Kereru (*Hemiphaga novaeseelandiae*) -

Impact injuries, morphometrics, moult and plumage.

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Abstract

The New Zealand Woodpigeon or Kereru (*Hemiphaga novaeseelandiae*) is a monomorphic pigeon that is often seen in urban and rural areas, feeding on native or introduced plants throughout the year. The Department of Conservation (DoC) offices around New Zealand, in particular the lower North Island, receive many Kereru each year due to predation and fatalities caused by impacts with windows and vehicles. Little scientific work has been conducted on such a valuable resource to date, so in this study I accessed and used 50 of these Kereru, as well as 76 reports from the Massey Wildlife Clinic (the wildlife surgery and rehabilitation wing of the Institute of Animal, Veterinary and Biomedical Sciences (IVABS)), 20 specimens from Massey's necropsy database and 119 moult records from other workers, to study four aspects of impact injuries and Kereru biology as outlined below.

(1) The type and extent of injuries that were sustained through collision events and how this affected rehabilitation. We used radiographs and necropsies to determine the skeletal and soft tissue injuries in 70 Kereru that died in such collisions, and radiographs of 61 birds that were assessed or treated having survived initial impacts. Vehicle collisions tended to result in damage to the extremities (wing and femur), whereas collisions with windows resulted in trauma to the head, fractures/dislocations of the coracoids and clavicles, and ruptured internal organs. Fractured coracoids frequently damaged flight muscles and ruptured the heart. Extensive bruising of pectoral muscles and haemorrhaging of the lungs was due to the force of impact. Rehabilitation time was not related to the number of skeletal injuries sustained, nor was the time until death for those that did not survive. Flight speed and force calculations suggest that a 570g Kereru would collide with 3-70 times the force that smaller birds (5-180g) would; this may explain the discrepancies between the injuries characterised here and those reported for North American passerines. The differences in injuries sustained from collisions with windows and cars can be used to inform rehabilitators about the possible nature of injuries if the source of impact is known.

(2) Morphometry, gastrointestinal organ masses and crop contents. Of 50 Kereru that died due to impact collisions, little physical variation was found between sexes; males had longer head/bill lengths. Overall, different structural measures were positively related (mass and tarsus, wing and tail, mass and head-bill and head-bill

and tarsus) but variation was generally high between individuals. Fat scores of Kereru were closely related to environmental seasonal variation and 80% of birds were in good body condition. Kereru lack caeca and there were no sexual differences in reference to dry organ mass (liver, intestine, gizzard and crop). Organ masses reflected body mass and size to varying degrees: liver mass was best explained by body mass, gizzard mass by tarsus length as much as body mass, and intestine mass only by body mass. Kereru intestines were proportionately shorter than those of herbivorous grouse, despite grouse having long caeca to help with digestion of plant matter. Kereru seem to rely on long retention times instead, and up to 68g of plant matter were found in the crop, gizzard and intestines. There were no sexual differences in mass of consumed materials found within the gastrointestinal tract, consisting of introduced and native material (foliage/flowers/buds/fruits). Digesta accounted for 0.12 – 13.4% of total Kereru body mass.

(3) Kereru flight feather moult, wing area and wing loading. One hundred and sixty nine Kereru moult records showed that Kereru moult over a nine month period (July – March/April), with a restricted moult of tail feathers during the breeding season. Kereru moult is symmetrical in relation to the number of primary feathers moulted, but not in respect to the position on the wing. Kereru often have multiple moult loci and do not follow a conventional moult sequence. This moult strategy reduces the effect that feather gaps have on wing area and thus wing loading. The moult strategy of Kereru is a solution that works to minimise the change in wing area, but at the cost of having a prolonged moult.

(4) Plumage colouration assessed using reflectance measurements from light spectrometry. This study is the first to assess UV signals in Kereru and UV signals were found in all eight regions investigated, five plumage (Breast, Crown, Mantle, Wing and Rump) and three bare parts (Bill base, Bill tip and Foot). The greatest intensity of maximum UV signal (uvmax) was in the bare parts with a covariance of the bill tip and foot. No sexual differences or condition dependent signals were found, but age-related UV signals were found in the crown and foot. In the visual spectrum, females had a greater intensity of maximum colour signal (rmax) in the wing. Age-related colouration was seen predominately in the bare parts, in particular the foot which has a higher intensity of colour in juveniles. Even with single-angle light spectrometry Kereru are a highly cryptic species.

Acknowledgements

This project would not have been possible without the support and assistance from the following people.

Extreme gratitude goes to my head supervisor, Phil Battley, for guiding me in the right direction, remaining positive and enthusiastic throughout the entire process. He saw it through from beginning to end with unending support and was willing to lend a hand and in some cases two even though he was extremely busy with a new addition to the family. I am also extremely thankful to my co-supervisor, Brett Gartrell (who also had a new addition to his family) for assisting me in interpreting radiographs, being involved with post-mortems and giving a veterinary perspective on things. Thanks to my advisor, Ralph Powlesland, who was so willing to pass on his superior knowledge about Kereru and for the support and input that he gave for addressing the aims of this study. Along with the time spent travelling to attend project meetings and for supplying substantial amounts of data on Kereru moult.

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I would like to express my gratitude to the Ornithological Society of New Zealand for giving me permission to reproduce their distribution atlas of New Zealand pigeon for use in my thesis. Also, to Geoff Baines, for physics analyses and

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Thanks to Nga Manu Nature Reserve for providing me with carcasses, access to captive Kereru, for allowing me to use their facility, on occasion, to autopsy my birds and for the use of excellent photographic images. Also, extreme gratitude for the Nga Manu Trust Scholarship, which covered a large proportion for the cost of x-rays.

And to my many note takers – Phil Battley, Rhys Mills, Mary Fawcet, McKenna Martindale, Alyssa Grove - if it was not for you guys the autopsy process would have taken twice as long. Thank you for your time and ability to put up with some interesting smells!!!

Finally, thank you to my partner in crime, Rhys Mills, who willing came on road trips to help collect carcasses and for the time he spent helping me get through the many post-mortems.

Photograph 1 Inquisitive Kereru at Nga Manu Nature Reserve.

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Chapter One - General Introduction

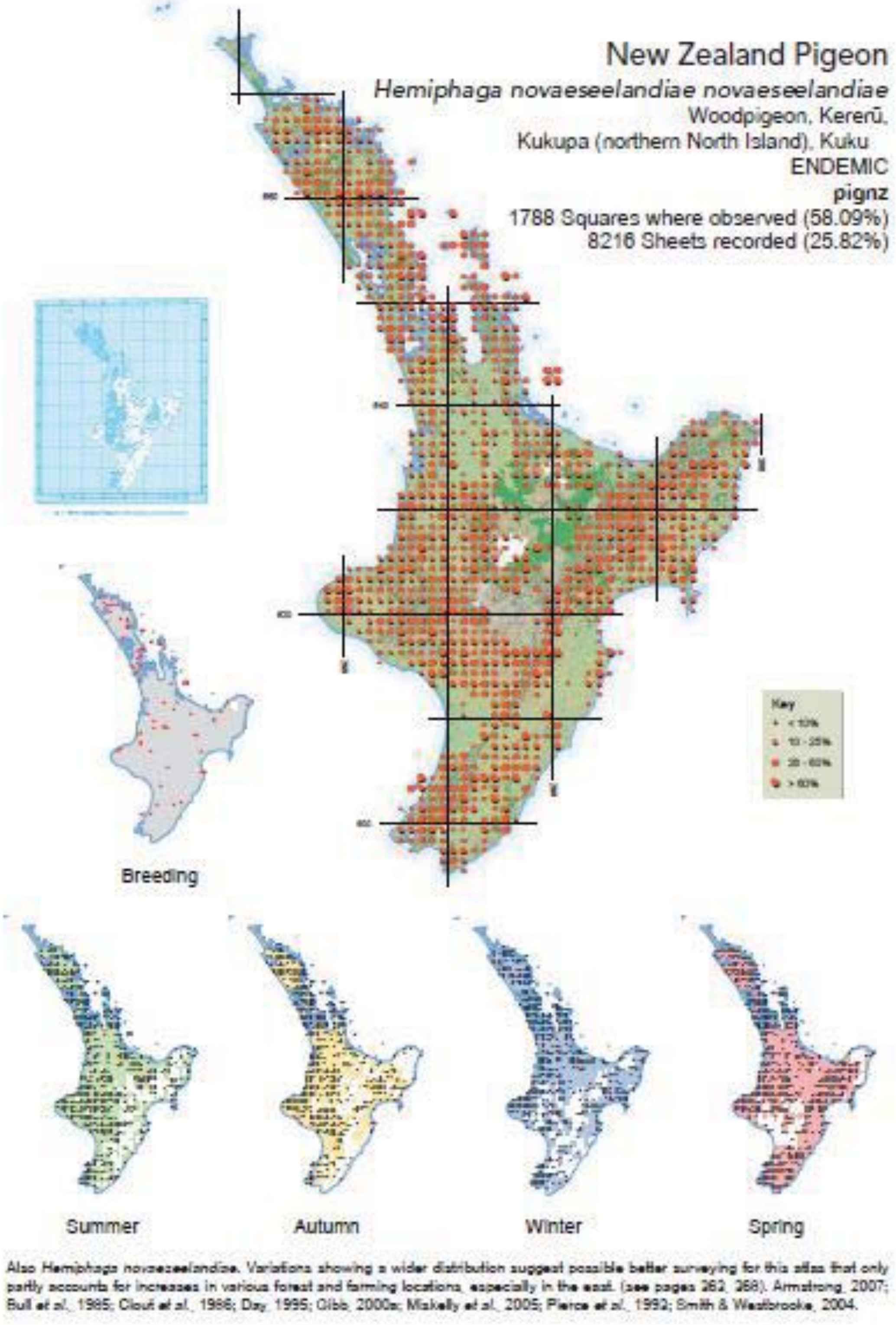
The New Zealand woodpigeon, *Hemiphaga novaeseelandiae*, is endemic to New Zealand and formerly Norfolk Island (Mander et al., 1998). It belongs to the family Columbidae, subfamily Treroninae (fruit eating pigeons of which there are approximately 115 species). These pigeons are found throughout South Asia, Malaya, Africa and New Zealand (Falla et al., 1979). The Kereru is one of the largest pigeons belonging to this subfamily. Kereru are the only extant species of the genus *Hemiphaga.* The Kereru is known by various names throughout New Zealand depending on what Maori tribe inhabits the region, for example, Kereru for the central and lower North island, Kukupa in Northland, Kuku in Upper Northland, Kokopa in the South Island and Parea on the Chatham Islands (Heather & Robertson, 1996).

1.1 Kereru Distribution and habitat

Kereru were once widespread throughout New Zealand. In the North Island they were sparsely scattered above Kaitaia, then in abundance from Northland through the Waikato, Volcanic Plateau, Hawke's Bay, Taranaki, Manawatu and Wairarapa to Wellington. In the South Island they were widespread in Marlborough, Nelson to Kaikoura, West coast, in Canterbury to the Banks Peninsula and scattered in Otago through Southland, and abundant on Stewart Island. They formerly occurred on Norfolk Island and possibly Raoul Island (Kermadec Group) (Higgins & Davies, 1996). Historical accounts indicate that they once numbered in their hundreds at the beginning of the 1900s up until 1950 when Maori hunters started to notice a decline in the number and ease with which they were capturing Kereru (Lyver et al., 2008).

Today they can still be found throughout the North and South Islands and some offshore islands of New Zealand from latitudes of 35^{o}S to 47^{o}S (Clout, 1990), however predominately in Northland, Taranaki, Hawke's Bay, and Wellington regions and in small remnant populations in the South Island. A species of Kereru, Parea (*Hemiphaga chathamensis*), can still be found on the Chatham Islands. Numbers have decreased significantly over the past 60 years due to many factors, including predation, intense hunting and forest destruction. Further causes of decline and history of the Kereru will be discussed in a later section (Section 1.7 – History of Kereru and causes of decline).

Kereru inhabit temperate lowland broadleaf forests and prefer forests that are complex, have a dense canopy that includes emergent trees, and that have a well developed shrub layer. They also occur in urban parks and residential areas where there are fruiting trees – native or introduced. They are rarely found above the tree line, but have been recorded up to c. 1300m a.s.l. (Challies, 1966; Child, 1975; Dawson et al., 1978).



New Zealand Pigeon

Hemiphaga novaeseelandiae novaeseelandiae
Woodpigeon, Kererū,
Kukupa (northern North Island), Kuku
ENDEMIC
pignz
1788 Squares where observed (58.09%)
8216 Sheets recorded (25.82%)

Also *Hemiphaga novaeseelandiae*. Variations showing a wider distribution suggest possible better surveying for this atlas that only partly accounts for increases in various forest and farming locations, especially in the east. (see pages 262, 268). Armstrong, 2007; Bull *et al.*, 1985; Clout *et al.*, 1986; Day, 1995; Gibb, 2000a; Miskelly *et al.*, 2005; Pierce *et al.*, 1992; Smith & Westbrooke, 2004. [1]

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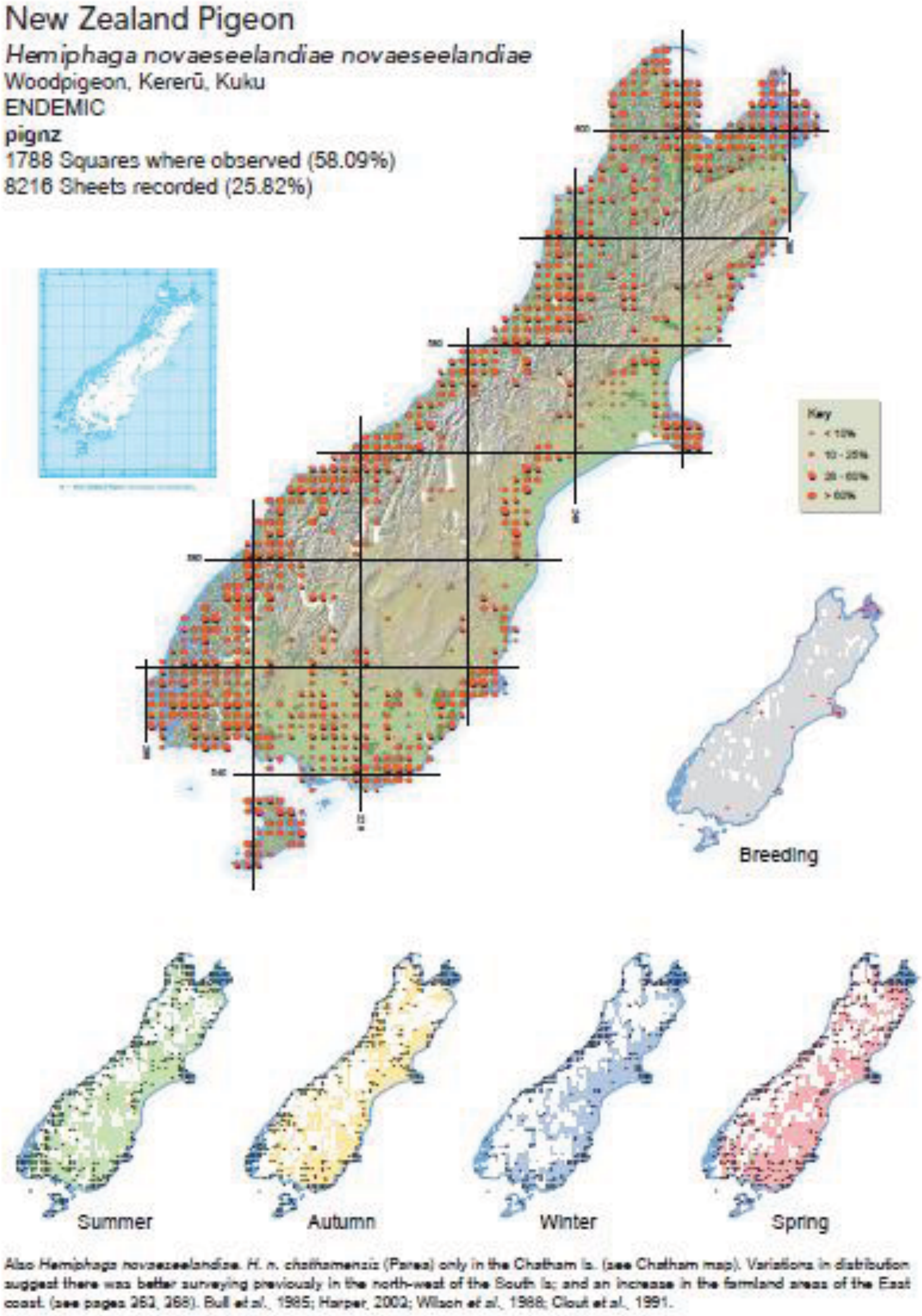
[1] Reproduced from pp. 222-223 *in* Robertson *et al.,* (2007), with permission from the Ornithological Society of New Zealand.



New Zealand Pigeon

Hemiphaga novaeseelandiae novaeseelandiae
Woodpigeon, Kererū, Kuku
ENDEMIC
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1788 Squares where observed (58.09%)
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Also *Hemiphaga novaeseelandiae. H. n. chathamensis* (Parea) only in the Chatham Is. (see Chatham map). Variations in distribution suggest there was better surveying previously in the north-west of the South Is; and an increase in the farmland areas of the East coast. (see pages 263, 268). Bull *et al.*, 1985; Harper, 2002; Wilson *et al.*, 1988; Clout *et al.*, 1991.

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[2] Reproduced from pp. 222-223 *in* Robertson *et al.,* (2007), with permission from the Ornithological Society of New Zealand.

1.2 Kereru diet

Members of the subfamily Treroninae feed largely on fruits, mainly drupes. The Kereru is an entirely herbivorous bird, feeding on the fruits and foliage of at least 70 native plants and a large selection of introduced plants (Clout & Hay, 1989; McEwen, 1978). It is the sole remaining animal in New Zealand that is capable of dispersing the large seeded fruits of the native flora, such as Tawa (*Beilschmiedia tawa*), Taraire (*Beilschmiedia tarairi*), Puriri (*Vitex lucens*), Karaka (*Corynocarpus laevigatus*), Pigeonwood (*Hedycarya arborea*), Miro (*Prumnopitys ferruginea*) and Maire (*Syzygium maire*) (Dunn & Morris, 1985; McEwen, 1978; Pierce, 1993). Other animals that were once capable of doing this task are now extinct such as Moa and Giant rail (*Diaphorapteryx hawkinsi*) (Sullivan et al., 2010). Kereru are able to consume these fruits because of their wide gape which other extant birds in New Zealand do not possess (Emeny et al., 2009; Wotton & Ladley, 2008). Many of these fruits require a passage through the gut of an animal before they can germinate, as intestinal enzymes help break down the cuticle of the seed readying it for environmental conditions. Studies have shown that retention time of seeds within the gut of a Kereru depends on the mass of the fruit. Five-finger (*Pseudopanax arboreus*) and Kahikatea seeds (*Dacrycarpus dacrydioides*) (smaller seeded fruits) were retained for an average of 37 – 45 minutes, whereas the larger seeded fruits such as Puriri, Taraire and Tawa averaged 109 – 181 minutes in the gut (Wotton & Ladley, 2008). For natural dispersal of these plants to be maintained, and for the current forest types to be preserved, the perpetual survival of Kereru in all areas of New Zealand needs to be assured.

Due to the nature of New Zealand's unpredictable climate and the type of flora that has developed here Kereru have to continually switch between fruits, flowers and foliage. The swaps between the food resources are timed with the seasons, with the greatest difference leading into the winter and summer months. Not only does a switch from fruits to foliage occur, but also the type of plant utilised changes from native to introduced flora. Baker (1999) found that most leaf eating occurred during June to September and the scarce months for fruit were July to December. Kereru resort to eating exotic foliage during times of native fruit ripening. Seasonal movements in conjunction with sightings of Kereru have been associated with food availability (Clout et al., 1986; Clout et al., 1991). A study on the diet of Kereru found 104 plant taxa were consumed and of these 78 were indigenous plants and 26 were exotic.

1.3 Kereru appearance

Kereru can be difficult to detect when roosting in the forest canopy as due to their colouration they appear camouflaged. Adults and juveniles are distinctly different based on colouration of feathers, beaks and feet. An adult Kereru has brightly coloured reddish feet and a beak that is red/pink with yellow/orange at the tip; the chest plumage is pure white; the breast is iridescent green and the back and rump feathers are bright green with some deep purple across the shoulders. Juveniles have dull feet and beaks, the chest plumage is smudgy grey, they have a green breast and dull green/grey back and rump feathers (Gill, 2006; McEwen, 1978). There is a difference in appearance between Kereru (mainland New Zealand pigeon) and Parea (Chatham Islands pigeon) in that the Kereru has a smaller bill, there is a absence of grey plumage and the under tail coverts are white (Oliver, 1955). There appears to be no seasonal variation in colour (Higgins & Davies, 1996). Even though the Kereru is a dominant feature in the forest canopy due to its size – adult Kereru weigh 400 – 750g (Clout et al., 1988; Gill, 2006; Mander, et al., 1998) - they are still difficult to sight unless there are tell-tale signs of residence. Like many New Zealand birds the sexes appear monomorphic.

Photograph 2 Male and female Kereru sitting in tree fuchsia. (Nga Manu Images)

1.4 Kereru breeding cycle and flight

The breeding season of Kereru is not well defined in that it is not just restricted to the spring and summer months (September to April). Some Kereru have been found to breed on the fringes of autumn. It is thought that their breeding is related to the availability of food resources (Dunn & Morris, 1985). Both the male and female Kereru help to build a flimsy nest out of twigs (~30cm in diameter) positioned approximately three to four metres above ground (Bell, 1980; Genet & Guest, 1976; James & Clout, 1996). The resulting product is like that of a bowl with many ‘cracks’ scattered around it.

