, poplar). Kanuka, pate, kamahi, tree lucerne, plum tree, eucalypt, poroporo, are spread along the Stream in the subcanopy (between 8 to 15 m. high), often as solitary trees or a small group. Little re-growth and open grassy areas within this zone were the result of grazing by stock. People are free to explore and use the adventure playgrounds.

**(3c) Kowhai stand**

Along one of the walkways is a kowhai stand which follows a stream branch of the Te Wharau Stream for about 200 m. The trees are about 12 m with a mainly closed canopy. This stand borders on one side with a kanuka stand and on the other side with a conifer plantation stand. Beyond these stands is open pasture. Other native species present were fushia *(Fuchsia excorticata)*, mahoe (*Melicytus ramiflorus*), pate, and pohuehue (*Muehlenbeckia* spp.*)*. Little re-growth was present. Public access is by walkway.

**(3d) Regenerating native stand (west of Big Rock)**

A stand of regenerating native vegetation is present along a stream branch of the Te Wharau Stream. Tree and scrub species that regenerate here are mainly native species (i.e., *Caprosma* spp., five-finger (*Pseudopanax arboreus)*) with heights of about 10 m. The area is about 400 m. x 160 m. The slope's aspect is north/northeast. Stock had access to this area due to the absence of a fence. Human access was difficult due to the thick vegetation and steepness of the terrain.

**(3e) Andersons Park (along Andersons Road)**

A 3 ha site was planted within the boundaries of Orton Bradley Park for recreational and educational purposes. A walkway gives access to this park with groups of introduced tree species, including conifer species from the Northern hemisphere. Native tree species are present amongst the planted trees: black beech (*Nothofagus solandri)*, kanuka, kowhai, five-finger, pate). Tree lucerne is present in part of this park. This park borders with open pasture on most sides, but one side it is connected to the Andersons Road poroporo-conifer stand by zone of kanuka (see above). Stock access appeared to be the cause for the lack of re-growth.

**4. Gardens**

In the proximity of the park's entrance and the recreational areas, trees and scrubs were planted for both educational and aesthetical reasons: chestnuts, walnuts, eucalypts, a variety of conifer species, rhododendron species, alder, and willow. Public access here means that people walk and drive cars through this area as it is the main entrance to the park.

**(4a) Historic buildings**

Among the historic buildings near the main entrance of Orton Bradley Park, tall, solitary trees were planted: conifers (15 m), walnuts (10-15 m), cabbage trees (4-10 m), chestnuts (15 m), and several fruit tree species (10 m). In between these trees and closer to the rhododendron walkway, grow a number of smaller native trees such as cabbage tree *(Cordyline* spp.*)*, pepper tree *(Macropiper excelsum)*, mahoe, and ngaio. This area extends towards the Park's manager's residence (see below).

**(4b) Orton Bradley Park's manager's residence**

The forested area around the manager's house consisted of a block with oak (*Quercus* spp.; about 20 m high), as well as a garden area with native and introduced trees, extending the Historic buildings (see above). Beyond the forested area is pasture.

# Appendix 3.

## Data sheet used for data collection in this study

**STUDY AREA**
**OBSERVER:**
**WIND:** calm moderate strong light
**TEMPERATURE:** cold mild hot
**WEATHER:** snow storm heavy rain light rain showers overcast partly cloudy clear

| Date | Time | GPS | Activity | Habitat type | Plant sps | Bird height | Canopy heigh | Food type | part | Aspect | No. birds seen | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | |
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# Appendix 4.

## List of plant species

Common name (*Scientific name)*

Sourced from Salmon (1980), Webb et al (1988), and Wilson (1992)

**A**

| | |
|---|---|
| Alder | (*Alnus glutinosa*) |
| Acacia | (*Racosperma* spp.) |
| Akiraho | (*Olearia paniculata*) |
| Apple tree | (*Malus Miller xdomestica)* |
| Apricot tree | (*Prunus* spp.) |

**B**

| | |
|---|---|
| Beech | (*Nothofagus* spp.) |
| Black beech/ Tawhairauriki | (*Nothofagus solandri)* |
| Broom | (*Cytisus scoparius*) |

**C**

| | |
|---|---|
| Cabbage tree | *(Cordyline* spp.) |
| *Coprosma rhamnoides* | *(Coprosma ramnoides)* |
| Chestnut | *(Aesculus hippocastanum)* |
| Cherry tree | *(Prunus* spp.) |
| Conifer | (*Pinus* spp./ *Macrocarpa* spp.) |

**E**

| | |
|---|---|
| Elm | (*Ulmus xhollandica)* |
| Eucalypt | (*Eucalyptus* spp.) |

**F**

| | |
|---|---|
| Five-finger/ Puakou | (*Pseudopanax arboreus)* |
| Fruit trees | (*Prunus* spp.) |
| Fuchsia | *(Fuchsia excorticata)* |

**K**

| | |
|---|---|
| Kamahi | (*Weimannia racemosa)* |
| Kanuka | (*Kunzea ericoides*) |
| Kawakawa | *(Macropiper excelsum)* |
| Kowhai | (*Sophora microphylla*) |
| Kahikatea | *(Dacrycarpus dacrydioides)* |

**L**

| | |
|---|---|
| Legume | (Fabaceae spp.) |

**M**

| | |
|---|---|
| Whiteywood/ Mahoe | (*Melicytus ramiflorus*) |
| Matai | (*Podocarpus spicatus)* |

**N**

| | |
|---|---|
| Ngaio | (*Myoporum laetum)* |

**O**

| | |
|---|---|
| Oak | (*Quercus* spp.) |

**P**

| | |
|---|---|
| Pate | (*Schefflera digitata*) |
| Pepper tree/ Kawakawa | *(Macropiper excelsum)* |
| Pigeon wood | (*Hedycarya arborea*) |
| Plum tree | *(Prunus cerasifera, P. xdomestica)* |
| Pohuehue | (*Muehlenbeckia* spp.) |
| Poplar | (*Populus* spp.) |
| Poroporo | (*Solanum aviculare, S. laciniatum)* |

**R**

| | |
|---|---|
| Red matipo | (*Myrsine australis)* |

**S**

| | |
|---|---|
| Silver wattle | (*Racosperma dealbatum)* |

**T**

| | |
|---|---|
| Titoki | (*Alectryon excelsus)* |
| Tree Fuchsia/ Kotukutuku | (*Fuchsia excorticata*) |
| Hall's totara | (*Podocarpus totara)* |
| Tree lucerne | *(Chamaecytisus palmensis)* |

**W**

| | |
|---|---|
| Walnut | (*Juglans* spp.) |
| Willow | (*Salix* spp.) |

# Appendix 5.

## Relative importance of food species as calculated for Church Bay and Orton Bradley Park. Proportions of =0.4 (considered relatively more used) are highlighted.

**A) Church Bay** — **Proportion of tagged kereru feeding on each plant species**

| | 2004 | | | | | | | | | | | | | | | | | | | | | | | 2005 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feb | Mar | | | April | | May | | June | | July | | Aug | | Sept | | | Oct | | Nov | | Dec | | Jan | | Feb | | Mar | |
| Ngaio | | 0.4 | 1.0 | 0.7 | | | | | | | | | | | | | | | | | | | | | | 0.3 | 0.8 | 0.4 | Ngaio |
| *C. rhamnoides* | | 0.4 | | | 1.0 | | | | | | | | | | | | 0.3 | | 0.3 | | | | | | | 0.3 | 0.3 | 0.4 | *C. rhamnoides* |
| Kawakawa | | 0.4 | | | | | | | | | | | | | | | | | | | | | | | | | | | Kawakawa |
| Five-finger | | 0.2 | | 0.7 | | | | | | | | | | | | | | | | | | | | | | | | | Five-finger |
| Tree lucerne | | | | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 0.5 | 1.0 | | 0.6 | 1.0 | 0.5 | 0.5 | 0.3 | 0.3 | | 0.5 | | 0.3 | | | | | | Tree lucerne |
| Fruit tree | | | | | | 0.3 | | | | | | | | 0.2 | 0.3 | 1.0 | 0.5 | 1.0 | | 0.5 | 1.0 | 1.0 | 0.7 | 1.0 | 0.8 | 0.8 | | | Fruit tree |
| Acacia | | | | | | | | | | 0.3 | | | | | | | | | | | | | | | | | | | Acacia |
| Kowhai | | | | | | | | | | | 0.5 | | 1.0 | 0.6 | | | 0.3 | | | 0.5 | | | | | | | | | Kowhai |
| Broom | | | | | | | | | | | | | | | | | | 0.3 | | | | | 0.7 | | 0.2 | | | | Broom |
| Poplar | | | | | | | | | | | | | | | | | | | 0.5 | | | | | | | | | | Poplar |
| Poroporo | | | | | | | | | | | | | | | | | | | | | | | | | | | 0.5 | 0.4 | Poroporo |