Photograph 3 Male Kereru incubating an egg in a nest built of sparse twigs. (Nga Manu Images)

Prior to the building of the nest a traditional courtship display, mutual preening and copulation take place. The flight display involves the male performing impressive ‘swooping’ flights. The male flies upwards from one branch, at the top of the flight he appears to ‘stall’, and then the direction of flight changes to a quick ‘swooping’ descent to another branch. This flight technique can also be indicative of a territorial display. From here the male display continues, he turns around on the perch (from left to right), places his bill tip into his wing, and stretches up the neck while bowing the head. In this position the neck feathers are displayed, the bill rests on the chest and he then bounces up and down on the perch (Hadden, 1993). If the female is receptive he will mount and mate with her (Hadden, 1993). One white egg is laid and if fertile will hatch within 28 days. The chick will fledge at 45 days old. If the first egg is lost or destroyed a second egg may be laid (Bell, 1980). Incubation is shared by both parents, with the female sitting on the nest over night until midmorning and then the male incubating for the remainder of the day (Thorsen et al., 2004). Crop milk is fed to the chick in the first few days from hatching.

When Kereru are in flight the wings make a distinctive ‘whooshing’ sound. This is produced by their alula or bastard feathers as the wind passes over and under the feathers. Because of this they are easily identified out of sight when passing over the canopy of a forest. Their call is a soft but sometimes quite penetrating *ku* or *oooo*....which can either end in a high pitched note or just trails off (Higgins & Davies, 1996). They generally use this call when feeding or resting.

Photograph 4 Fan of feathers during flight; the alula feathers can be seen along the leading edge of the wing. (Nga Manu Images)

1.5 Moult

Most birds have a regular breeding and moulting cycle so that they are not expending energy moulting at the same time as they are nesting. Just like the breeding cycle the moult cycle is not well known in Kereru. This may relate to there not being a set season in which Kereru breed so perhaps moult occurs on an individual basis throughout the year, depending on age, breeding status and energy requirements. Generally birds will moult in a symmetrical fashion (equivalent and simultaneous replacement of feathers on both sides of the body) so that there is little interference with their ability to fly.

A study based on 115 museum specimens concluded that Kereru have a slow continuous moult with frequent pauses, with no distinct moulting season (Gill, 2006; Mander, et al., 1998). Primary feathers tended to moult from the inner wing, out, usually only one feather at a time. Sometimes there would be two waves of moult along the primaries. Tail feathers showed a pattern of moulting outwards from the centre (Higgins & Davies, 1996). Head and body feathers appeared to be replaced continuously, and the total length of moult is unknown.

1.6 Status of Kereru

These birds were once plentiful and were often seen in large flocks of up to 50-70 individuals (Pullman & Pullman, 1997). Nowadays, the largest flock unofficially recorded has been 40 birds (Powlesland, 2008). The Department of Conservation (DoC) Kereru status has changed from declining in 2005 (Hitchmough et al., 2007) to not threatened in 2008 (Miskelly et al., 2008).

1.7 History of Kereru and causes of decline

Kereru numbers drastically declined upon the arrival of Maori and Europeans to New Zealand shores. Kereru were and still are considered a valuable food source as well as being of cultural significance to the Maori. The indigenous peoples' (Maori) traditional knowledge or *matauranga* is useful to gain an insight into how Kereru were and are valued and used (Lyver, et al., 2008). Kereru were originally captured via snare and spear techniques, and preserved in their own fat (Pullman & Pullman, 1997). Feathers were/are collected for use in traditional cloak design (Dunn & Morris, 1985; Feldman, 1998). Maori realized that for this resource to be available in the future, restrictions on the number and when to harvest needed to be in place for Kereru to remain as a sustainable resource (Keene & Jeffs, 1994). This was achieved until the arrival of Europeans, who thought that "woodpigeons are found in abundance everywhere – much larger, fatter and more beautiful in plumage than our English pigeons. The flesh is delicious....These birds are easily shot, for they are so tame as to allow you to approach within a few yards" (Hodgskin, 1841).

Excessive hunting of Kereru led to them becoming extinct in several areas, such as the upper reaches of Northland and some areas of Central Otago, and drastically declined in Northland and Manawatu (Dunn & Morris, 1985; Mander, et al., 1998). The early Europeans said "owing to the loud beating of its wings in its laboured flight it is readily found, even in the thickest part of the bush, and being naturally a stupid bird it is very easily shot; so that in a favourable locality it is not an unusual thing for a sportsman single handed to bag fifty or more in the course of the morning" (Buller, 1873).

However, Kereru were under pressure not only from humans, but also from introduced mammals that arrived with the Europeans (Innes et al., 2010). Ship rats (*Rattus rattus*), mustelids (stoats (*Mustela erminea*), ferrets (*Mustela putorius*), and weasels (*Mustela nivalis*) pigs (genus *Sus*), goats (genus *Capra*) and possums (*Trichosurus vulpecula*) not only destroyed bird nests, chicks and some adults, but increased defoliation of food supply which increased competition. Logging, fires and forest clearance for the development of settlements removed vast areas of native forest that was being used by Kereru (Heather & Robertson, 1996; Mander, et al., 1998; Pullman & Pullman, 1997). All of these pressures caused Kereru numbers to decline and in some areas this is still happening to the present day.

Photograph 5 Ship rat (*Rattus rattus*) (left) and Brush-tailed possum (*Trichosurus vulpecula*) (right) scavenging eggs from an abandoned Kereru nest (Nga Manu Images).

Another possible factor that could limit Kereru populations is that they are frequent casualties from collisions with vehicles or infrastructure windows. Many people find birds sitting stunned in their backyard or on their deck and take them to bird rehabilitators or to the Department of Conservation. Department of Conservation offices around New Zealand receive dozens of Kereru per year that have died or are injured from such collisions and no one but Brian Gill in Auckland has used these carcasses to any extent for scientific investigation (Gill, 2006).

Why do so many birds collide with windows? Could it be because they do not see the window, due to reflection of surrounding habitat? (Klem et al., 2004; Klem Jr, 1989).

Are they 'drunk' or intoxicated from consuming fruits from a nearby tree, thus restricting their ability of avoiding structures? Or, is it that buildings and roads are being constructed in previously well used flight paths and the bird's depth perception and recognition of impending collision does not respond in time to divert flight? (Le-Qing et al., 2005; Qian et al., 2006; Ramp et al., 2006).

1.8 Impacts and injuries sustained

Studies from America have looked at incidents of bird strike in relation to windmills, skyscrapers and vehicles (Dunn, 1993; Klem, 1990; Klem, et al., 2004; Klem Jr, 1989; Klem Jr, 1990; Veltri & Klem, 2005). They have reported that birds that fly into windows either, 1) become stunned, recuperate (defined as the time elapsed from impact to unassisted departure from the collision site or the appearance of normal activity (Klem, 1990)) and then fly off, 2) impact with the window and immediately fly away or 3) die on impact. Autopsies of birds that subsequently die from these injuries have revealed that some birds also sustain head trauma (Klem, 1990). This raises the question of what happens to those birds that are able to fly away immediately after impact and appear 'fine'? Do they die later from complications associated with their injuries?

It is not yet understood why birds collide with windows. One possibility is that windows reflect the surrounding environment, thus tricking the bird into thinking it is flying into another tree, and another is that the bird is spooked and takes evasive action and without realising the direction of flight hits a nearby window. This may be related to intensive urbanisation in what was once a forested landscape. The birds are used to using a particular flight path, a building is erected and before long there are frequent impacts with windows. The same can be said for birds colliding with vehicles. With urbanisation come roads, and with roads come cars. A bird will see that the path is clear will take flight and before long a car travelling at 100km/hr impacts at right angles with a bird flying across the road.

Ramp *et al* (2006) investigated the impact of developing roads in the Royal National Park of New South Wales, Australia, and the effect this had on the wildlife.

Developing roads in areas of high wildlife use substantially increases the likelihood of wildlife death due to injuries sustained from hitting a vehicle or a vehicle hitting the wildlife. Roads fragment habitat thus decreasing the area that can be used for flight or walking routes for the wildlife. Because of this wildlife come into greater contact with vehicles as they use the roads as an access route to the next fragment. Some animals such as birds of prey are attracted to roads as they scavenge on road kill, bringing them into close proximity with vehicles. This is often seen with Australasian harriers (*Circus approximans*) in New Zealand, which end up becoming road kill themselves as they do not have enough time to become airborne when a car is approaching them at 100km/hr. This is just one factor that makes a species more vulnerable as a road fatality, others include the mobility of the species, whether it is a habitat specialist, the reproductive rate of the species, resource needs and finally the amount of space that is used by the species (Ramp, et al., 2006). The frequency of vehicle incidents is probably related to three factors (both spatial and temporal components):

1) Likelihood of animal presence on the road,
2) Likelihood of vehicle being present, and
3) Likelihood of there being a collision.

Ramp *et al* (2006) came to the conclusion that the likelihood of bird fatalities decreases with increasing canopy height, enabling a higher flight path over the road, thus avoiding the traffic. Although the presence of roads in reserves has implications for conservation as they enable access for the public to view wildlife in their natural environment, roads at the same time may be acting like population sinks.

Infrastructure windows are another problem for birds. Several experiments have found that birds do not recognise clear or reflective panes of glass as barriers or obstacles to avoid (Klem, et al., 2004; Klem Jr, 1989). Reflective windows are thought to mirror the habitat that surrounds the building, causing the bird to assume that there is a passage through the bush in the direction of the window (Klem Jr, 1989). The type of bird, the environmental conditions and the window are all factors that can cause a window impact. Bird factors include density, behaviour and flight habits. It has been reported that birds that live around humans and their structures seem to ‘learn’ that windows are hazards (Klem Jr, 1989). Environmental factors potentially involved include season, as this is related to the density of birds (breeding and migration), time of day (usually early to late morning which is time of foraging for most birds), and finally the weather. Window factors involve the type of glass, size, placement and whether there are bird attractants in front of the window (feeding stations or water baths). However, on further inspection Klem (1989) found that age, sex, weather, time of day and season did not play a part in causing window collisions. Dunn (1993) found that those bird species that frequent bird feeders collide with windows more regularly as they are in closer proximity to the window during takeoff and the direction of flight may be towards windows due to the reflection of habitat. Incidents of panic flights into windows have been reported where birds responded to loud noises or took evasive action to avoid danger (e.g. avoid predation from hawks: (Dunn, 1993)). Migrants flying at a more consistent speed may strike with greater momentum and force, causing greater injury than for birds near the ground flying at more variable speeds from vegetation or feeders (Klem, et al., 2004; Veltri & Klem, 2005).

Injuries that are sustained from such collisions generally involve bleeding from the mouth/nasal cavity, trauma to the head, haemorrhaging under the skin, soft tissue damage, and skeletal fractures or dislocations (Klem, 1990; Veltri & Klem, 2005). Radiographs are used to assess bone fractures. Documentation of these injuries provides an aid for bird rehabilitators and veterinary professionals and others attempting to diagnose and treat avian collision casualties at impact sources. Prior to death, impact casualties are often completely or intermittently non-responsive, lack balance, normal posture or co-ordinated muscle action, have drooping eyes, wings, all have dilated pupils and rapid, shallow breathing (Veltri & Klem, 2005). Deterrents to prevent these incidents from occurring may need to be used in areas where such events occur frequently.

As a preventative against window strikes variations of window deterrents have been developed. Several studies have developed and implemented hawk decoys, or hung moving objects such as CDs in windows to reduce window strikes; however, Dunn (1993) did not find these reduced the incidence of window impacts. A company in America has developed window deterrents that rely on ultraviolet detection by birds to avoid hitting the window (Figure 1.1; see Box 1 below). To the human eye it looks like the window has a frosted pattern, but to a bird's eye the ultraviolet reflection is detectable, thus giving it definition and a means of identifying the window.

Figure 1.1 Bird deterrents produced by WindowAlert.com in America. This relies on ultraviolet detection by the bird's eye.

Another method that could be implemented is tinting windows and angling the window in such a way that it reduces the reflection. Experiments indicated that window strikes can be reduced if panes of glass are angled downwards by 20^0 and 40^0 from vertical (Klem, et al., 2004). Angling the pane of glass will prevent reflection of the habitat; instead it will reflect the ground. The force at which a bird hits a window may also be reduced by angling the glass pane. Other people have attempted to place a physical barrier in front of the window such as a netting screen; this technique will also reduce the reflectance on the window (Klem, et al., 2004; Klem Jr, 1990).

Box 1: How birds' eyes work

For bird deterrents to work effectively they need to take into account the way a bird perceives objects, and how it adjusts its flight to avoid barriers. Two studies have looked into great depth about the way the bird's eye functions and what responses are generated by the firing of different nerves in the eye and brain. Both of these studies were conducted on racing pigeons. Images that are perceived by the eye send nerve pulses to the brain, and those that are seen as being a danger or barrier to the bird ignites the response from the diencephalic nucleus, which is involved in defensive behaviour (Le-Qing, et al., 2005). This response allows the bird to determine the time to collision.

Three types of tectal cells are initiated when approaching an object. These are differentiated by the type of firing response that they produce. Tau cells fire at a constant rate during normal flight, but increase exponentially upon approach to an object and peaks at moment of collision, whereas rho and eta cells initiate at an earlier stage and detect larger objects at lower velocities (Le-Qing, et al., 2005). In the process of monitoring the response of looming objects on neuron firing rates the scientists also monitored the pigeon's heart rate. They found that on the approach of a looming object the pigeon's heart rate increased as the diameter-velocity ratio of a looming object became larger (Le-Qing, et al., 2005). These responses implied that the visual information signalled by tectal rho and eta cells established an early warning of impending objects, whereas tau cells may be used for initiating an avoidance response based on the rate of firing nerve impulses (Qian, et al., 2006).

Factors involved in Kereru window strikes have been poorly documented. Therefore, a pilot survey assessing the type of property, direction of flight, surrounding foliage, time of day and weather conditions at time of collision of Kereru was conducted during the commencement of this study (see Appendix 1 for survey sheet). Preliminary results from 31 surveys returned showed that Kereru collided more frequently with windows that 'appeared' to have a clear thoroughfare through the house (78%), were single storied (81%), residential (32%) or rural (26%), and the window was east facing (61%). Conditions on the day were predominantly overcast (55%) and the result of the collision was that the bird died a short time after impact (65%). The nearest known feeding tree tended to be approximately 0-5m from the house at an average height of 9.6m with both introduced and native species being used. This height would be adequate for the swooping displays that Kereru do. The time(s) of day that collisions appeared to occur were mid morning (9-11am) (42%) and mid afternoon (1-3pm) (39%). These times coincide with when the sun is rising and setting throwing the most light on the windows, making them near invisible (if shining directly on the window). At these times the sun is in an east to west position, the same as the flight of Kereru that collided with houses. This indicates that there is a high probability that the sun plays a factor in window collisions of Kereru and other birds.

In this study I endeavour to describe in detail the injuries sustained by Kereru in collisions with vehicles and infrastructure (Chapter 2). To do this I sourced 50 dead Kereru that had been handed in to DoC offices across the lower North Island. These birds were assessed by radiograph (X-ray) and necropsy. These carcasses also provide a valuable resource for studying the internal and external morphology of Kereru. Here I analyse the biometrics, foods and size of the digestive tract in Kereru (Chapter 3), flight feather moult (Chapter 4) and plumage colouration via light spectrometry (Chapter 5). Collision injuries (Chapter 2), feather moult (Chapter 4) and plumage colouration (Chapter 5) have varying degrees of impact on Kereru Conservation. This involves rehabilitation (extent of time and techniques used) and the amount of management effort which is required for this vulnerable species in regards to sexing.

Chapter Two - Impact injuries and probability of survival in a large semi-urban pigeon, *Hemiphaga novaeseelandiae*.

2.0 Abstract

The New Zealand Woodpigeon or Kereru (*Hemiphaga novaeseelandiae*) is a pigeon that frequently collides with windows and vehicles. In this study we used radiographs and necropsies to determine the skeletal and soft tissue injuries in 70 Kereru that died in such collisions, and radiographs of 61 birds that were assessed or treated having survived initial impacts. Vehicle collisions tended to result in damage to the extremities (wing and femur), whereas collisions with windows resulted in trauma to the head, fractures/dislocations of the coracoids and clavicles, and ruptured internal organs. Fractured coracoids frequently damaged flight muscles and ruptured the heart. Extensive bruising of pectoral muscles and haemorrhaging of the lungs was due to the force of impact. Rehabilitation time was not related to the number of skeletal injuries sustained, nor was the time until death for those that did not survive. Flight speed and force calculations suggest that a 570g Kereru would collide with 3-70 times the force that smaller birds (5-180g) would; this may explain the discrepancies between the injuries characterised here and those reported for North American passerines. The differences in injuries sustained from collisions with windows and cars can be used to inform rehabilitators about the possible nature of injuries if the source of impact is known.

2.1 Introduction

Interactions between wildlife and humans are increasing as human development expands. Interactions include modification of landscapes (logging, habitat clearance, and urbanisation), increased traffic (foot or vehicle), and the introduction of novel diseases. As a result of these factors the biodiversity and biotic integrity of wildlife communities may become compromised and fragmented (Bradley & Altizer, 2006; Kretser et al., 2007). Wildlife typically have no inherent behavioural responses to humans inducing changes to the environment. A common result of wildlife-human interactions is trauma due to collisions with vehicles and, for birds, stationary objects such as buildings. The incidence of the public and wildlife rehabilitators receiving injured wildlife increases when new buildings and roads are developed (Harden, 2002).

Studies in North America have documented collision incidents by birds in relation to windmills, skyscrapers and vehicles that involve skeletal and soft tissue damage (Dunn, 1993; Klem, 1990; Klem, et al., 2004; Klem Jr, 1989; Klem Jr, 1990; Veltri & Klem, 2005). Fatal injuries that were sustained from such collisions were typically due to blunt trauma and generally involved haemorrhage from the mouth/nasal cavity, trauma to the head, subcutaneous haemorrhage, soft tissue damage, and skeletal fractures or dislocations (Klem, 1990; Veltri & Klem, 2005). The main diagnostic tool for assessing bone fractures is radiographs. Characterisation of fatal and non-fatal injuries provides an aid to the triage, prognosis and treatment of wildlife casualties. In birds where traumatic collisions are not immediately fatal, central nervous system dysfunction can result in clinical signs of complete or intermittently non-responsive mental status, loss of balance, normal posture or co-ordinated muscle action, drooping eyes, wings, dilated pupils and rapid, shallow breathing (Veltri & Klem, 2005). It is often difficult to identify the extent of soft tissue injuries in live birds, as internal investigations are generally not possible unless with the aid of an endoscope.

In New Zealand, a large fruit pigeon, the Kereru (*Hemiphaga novaeseelandiae*), frequently collides with moving vehicles or structures such as infrastructure windows (Devenshire, 1980). Some of the factors predisposing Kereru to impacts may include: its size (at 400 – 750 g) and consequent lack of manoeuvrability on the wing, display dives that include stalling and deep swooping, and the fact that they often feed on fruiting trees in residential areas, in addition to their native temperate lowland broadleaf forest habitats. Consequently, Kereru are frequently handed in deceased to the Department of Conservation (DoC) offices or alive but injured to bird carers. Bird carers typically have limited capacity for diagnosing internal injuries, and post mortem examination of birds that die during rehabilitation is rarely undertaken. At present DoC lists the Kereru as Conservation Dependent but increasing (Miskelly, et al., 2008), having previously been listed as declining (Hitchmough, et al., 2007).

In this paper we document in detail the injuries sustained by Kereru in collisions with vehicles or structures. We assessed a comparatively large number of samples including birds that died upon impact, birds that died during rehabilitation (or were euthanased after veterinary examination) and birds that survived and were either released back into the wild or retained in captivity. We examined radiographs and undertook necropsies to detect and characterise skeletal injuries. We aim to determine if there is any effect of the extent of skeletal injuries on survival and rehabilitation and to test whether a bird’s chance of survival from an impact is related to the nature and number of injuries received. We aim to determine the effect of the severity and extent of soft tissue and skeletal injuries on surviving the initial impact and the success rates for rehabilitation.

2.2 Materials and methods

We examined a total of 146 Kereru. Seventy specimens were collected from the lower North Island Department of Conservation (DoC) offices – New Plymouth, Palmerston North, Kapiti, Wellington, Wairarapa, Hawkes Bay, and an outgroup from Opotiki or had been delivered to the Institute of Veterinary, Animal and Biomedical Sciences (IVABS), Massey University, New Zealand for necropsy ($n = 20$) (Appendix 2). Seventy-six live birds had been admitted to the Wildlife Ward at IVABS for potential treatment and rehabilitation. Radiographs were taken to identify skeletal injuries from dead birds ($n = 57$) and live birds requiring treatment ($n = 49$). Two standard radiographic positions (lateral and ventral-dorsal) were used for each bird to facilitate detection of fractures and dislocations. A large detail cassette (with a single intensifying screen) was used and the radiograph machine was set at 48 kV and 6.3 mAs, with 110 cm FFD.

Necropsy examinations were carried out on all dead birds to assess both skeletal and soft tissue injuries (e.g. haemorrhaging, trauma to the head, lacerations to internal organs), body condition and fat score. Age of birds was determined from feather condition, moult and development of reproductive organs. Sex was established for dead birds by the presence of testes or an ovary. General morphological measurements were taken (weight, tarsus, wing, head/bill, bill and tail lengths).

To evaluate the probable impact force for birds of different mass, we calculated the flight speeds for Kereru and smaller passerines with Flight 1.11 (Pennycuick, 1999). The force of impact (Newtons kg ms^{-2}) was calculated from these predictions by using the equation $avgF = m\Delta v/\Delta t$, where m = mass (g), $\Delta t = d/v$, d = distance covered by individual during impact (25% of body length). Wing area was measurement in five Kereru following Pennycuick (1999) involving dimensions of wing span, root chord and wing length. Graphing and statistics (Descriptive statistics for all variables, Kruskal-Wallis – test for differences in rehabilitation stay for those that subsequently died or survived) were analysed with SigmaPlot 11.0 and Minitab 15 software.

2.3 Results

2.3.1 Nature of injuries

Of 146 Kereru examined (vehicle n = 40, window n = 70, fence n = 2, unknown n = 34), 70 had died immediately on impact, eight died before receiving medical attention and 13 were euthanased after preliminary examination (Table 2.1). One hundred and eighteen were radiographed for skeletal injuries, while 91 post-mortems were conducted for skeletal and soft tissue damage. Thirty birds that survived the impact and received medical attention were rehabilitated and released, and the remaining ten that survived were used for advocacy.

Table 2.1 Summary of Kereru samples in relation to status when received, outcome of rehabilitation, and types of analyses undertaken.

Fate of Kereru Examined	Dead on impact	Died in rehabilitation	Survived	Unknown Outcome[3]	Total
Group size	70	21	40	15	146
Radiographed	57	15	34	12	118
Necropsy	70	21	0	0	91
Sexed	60	3	4	1	68
Aged	70	17	40	14	141

The radiographs conducted on 118 Kereru showed multiple fractures in 70 birds including fractures to coracoids, clavicle, radius/ulna and femur or dislocations of the coracoids from the keel (Table 2.2). The most common injuries involved the coracoids and clavicle (35% and 33% of all skeletal injuries respectively) and the wings (25% of all skeletal injuries). Leg injuries (fractured femur) were less frequent (7%). Coracoid injuries involving dislocations from the keel represented 38% of all coracoids injuries. In most birds (89%) injuries were sustained on only one side of the body (the exceptions being eight birds with bilateral coracoid and five clavicle fractures). Eight percent of Kereru had only a single fracture and 14% of Kereru had no fractures detected on radiographs.

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[3] Unknown outcome defined as deceased Kereru received with no known history or means of death.

Table 2.2 Skeletal injuries sustained by 70 Kereru involved in collisions with infrastructure. The wing includes fractures to the femur, radius, ulna and carpometacarpals. The leg includes fractures to the femur, tibiotarsus, tarsometatarsus and phalanges.

Bone injuries	Alive	Dead	Total
Coracoid			
Left	10	4	14
Right	5	10	15
Bilateral	1	7	8
Clavicle			
Left	5	8	13
Right	6	11	17
Bilateral	1	4	5
Wing			
Left	9	5	14
Right	11	1	12
Bilateral	0	0	0
Leg			
Left	4	2	6
Right	2	0	2
Bilateral	0	0	0

Soft tissue damage observed included haemorrhage (from or within organs, and bruising to the breast muscle and legs: 62 cases), head trauma (haemorrhage on the meninges or within the cortex of the brain: 14 cases) and lacerations to organs (29 in total) (Table 2.3). Most of the lacerations to the heart (10 of 12) were caused by a dislocated or fractured coracoid rupturing an atrium of the heart. Fifteen cases of bruising/haemorrhaging of the breast muscle were related to a blunt impact; a further two were associated with lacerations of the skin. Seven of twelve birds that were euthanased had injuries that involved the wings and shoulder girdle. Forty-eight percent of all injuries occurred on the left side of the body, 43% to the right with only 9% with bilateral injuries.

Table 2.3 Soft tissue damage sustained by 85 Kereru involved in collisions with infrastructure. N/A represents organs that were not assessed in the live birds. Head trauma was diagnosed in live birds by attending veterinarians on the basis of neurological examination.

Soft tissue	Alive	Dead	Total
Haemorrhage	16	46	62
Head trauma	5	9	14
Lacerated heart	N/A	12	12
Lacerated liver	N/A	8	9
Lacerated intestine	N/A	4	4
Lacerated crop	0	4	4

Identification of internal soft tissue injuries in live birds was limited to haemorrhaging seen externally from the eye and mouth. In eight cases, from dead birds, extensive damage to the heart from broken coracoids was the ultimate cause of death. From all necropsy cases, 30 birds (33%) had both skeletal and soft tissue damage. Less than fifty percent of birds sustained greater than two skeletal or three visceral injuries. This suggests that there is a prevalence of less than or equal to two skeletal and three visceral injuries found in the majority of birds received by rehabilitators (Figure 2.1).

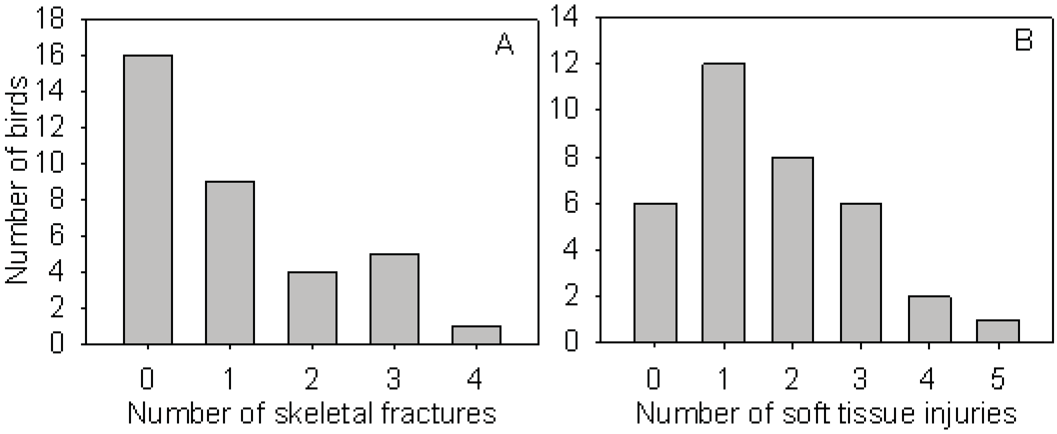

Figure 2.1 Frequency of (A) skeletal and (B) soft tissue (visceral) injuries sustained by Kereru in collisions with infrastructure (vehicles and windows). Total sampled assessed = 35 for skeletal and 35 for visceral injuries.

Table 2.4 Combinations of skeletal fractures and soft tissue injuries in 19 Kereru that died from impacts with infrastructure.

		Visceral injury							
Skeletal injuries	Number of birds	Head	Breast	Heart	Lungs	Liver	Intestine	Major blood vessels	Neck
Coracoid	3	1	1	3	2	1			
Clavicle	6	2			4				2
Coracoid/clavicle	6	1		5	3	2	1	1	
Clavicle/wing	1		1						
Coracoid/keel	1			1	1				
Keel	1		1	1	1				
Keel/ribs	1				1	1	1		

Only 19 of 50 Kereru sustained both skeletal and visceral injuries (Table 2.4). Of these, coracoid and clavicle fractures (17) dominated the skeletal injuries. These were combined with soft tissue injuries to a range of organs, but most commonly the heart (n = 9) and lungs (n = 10). Few birds had injuries to their extremities.

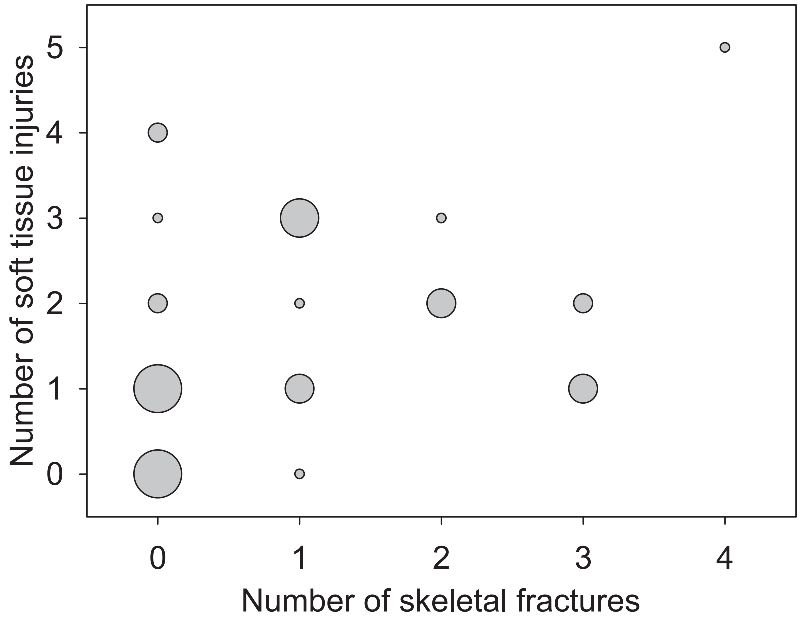

Figure 2.2 Total number of soft tissue and skeletal injuries in individual Kereru. Area of symbol represents the total number of birds with associated injuries. Frequencies range from 1 - 11.

There was a gradual decline in visceral injury as incidence of fractures increases (Figure 2.2), due to the force of collision being dissipated by the deformation and fracturing of bones. Few birds presented with high numbers (>3) of soft tissue damage. The majority of Kereru with impact injuries presented with one or two soft tissue injuries (Figure 2.2).

Table 2.5 Kereru skeletal injuries in relation to the type of infrastructure collided with, data includes multiple injuries per bird. Overall sample sizes assessed: vehicle = 40, window = 70, fence = 2 and unknown = 34.

	Type of injury						
Infrastructure	Coracoid	Clavicle	Wing	Leg	Keel	Head	No Damage
Window	24	20	5	1	6	5	15
Vehicle	5	5	16	6	5	3	9
Fence	1	1	0	0	0	1	0
Unknown	7	9	5	1	4	5	10

Where documented, injuries were sustained from collisions with vehicles, building windows and other structures (Table 2.5). Window collisions resulted in coracoids, clavicle and internal organ damage, whereas most vehicle injuries were associated with the wing and leg (Table 2.5). Spinal injury causing paralysis occurred twice.

2.3.2 Comparison of injuries between dead and alive, died in rehabilitation and survived Kereru

There was no substantial difference in the total number of fractures sustained by Kereru that died on impact or soon thereafter and those that survived until reaching IVABS (Figure 2.3a). Likewise, of those received alive, there was no difference apparent in the total number of fractures between those birds that were successfully rehabilitated and those that died or were euthanased (Figure 2.3c). Survival probability for those birds that survived treatment and those that were euthanased are probably related to internal soft tissue injuries that were not identified. Extensive investigation for these injuries would involve the regular use of diagnostic laparoscopy. There was a substantial drop in the probability of survival when there were greater than two fractures per bird (Figure 2.3b). The same is seen in the probability of survival when in rehabilitation; having greater than two fractures reduces the chances of being successfully rehabilitated (Figure 2.3d).

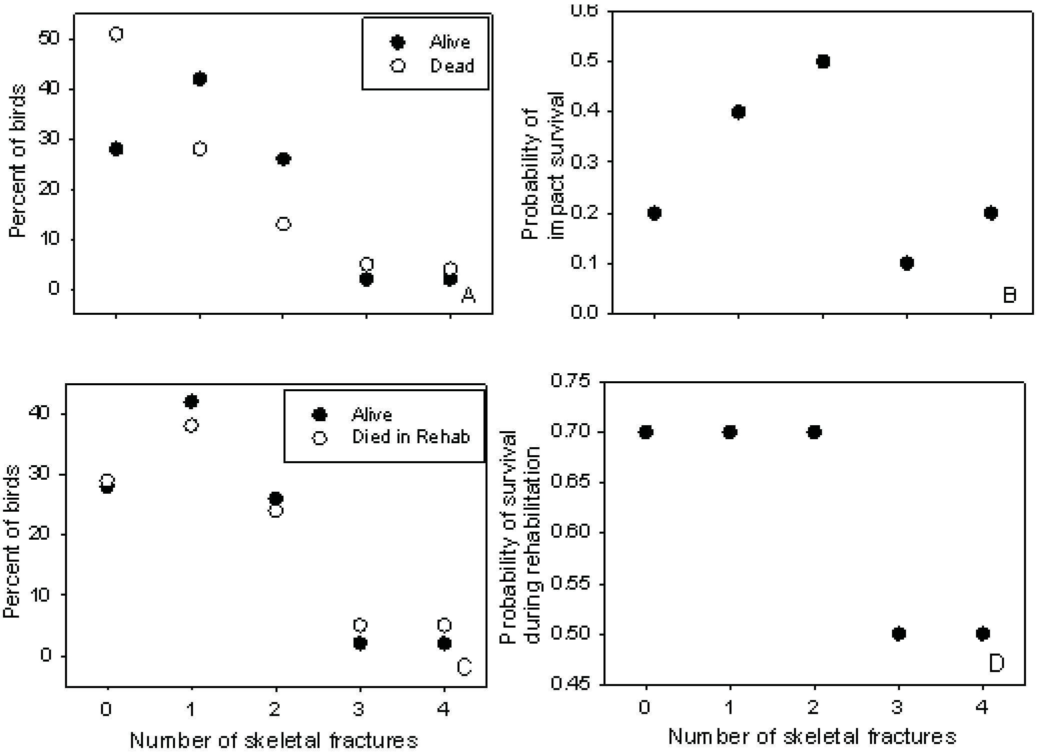

Figure 2.3 Survival probability in relation to the number of skeletal fractures in Kereru. (A) and (B) – survival outcome after impact (alive n = 40, dead n = 70); (C) and (D) – survival outcome during rehabilitation (alive n = 40, died in rehab n = 21).

There was a slight difference in the number of days that a Kereru remained in rehabilitation based on the number of skeletal injuries sustained (Kruskal-Wallis test, H = 10.058, DF = 4, P = 0.039) (Figure 2.4). However, during pairwise multiple comparisons (Dunn’s Method) this slight difference was not found. This may be due to a bias in the sample size of birds that had greater than three skeletal injuries, because even those birds with few (< 3) skeletal injuries remained in the ward for an extended period.

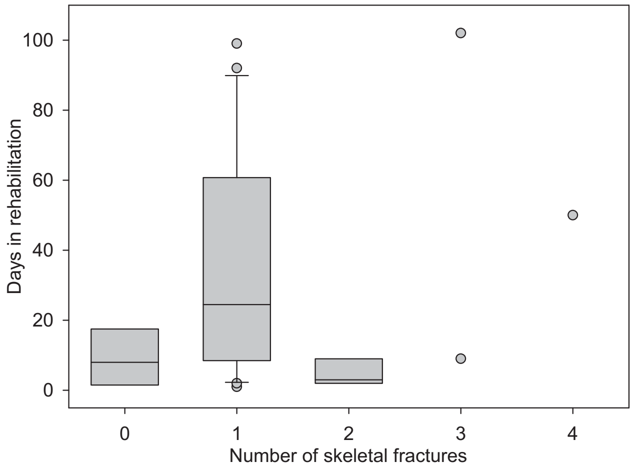

Figure 2.4 Total number of days Kereru remained in rehabilitation, before they were released, in relation to number of skeletal fractures sustained. Sample sizes were 5, 22, 8, 2 and 1 for 0-4 fractures respectively.

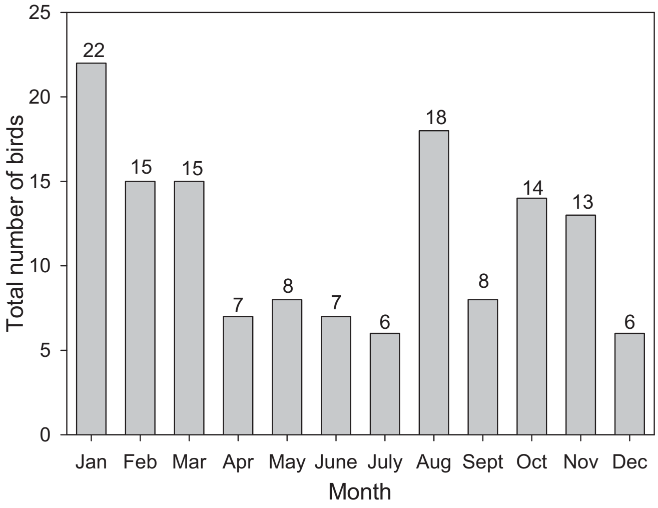

Figure 2.5 Monthly number of Kereru collisions (n = 146) with vehicles and infrastructure. Data collected span from 1996 - 2009. Sample sizes are given above the bar.

The number of Kereru that impacted with infrastructure decreased from a peak in January with few during the winter months (June – July) (Figure 2.5). There was a considerable increase in August before tailing off again towards December. This trend coincides with the onset of foliage and flower set and the lead up to the breeding season.

Table 2.6 investigates the effect that a bird's mass has on the potential speed that it can fly. In conjunction with mass and speed the force at which a bird would collide with an infrastructure can be determined. Kereru would impact at 3 – 70 times the force of smaller birds (≤ 23g) when flying at minimum power speed (Table 2.6). This implies that the extent of injuries (due to blunt force impact) would be far less than those sustained by a Kereru.

Table 2.6 Flight impact forces for birds of various sizes relative to the Kereru. Ie: A Goldcrest impacts with 0.01 of the force of a Kereru at minimum power speed.

Species	Mass (kg)	Length (cm)	Min power speed (m/s)	Impact force (N)	Relative to Kereru	Max range speed (m/s)	Impact force (N)	Relative to Kereru
Kereru	0.57	51	13	772	-	22.4	2280	-
Jackdaw	0.181	32	10.3	239	0.31	18.3	753	0.33
Starling	0.0819	18	9.9	180	0.23	17.8	583	0.26
Song Thrush	0.0716	18	9.8	153	0.20	17.4	479	0.21
Chaffinch	0.023	15	7.8	37	0.05	14.7	130	0.06
Nightingale	0.023	16	9.1	48	0.06	16.9	162	0.07
Warbler	0.022	10	8.7	66	0.09	16.2	238	0.10
Siskin	0.0112	15	6.9	14	0.02	13.2	51	0.02
Goldcrest	0.00542	8	6.3	11	0.01	13.2	48	0.02

2.4 Discussion

From 68 Kereru (Table 2.1) there was no substantial sex bias in the sample of Kereru involved in collisions (male 29: female 39). However, age is a factor with there being greatly more adults (88) involved in impacts as opposed to juveniles (22). This could be due to adults being more active than juveniles, there possibly being a low reproductive output (although age structure is unknown) or different habitat use between the age groups. These results are comparable to those in a study conducted by (Klem Jr, 1989) who found that few juveniles (study material from museum specimens of various bird species) were casualties of impacts.

2.4.1 Nature of injuries

Skeletal damage caused by impacts involved the coracoids, clavicles, wing bones (radius/ulna) and leg bones (femur). Dislocations from the keel constituted 89% of coracoid injuries in all mortality cases. Coracoid fractures (from all sources) made up 40% of all recorded injuries (Table 2.2). Seventeen coracoid injuries were pinned together in live birds. Coracoid fractures and dislocations can and do cause damage to underlying organs such as the heart (Table 2.4). Clavicle injuries generally occurred at the apex between the two clavicles, or off-set to one side. From all data sources there were 31 clavicle fractures (41% of all injuries) with an even ratio between the two sides of the body. Wing fractures were present more frequently in birds received alive (20/76) than dead (6/70). Breaks to the femur (leg) occurred a total of eight times (Table 2.5); six of these were in live birds. There does not appear to be a skewed bias for which side of the body was injured (left 48%: right 43%) and the chance of injuries occurring on both sides of the body was only 9%.

Chest damage in the form of fractures to the coracoids and clavicles indicates that the birds hit an object with full frontal force, such as colliding with a window in a building. Little wing damage occurred in those birds that collided with windows (19%), as opposed to those that had been struck by a vehicle (62%) (Table 2.5). In vehicle related cases, wing, radius and ulna damage were the dominant skeletal fractures. This may be directly linked to the orientation of the bird in relation to the vehicle. The bird is likely to have been flying at right angles to the vehicle; therefore, the wings would collide first and receive the full force of impact. This is why there are fewer birds with wing damage in window impacts, as the wings would be fanned open and therefore would lie parallel to the window, decreasing the extent of damage to the wing (Flux, 1990). This reasoning would also help explain why few birds involved in vehicle accidents have chest damage (coracoids and clavicle) as the keel is not the first point of impact.

Small bird (<39 g) casualties with towers and plate glass windows in America have shown little or no skeletal fractures (Veltri & Klem, 2005) in contrast to this study with a large bird (>400 g). This may reflect the force with which birds of different sizes collide with objects. Large birds with their increased mass, such as the Kereru or birds that are flying from a long distance, may impact at a greater velocity than smaller species or those that have only travelled a short distance (Veltri & Klem, 2005). For example a Kereru flying across the path of a car travelling at 50km/hr would impact with a force of 550N (this is less than an impact with a building window due to the speed of the bird becoming relevant because of the right angle flight path across the car). A car speed of 100km/hr results in 2200N, but in a head-on collision would result in an increase of force to 4746N. This supports the analysis of flight speeds and impact forces (Table 2.6). Birds the size that Veltri and Klem studied (approximately 23g) impact with 0.06 - 0.07 of the force (at maximum range speed) of a Kereru. The lack of skeletal injuries in the birds studied by Veltri and Klem probably reflects their small sizes and masses. There were only two incidents in Kereru where there was cervical spinal injury, causing paralysis, indicating that this type of injury is not common. These findings contradict Veltri and Klem (2005) who claimed that birds that collide with windows only sustain injuries to the head and neck region, and because of this there is no real reason to examine other areas of the bird for injury.

Along with skeletal damage there are soft tissue injuries that can have impacts on bird's health and flight ability. The most frequent soft tissue damage was haemorrhaging in the lungs, bleeding from the mouth and bruising to the breast muscle (Table 2.3). In all cases that involved haemorrhaging in the lungs there was associated bleeding from the mouth; these constituted 60% of all soft tissue injuries. Bruising to the breast muscle was indicative of the site of impact. In some cases the force of impact left an indentation on the breast along with bruising. Haemorrhage of the lungs is an artefact of the impact, with increased pressure on the thorax and underlying organs rupturing capillaries and subsequently causing bleeding (A. Wilson, pers. comm. 2009.).

Other soft tissue injuries that Kereru sustained were lacerations to the heart, liver and intestines and also ruptured crop (Table 2.3 & 2.4). Eighty percent of lacerations to the heart were a result of coracoid dislocations. Laceration to the liver and intestines can be associated with increased pressure to the keel and ribcage at the time of impact, pressing these structures against internal organs and subsequently rupturing them. These injuries were not common and only accounted for 12% of all soft tissue injuries. Crop ruptures also represented a small portion of soft tissue injuries (4%) (Table 2.3). A soft tissue injury that could potentially be fatal is severe trauma to the head in the form of bleeding on the brain. This injury was evident in 13 of the 145 cases. Other studies have suggested that head trauma is more prevalent (>50%) than was found in this study (Veltri & Klem, 2005). Only 19 of 50 Kereru (that were received from DoC) had both skeletal and soft tissue injuries (Table 2.4). Birds from the Wildlife Ward cannot be included in this sample as the extent of internal injury for those birds that survived is unknown. These 19 birds had a total of 35 soft tissue injuries, or 1.8 soft tissue injuries per bird, and 36 skeletal or 1.9 skeletal injuries per bird (Figure 2.1a). This suggests that up to 20% of birds may sustain soft tissue injuries and not immediately present with clinical signs of injury (Figure 2.1b). Soft tissue injuries are not as easily identified as skeletal ones, and unless there is an internal rupture (laceration to liver, intestines) that would immediately result in clinical diagnosis of injury, little can be done other than monitoring to assess the extent of damage.