**B) Church Bay** — **Proportion of feeding observations on each plant species**

| | 2004 | | | | | | | | | | | | | | | | | | | | | | | 2005 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feb | Mar | | | April | | May | | June | | July | | Aug | | Sept | | | Oct | | Nov | | Dec | | Jan | | Feb | | Mar | |
| Ngaio | | 0.3 | 1.0 | 0.6 | | | | | | | | | | | | | | | | | | | | | | 0.2 | 0.5 | 0.3 | Ngaio |
| *C. rhamnoides* | | 0.3 | | | 0.4 | | | | | | | | | | | | 0.1 | 0.0 | 0.3 | | | | | | | 0.2 | 0.2 | 0.3 | *C. rhamnoides* |
| Kawakawa | | 0.3 | | | | | | | | | | | | | | | | | | | | | | | | | | | Kawakawa |
| Five-finger | | 0.1 | | 0.4 | | | | | | | | | | | | | | | | | | | | | | | | | Five-finger |
| Tree lucerne | | | | | 0.6 | 0.9 | 1.0 | 1.0 | 1.0 | 0.9 | 0.6 | 1.0 | | 0.5 | 0.7 | 0.2 | 0.2 | 0.1 | 0.3 | | 0.3 | | 0.1 | | | | | | Tree lucerne |
| Fruit tree | | | | | | 0.1 | | | | | | | | 0.1 | 0.3 | 0.8 | 0.6 | 0.8 | | 0.5 | 0.7 | 1.0 | 0.6 | 1.0 | 0.9 | 0.6 | | | Fruit tree |
| Acacia | | | | | | | | | | 0.1 | | | | | | | | | | | | | | | | | | | Acacia |
| Kowhai | | | | | | | | | | | 0.4 | | 1.0 | 0.4 | | | 0.1 | | | 0.5 | | | | | | | | | Kowhai |
| Broom | | | | | | | | | | | | | | | | | | 0.1 | | | | | 0.3 | | 0.1 | | | | Broom |
| Poplar | | | | | | | | | | | | | | | | | | | 0.5 | | | | | | | | | | Poplar |
| Poroporo | | | | | | | | | | | | | | | | | | | | | | | | | | | 0.3 | 0.3 | Poroporo |