In total there were 30 birds that presented with some form of injury (19 skeletal, 29 soft tissue (Figure 2.1a, b)). The total number of birds with skeletal fractures declined in relation to the total number of fractures sustained (Figure 2.1a). The same trend was present for soft tissue injuries (Figure 2.1b). Forty six percent of Kereru that died presented with no skeletal injuries possibly dying from the stress of impact, aftershock or underlying illness. These birds are presumably the ones that appear stunned at the window, after impact, and do not recover. On the other hand fifty seven percent of soft tissue injuries consisted of one or two injuries. Figure 2.2 depicts the number of soft tissue and skeletal injuries discovered per bird. This indicates that many birds presented with no skeletal injuries, however they could have anywhere from zero to four soft tissue injuries. Only one bird had four skeletal injuries and this coincided with five soft tissue injuries. The soft tissue injuries sustained by that bird was strongly related to the type of skeletal damage that it contracted (both coracoids and clavicles, with one dislocated coracoid rupturing the heart). With the exception of that bird as the number of fractures increased the number of soft tissue injuries decreased. The explanation for this is unclear.

2.4.2 Comparison of injuries between dead and alive, died in rehabilitation and survived Kereru

Birds that were received dead presented with similar injuries to those that survived (Table 2.2). Birds that survived (40%) may have died if they did not receive medical treatment, such as pinning bones and administration of fluids and care due to the extent of their injuries. From these results, birds that impact with structures and have coracoid or humerus fractures and minimal soft tissue damage have potential to be mended to a standard best for rehabilitation or for advocacy purposes.

One finding that is counterintuitive is that the proportion of birds that survived and presented with no fractures is almost 50% less than those that died with no fractures. A likely explanation is that many birds that do not sustain fractures escape relatively unscathed and do not enter our data. Additionally, the public or bird carers may hold Kereru with only minor injuries for longer, without them coming to Massey University for treatment. Fewer birds may appear to survive with no fractures due to live birds actually getting away from the site of impact, a sample size effect or the dependent variable of public retention time of holding injured Kereru. There was no difference between the number of birds that survive or die with one or more fractures (Figure 2.3a). However, the probability of survival (Figure 2.3b) decreased with an increasing number of fractures. The same is seen for those birds that are received alive at the Wildlife Ward and subsequently die/euthanased or survive through to rehabilitation (Figure 2.3c). The probability of survival in this case is greater than for those birds that died or otherwise did not receive medical attention (Figure 2.3d). This indicates that intervention in the form of medical care (administration of fluids or surgery) is a means of increasing survival rate of birds that are injured. However, this is dependent on time elapsed from impact, total number of fractures/soft tissue injuries and ability to perform appropriate surgery and after care. The number of skeletal injuries in relation to the number of days spent in rehabilitation does not proportionally increase with increasing number of injuries (Figure 2.4). However, there is a bias in this sample due to few Kereru entering with Ward with more than two skeletal injuries. This could imply that birds with more than two skeletal injuries are less likely to make it to the Ward alive and are therefore not assessed. The time spent in the Ward with only one skeletal injury varied from zero to 102 days. This large variation of rehabilitation time may be due to internal complications that are not assessed unless via endoscopy.

For birds that did not die immediately upon impact, their condition before death is unknown. For example - was the bird in a fit and healthy condition prior to the injury? Or was its health jeopardised prior to impact and this was a pre-cursor for collision? Body condition score (BCS) is a means of assessing the extent of flight muscle over the keel. It is used as a means of determining the health or starvation state of a bird. Of those birds that were autopsied nine of those showed signs of starvation/degradation prior to death (BCS 1-4 unhealthy) (Appendix 3). Most Kereru collisions occurred in late summer (Jan-Mar) and late winter (Aug) (Figure 2.5). The increase of collisions in August coincides with territorial bouts between neighbouring/intruding Kereru for access of food. Food resources substantially increase during the lead up and beginning of spring increasing interactions with co-specifics for consumption of readily available fresh foliage (P. McKenzie, pers comm., 2009). The smaller peak that occurs around October/November may be in relation with breeding flight displays, where males display to females with their swooping dives and mid flight stalls (Pierce, 1993). With fast speed flight (13 – 22m/s) through dense bush and over open fields or in urban/residential areas, in pursuit of a mate, the occurrence of collisions with vehicles and windows is more readily explained.

2.5 Conclusion

Injuries that are sustained through impacts with stationary objects, windows, or with moving objects, such as cars, can be classified into three types of injury;

1) Skeletal damage in the form of bone fractures and dislocations;
2) Soft tissue damage in the form of haemorrhaging/bruising to organs, muscles and skin, laceration to intestines and crop, and trauma to the head;
3) Injuries that involve soft tissue and skeletal damage with some fractures causing damage to organs (laceration to the heart and liver by coracoid).

It could be said that vehicle impacts and thus injuries are more detrimental for rehabilitation than window collisions, due to the nature of the injuries sustained. This is because wings are the main skeletal structures that are damaged making it difficult for the bird to sustain any quality of life, unless the probability of successful surgery (pinning of wing) and rehabilitation was guaranteed. Coracoid and clavicle injuries dominate skeletal injuries found in those birds that collide with windows, with the greatest number involving dislocations from the keel (89%). Few window casualties sustain injuries to their extremities (wings/legs). Those birds that impact with windows and survive the initial shock are often able to recover fully, as long as coracoid fractures have not damaged underlying organs such as the heart. With surgery such fractures can often be realigned and pinned and the prognosis of recovery from such an injury is high. With flight training and rehabilitation these birds may be released back into the wild. If their rehabilitation is such that carers believe their quality of life without continued support is inadequate, then they may subsequently be euthanased or be used as advocacy birds.

The characterisation of injuries shown here means that it may be possible to infer the cause of an injury from the damage sustained. If the wing and legs are involved there is a high probability that the bird was in an accident with a vehicle, as opposed to coracoid, clavicle and head trauma which would indicate a possible impact with a stationary object such as an infrastructure window. This is due to the nature of the object, the angle and force at which the bird collides. Bleeding from the mouth indicates internal damage, generally haemorrhaging of the lungs (due to force of impact); therefore, monitoring of the bird is required to identify further internal injury if there is no apparent skeletal damage. Just as many birds die from soft tissue injuries as do those with skeletal. The force with which a bird collides has a bearing on the extent of injuries that it sustains, whether it is just soft tissue, skeletal or a combination of the two. In the case of the Kereru, its substantial mass (>500g) and the force (772 - 2280 N) with which it collides inherently predisposes it to extensive damage.

Increased occurrence of collisions during Augusts suggests there is a relation in time with prolific flowering and fruiting of preferred foliage. Collisions during October/November coincide with the onset of breeding indicating that the later five months of the year are repeated times for impacts. With the identification of these times of increased collisions wildlife rehabilitators will be able to prepare in advance for an influx of Kereru towards the end of the year as opposed to during autumn and winter months, when collisions are less likely to occur. The amount of time that a Kereru remains in rehabilitation is not closely related to the number of skeletal injuries that it sustains. A bird with three fractures can survive just as long as an individual with one fracture, also there is a substantial variation in the time that a bird that receives only one fracture can remain in the Ward for. Therefore, there is no clear indication that a bird with one fracture will stay in rehabilitation for a predicted number of days.

Being able to identify the type of impact enables wildlife rehabilitators and carers to investigate injuries that may not immediately be apparent on arrival, subsequently giving them a head start in relation to medical care and probability of immediate survival. Contact and close interactions between Kereru and humans is increasing quickly due to continual residential developments, increased traffic and destruction of natural habitat. Due to this and the slow increase in Kereru numbers (Miskelly, et al., 2008), more collisions per year are inevitable, increasing the demand for knowledge by rehabilitators. There is also more need for the public to be made aware of such incidents and what actions to take; whether to leave the bird, see if it recovers, or to collect it immediately after impact. Also, knowledge about reasons why such impacts occur, especially at windows, is needed.

Chapter Three - Kereru morphometrics, body condition, organ masses and crop contents.

3.0 Abstract

Morphometrics often enable an observer to determine the age and sex of an individual, however, in the case of Kereru (*Hemiphaga novaeseelandiae*) this is not possible. Of 50 Kereru that died due to impact collisions, little variation was found between sexes; males had longer head/bill lengths. Positive relationships were found between mass and tarsus, wing and tail, mass and head-bill and head-bill and tarsus lengths. Fat scores of Kereru were closely related to environmental seasonal variation and 80% of birds were in good body condition (score greater than 4/9). Kereru do not have caeca and there were no sexual differences in reference to dry organ mass (liver, intestine, gizzard and crop). Organ masses were positively related to body mass, though gizzard mass was additionally related to tarsus length. Tarsus length in conjunction with body mass best explained liver mass variation. Intestine length was related to both mass and tarsus length. There was seasonal variation of organ and body mass which is governed by dietary and physiological requirements. There were no sexual differences in mass of consumed materials found within the crop, gizzard and intestines. Kereru contained up to 68g of consumed material within their crop, consisting of introduced and native material (foliage/flowers/buds/fruits). Digesta accounts for 0.12 – 13.4% of total Kereru body mass.

3.1 Introduction

Parameters such as shape, size and colour are generally what humans use to assign sex and age; they can also allow the identification of individuals. The ability to recognise vocalisations is another means of identifying species or individuals. However, there are many individuals that are cryptic or appear 'cryptic'. This makes identification difficult, and other means of identifying individuals need to be used, such as phenotypic measurements (e.g. head, bill, tarsus, wing, tail and mass). Sometimes even with these indicators it is difficult to determine sex. Darwin (1874) once said that 'the male of many birds are larger than the female, and this no doubt is the result of the advantage gained by the larger and stronger males over their rivals during many generations'. Opposing this, it is said that monomorphism developed due to social mating systems and variation from this depends on the extent of the parental care (Bennett & Owens, 2002). Observations worldwide have found that social monogamy dominates mating systems (85%), however DNA sexing and paternal tests now often contradict this claim (Bennett & Owens, 2002). For sex to be determined in these incidences DNA needs to be analysed, which is an expensive adventure. This is why techniques that enable gender identification externally and without too much intervention are preferred.

Assessment of body condition and consumed materials can give an indication about the birds' health, immunity and availability of food resources. Overall body condition is ultimately governed by the above and parasite load (internal/external). Deterioration can be classified as showing signs of illness – lethargy, pain, and loss of appetite or becoming emaciated. Mass is an immediate indicator of health, if the initial mass is known; however, this can be confounded by the amount of food that is retained in the crop, gizzard and intestines. Body condition can be assessed using two different ratings, body condition score (BCS) and fat score (FS). Both of which are used in this study. BCS rates the fat and muscle content in the area of the keel; this is given a rating from 1 (emaciated) to 9 (obese). FS is based on the amount of fat lying beneath the skin and around the internal organs, from 0 (no fat) to 4 (extensive fat around organs).

Many studies have investigated the breeding (Bell, 1980; Clout, et al., 1988; Genet & Guest, 1976; Hadden, 1993; Thorsen, et al., 2004) and feeding habits (Devenshire, 1980; Wotton & Ladley, 2008) of Kereru, and a limited number have studied the morphometrics (Gill, 2006; Mander, et al., 1998). The ability to determine sex morphologically would aid conservation workers by reducing the cost and time currently required for identification with DNA sexing. The proportion of mass that consists in consumed, un-excreted food is not well documented. Therefore, it is difficult to assume the actual mass of Kereru as it is known that the retention time of food can be up to 16 hours (Wotton & Ladley, 2008) and that they ingest a huge quantity of food. Further analysis of Kereru morphometrics, including mass, and investigation into the amount of mass that is assimilated in consumed food, along with intestinal tract dry mass are undertaken in this study.

3.2 Materials and methods

Fifty Kereru were sourced from the Department of Conservation (DoC) freezers around the lower North Island of New Zealand. Morphometrics were taken for each bird; these included mass (g), bill, head/bill, tarsus, wing and tail length (mm) (Table 3.1). Birds were weighed with digital scales and body measurements taken with a wing-rule and callipers. General parameters such as age and sex were noted during necropsy.

Table 3.1 Position of callipers and ruler for body measurements on a bird.

Bill	Base of the upper mandible (edge of leading feather on to bill) to tip of the upper mandible
Head/Bill	Tip of upper mandible to back of head
Tarsus	Notch on the tibio-tarsal joint to the bend of the foot
Wing	Top of elbow to tip of longest straightened wing feather
Tail	Base of tail to tip of longest feather

Body condition was analysed using a Body Condition Score (BCS) which gives a rating from zero to nine (Table 3.2) and a Fat Score (FS) rating zero to four (Table 3.3) – these were determined during necropsy.

Table 3.2 Description of Body Condition Score (BCS) when assigning the body condition of a bird. BCS system adapted from R. Powlesland (per. comms. 2009) and own assessment.

0	Virtually a skeleton
1	Little muscle on keel – (very concave, keel knife-like)
2	Small amount of muscle remains – keel becomes prominent
3	Keel more pronounced
4	Little protrusion of keel
5	Breast muscle and keel produce a flat unified surface
6	Some muscle/fat over keel – can still detect keel
7	No detection of keel, breast muscle/fat extends above keel
8	Breast muscle/fat covers keel and begins to become convex
9	Extremely overweight – very convex muscle (cannot distinguish the keel)

Table 3.3 Description of Fat Score (FS) for assigning to the body condition of a bird, based on description from Gill (2006) and assessment from Cato (1986) and Foster and Cannell (1990).

0	No or little fat
1	Light fat (thin layer beneath skin)
2	Moderate fat (layer beneath skin and some fat in abdominal cavity)
3	Heavy fat (much fat in abdominal cavity)
4	Very heavy fat (intestines hardly visible)

Crop, gizzard, liver and intestines were removed during necropsy and any contents were removed from all organs and organic material from the crop was identified. Intestine length was measured using a metric ruler (to the nearest millimetre), every effort was made to reduce the effect of stretch when laying out the intestines. Fresh masses for all were taken. The organs were then dried for 14 days at 70^0C to a constant mass. All results are based on dry masses to two decimal places. Any organs that were damaged due to collision impact injuries were not assessed in this study, therefore, sample sizes are variable.

SigmaPlot 11.0 was used for graphs and Minitab 15 for statistical analysis using Mann-Whitney tests, Descriptive statistics, t-tests and linear regressions were used to test for relationships between test groups (morphometrics) and if there were any significant differences between age and sex groupings. After initial assessment only adults were further assessed for this study due to the small sample size (n = 9) of juveniles.

3.3 Results

3.3.1 Morphometrics

The only significant difference in measurements between males and females, albeit small, was in head-bill length. This difference was apparently largely due to the variation in the size of the head as there was no difference between sexes in bill length (Figure 3.1a, b).

Table 3.4 Descriptive statistics of Kereru morphometrics. Adults only. N.B: NS = not significant

Measurements	Sex	Mean	*n*	SD	Range	Sexual difference
Weight (g)	♀	555.7	24	87.5	423 - 741	NS
	♂	601.1	18	122.2	373 – 767	
Bill length (mm)	♀	16.9	24	1.8	14.6 - 19.3	NS
	♂	16.9	18	1.3	14.7 - 19.3	
Head/Bill length (mm)	♀	64.8	24	2.5	59.5 - 69.5	$F_{1,41} = 5.70$; $P = 0.022$
	♂	66.3	18	1.6	63.6 - 68.9	
Wing length (mm)	♀	255.5	24	7.3	243 - 271	NS
	♂	255.6	18	6.46	240 - 268	
Tail length (mm)	♀	180.1	24	9.5	166 - 201	NS
	♂	186.1	18	12.7	167 - 218	
Tarsus length (mm)	♀	37.2	24	1.6	33.4 - 39.7	NS
	♂	38.1	18	1.7	35.4 - 42.3	

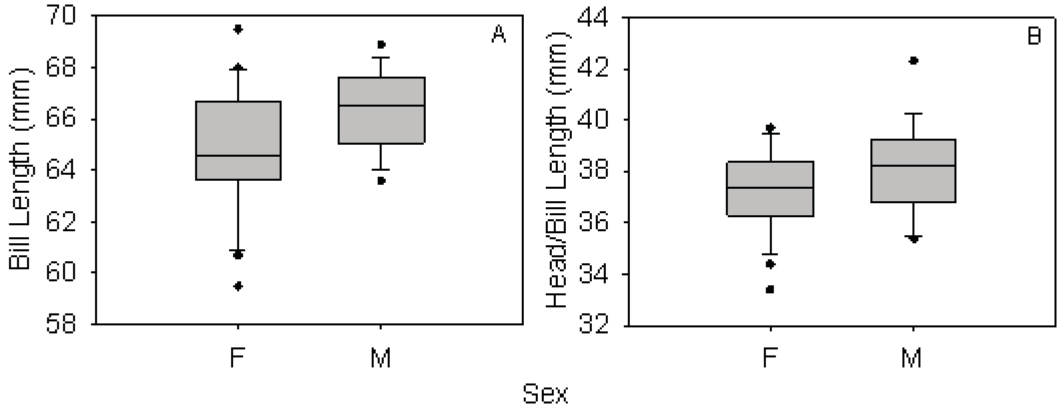

Figure 3.1 A) Difference in bill lengths between sexes of Kereru (Female *n* = 24, Male *n* = 18). B) Comparison of head/bill lengths between sexes of Kereru (Female *n* = 24, Male *n* = 18).

Overall, five combinations of mass, bill, head/bill, tarsus, wing and tail measurements were positively related, though none particularly strongly (correlations <0.5) (Table 3.5).

Table 3.5 Correlations showing the degree of positive relationships between Kereru morphometrics. Correlation is significant at the 0.05 level. NS = Not Significant.

	Statistic	Mass	Bill	Head/bill	Wing
Head/bill	Pearson Correlation	0.345	0.387		
	P value	0.025	0.011	NS	NS
	N	42	42		
Tarsus	Pearson Correlation	0.499		0.320	
	P value	0.001	NS	0.041	NS
	N	41		41	
Tail	Pearson Correlation				0.417
	P value	NS	NS	NS	0.007
	N				40

3.3.2 Body condition

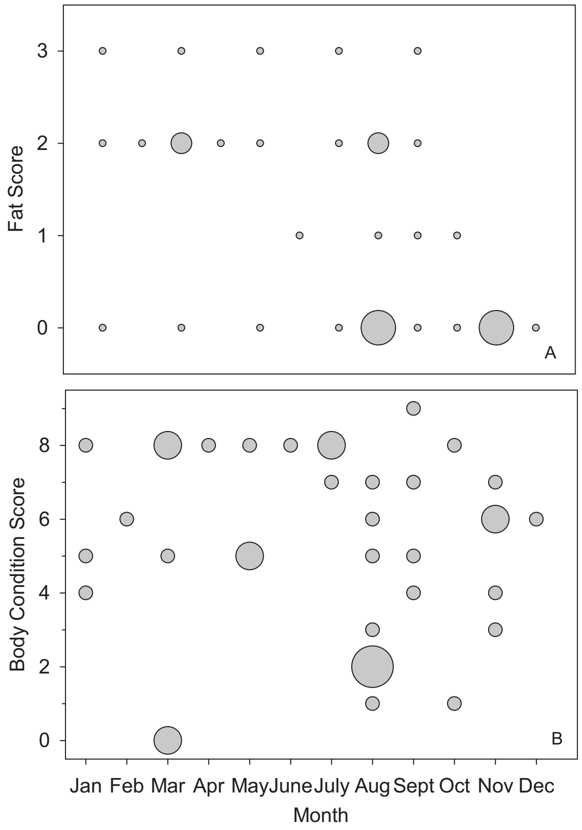

Figure 3.2 Symbol area represents the number of Kereru (total individuals 44). A) Fat score (FS) at any given month, . B) Body condition score (BCS) at any given month.

More birds in late Spring/Summer had no fat stores than in autumn and winter (fat score 2 (Figure 3.2a)). Lowest body condition scores were in March (when eight birds had scores of zero). More than 80% of the birds that died due to collision impacts had BCS's greater than four (Figure 3.2b).

3.3.3 Internal organ masses

No caeca were found in any birds. There was no difference between sexes in relation to dry mass of internal organs (T-tests; Liver P = 0.49, Intestine P = 0.82, Gizzard P = 0.28) so sexes were combined for further analysis. Fresh organ mass and intestinal length varied greatly between individuals (Table 3.6), but organ mass was related to body mass (Table 3.6; Figure 3.3). The entire gastrointestinal tract accounted for only seven percent of Kereru mass.

Table 3.6 Descriptive statistics of fresh Kereru organs. Adults only. Average Kereru mass 560g.

Measurement	Mean	*n*	SD	Range	% body mass
Intestinal Length (mm)	79.34	32	18.65	52 - 112	N/A
Liver (g)	12.865	32	4.13	6.17 – 22.86	2
Gizzard (g)	11.52	34	3.44	5.55 – 20.30	2
Intestine (g)	14.92	34	3.53	8.31 – 23.44	3

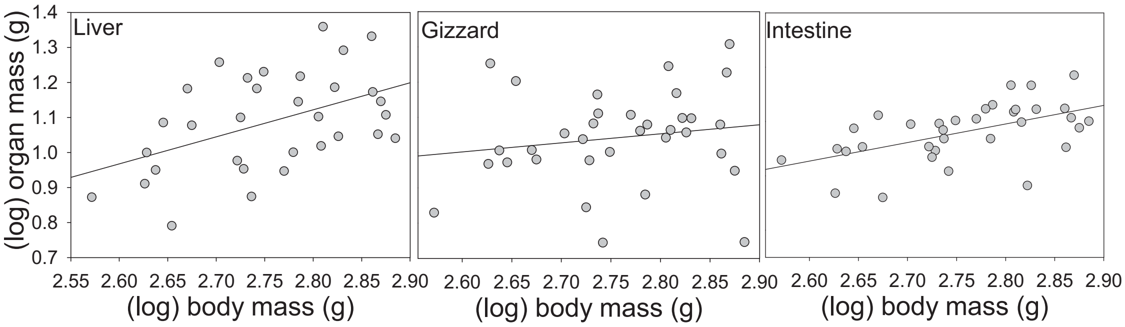

Figure 3.3 Fresh masses of the liver, gizzard and intestine (gizzard and intestine emptied of contents). Sample size varies between organs (Liver n = 32; Gizzard n = 34; Intestine n = 34).