**C) Orton Bradley Park** — **Proportion of tagged kereru feeding on each plant species**

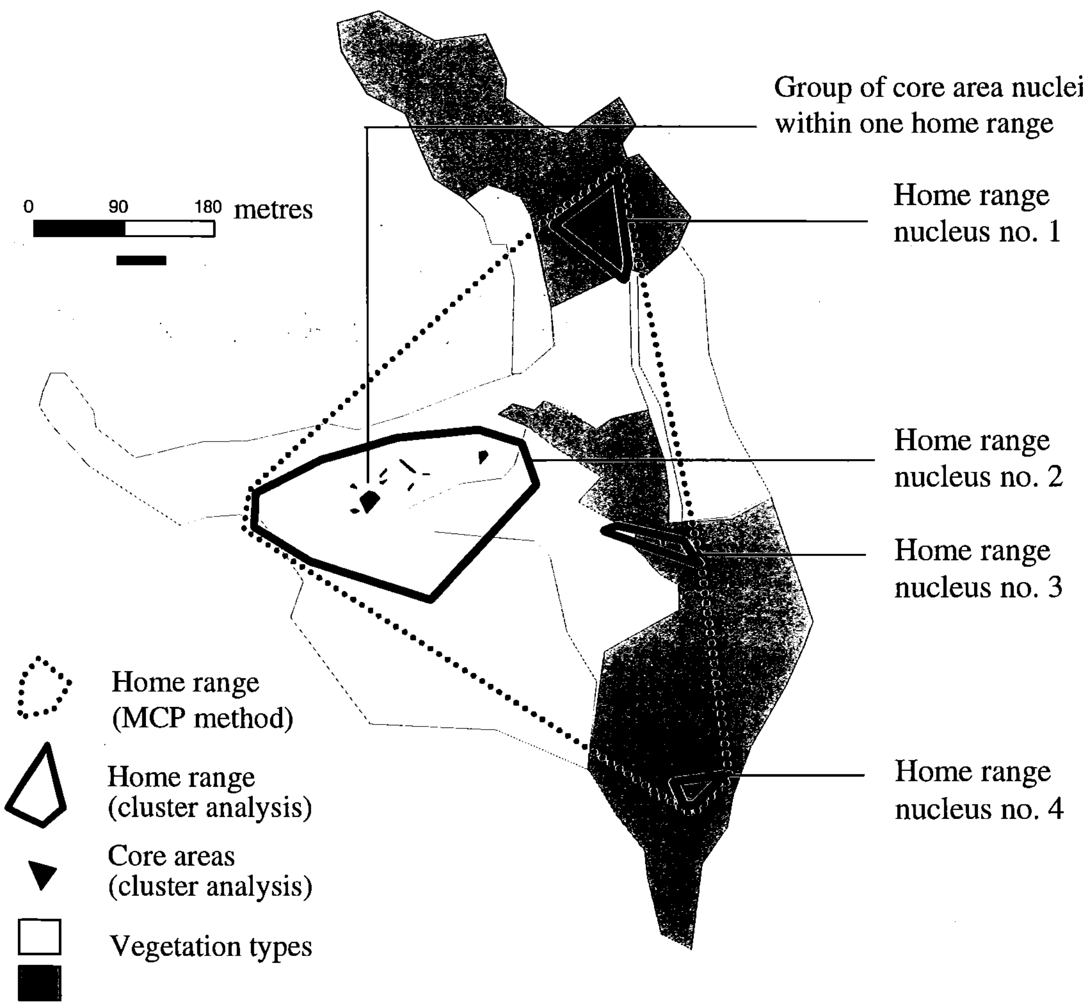
| | 2004 | | | | | | | | | | | | | | | | | | | | | | | 2005 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feb | Mar | | | April | | May | | June | | July | | Aug | | Sept | | | Oct | | Nov | | Dec | | Jan | | Feb | | Mar | |
| Cabbage tree | 0.2 | 0.1 | | 0.5 | | | | | | | | | | | | | | | | | | | | | | | | | Cabbage tree |
| Poroporo | 0.8 | 0.7 | 1.0 | 0.3 | | | | | | | | | | | | | | | | | | | | | | 0.3 | 0.8 | 0.7 | Poroporo |
| *C. rhamnoides* | 0.2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | *C. rhamnoides* |
| Willow | 0.3 | 0.1 | | | | | | | | | | | | | | | 0.5 | 0.7 | 0.3 | | | | | | | 0.1 | | | Willow |
| Tree lucerne | 0.2 | | | 0.5 | 0.8 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 0.8 | 1.0 | 1.0 | | | 0.8 | 0.3 | 0.3 | 0.5 | | 0.7 | 0.3 | | | | | | | Tree lucerne |
| Ngaio | | 0.1 | 0.2 | | | | | | | | | | | | | | | | | | | | | | | | | 0.3 | Ngaio |
| Fuschia | | | | | 0.2 | | | | | | | | | | | | | | | | | | | | | | | | Fuschia |
| Alder | | | | | 0.4 | | 0.3 | | | | | | | | | | | | | 0.4 | | | | | | | | | Alder |
| Fruit tree | | | | | | | | | | | | | | | | 0.4 | 0.3 | 0.7 | | | | 0.3 | 1.0 | 0.7 | 1.0 | 0.4 | | | Fruit tree |
| Kowhai | | | | | | | | | | | 0.8 | | | | 0.5 | | | | 0.5 | 0.2 | | | | | | | | | Kowhai |
| Titoki | | | | | | | | 0.2 | | | | | | | | | | | | | | | | | | | | | Titoki |
| Mahoe | | | | | | | | | | | | | | | 0.5 | | | | | | | | | | 0.0 | 0.3 | 0.2 | | Mahoe |
| Oak | | | | | | | | | | | | | | | | 0.2 | | | | | | | | | | | | | Oak |
| Broom | | | | | | | | | | | | | | | | 0.0 | 0.2 | 0.0 | 0.3 | 0.4 | 0.3 | 0.3 | | | 0.2 | | | | Broom |
| *L. anagyroides* | | | | | | | | | | | | | | | | | 0.2 | | | 0.2 | 0.0 | 0.3 | | 0.3 | 0.2 | | | | *L. anagyroides* |
| Pohuehue | | | | | | | | | | | | | | | | | | 0.3 | 0.3 | | | | | | 0.4 | | | | Pohuehue |
| Chestnut | | | | | | | | | | | | | | | | | | 0.2 | | | | | | | | | | | Chestnut |
| Elm | | | | | | | | | | | | | | | | | | | | 0.2 | | | | | | | | | Elm |

**D) Orton Bradley Park** — **Proportion of feeding observations on each plant species**

| | 2004 | | | | | | | | | | | | | | | | | | | | | | | 2005 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feb | Mar | | | April | | May | | June | | July | | Aug | | Sept | | | Oct | | Nov | | Dec | | Jan | | Feb | | Mar | |
| Cabbage tree | 0.1 | 0.2 | | 0.4 | | | | | | | | | | | | | | | | | | | | | | | | | Cabbage tree |
| Poroporo | 0.5 | 0.7 | 0.9 | 0.3 | | | | | | | | | | | | | | | | | | | | | | 0.3 | 0.7 | 0.7 | Poroporo |
| *C. rhamnoides* | 0.1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | *C. rhamnoides* |
| Willow | 0.2 | 0.1 | | | | | | | | | | | | | | | 0.3 | 0.3 | 0.1 | | | | | | | 0.1 | | | Willow |
| Tree lucerne | 0.1 | | | 0.4 | 0.7 | 1.0 | 0.7 | 0.9 | 1.0 | 1.0 | 0.5 | 1.0 | 1.0 | | | 0.6 | 0.3 | 0.1 | 0.3 | | 0.5 | 0.3 | | | | | | | Tree lucerne |
| Ngaio | | 0.1 | 0.1 | | | | | | | | | | | | | | | | | | | | | | | | | 0.3 | Ngaio |
| Fuschia | | | | | 0.1 | | | | | | | | | | | | | | | | | | | | | | | | Fuschia |
| Alder | | | | | 0.2 | 0.0 | 0.3 | | | | | | | | | | | | | 0.2 | | | | | | | | | Alder |
| Fruit tree | | | | | | | | | | | | | | | | 0.3 | 0.2 | 0.3 | | | | 0.2 | 1.0 | 0.8 | 0.6 | 0.4 | | | Fruit tree |
| Kowhai | | | | | | | | | | | 0.5 | | | | 0.5 | | | | 0.3 | 0.1 | | | | | | | | | Kowhai |
| Titoki | | | | | | | | 0.1 | | | | | | | | | | | | | | | | | | | | | Titoki |
| Mahoe | | | | | | | | | | | | | | | 0.5 | | | | | | | | | | | 0.3 | 0.3 | | Mahoe |
| Oak | | | | | | | | | | | | | | | | 0.1 | | | | | | | | | | | | | Oak |
| Broom | | | | | | | | | | | | | | | | | 0.1 | | 0.1 | 0.4 | 0.5 | 0.2 | | | 0.1 | | | | Broom |
| *L. anagyroides* | | | | | | | | | | | | | | | | | 0.1 | | | 0.1 | 0.0 | 0.3 | 0.0 | 0.3 | 0.1 | | | | *L. anagyroides* |
| Pohuehue | | | | | | | | | | | | | | | | | | 0.1 | 0.1 | | | | | | 0.3 | | | | Pohuehue |
| Chestnut | | | | | | | | | | | | | | | | | | 0.1 | | | | | | | | | | | Chestnut |
| Elm | | | | | | | | | | | | | | | | | | | | 0.2 | | | | | | | | | Elm |