Both mass and tarsus were significantly related to gizzard mass when tested singly, but because of the covariation between these two measures, neither was significant when tested in a multiple regression. Body mass affected liver mass independent of tarsus length (which was apparently negatively related to liver mass). Intestine varied only with body mass (Table 3.7).

Table 3.7 Regression assessment of internal organ mass (g) in relation to Kereru mass (g) and tarsus length (mm).

Organ	Predictor	T value	P value	F value
Gizzard	Mass	3.90	0.000	$F_{1,33} = 15.18$
Gizzard	Tarsus	2.73	0.010	$F_{1,33} = 7.47$
Liver	Mass	2.45	0.020	$F_{1,31} = 5.99$
Liver	Mass	3.43	0.002	$F_{2,31} = 5.98$
	Tarsus	-2.27	0.031	
Intestine	Mass	4.60	0.000	$F_{1,33} = 21.18$

No sexual differences were found in intestinal lengths, however, there was a highly positive relationship with mass (T = 3.94, P = 0.000, $F_{1,31} = 15.50$) and also tarsus length (T = 3.01, P = 0.005, $F_{1,31} = 9.08$) when assessed as individual predictors. Mass and tarsus length together explained intestine length better, even though tarsus length in itself became no longer significant (tarsus T = 1.24, P = 0.225; mass T = 2.56, P = 0.016; $F_{2,31} = 8.66$). Correlations of dry organ masses showed that intestine length was positively correlated with both the liver and gizzard masses, and there was no significant correlation seen between the gizzard and liver masses (Table 3.8).

Table 3.8 Correlations showing the degree of positive relationships between Kereru dry organ masses. Correlation is significant at the 0.05 level.

	Statistic	Liver	Gizzard
Gizzard	Pearson Correlation	-0.046	
	P value	0.803	
	N	28	
Intestine	Pearson Correlation	0.434	0.368
	P value	0.013	0.032
	N	28	29

The scaling between individuals of organ size with body mass (Table 3.9) shows that intestines (dry mass) changed more than the other organs with changes in body mass, and are almost significantly isometric (slope of 1, rather than ~0.67). But the confidence intervals of all relationships are very wide, which reinforces the lack of a strong structural/mass influence.

Table 3.9 Log-log regressions between fresh and dry organ masses (g) and body mass mass (g). From ANOVA tests.

Organ	Fresh/ Dry	Slope	Significance	Lower 95 percentile	Upper 95 percentile
Gizzard	Fresh	0.26	0.362	-0.31	0.82
Intestine	Fresh	0.68	0.001	0.30	1.07
Liver	Fresh	0.77	0.006	0.24	1.31
Gizzard	Dry	0.68	0.001	0.29	1.07
Intestine	Dry	1.09	0.000	0.66	1.51
Liver	Dry	0.76	0.001	0.18	1.3

There is a suggestion that body masses may have on average been slightly higher in winter than in other seasons, liver mass lower in winter, intestine declining through spring and gizzard fairly constant (Figure 3.4). Again, the variation in all measures is high, suggesting that the organ sizes do not reflect the same factors.

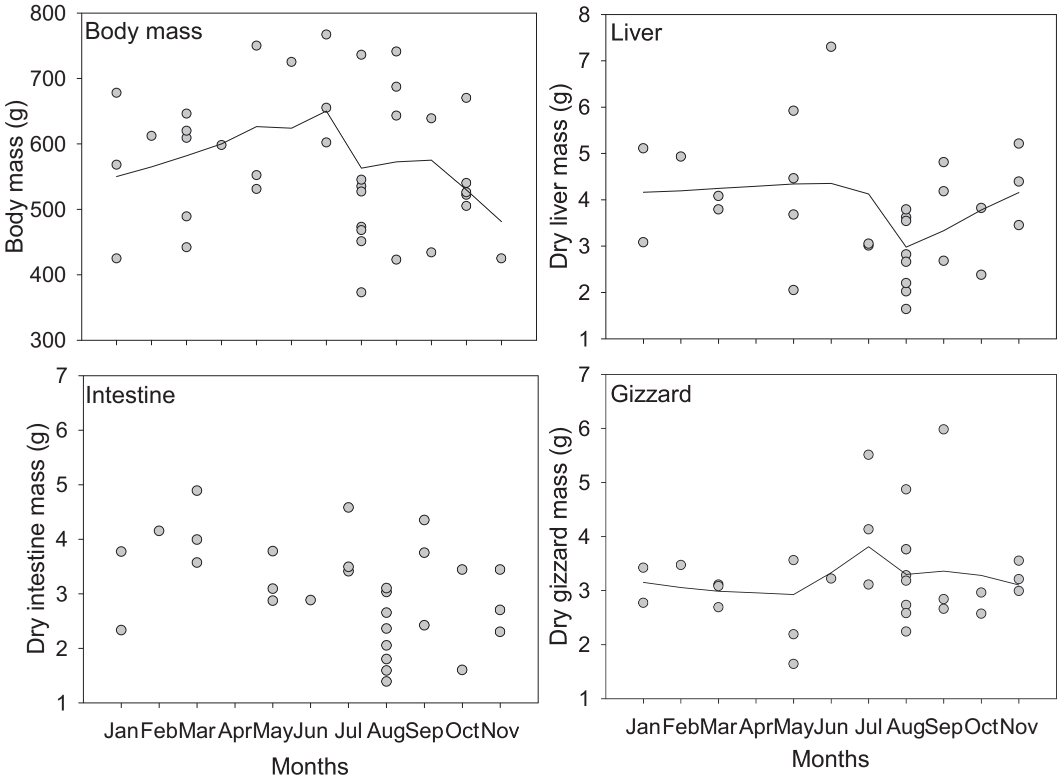

Figure 3.4 Seasonal variation of Kereru body and dry organ masses (liver, gizzard and intestine). Sample sizes vary per month, each dot represents an individual. Lines are Lowess smoothing curves (f = 0.5) to elicit trends; y axis varies between graphs.

3.3.4 Crop contents

Of fifty Kereru examined for crop contents only 32 had any crop contents. There were no sexual differences in the amount of food consumed or held within the organs (crop, gizzard and intestine). Material within the crop consisted of 64% organic material, either native (50%) or introduced (12%) foliage, or fruits and vegetables (38%) (Table 3.10). Presence of crop contents varied throughout the year, being most frequently recorded in August, September and March. Mass of contents ranged from 0.13g to 67.51g, with an average mass of 15.0g (Appendix 4).

Table 3.10 Type of organic material found in 32 crop content samples from Kereru and the frequency of their occurrence (juveniles and adults included).

Type of organic material	Frequency	Type of organic material	Frequency
Unknown exotic broadleaf	4	Puriri (fruit)	2
Fruit/vegetables	12	(*Vitex lucens*)	
Kowhai (leaves/flowers)	5	Karaka (fruit)	1
(*Sophora tetraptera*)		(*Corynocarpus laevigatus*)	
Tree lucerne (leaves/flowers)	4	Tawa (fruit)	1
(*Chamaecytisus palmensis*)		(*Beilschmiedia tawa*)	
Lacebark (leaves)	2	? Fruits	1
(*Hoheria populnea*)			

Fruits were only present in crop contents from January to May, leaves March to November and flowers from September to November (Table 3.11). There was no difference in the mass of consumed materials between sexes (Mann-Whitney U-test, $P = 0.806$) or ages ($P = 0.747$). The fresh mass of consumed material ranged from 0.12% to 13.4% of the body mass of Kereru (Appendix 5).

Table 3.11 Food items found in crop contents of 32 Kereru in relation to time of year and type of foliage (F = flower, L = leaves, *f* = fruit/seed, * = presence).

	Species								
Month	Broadleaf	Fruit/ Vegetable	Kowhai	Tree lucerne	Lacebark	Puriri	Karaka	Tawa	? fruit
Jan		*				*f*			
Feb							*f*		
Mar	L	*			L	*f*		*f*	
Apr	L	*							
May		*/*							*f*
June			L						
July				L					
Aug		*/*/*/*/*		L					
Sept	L		F	L	L				
Oct	L	*							
Nov				L&F					
Dec									
Unknown		*	*f*/L/L&F						

3.4 Discussion

3.4.1 Morphometrics

Analysis of Kereru body measurements (morphometrics) found little variation between the sexes (Table 3.4), the only significant difference being in head-bill lengths (Figure 3.1b). This is similar to the findings of Gill (2006) who found only a difference in bill lengths; contrary to this study, however, he found that males had shorter bills than females (Figure 3.1a). This may be due to sampling variation and the fact the differences between individuals tended to be small. There was no significant difference in wing length between the sexes in my study, whereas Gill (2006) found males to be larger winged on average. As expected, larger birds were heavier, with body mass being positively related to tarsus, bill and head-bill measurements. Perhaps unexpectedly, there were only weak correlations between different structural measures (Table 3.5). This slight variability fits with how variable the morphometric sizes are overall within the Kereru sample.

As in other morphometric studies of Kereru (Gill, 2006; Mander, et al., 1998; Pierce, 1993; Pierce & Graham, 1995) there are no structural measurements that can accurately determine sex of Kereru. Because of this there is a need for continued investigation into other means of sexing Kereru which do not require intervention by a vet (e.g. taking of blood samples). This would mean investigating and developing techniques that use visual aids to determine sexes, or we need to accept that morphometric sexing of Kereru is impossible!

3.4.2 Body condition

As expected there is a positive relationship between fat score and general body condition, as increasing body condition reflects increasing muscle and fat content. Fat stores also tended to be high leading into autumn/winter (Figure 3.2a). This presumably relates to the quantity and quality of food resources available during mid to late Summer and preparation for the onset of colder months (Baker, 1999). Lower fat scores were present leading out of the winter months to spring. Fat stores apparently become depleted due to reduction of high-energy and high-quality food availability, and increased energy expenditure for metabolism to keep warm (Clout, et al., 1986). There is a strong indication that birds do not begin to assimilate fat stores until late summer (Jan – Feb) because during mid spring (Oct – Nov) to early summer (Dec) there were no birds with any fat stores.

Body condition varied greatly between individuals (see e.g. Aug – Nov, Figure 3.2b). Because of this variation, Kereru condition cannot be predicted directly from the time of year. Even these body condition scores cannot be assumed to be the condition of the birds at impact, as the elapsed time between impact and subsequent collection is unknown for 80% of the specimens. Some birds had evidently been in rehabilitation, judging by the presence of peas and corn in the digestive tract, but the extent of deterioration of condition during the (failed) rehabilitation attempts is unknown. Overall body condition and fat stores can also be affected by ill health. Part of the variation between individuals may reflect sickness or the inability to assimilate enough stores for winter months. This inability to assimilate fat stores may be related to parasite infestation (internal/external), onset of disease or genetic factors that enable the bird to acquire assimilates.

3.4.3 Internal organ masses

No caeca were found in all fifty Kereru sampled during necropsy; for such a large herbivorous bird the absence of caeca is surprising, as they play an important role in the breakdown of cellulose in other herbivores (Clench & Mathias, 1995). Other pigeon species have been found to lack caeca as well (Clench & Mathias, 1995), suggesting that there has been loss of caeca in the pigeon group early in their evolution. One explanation for this could be related to their ability to produce crop milk. Cellulolytic bacteria have been isolated from the crops of Rock pigeons (*Columba livia*) (Shetty et al., 1990), so digestion of dietary fibre apparently begins before the start of the true gastrointestinal tract in this species. Production of crop milk would not be possible if digestion only occurred further down the digestive tract. This explanation would suggest that the loss of caeca was enabled by pigeons digesting their food differently to other birds. Vispo *et al* (1997) question whether the presence of cellulolytic bacteria in the caecum is actually an artefact of cellulose digestion, as microbial fermentation of uric acid yields the same results for cellulose digestion and can be traced in the caeca. High rates of cellulose breakdown within the caeca are seen clearly in those birds that are retained in captivity and are fed an 'unnatural' fibre diet as opposed to wild individuals (Duke et al., 1984). Therefore, whether caeca are essentially important for cellulose breakdown in birds that retain them is still unknown.

Kereru intestines ranged from 52-112cm long in this study, with an average of 79cm. This is not especially long for a bird of its size. Comparison with eight grouse or ptarmigan species from Moss (1983) shows that despite lacking caeca, Kereru have proportionately shorter guts than herbivorous galliformes (Figure 3.5). This difference is probably even larger than shown, as Moss's data did not include the large intestine, where as my sample of Kereru guts did (due to the unclear distinction between large and small intestine, which is normally identified by the point at which the caeca arise).

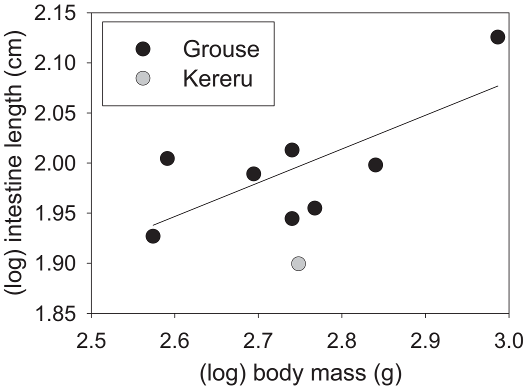

Figure 3.5 Relationship between intestine length and body mass, comparing eight grouse or ptarmigan species (Moss, 1983) and an average Kereru (this study).

If caeca are important in digestion, then Kereru ought to have some compensation for their lack, such as a larger or longer intestine or a longer retention time. During dissections, we noted that some intestines were finger-thick, and packed full of plant matter along their entire length. Thus, it seems that Kereru may compensate for a lack of caeca not by having a large gut but by retaining their food for a long time (passage time of Kereru guts has been estimated at ~16 h (McEwen, 1978)). Kereru may also differ from grouse in that they are also frugivores not just herbivores, and gut length has been found to reflect diet (Battley & Piersma, 2005; Leopold, 1953). The thickness of the gut wall was surprisingly thin in the Kereru (pers. obs.); whether this is an artefact of possible stretching during examination or the actual thickness is unclear.

All organ masses had a large range of size and the entire gastrointestinal tract only accounted for seven percent of Kereru body mass (Table 3.3). All organs, investigated here had a positive relationship with Kereru mass (Figure 3.6), and only the gizzard had a relationship with tarsus length when assessed as an individual predictor. Tarsus length alone in relation to the gizzard is the best predictor to explain organ mass variation (Table 3.7). In the case of the liver a multiple-linear analysis with mass and tarsus length best explains the variation. There is no difference in the length of intestines with respect to sex. There are highly significant relationships when mass and tarsus are used as individual predictors for intestinal length, although a combination of these two predictors enables a greater assessment of intestinal length variation. The mass of organs and the contents that they contain, especially the crop, gizzard and intestines, can directly affect flight performance based on mass to wing area ratio. This is because the wing loading varies with the mass of the bird. Kereru can contain large amounts of food in their guts (up to 80g). The effect that a large daily food change has on Kereru flight may be minimal due to their large wing area. It has been found that those birds that pursue their prey (e.g. harriers) have shorter guts than searching species such as the Kereru (Hilton et al., 1999). This may explain why Kereru have a shorter gut and long food retention times compared to grouse (Moss, 1983) (Figure 3.5) Correlations of organs suggest size and function dynamics (Table 3.8, Figure 3.3).

Organs in the digestive tract are known to respond differently to changes in diet and energy intake (Battley & Piersma, 2005), and over quite short durations. So some of the variation we found between organs and individuals could relate to diet differences (e.g. fruit versus vegetation at different times of the year and at different places). Overall, it seems that gizzard scales at least partly with body size in a way that liver and intestine do not, and it is arguably the least variable over the year (Table 3.9). Dietary changes due to seasonal variation of food supply has been found to alter the size and function of the gizzard in frugivorous birds, such as found in the Phainopepla (*Phainopepla nitens*) (Walsberg & Thompson, 1990). The size and shape of the gizzard indicates the need for strength and durability to process/grind large, tough fruits and seeds such as the Karaka fruit/seed. Fibre content of food can influence the size of the gizzard (Kehoe et al., 1988; Miller, 1975; Starck, 1999). However, in Kereru there was no increase in gizzard mass at the time of year (Table 3.11). We suggest that the workload of the gizzard may not differ much over time (grinding vegetation, defleshing large fruits), and intestine and liver sizes may reflect energy extraction and transfer more. The intestine represents digestion and the efficiency of digestion should vary with the size and length of this organ. It was noted during necropsy that the intestinal wall was very thin, especially in birds that had lots of food present, possibly as an aid to reduce energy requirements for absorption of nutrients. The liver (as has been found in other studies (Ankney & Afton, 1988; Drobney, 1984)), increased in size prior to and during the egg laying season. At this time of year sexual differences are generally found as the female's liver increases in size in order to maintain increased requirements for energy; this was not the case for Kereru. Seasonal variation in body mass is closely related to the time of year in relation to availability and quality of food resources. Though rather variable between individuals, it seems that seasonal changes of Kereru organ masses are related to their function and adjust to dietary and physiological requirements and that the relationship between organ and body mass is in proportion to that seen in other birds (Battley & Piersma, 2005).

3.4.4 Crop contents

There were no sexual or age related differences in the amount of food consumed, held or in the variety of material found in the organs (crop, gizzard and intestine), indicating that there are no behavioural traits that require the sexes or different age groups of Kereru to consume different materials as in the case of the Huia (*Heteralocha acutirostris*) (Frith, 1997; Jamieson & Spencer, 1996). This observation fits with not being any differences in morphometrics between the sexes.

The organic materials encountered most frequently were fruit and vegetables (Table 3.10) which indicates that the Kereru had been in care of rehabilitators prior to death (Devenshire, 1980). Native foliage was the most abundant food collected naturally by the birds throughout the year (Table 3.11) (Baker, 1999; Clout & Hay, 1989;

McEwen, 1978). August was the month where most birds were presenting with fruit and vegetables, indicating that more birds are possibly taken to rehabilitators at this time of year. With the exception of readily available fruit and vegetables, crop contents consisting of native fruits (Puriri, Karaka, Tawa) weighed the most (Appendix 4) (Clout & Hay, 1989; Wotton & Ladley, 2008). This is due to the sheer mass of the fruits compared to leaf material. In two incidences crops were packed tightly with Kowhai leaves or flowers (38.50g and 30.58g respectively). Kowhai and Tree lucerne appear to be the most preferred native foliage in this study. No contents showed combinations of foliage, suggesting that birds focus on one plant at a time until digested.

Few birds were found to have crop contents from October to February, which may be related to a bias in sample size, with fewer birds in those months (Table 3.11). However, the same was found in a study conducted by (McEwen, 1978), who related the bias to fewer birds being poached due to their smaller mass during these months. These are both unrelated studies so perhaps there is some significance in the absence of large quantities of crop material during these months, relating directly to the availability of foliage at this time. Type of foliage found in the crop contents relates closely to the type of foliage that is available at that time of year, for example flowers are consumed in Spring when plants are actively reproducing in abundance; fruits in Summer when they are ripening and leaves during the Autumn and Winter months.

Consumed food constituted 0.12% to 13.4% of the total mass of Kereru (Appendix 5). This alters the actual mass of Kereru substantially and this would vary throughout the year due to energy requirements, availability of food and food retention time (~16 h). The extent of food that was found in these birds could be used as an indicator for wildlife rehabilitators as to the amount of food that needs to be supplied daily and the type of variety that they require throughout the year.

3.5 Conclusion

The morphometric analysis confirmed the lack of substantial sex-related size differences in Kereru. It seems unlikely that there will be a reliable non-invasive way of sexing Kereru. Therefore, until further studies are conducted on identifying and developing means to determine Kereru sex, Kereru will always need to be handled in order to assign sex.

Birds tended to be fatter with better body condition in late summer moving into winter than those in late winter leading into spring. These trends assume that most birds are assimilating fat stores in preparation for winter when food availability and quality is at its greatest. A factor that would have an effect on these categories is the time elapsed between impact, collection by the public to delivery of the bird to rehabilitators. Because of these confounding factors predictions as to the health of the bird prior to impact cannot be developed.

Assessment of internal organs shows that there is no difference in mass between sexes and in the amount of food consumed, again confirming limited dimorphism in Kereru. Kereru do not have caeca and compensation for this is not in the form of lengthening the gut, but potentially in the retention time of food. The actual mass of Kereru can vary greatly not only in relation to age (adult and juvenile) but also in the amount of water that is retained in organs, foodstuffs and also in the actual amount of consumed food. Apparently body mass of Kereru can potentially be 80 or more grams greater than the bird’s ‘true’ body mass without food. This can potentially have consequences on techniques such as the attachment of transmitters which are meant to be less than equal to 10% of a birds’ mass. Organ (liver, gizzard and intestine) and body mass showed weak seasonal variations, which may reflect dietary and physiological requirements.

From the assessment of 50 Kereru (adult and juvenile) 64% contained some type of organic material in their crops, of this material native foliage and fruits predominated. Due to the presence of other fruits and vegetables (stewed apple, peas/corn and carrot) this indicates that many Kereru were in captivity at the time of death due to complications of impact. This indicates that even with intensive care and rehabilitation a large number of Kereru still die. On average crop content weighed 15g, however, this does not adequately describe how full the crop is as 15g could represent three Karaka fruits or a large handful of Kowhai leaves and flowers. The type of crop content present at particular times of the year is closely determined by the season: fruit (Tawa, Puriri and Karaka) predominates in summer, foliage (Kowhai, Tree lucerne) – in autumn and winter, then flowers (Kowhai and Tree lucerne) in spring. These results show that Kereru consume a variety of foodstuffs, preferring native foliage where available and the type of food consumed is related to the time of year and therefore availability.

Chapter Four - Flight feather moult of New Zealand’s endemic pigeon, the Kereru (*Hemiphaga novaeseelandiae*).

4.0 Abstract

Limited information has been documented on the moult of Kereru (*Hemiphaga novaeseelandiae*), a New Zealand endemic pigeon. Study of 169 Kereru moult records found that Kereru moult over a nine month period (July – March/April), with a restricted moult of tail feathers during the breeding season. Kereru moult is symmetrical in relation to the number of primary feathers moulted, but not in respect to the position on the wing. Kereru often have multiple moult loci and do not follow a conventional moult sequence. This moult strategy reduces the effect that feather gaps have on wing area and thus wing loading. The method of moult seen in Kereru is a solution that works to minimise the change in wing area, but this is at the cost of having a prolonged moult (≥ nine months).