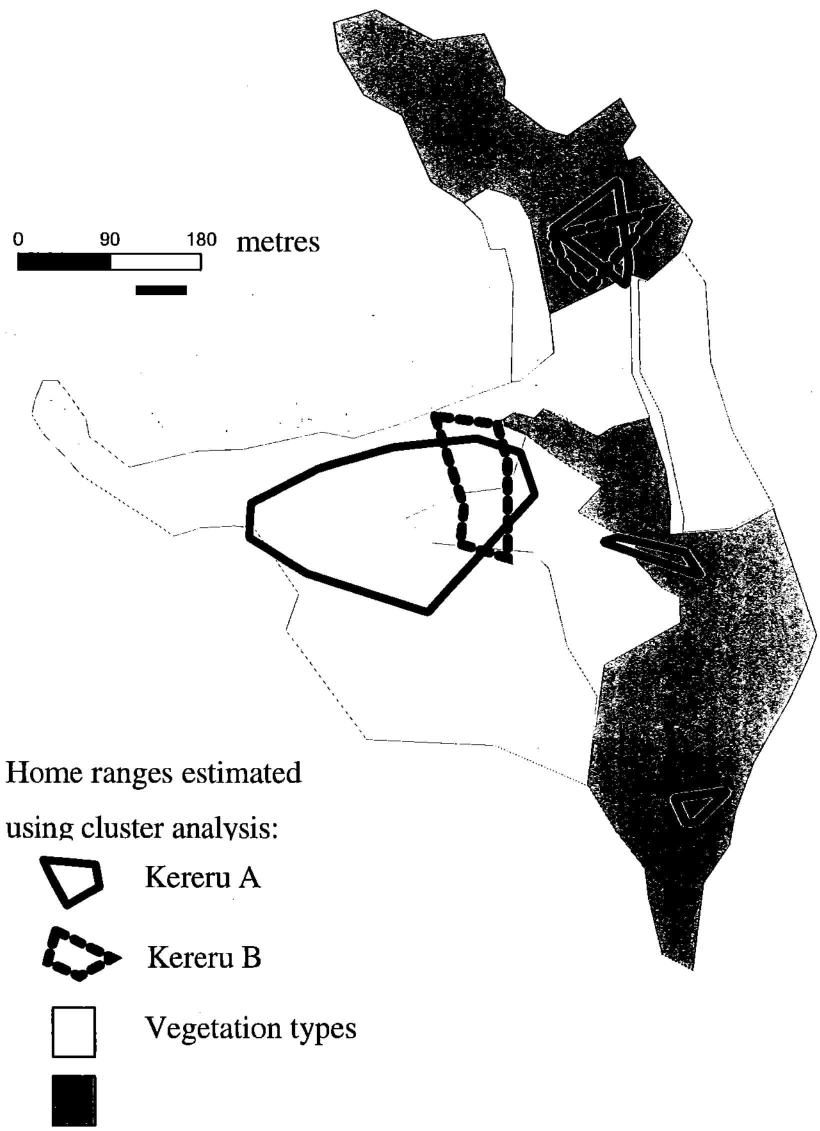
## Appendix 6.

## Home range and core area estimated using cluster analysis and MCP method.



# Appendix 7.

## Home range overlap



# Appendix 8.

## The number of data points at which the area-location curves showed stability for the Minimum Convex Polygon (MCP) method and cluster analysis

Area-location plots were created for all the kereru data sets using both the option available for the minimum convex polygon (MCP) method and cluster analysis in Ranges 6 (Kenward *et al.*, 2003). The table shows the number of locations required for a reliable area/ home range estimate by each of the home range estimation techniques for each kereru data set.

| Kereru | Total no. of locations collected of each kereru | No. of data points at which the area-location curve showed evidence of stability | |
|---|---|---|---|
| | | MCP | Cluster analysis |
| 10 | 188 | 185 | 180 |
| 14 | 104 | 85 | 95 |
| 16 | 175 | ~ | 150 |
| 18 | 193 | ~ | ~ |
| 20 | 200 | ~ | ~ |
| 22 | 96 | 90 | 85 |
| 24 | 156 | 105 | 140 |
| 26 | 58 | 55 | 35 |
| 28 | 164 | ~ | ~ |
| 30 | 185 | ~ | ~ |
| 32 | 152 | 145 | 140 |
| 34 | 210 | 205 | 205 |
| 36 | 198 | 165 | 164 |
| 38 | 202 | ~ | ~ |

~: no evidence of stability

# Appendix 9.

## Percentages of location data used to define the home ranges and core areas.

| Kereru | Core area (%) | Home range (%) | Outliers (%) |
|---|---|---|---|
| 10 | 45 | 98 | 2 |
| 14 | 60 | 92 | 8 |
| 16 | 55 | 94 | 6 |
| 18* | 60 | 95 | 5 |
| 20* | 60 | 95 | 5 |
| 22 | 55 | 96 | 4 |
| 24 | 60 | 98 | 2 |
| 26 | 45 | 89 | 11 |
| 28* | 60 | 97 | 3 |
| 30* | 55 | 91 | 9 |
| 32 | 70 | 94 | 6 |
| 34 | 70 | 96 | 4 |
| 36 | 50 | 90 | 10 |
| 38* | 45 | 96 | 4 |

*: The area-location curve of these kereru did not show stability, therefore the home range estimation is likely inaccurate and underestimated.

# Appendix 10.

## Proportions of short-distance movement and long-distance movements within different categories during the non-breeding and breeding seasons

**A) Non-breeding season**

| Kereru no. | 0-250 | 251-500 | 501-750 | 751-1000 | 1001-1250 | 1251-1500 | >1500 |
|---|---|---|---|---|---|---|---|
| 10 | 0.90 | 0.05 | | | 0.03 | | 0.03 |
| 14 | 0.45 | 0.05 | | | 0.02 | 0.02 | 0.39 |
| 16 | 0.96 | | 0.04 | | | | |
| 18 | 1.00 | | | | | | |
| 20 | 0.96 | 0.04 | | | | | |
| 22 | 0.73 | 0.05 | | 0.03 | 0.15 | | 0.03 |
| 24 | 0.69 | 0.04 | 0.04 | 0.20 | | | 0.04 |
| 26 | 0.79 | | | | 0.03 | | 0.18 |
| 28 | 0.77 | 0.18 | 0.01 | | | | 0.02 |
| 30 | 0.83 | 0.09 | 0.04 | | | | 0.03 |
| 32 | 0.78 | 0.04 | 0.06 | 0.09 | | | 0.04 |
| 34 | 0.96 | 0.04 | | | | | |
| 36 | 0.82 | 0.18 | | | | | |
| 38 | 0.79 | 0.21 | | | | | |
| Total | 0.84 | 0.08 | 0.01 | 0.02 | 0.01 | 0 | 0.03 |

**B) Breeding season**

| Kereru no. | 0-250 | 251-500 | 501-750 | 751-1000 | 1001-1250 | 1251-1500 | >1500 |
|---|---|---|---|---|---|---|---|
| 10 | 0.93 | 0.06 | | | | | 0.02 |
| 14 | 0.25 | 0.27 | 0.08 | | 0.02 | | 0.37 |
| 16 | 0.81 | 0.09 | 0.09 | | | | |
| 18 | 0.97 | 0.02 | | | 0.01 | | |
| 20 | 0.87 | 0.07 | 0.05 | 0.01 | | | |
| 22 | 1.00 | | | | | | |
| 24 | 0.61 | | 0.10 | 0.15 | 0.05 | | 0.10 |
| 26 | 0.75 | 0.13 | | | | | 0.13 |
| 28 | 0.83 | 0.16 | 0.01 | | | | |
| 30 | 0.78 | 0.13 | 0.09 | | | | |
| 32 | 0.58 | 0.00 | 0.10 | 0.09 | 0.21 | | 0.02 |
| 34 | 0.79 | 0.07 | | 0.07 | 0.04 | | 0.03 |
| 36 | 0.67 | 0.28 | 0.05 | | | | |
| 38 | 0.68 | 0.29 | | | | | 0.04 |
| Total | 0.75 | 0.11 | 0.04 | 0.03 | 0.03 | 0 | 0.04 |