4.1 Introduction

Moult is a critical means of replacing juvenile plumage or old, damaged feathers and by seasonally gaining a new compliment of quality feathers. Juveniles will moult just prior to fledging to gain a full adult plumage and adult moult usually occurs prior to or after the breeding season and in preparation for migration (Battley et al., 2006). Birds will seasonally moult body plumage, wing and tail feathers with the majority of birds having ten primary and secondary flight feathers and twelve tail feathers. Primary feather moult is generally conventional in that the feathers will moult from inner to outer feather tract. Moult generally occurs at least once in a twelve month period and most importantly it is governed by energy expenditure. With not enough food resources moult can be delayed, and moult generally suspends or ceases (Pulido & Coppack, 2004) with the on-set of winter or with progression into the breeding season (Boddy, 1981; Guillemette et al., 2007). European starlings (*Sturnus vulgaris)* have been found to use 32% more energy over a 12hr period during moult than non-moult (Cyr et al., 2008). Most adults moult their feathers in a symmetrical fashion to ensure flight ability is not impaired (Bridge, 2003); some will moult all feathers at once making them temporally flightless (e.g.: waterfowl, (Weller, 1980)), others one feather at a time (e.g. parrots (Forshaw & Cooper, 1989)).

In pigeons, primary feather moult generally starts from the innermost primary and progresses outwards, however, there can be several moult loci active at the same time. In European woodpigeons (*Columba palumbus*) this occurred in approximately 10 – 15% of pigeons (Boddy, 1981). The time period for complete primary moult in mourning doves (*Zenaida macroura*) is 140 -150 days (Sadler et al., 1970), and there is no difference in the time to complete moult between male and female mourning doves (Haas & Amend, 1976). This progression of moult has also been determined in the annual routines of non-migratory birds conducted by Barta *et al* (2006). Barta *et al*. (2006) modelled the moult progress of temperate birds and found inner primaries should be moulted prior to outer ones based on energetic costs. These costs are related to environmental factors such as season and food availability. The outer primaries have the greatest effect on flight, by altering the aerodynamics of the wing; this is why they are moulted last. When moult is conducted late in the season, the quality of feathers is reduced. This is due to the quick succession of feather loss and little time available to produce quality feathers late in the season (Barta, et al., 2006). Late moult also comes at a potential cost of reproduction and survival (Hinsley et al., 2003; Wiggins et al., 1998).

The speed at which feathers are moulted and subsequently developed depends on the availability of resources and time of year. Moult is governed by day length and it has been found that with decreasing light hours new feathers are shorter, have a narrower rachis and are less rigid (Dawson et al., 2000). Decreased feather quality has an effect on flight ability, directly increases metabolism and because of this may reduce the bird's ability to effectively escape predators (Barta, et al., 2006). The process of moult reduces the effect that worn feathers have on flight ability, however, in doing so moult temporally has the same effect as worn feathers due to the formation of gaps in the wing. Gap formation reduces wing aerodynamics by allowing air to pass through instead of over and under, reducing the uplift that can be gained by having an appendage that acts like an aerofoil (Warrick & Dial, 1998). Therefore, acceleration and manoeuvrability are reduced because of the inability of the remaining feathers to act in the same way as a fully feathered wing. It is because of these direct effects of moulting that birds have tradeoffs in relation to timing of reproduction, migration, body mass and flight (Hinsley, et al., 2003; Senar et al., 2002). Some birds become fully grounded during moult, some will acquire breeding plumage prior to breeding and others so that flight is not impaired during long distance flights (e.g.: Bar-tailed godwits; *Limosa lapponica*).

Kereru like most birds have ten primary and secondary wing feathers, and the tail consists of twelve. The total length of moult stages is unknown. A study based on 115 museum specimen of Kereru concluded that they have a slow continuous moult with frequent pauses, with no distinct moulting season (Higgins & Davies, 1996). Primary feathers tended to moult from the inner wing, out, usually only one feather at a time. Sometimes there could be two waves of moult along the primaries and tail feathers showed a pattern of moulting outwards (Higgins & Davies, 1996). Head and body plumage appeared to be replaced continuously. There is also no known information about the relative wing area during moult and how this affects flight performance. Kereru are not the only species of bird with little known information in this field; Hedenstrom (1998) reports that wing areas of birds are rarely reported and wing areas during moult are virtually non-existent in the literature. There is also little information available on Kereru moult and how this affects flight performance (R. Powlesland, per comm.). In this study we aim to assess Kereru flight feather moult and in more detail how primary moult affects wing area and loading and finally suggest predictions of how this may affect flight performance.

4.2 Materials and methods

Forty five Kereru specimens were collected from lower North Island Department of Conservation (DoC) offices (Wellington, Kapiti, Palmerston North, Wairarapa, New Plymouth, Hawkes Bay/Napier and Opotiki). A further 116 Kereru moult surveys were contributed by R. Powlesland from DoC Wellington (samples came from Southland, Stewart Island, Picton, Palmerston North, Wairarapa, New Plymouth and Kapiti[4]). All specimens were analyzed to assess their stage of moult, in relation to season and breeding status. Moult criteria for this study followed the moult recording techniques that are set out by the Ornithological Society of New Zealand (OSNZ). This involved recording whether there was moult of the wings (primary and secondary feathers), tail, and what developmental stage the feather is at (ranked on a scale from 0-5, Table 4.1).

Table 4.1 Classification for bird moult score, ranging from 0 (old feather) – 5 (fully developed new feather).

Score	Moult criteria
0	Old feather
1	Feather missing, or new feather completely in pin
2	New feather just emerging from sheath and up to 1/3 grown
3	New feather between 1/3 and 2/3 grown
4	New feather more than 2/3 grown, with remains of waxy sheath at the base
5	New feather fully developed with no trace of waxy sheath

Both primaries and secondaries were scored from the junction of those tracts: primaries were numbered outwards, secondaries inwards. Tail feathers were scored from the centre outwards. Moult scores were calculated by summing the stage of moult for each feather within the feather tract (e.g.: primary sequence 5555320000, moult score 25). Age, sex and reproductive status were determined at time of necropsy; samples include adults and juveniles. If it was possible that feathers missing were due to injury rather than moult, these were not included in the analysis. To assess the impact that different moult sequences or strategies would have on Kereru, we first estimated wing area and loading. Following Pennycuick's (1999)

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[4] Acknowledgement of Les Moran, Kirsty Moran & Ralph Powlesland, Research & Development Group, Department of Conservation for use of their Kereru survey data.

“Measuring birds’ wings” we determined moult and made wing tracings, for five specimens. Then using a scanned image of a reference tracing we analysed wing area using ImageJ software. Individual feather areas were analysed by measuring the overlap of feathers and the portion of the actual feather that would have an effect on wing area if missing for both Kereru and Bar-tailed Godwits (Figure 4.1). Conventional moult sequences were taken from Bar-tailed godwit data supplied by P. Battley (Massey University) in order to assess how Kereru wing area and loading would be affected if moulted conventionally. All sequences taken from Kereru were sorted in Excel to determine moult patterns and to assess if Kereru moult is symmetrical.

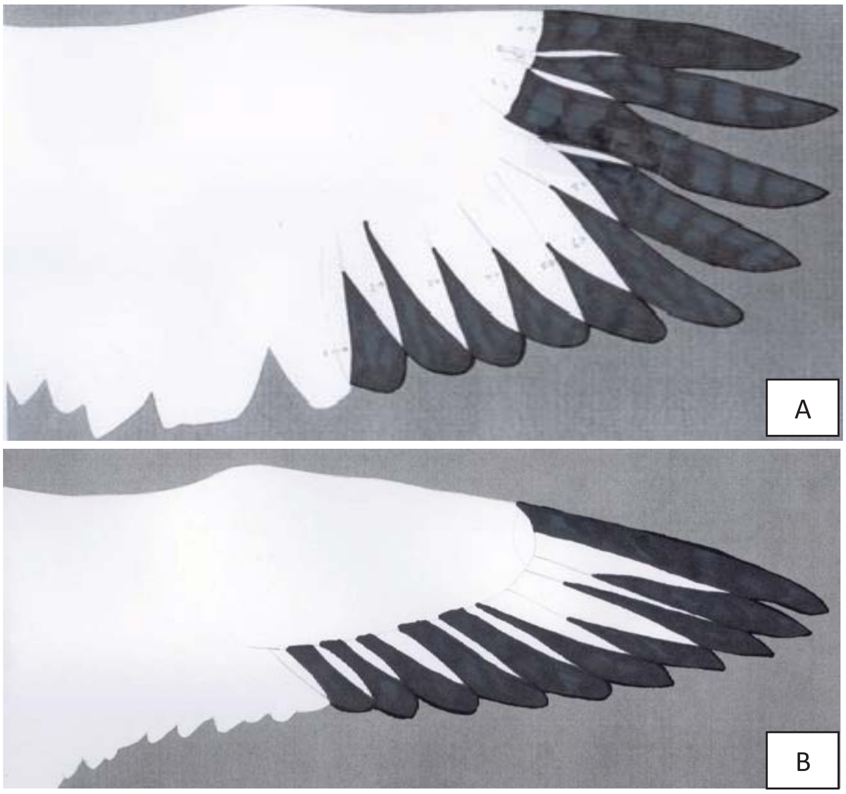

Figure 4.1 Tracing of a Kereru (A) and Bar-tailed godwit (B) wing showing the spread, shape and size of primary feathers. Black shading - area of primary feather excluding overlap. Average biometrics of (A) mass 570.4g, wingspan 81.2cm, semispan 34.7cm, width 15.6cm, wing area 485cm^2, wing loading 0.49g/cm^2; (B) mass 434g, wingspan 68.8cm, semispan 30.3cm, width 9.9cm, wing area 231cm^2, wing loading 0.41g/cm^2.

Graphs were produced with the use of SigmaPlot 11 software and statistics (linear regressions and basic statistics) were analysed using Minitab 15, to investigate if there were any significant relationships between groups and how varied the sample may be.

4.3 Results

4.3.1 Seasonality and overlap

Primary moult was recorded from July – May, secondary July – May and tail throughout the year (Table 4.2). There was a complete overlap of tracts timewise; there was a general drop-off in winter, but active moult was 11 – 12 months for all. The data show that Kereru have a slow and long moult that progresses substantially over a nine month period (July – March/April), however, there is some limited moult occurring during winter suggesting that there is no defined moult season. It appears that Kereru moult and breed simultaneously, as reproductive months are between September – April and moult records show moult at this time (Table 4.2).

Table 4.2 Seasonal occurrence of flight feather moult in Kereru (n = 74), values represent percent of total birds checked that were moulting each tract. Number of females reproductive during moult (♀) (n=7/12).

						Month						
Feather tract	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Primary	5	12(♀)	4(♀)	5	1	0	4	4(♀)	4(♀)	3	4(♀)	5
Secondary	4	8(♀)	4(♀)	1	1	0	3	4(♀)	4(♀♀)	1	4(♀)	1
Tail	5	9(♀)	3	3	1	1	5	5	3(♀)	1	3	8
Breeding[5]	▨	▨	▨	▨					▨	▨	▨	▨

Table 4.3 Feather tract in moult and associated combinations: 1^0 = primary, 2^0 = secondary, T = tail.

Feather combination	Number of birds
1^0 only	17
1^0 & 2^0	7
2^0 only	6
1^0 & T	11
1^0, 2^0 & T	12
2^0 & T	5
T only	16
Total	74

At the individual level, there was substantial variation in which flight feather tracts were moulting simultaneously (Table 3). Primaries and tail only appeared most

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[5] Kereru breeding season taken from literature Bell (1980); Clout (1995)and Mander (1998).

frequently indicating that these feather tracts are regularly moulted separate to other combinations. Combinations that occur frequently are primaries and tail or primaries, secondaries and tail (Table 4.3). Secondaries were in moult less frequently in this sample than were primaries and tail.

4.3.2 Symmetry of moult and sequences

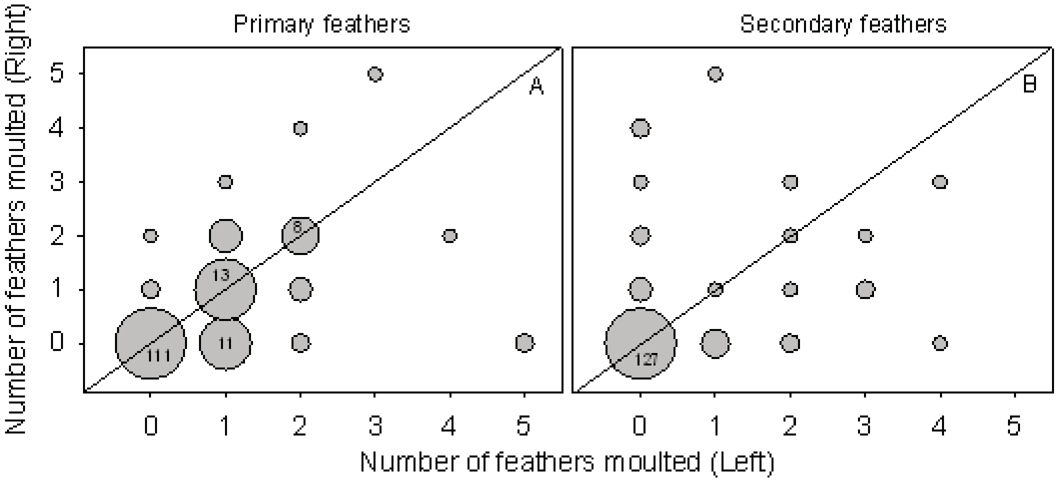

Figure 4.2 Symmetry of wing moult. Number of feathers moulting in each wing for A) Primaries and B) Secondaries. Straight line represents a 1:1 ratio. Both relationships were significant. A) Linear regression $F_{1,155}$ = 72.5, P = 0.001; B) Linear regression $F_{1,\ 152}$ = 21.8, P = 0.001. Size of symbol represents the number of Kereru with that combination of feather moult; symbols without numbers have fewer than five individuals.

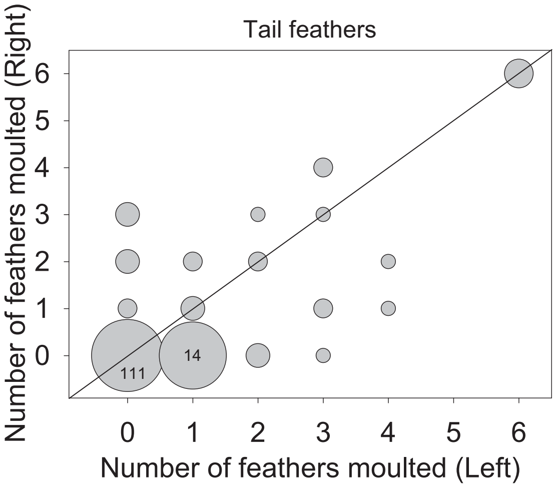

Figure 4.3 Symmetry of tail moult. Straight line represents a 1:1 ratio. Linear regression $F_{1,153}$ = 240.7, P = 0.001. Size of symbol represents the number of Kereru with that combination of feather moult; symbols without numbers have fewer than five individuals.

Overall, there was a strong relationship between the numbers of feathers moulted on each wing for both primaries and secondaries (Figure 4.2a, b), but variation was high (r^2 = 0.126 and r^2 = 0.320 respectively) reflecting the presence of asymmetry. Tail moult (Figure 4.3) showed less variation (r^2 = 0.613).

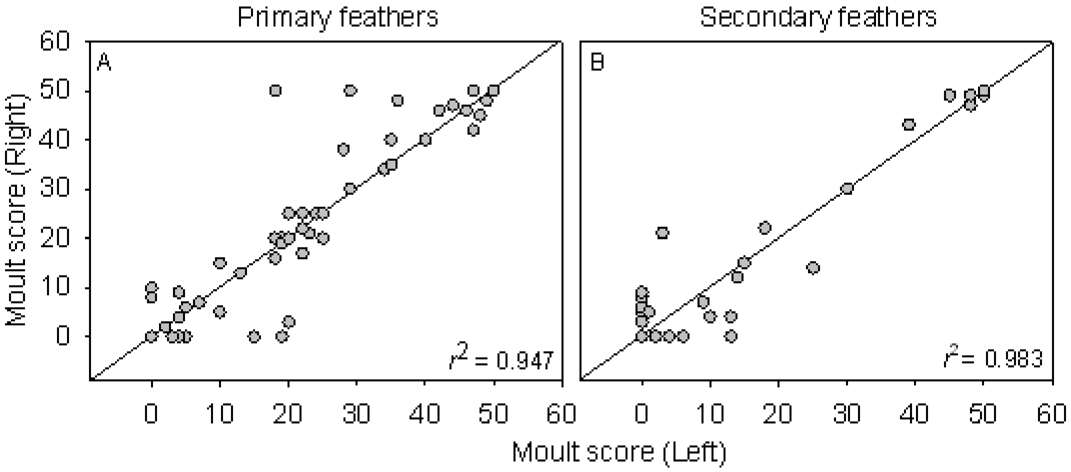

Figure 4.4 Relationship between left and right moult score of flight feathers. A) Primaries $F_{1,129}$ = 2297.703, P = 0.001, r^2 = 0.947. B) Secondaries $F_{1,131}$ = 7504.881, P = 0.001, r^2 = 0.983.

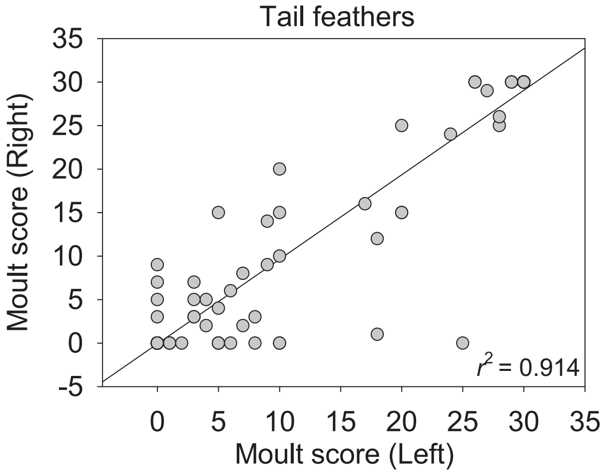

Figure 4.5 Relationship between left and right moult score of tail feathers, $F_{1,132}$ = 1404.192, P = 0.001, r^2 = 0.914.

For birds in active moult there was a highly significant (P= 0.001) relationship between moult scores of the left and right primaries, secondaries (Figure 4.4a, b) and tail feathers (Figure 4.5). However, few birds had symmetrical moult sequences per se and there were substantially more asymmetrical moults than conventional symmetrical moults in the data (symmetrical moults in 12/44 primary moults, 1/29 secondary and 4/43 tail moult). This was probably due to the frequent occurrence of multiple moult loci (Table 4.4).

Table 4.4 Number of birds with active moult loci in relation to region of wing (1^0 = primary, 2^0 = secondary) and T = tail. N = 76.

	Primary			Secondary			Tail		
# of Moult Loci	Left	Right	Subtotal	Left	Right	Subtotal	Left	Right	Subtotal
1	33	22	55	12	13	25	25	18	43
2	10	8	18	4	7	11	11	7	18
3	0	2	2	3	2	5	1	2	3
4	0	1	1	0	0	0	0	0	0
Total	43	33	76	19	22	41	37	27	64

Total number of moult loci across the wing and tail feathers is asymmetrical, indicating that each wing does not follow a set moult pattern (Table 4.4). Sixty eight percent of all moult loci consisted of one leading site with progressive moult thereafter. Twenty five percent of all moult loci were present in February; 50% of these consist of one moult loci (Appendix 6). Even with the single locus moults few followed a conventional progression (moult starting at the innermost feather and progression outwards in sequence; Table 4.5). Up to four moult loci were present in primaries and three in secondaries and tail. Of the 75 birds in active moult, across all regions investigated (primary – left & right, secondary – left & right and tail – left & right = 450 feather tracts,) only nine percent of these followed a conventional moult (Table 4.5). From all 161 Kereru studied only five percent showed a potential conventional moult. In relation to solely primary moult only eight percent of all birds followed a conventional moult. Table 4.5 shows how diverse Kereru moult is and how infrequently Kereru follow a conventional moult. There are potentially greater than 170 sequences (224 sequences found in this sample), involving potential conventional and non-conventional moult that could be seen when assessing Kereru in relation to primary, secondary and tail moult (greater number of sequences to number of birds due to asymmetry across wings). These moults are stated as 'potential' because it was not sure that blocks of feathers were necessarily moulted in that way. Only 24 sequences followed a potential conventional moult, and of these only 10 occurred more than once.

Table 4.5 Moult sequences of wing and tail feathers. Data represent 74 birds and sequences for both sides of the body are combined. Frequencies are one unless numbered otherwise. Sequences in grey are ones that are potentially 'conventional'.

Primary	Freq	Primary cont.	Freq	Secondary	Freq	Tail	Freq	Tail cont.	Freq
00000000		554000000		00000000		00000	3	500040	
00000000		555300000	2	00000011		00001		504000	
00000005		555400000	3	00000011	2	00001		511155	
00000011	2	555400000	3	00002000		00003		535555	
00000300		555400004		00002000		00005	2	540540	
00004000	2	555455555		00004000		00010		545555	
00004444		555500000	2	00004040		00011		553553	
00004555		555540000		00010011		00030		553555	
04001040		555541000		00022220		00050		555155	
04105455		555550000	2	00044400		00050		555333	
04555000	2	555552255		00200300		00111		555444	
05000050		555553000		00400000		00300		555545	2
05555555		555554000		00500000		00333		555553	
10000000		555555000	2	01000000	2	00400		555554	
10455555	2	555555155		01022011		00444			
11111000		555555255		01431000		00511	2		
15155555	2	555555400	2	03000000		00544			
15155555		555555455		04004040		00555			
15555400		555555515		10111122		01110	2		
15555540		555555522		11000000		03300			
15555555	4	555555530	2	11111000	2	03400			
20000000	2	555555554		11111111		04031			
22555555				11155000	2	05005			
30000000				30300000		05050			
35555555				40000000	3	10000			
40000000				40004303		10100	2		
40402303				40020000		10101			
41555555				45545555	2	11000			
50000005				50500000		11111	5		
50000555	2			51555000		11444			
50541030				53555555		12221			
51550050				55002000		15515			
52000000	2			55435555		20000			
54444555	2			55500000	2	30000	3		
54555555	2			55500505		30400	2		
55420000				55545545		34020			
55450000	2			55554555		35553			
55500000				55555055		40000	2		
55500000				55555455		40002			
55500000				55555515		40400			
55505000				55555533		40404			
55522005				55555545		40420			
55005500				55555555		44444	3		
55300000	3			55555555		50000	3		

Table 4.6 Frequency of adjacent primary feathers being in moult. Data represent 74 Kereru. Number of adjacent feathers in moult relates only to those birds that were moulting more than one feather. '1' means that the moulting feather was adjacent to a newly moulted feather.

Number of feathers moulting	Frequency	Number of adjacent feathers moulting*	Frequency
1	43	1	19
2	27	2	12
3	2	3	0
4	5	4	4
5	3	5	2
Total	80	Total	37

* One feather moulted and one or more feathers adjacent to it are moulting at the same time.

Kereru tended to only moult one or two feathers concurrently on a single wing, so adjacent feathers were rarely in moult simultaneously (Table 4.6). This reduced the occurrence of large gap formation. More than 80% of these birds were only moulting one or two feathers, and of those birds that had the potential to moult adjacent feathers only 49% did this. As a consequence of moulting few feathers simultaneously and having multiple moult loci, only a small minority of moult sequences were adjacent feathers or sets of feathers growing at the same time (Table 4.6).

4.3.3 Impacts of primary moult on wing parameters (wing area and wing loading)

In order to evaluate how wing areas (and consequently wing loading) change with moult, we estimated the changes in wing area that would occur in the observed Kereru moult sequences, and compared that with the change in area that would occur if Kereru followed a more conventional wing moult sequence. For the latter, we based the moult sequences on those of Bar-tailed godwits, a medium-large shorebird (See Appendix 7 for godwit sequences used).

The lowest wing area (and hence highest wing loading) in Kereru were predicted under a conventional moult to occur at moult scores of ~5 – 10 (Figure 4.6a, b). This represents the loss of multiple inner primary feathers having the greatest bearing on wing area as these feathers have the greatest overlap between neighbours. In contrast, no such systematic drop was evident in the actual Kereru moults. The greatest reduction for wing area for Kereru occurred at moult scores of 27 and 37, however even with these reductions in wing area, wing loading is not greatly affected, only increasing by 2.2% and 1.9% respectively. Moult scores of less than 10 still reduce wing area and loading as in a conventional moult but not as considerably (reduced by 1.3%) (Figure 4.6a, b). The comparison of a conventional moult, from Bar-tailed godwits, to that of a Kereru in relation to moult score varies substantially in respect to the position of feather in moult that gives particular moults score (Appendix 7). godwit moult sequence may overestimate the change in wing area as their inner primaries are smaller so Kereru might never moult in that fashion. The average wing loading of an adult Kereru weighing approximately 570.4g, wing area 1150cm^2, with a full array of flight feathers, is 0.5g/cm^2. Because of the different shapes of Kereru and godwit wings, the patterns of change are different in godwits such that its conventional moult resulted in only a similar amount of change to that shown by Kereru, despite the simultaneous moult of several feathers.

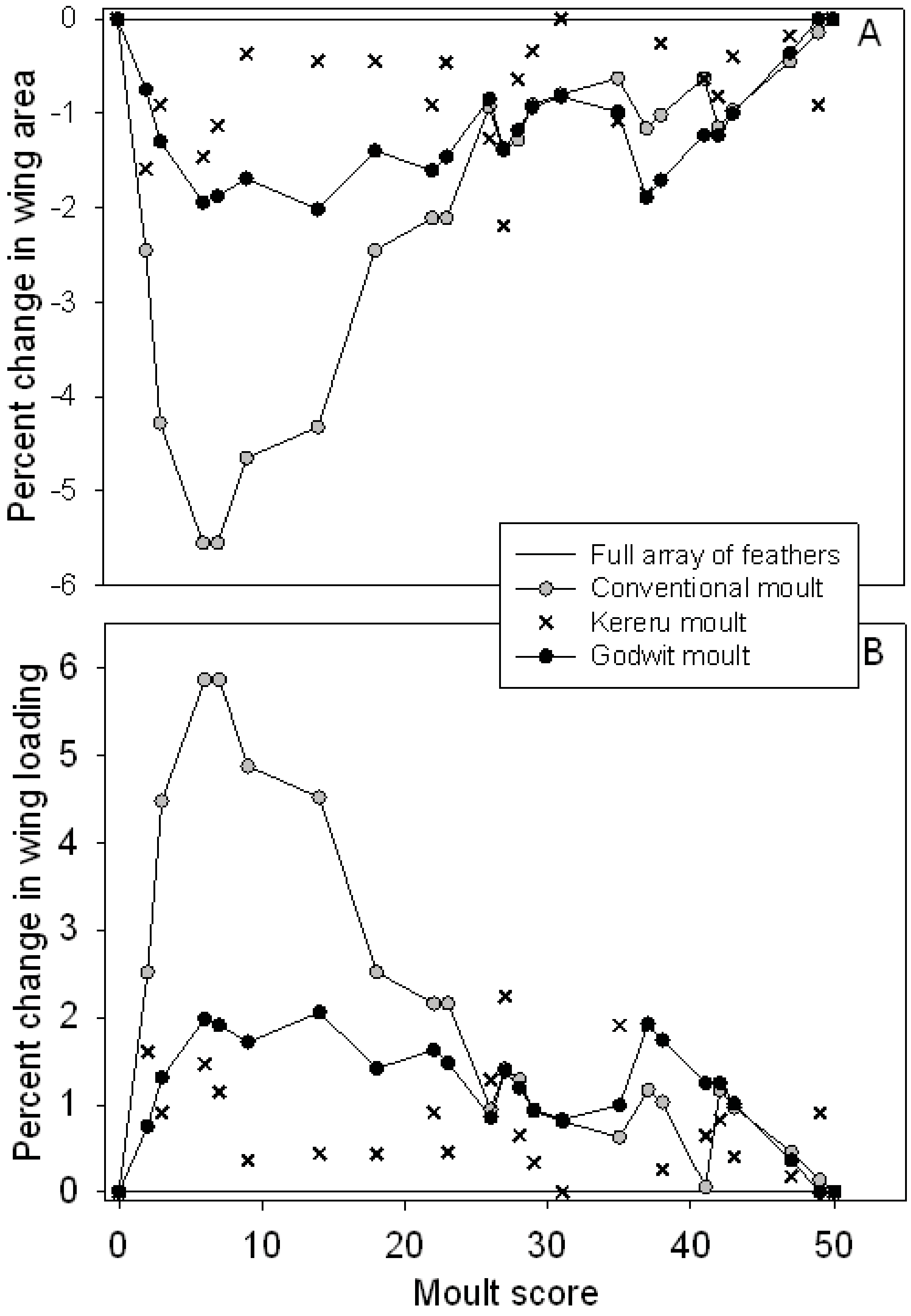

Figure 4.6 Relative percent change of wing area and loading in comparison with a full array of feathers; conventional primary moult derived from moult scores of Bar-tailed Godwits, incorporating feather area figures from Kereru (based on wing area of 1150cm^2 and body mass of 570.4g), and assessment of actual Kereru and godwit moult (based on wing area 1069cm^2 and body mass of 434g). A) Change in wing area. B) Change in wing loading.

4.4 Discussion

4.4.1 Seasonality and overlap

From a population sample of 161 Kereru 74 were in active moult; 57% of moulting birds were female suggesting that there is no sex major bias in the sample. Table 4.2 shows that Kereru flight feather moult can occur over a twelve month period with a period of halted/reduced moult during the winter months, indicating that the Kereru moult cycle may take approximately nine months to complete. Generally full body moult should occur after breeding, but due to their prolonged moult this biological event does not occur. The substantial moult of feathers during spring and summer relates to the presence of ample food supplies (Baker, 1999; McEwen, 1978), therefore, moult occurs when energy expenditure of moulting can be balanced with adequate energy gain. It appears that Kereru are able to simultaneously moult (July – March/April) and breed (September – April), this is potentially possible due to an abundance of food during the spring and summer months (Table 4.2). Forgoing the moult of, in particular wing feathers, during breeding eliminates extensive energy loss when net energy output could solely go into producing young. Kereru possibly avoid this complication by having a prolonged and slow individual feather moult. Many birds will moult prior to the breeding season to acquire best quality feathers in order to attract the highest quality mate (Dawson, et al., 2000). Kereru may not do this due to their continual slow moult.

Gill (2006) studied primary moult in 66 Kereru received by the Auckland Museum between the years of 1985 – 2000. Tail and wing moult occurred between October and May, with no moult of these tracts in June – September suggesting no moult in winter. This is similar to what was found in my study, however, a small sample did moult during this period (Table 4.2). The bulk of primary moult in Gill's study was in the March – May period, again similar to this study, although, our period begins in February, indicating the onset of post-breeding. There appears from this data that there is no definite moult season and that Kereru are able to moult and breed simultaneously because of this slow continual moult. It may be because of this form of moult that they are able to balance energy loss through moult and breeding to such a degree that both activities are not compromised.

It appears that tail and primary feathers are often moulted separately to other body regions, however, simultaneous body moult (includes primary, secondary and tail) also occurs suggesting that Kereru have a varied moult pattern in relation to the region in moult at any one time (Table 4.3). This may be governed by energy expenditure of breeding while moulting or in relation to the health, immune activity, age or reproductive status of the individual. Martin (2005) demonstrated that in house sparrows (*Passer domesticus*), those birds that were growing more feathers were unable to mount the same level of immune defence as to those birds that were not injected with phytohemaglutinin which causes an immune response. The same was found in pied flycatchers and the females who were caring for the young delayed the onset of moult compared to males (Moreno et al., 2001). A study by Svensson (1997) has also found that birds moulting while raising young will reduce their parental effort possibly to manage with the energy demands of moult.

4.4.2 Symmetry of moult and sequences

While bilateral at a basic level (birds moulted left and right sides at the same time) (Figures 4.2a, b & 4.3), Kereru moult was highly variable within individuals and was frequently highly asymmetrical (Figures 4.4a, b & 4.5). This indicates that Kereru potentially do not moult conventionally and certainly do not moult symmetrically. Generally (and especially in small passerines), birds will moult symmetrically in order to reduce the effect that gaps and imbalances in the wing will have on energy expenditure, uplift, wing loading, flight performance and predator avoidance (Hedenstrom, 1998; Hedenstrom & Sunada, 1999; Senar, et al., 2002), however, in the case of Kereru, who have few natural predators today this process of moult would not have the same effect as in smaller birds. The similarity viewed over the wings is related to the number of feathers in moult, yet in the case of Kereru moult score does not follow a conventional moult due to multiple moult loci (Table 4.4). Only 27% of primary moult, three percent of secondary moult and eight percent of tail feather moults were symmetrical (Table 4.3).

The frequency of multiple moult loci indicates that Kereru do not readily follow a conventional moult, however, even those with a single moult locus do not always follow a conventional moult. Primaries, for instance in 33 cases with a single moult locus did not start and progress from inner to outer feather (Table 4.4). This asymmetry may be an evolutionary adaptation to prevent large gaps forming, limiting the affect on flight performance or to allow breeding to occur simultaneously with moult as a means of reducing energy expenditure spreading the moulting energy required for feather production out over a long time. Gill (2006) found that Kereru generally moulted 1 - 2 feathers at a time on the primaries and 1 – 3 on the tail, suggesting that for the primaries this is a means of reducing the potential for large gaps to form; the same result was found in this study (Table 4.6). Twenty-five percent of all moult loci occurred during February (Appendix 6) indicated either the initial onset of moult or the convergence of all moult stages nearing completion.

There is an extra-large percent of Kereru (92%) studied that did not follow a conventional primary moult. Even when assessing the asymmetrical sequences there is no particular sequence/s that frequently appear within this population (Table 4.5), to say that there is an asymmetrical pattern with which the majority of Kereru track. Because there is no recurrent pattern that the majority of Kereru follow, Kereru may then moult in regard to individual health, age, reproductive status, and/or environment.

4.4.3 Impact of primary moult on wing parameters (wing area and loading)

Due to the size and shape of Kereru wings, wing area was most affected by the loss of several adjacent primary feathers as seen if they moulted conventionally (Figure 4.6a and 4.7a); this reduction in wing area is due to there being greater overlap of inner primary feathers compared to outer primaries. However, the removal of outer primaries may affect turning ability more than uplift as reported by Berg (2008) and others (Tobalske & Dial, 1996; Warrick & Dial, 1998) in other species of birds. In theory there would be a U-shaped relationship between relative wing area and primary moult score, with a minimum wing area occurring at intermediate primary moult scores (Hedenstrom, 1998). This was not true for Kereru because the moult scores of Kereru were not conventional. In hawks, where the primaries are used as wing tip slots making the wing non-planar and spreading the vortices both vertically and horizontally the loss of primaries (that serve as wing tip slots) should result in a greater reduction in flight performance than the loss of other flight feathers (Hedenstrom & Sunada, 1999). Kereru use their wing tips in this manner and because of this the effect that this reduction of area has on wing loading is to the extent of 4.9% (Figures 4.6b and 4.7b).

The slow moult of Kereru is unconventional in that generally few neighbouring feathers were moulted simultaneously. The effect of this is that the change in wing area and hence wing loading is small. Predictions of change in wing area if Kereru moulted with the same sequence as Godwits showed that birds would have a drop of 5% in area (and an increase of 6% in wing loading) (Figures 4.6c,d). In contrast, Godwits themselves experienced 2% drop in wing area and 2% increase in wing loading, as their inner primaries are proportionally much smaller than those of Kereru (Figure 4.1). The moult strategy seen in Kereru is a solution that works to minimise the change in wing area, but this is at the cost of having a prolonged moult (≥ nine months). They are able to do this as they are largely sedentary birds that do not have lifestyle time constraints as seen in Godwits for migration.

Removal of feathers either through moult or predation causes gaps to develop in the wing which can and do have an effect on the wing area and wing loading. Variation in these wing parameters can have a bearing on ability of flight and thus predator avoidance. Several studies (Chandler & Mulvihill, 1992; Senar, et al., 2002) have looked at variation of mass in relation to moult to compensate for loss of wing area. It is thought that some birds may intentionally reduce body mass and/or consumption in response to reduction in wing area to avoid increasing wing loading to an extent that it would be energetically costly, thus reducing predation risk due to reduction in flight performance (Lind, 2001; Swaddle & Witter, 1997). The same energy cost is seen for those birds that carry prey items (loaded flight) or that travel long distances (Hambly et al., 2004; Piersma, 1998). Birds that do not reduce body mass in response to increased wing loading are predicted to instead alter flight speed and wing beat frequency (Hambly, et al., 2004; Hedenstrom & Sunada, 1999; Tobalske & Dial, 1996). It is not known whether Kereru moderate their mass or adjust their flight speed and wing beat frequency in response to moult.

The impact that the loss of several feathers has on loading would constitute no more than what an individual meal (~80g – Chapter 2) has when Kereru have food in ample supply. The increase of body mass with consumption would have the same effect as feather loss; therefore, because of these regular changes in food intake Kereru may be adapted to these slight changes during moult. This may be the reason for Kereru being as large as they are so that they do not have to change energy requirements every time they lose a feather or have a sizeable meal.

4.5 Conclusion

The data from this study add to the limited knowledge that ornithologists have about how Kereru moult and whether it follows a conventional and/or symmetrical process. From this sample of 161 birds 74 were in some form of active moult. The absence of a clearly defined moult season in Kereru matches there not being a distinct breeding season. It is possible due to their varied breeding season that moult occurs simultaneously while raising young. The energetic costs of simultaneous activities (breeding and moulting) are presumably balanced by what feathers are moulted at any given time and the availability of food resources. Kereru are possibly able to do these activities simultaneously because of their extended moult (> nine months). The occurrence of 25% of all moult centres occurring during February either indicates that initial onset of moult or the convergence of all moult stages nearing completion.

Kereru do not show an obvious conventional moult, however, some form of moult is seen bilaterally across the wings (92% of those in moult did not show signs of a conventional moult). The absence of a conventional moult, with the presence of a long sustained moult (> nine months) indicates that they do this to reduce the effect that large gaps in the wings would have on flight performance, manoeuvrability (turning radius) and energetic costs. Kereru moult is symmetrical in that both wings will be in some form of moult at any one time; however this is where the symmetry ends, as moult scores and position of feathers in moult are asymmetrical across the wings. In small passerines this lack of symmetry would make them more vulnerable to predation, due to the reduction in manoeuvrability; however, this is not the case for Kereru as they have few current natural predators so quick avoidance from predation is not an issue. The presence of multiple moult loci also indicates the lack of symmetry and suggests that they intentionally do so to reduce moult gaps to reduce this effect. Another reason for having multiple moult loci means that generally no two sequential feathers are in moult at the same time, again reducing the existence of large gaps. It has been found from this study and others that Kereru will normally only moult 1-3 feathers at any one time on the same wing, again a technique to reduce gap formation. Investigation of the asymmetrical moults does not obviously signify a pattern that the majority of Kereru follow. Due to this Kereru may moult in regard to individual health, age, reproductive status, and/or environment.

If moult in this bird is governed by the formation of gaps and loading on the wing then Kereru are adapted to wing area changes due to their extensive wing area in relation to body mass. The loss of a particular feather does not have a substantial impact on the wing area and loading of this bird. Another factor that helps reduce the effect of feather removal, especially on the inner primary feathers, is that these feathers display a lot of overlap; therefore, even with the loss of a feather in this region wing area is not considerably affected. As Kereru do not follow a conventional moult, like Bar-tailed Godwits, they are able to simultaneously breed and moult, whereas, due to all primary feathers of the Godwit showing substantial overlap, formation of gaps and the lifestyle of Bar-tailed Godwits Kereru are not able to do the same. Outer primary feather removal due to their spread nature while in flight would have more of an effect on flight manoeuvrability (when banking for landing or during display flights) than on wing area. Generally, birds will adjust their body mass, or wing beat frequency in respect to the extent of moult. It is predicted that Kereru would not need to do this due to their extensive wing area. The impact that the loss of an individual feather has on loading would constitute no more than what an individual meal (~80g) has when Kereru feed heavily.

Therefore, from this investigation it is clear that Kereru do not follow a conventional, symmetrical moult. Instead Kereru flight feather moult is frequently asymmetrical, often involving multiple moult loci and seldom follows a conventional in – out sequence. This combined with a long duration of moult, probably serves to minimise the impact that gaps in the wing have on wing area. The broad wings of Kereru have proportionally larger inner primaries than those of birds with more pointed wings. Kereru moult seems to avoid the development of large gaps in the inner wing that would occur if Kereru moulted more conventionally. They are able to moult and breed simultaneously by reducing energetic costs of moulting feathers that are less expensive to grow and because of their impressive wing area to body mass wing loading is not greatly affected when in moult. However, the extent that this form of moult has on flight performance is still to be investigated.

Chapter Five - Kereru (*Hemiphaga novaeseelandiae*) – Monochromatic or a dichromatic species?

5.0 Abstract

Light spectrometry is a tool used to assess colour, in this study of 50 Kereru (*Hemiphaga novaeseelandiae*), reflectance was the measurement assessed. This study is the first to assess UV signals in Kereru and it was found that UV signals are in all eight regions investigated, five plumage (Breast, Crown, Mantle, Wing and Rump) and three bare parts (Bill base, Bill tip and Foot). The greatest intensity of maximum UV signal was in the bare parts with a covariance of the bill tip and foot. No sexual differences or condition dependent signals were found, but age-related UV signals were found in the crown and foot. In the visual spectrum, females had a greater intensity of maximum colour signal in the wing, but there were no condition dependent features. Age related colouration is seen predominately in the bare parts, in particular the foot which has a higher intensity of colour in juveniles. However, even with single-angle light spectrometry Kereru are a highly cryptic species.

5.1 Introduction

The colouration of a bird can signal the species, body condition, social status and in many cases sex. Elaborate or showy traits can often be a reliable indicator for reproductive status and sex, but, they are costly to produce; this may be the reason why many birds appear monomorphic (no sexual differences in colouration (Eaton, 2007)) to lessen energy expenditure.

Structure, design and colouration of plumage consist of many properties which constitute the final product, a feather. Plumage colouration is derived from three factors, two types of pigmentations and a structural mechanism. Pigmentations include (Bennett & Owens, 2002; Peters et al., 2008):

1) Melanins – synthesised by the body, are responsible for most black, brown and brick red colours, and are not costly to produce;
2) Carotenoids – obtained from the diet, are responsible for most bright yellows, orange, reds, greens and purples, and are costly to produce.

Whites and most iridescent colours, such as purples, blues and greens are produced by structural mechanisms; these are the ultimate source of UV reflection. Studies have shown that some birds use UV light for sexually dimorphic plumage, active courtship displays and mate choice (Bennett & Owens, 2002; Hausmann et al., 2003; Hunt et al., 2001; Santos et al., 2006). Bennett and Owen (2002) found that of 108 species tested 88 showed UV reflectance in one or more sections of the body. These were found to be used solely for courtship displays in monochromatic and dichromatic species, although UV signals are not solely used for sexual dimorphism, but instead for mate selection based on feather quality and overall condition.

Plumage colourations, especially carotenoid based colours, are dependent on the foraging ability of the bird and can therefore be condition dependent. These aspects of plumage are used in social status or mate quality signals, especially in adult males. Reflectance measurements have found that the intensity of carotenoid colours is less when intake of carotenoid dietary components is lacking. Peters (2008) found, with experimental adjustment of lutein in the diet of male greenfinches (*Carduelis chloris*), that the reflectance of the yellow tail was reduced with a diet low in lutein; this was closely related to general condition (mass).

Reflectance is the measure of light which is not absorbed by an object, but reflected (i.e. the ratio of reflected light to incident (ambient or reference standard) light (Hill & McGrass, 2006). These reflected wavelengths are what are seen as an object's colour. Few studies have investigated whether bare part colouration (i.e.: eye-rings, bills and legs of birds) is condition dependent and at what rate this changes with variation in diet. A study on Red-legged partridge (*Alectoris rufa*) found that the eye-ring pigmentation was positively related to body condition and that different ornaments on the bird seemed to reflect changes in the body at different rates; soft features such as the eye ring depicted changes quicker than the bill (Perez-Rodriguez & Vinuela, 2008). Bare parts ultimately portray condition changes faster than plumage, as variation in plumage is only seen once feathers have moulted whereas bare parts continually adjust with condition. Therefore, it is conceivable that bare parts of dead birds would reflect condition more accurately than plumage.

Perceived colouration is dependent on visual properties of an individual where apparent monochromatism is not necessarily true monochromatism, as birds' visual sensitivity extends further than humans'. The human visual spectrum spans 400 – 700nm, but birds are capable of seeing deeper into the ultraviolet spectrum (320 – 400nm) (Santos & Lumeij, 2007). Birds may have 'hidden' dichromatism or plumage signals that can only be detected in the ultraviolet spectrum. The ability to perceive colour relies on three processes within the eye (Eaton, 2005):

1) Physics of light reflectance and transmission to the surface of the eye
2) Light transmission, reflectance and photoreception within the eye
3) Neural processes in the retina and brain

Both mammals and birds use these processes, however, birds are able to see deeper into the light spectrum because, unlike mammals, birds have an additional fourth cone cell in their retina that enables them to detect UV wavelengths (Cuthill et al., 2000; Odeen & Hastad, 2003). Using light spectrometry, Eaton (2007) surveyed North American 'monochromatic' passerines and found that 91.6% of these assumed monochromatic birds were actually dichromatic if the full range of wavelengths was considered. In another study of over 1000 bird species no cryptic sexual dimorphisms were found (Mullen & Pohland, 2008), unlike in Blue Tits (Andersson et al., 1998; Hunt et al., 1998) where males appear to use UV signals as a means of assessing mate quality. Methods currently used to sex monomorphic species include DNA sexing, gonad visualisation (necropsy or laparoscopy) and for a restricted number of species day old chicks are cloacal sexed (Halverson, 1997). All of these methods require time, money, experience and in the case of necropsy, death.

The Kereru (*Hemiphaga novaeseelandiae*) is a large, apparently monomorphic pigeon. No significant differences between sexes in mass or measurements have been found (Gill, 2006; Hadden, 1993; Worthy & Brassey, 2000). However, adults and juveniles are distinctly different based on colouration of feathers, beaks and feet. An adult Kereru has brightly coloured reddish feet and a bill that changes from red/pink at the base to yellow/orange at the tip; the chest plumage is pure white; the breast is iridescent green and the back and rump feathers are bright green with some deep purple across the shoulders. Juveniles have dull feet and beak, the chest plumage is smudgy grey, and they have a green breast and dull green/grey back and rump feathers (Gill, 2006). Methods to sex adult Kereru to date rely solely on DNA sexing or at time of necropsy. Some native captive management teams believe there is a slight seasonal difference, especially leading up to breeding season; the male becomes a lot brighter, and the female appears drab (R. Schlaepfer, pers. comm.). In this study light spectrometry was used to assess the reflectance of various plumage traits and bare parts of Kereru processed for post mortems after collisions with vehicles or infrastructure. The aim was to discern whether there are any differences in colouration relating to age, sex or condition.

5.2 Materials and methods

Fifty dead Kereru (nine juveniles and 41 adults) were acquired from Department of Conservation (DoC) offices in the lower North Island, New Zealand. Reflectance of five feather patches and three bare part regions were analysed; crown (CR), breast (BR), mantle (M), rump (R), wing patch (W), bill tip (BT), bill base (BB) and foot (F). As birds were partly frozen at the time of scanning, sometimes certain regions could not be scanned so sample sizes vary between regions. Reflectance was measured using an Ocean Optics HR4000 spectrometer with a PX2 Xenon light source (settings: integration time 250µs, spectra average 5, and boxcar smoothing 5). White (WS-series Diffuse Reflectance) standard and dark references were taken between each bird. A black rubber sheath was attached to the end of the probe to maintain a standard distance from fibre end to plumage/bare part, and a standard probe angle of 90^0 was used for all measurements. Preservation techniques can alter the true reflectance and UV signal of plumage, especially if pesticides and tanning techniques have accidentally contaminated the plumage (Pohland & Mullen, 2006). However, the threat of staining contamination in respect to skins used for this study is minimal due to the preservation technique used (freezing). The reflectance spectrum was measured over an area of approximately 2mm diameter. Three scans were made at each site, with the probe repositioned between each scan. For analysis, the three scans were averaged and the spectral range restricted to 320 – 700nm. Averages of the three scans per region were put into bins of five (nm).

From the associated graphs of reflectance versus wavelength, key wavelengths of interest were determined for each region (Figure 5.1). Rmax (maximum intensity), raverage (average intensity), rchromauv (total chroma in UV region (320-400nm)), uvmax (max. UV intensity) were determined for each region. Chroma is perceived as the percent of total reflectance contained within a specified wavelength range (i.e.: red, yellow or green). Overall average reflectance is the average of reflectance over a range of wavelengths, in this case 320 – 700nm. Peak reflectance is the maximum reflectance across the spectrum, whereas UV peak reflectance is restricted to 320 – 400nm. 'Colour' chromas were determined dependent on region (rchroma = total chroma found within particular colour region investigated):

Table 5.7 Chroma (colour) measurements assessed for each region.

'Colour' chroma measurements of interest	Wavelengths (nm)
rchromauv	320-400
rchromayellow	500-640
rchromaorange	540-660
rchromagreen	500-600
rchromared	600-700

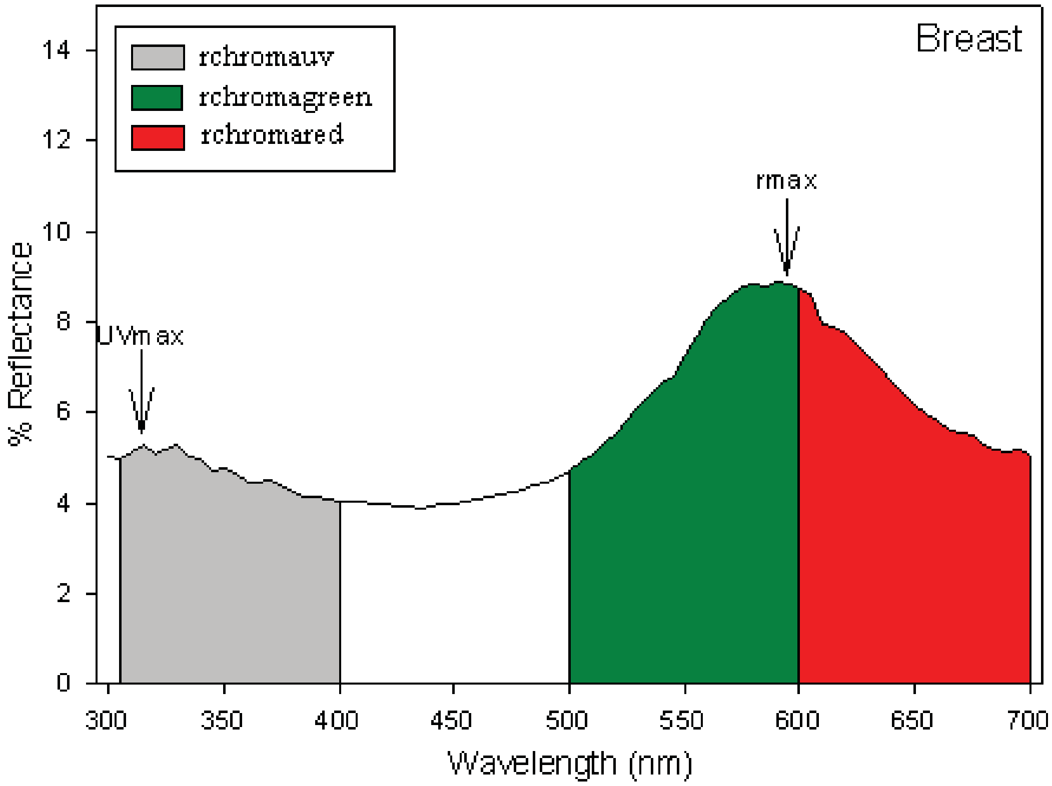

Figure 5.1 Reference colour areas for reflectance parameters. Rchromayellow and rchromaorange lie within the boundaries of rchromagreen and rchromared.

Statistical analyses using Minitab 15 involved t-tests, ANOVA and ANCOVA to compare the extent of variation between sex and age groupings within and between all regions (plumage and bare parts). Graphs produced with SigmaPlot 11 software.

5.3 Results

5.3.1 UV signal

A UV signal was present in all eight regions (Bb, Bt, F, Br, Cr, R, M & W), but was strongest in the bare parts (foot, bill base, and bill tip) (Figure 5.1). A Kruskal-Wallis test indicated that there was a significant difference in UVmax between regions (H_7 = 175.128, P = 0.001), specifically between the bare parts and the plumage (Dunn's method, P < 0.05). The Rump was significantly different to all other plumage regions, except the Crown. There was no relationship between UV signal (uvmax or rchromauv) and body mass for any region.

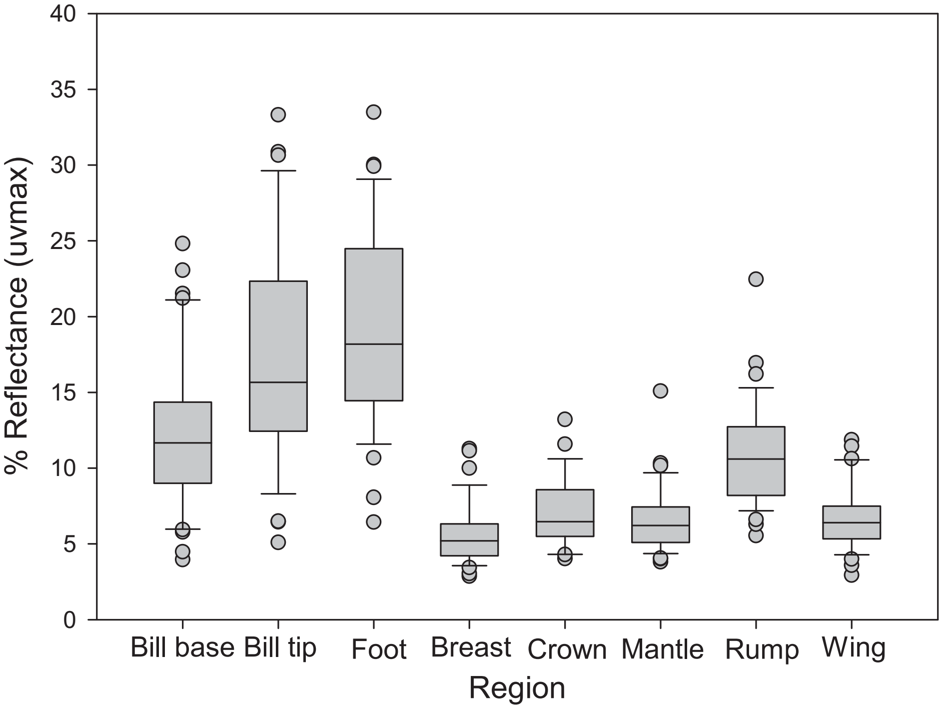

Figure 5.2 Ultraviolet reflectance (uvmax) across all regions for adult Kereru. Boxes give the median and 25th and 75th percentiles, whiskers give the 2nd and 98th percentiles, and outliers are shown as dots. Sample sizes vary from 35 to 49 for each group.

UV intensity did not co-vary among the bare parts (F, Bb & Bt) – all but one pairwise comparison between the bare parts regions varied significantly in mean reflectance between all bare parts regions, the exception was Bill tip uvmax and Foot uvmax (Table 5.2 & Figure 5.2).

Table 5.2 Differences between UV reflectance of bare parts of Kereru

Region	Region	T value	P value
BB rchromauv	BT rchromauv	$T_{72} = 6.26$	0.000
	F rchromauv	$T_{69} = -2.92$	0.005
BT rchromauv	F rchromauv	$T_{75} = -11.02$	0.000
	F uvmax	$T_{75} = -1.27$	0.209
BB uvmax	BT uvmax	$T_{67} = -3.63$	0.001
	F uvmax	$T_{41} = -5.38$	0.000

Sex and age

No sexual differences were found in any UV reflectance measures (one-way ANOVAs, P>0.05 for all). An age effect was found for Crown rchromauv (ANOVA $F_{1,32} = 4.66$, $P = 0.039$) and Foot rchromauv (ANOVA $F_{1,45} = 6.38$, $P = 0.015$), where juveniles have a greater intensity of rchromauv for both regions.

5.3.2 Plumage – visual spectrum

The visual reflectance spectra of the plumage confirmed that the conventional colours attributed to different regions are very close to the ‘actual’ colourations described by reflectance (Table 5.3 & Figure 5.3). However, humans do not detect the clear presence of a UV signal that pigeons would be able to detect.

Table 5.3 Plumage colouration based on visual and spectrometry reflectance signals on eight regions of the Kereru body.

Regions	Appears	Actual	Reflectance (nm)
Bill Base	Red	Red	600-700
Breast	Green/Amber	Yellow/Orange	500-640
Crown	Green/Amber	Orange/Red	540-660
Rump	Green	Green	500-600
Foot	Red	Red	600-700
Bill Tip	Red/Yellow	Red	600-700
Mantle	Purple	Red	600-700
Wing	Purple	Red	600-700
All regions	Not seen	UV	320 – 400

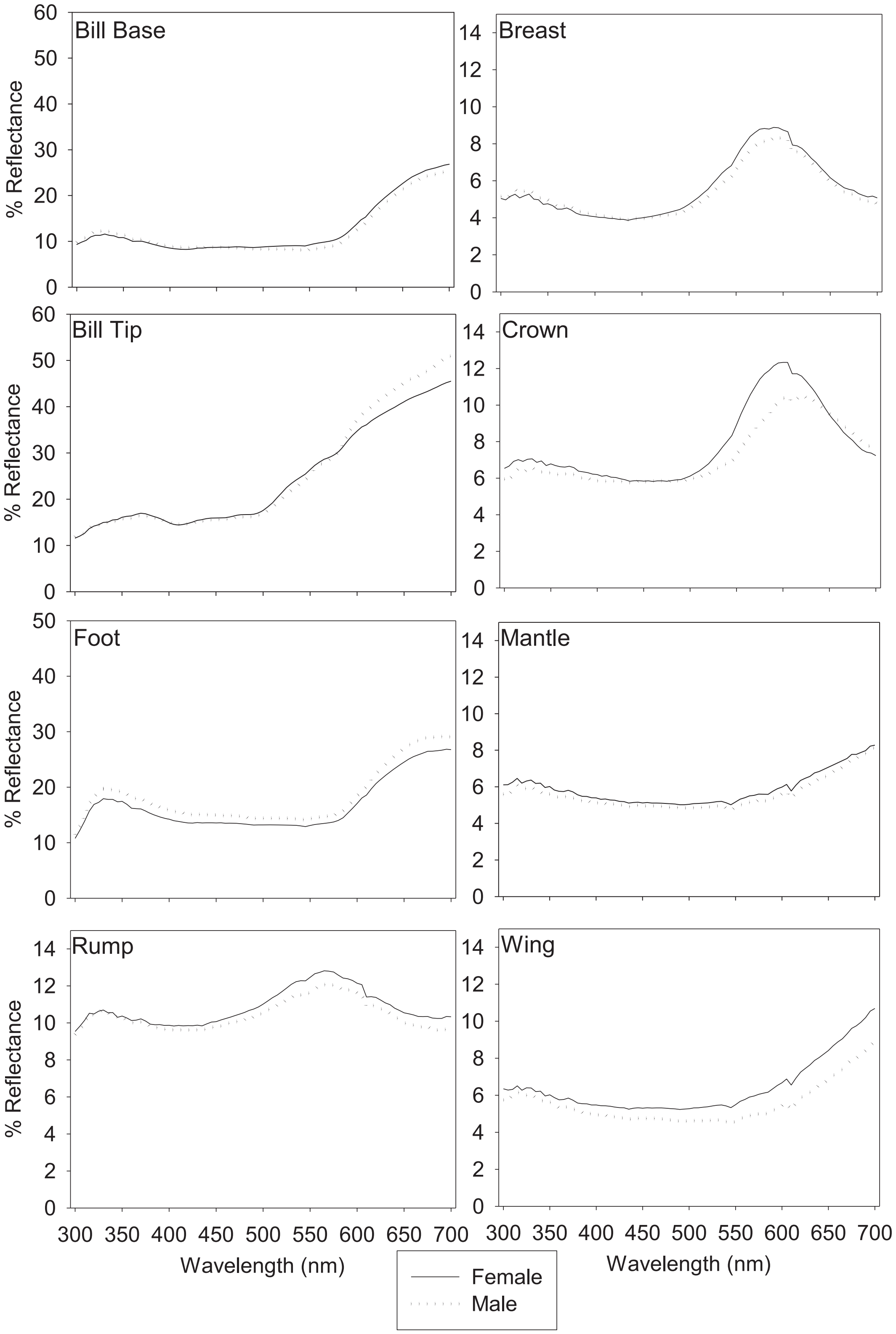

Figure 5.3 Mean reflectance curves of male (n = 18) and female (n = 24) adult Kereru, assessing five plumage (Breast, Crown, Rump, Mantle & Wing) and three bare part regions (Bill base, Bill tip & Foot). * Note that the y axis scale differs between the bare parts and the rest.

Sex

There were no significant differences between sexes in the average reflectance across all wavelengths. However, rmax of the Wing was significantly higher in females than males (ANOVA $F_{1,37} = 6.05$, $P = 0.019$), and females also had a significantly brighter green crown than males (ANOVA $F_{1,25} = 5.29$, $P = 0.030$). Condition (mass and wing/or tarsus) does not appear to have a bearing on the intensity or amount of colour that is produced for any region (using ANCOVA mass, or mass and size as covariates, $P > 0.05$ for all parameters).

Age

In contrast to sexual differences, there were several bare part regions and measures that differed between juveniles and adults (Table 5.4), with all foot measures being brighter (redder) in adults and bill base being marginally significantly redder. Two plumage regions were affected by age; the breast was brighter and the crown was more orange in adults. Inclusion of body condition (body mass and wing or tarsus as covariates) did not change these significance patterns.

Table 5.4 ANOVA results showing where age related differences are found within the reflectance curve of Kereru plumage and bare part regions.

Region	F value	P value
Bb rchromared	$F_{1,46} = 3.81$	0.057
Br rmax	$F_{1,39} = 6.13$	0.018
Cr rchromaorange	$F_{1,32} = 4.25$	0.048
F rmax	$F_{1,45} = 10.07$	0.003
F raverage	$F_{1,45} = 6.33$	0.016
F rchromared	$F_{1,45} = 6.16$	0.017

5.4 Discussion

5.4.1 UV signal

Spectrometry confirmed that Kereru of all ages and sexes produce UV signals to varying degrees in all eight regions investigated in this study (Figure 5.2). The bare part regions (Bill base, Bill tip and Foot) had stronger UV reflectance than the plumage regions (Breast, Crown, Rump, Mantle and Wing) (Figure 5.3). The bare parts may be more readily visible when birds are perching or sitting in a nest so provide a better signal in forest; alternatively, due to the cost of producing colourful feathers it may be easier and less expensive to produce UV signals in large quantities in those areas that are not seasonally moulting or parts that are easily removed (Peters, et al., 2008). The strongest UV signals were from the Bill tip and Foot (Table 5.2) – these would enable some signalling when birds were perched (feet and/or bill if not sleeping) or sitting low (bill tip visible). What form of communication these regions are signalling was not determined in this study; however, it may relate to behavioural, sexual, age specific traits, or a means of displaying body condition/immunity while in moult (Hunt et al., 1999; Siitari & Huhta, 2002).

There do not appear to be any sexual UV differences between adult Kereru, even though it is known that differences in UV signal have been found to be a mate choice indicator in other species. For example, in the Picui Dove (*Columbina picui*), three of the twelve regions investigated indicated that males had stronger UV reflectance than females (Mahler & Kempenaers, 2002). In regards to the crown of male blue tits the UV and honesty signal of mate quality varied with altering levels of testosterone (Roberts et al., 2009) after moult, prior to the breeding season. Differences were found in relation to Kereru age. The Crown and Foot reflected age, and may be used for age-related communication, i.e.; for when young are sitting on the nest only the Crown is visible and the Foot for when individuals are perched in trees. The intensity of the UV chroma may signal age to conspecifics. Condition dependence (mass) has been known to influence UV signal of juvenile Florida Scrub-jays (*Aphelocoma coerulescens*) tail plumage (Siefferman et al., 2008). In contrast, there was no evidence that body condition influenced UV signals in Kereru. For plumage, this might not be unexpected, as the condition when birds died might be largely unrelated to the birds' condition when they were moulting (which in itself might be spread over a long time, greater than nine months). In contrast, bare part colouration might be expected to be more sensitive to body condition changes, however in this case there was none.

5.4.2 Plumage – visual spectrum

The colour that appears to the human eye is very close to the actual colour recorded with light spectrometry (Table 5.3). The discrepancies that occurred were in those regions with greatest iridescence (i.e.: Crown and Breast) and within the wavelength of 320 – 400nm (UV) (Figure 5.3). This is because humans do not have the ability to perceive wavelengths below 400nm (Cuthill, et al., 2000; Odeen & Hastad, 2003). For all regions there were no greater than two distinct reflectance peaks (overall chroma (rmax) and UV (uvmax)) (Figure 5.2 & 5.3), whereas McGraw (2004), on Rock pigeons (*Columba livia*), found that the 'purple' iridescent feathers of the neck exhibited four distinct reflectance peaks (two in the human visual field – blue and red – to produce purple colouration, and two in the UV region). It is possible that this was not detected in this study due to use of only single angle spectrometry.

Assessment of the average reflectance across all wavelengths suggests that adult Kereru plumage does not differ between sexes. However, significant differences were found in the rmax of the Wing, with females having higher reflectance/chroma than males and of the green chroma of the Crown; again females were brighter than males. Some nature reserve workers believe that there are subtle differences between sexes in Mantle colouration, especially leading into the breeding season; this variation was not found here. It may be that small yet biologically meaningful differences do exist but are difficult to detect in comparisons between individuals (rather than changes in the same birds over time). In any case, plumage colouration does not seem to be a reliable way of sexing Kereru in the hand.

Further investigation using this method in respect to feather iridescence may yield significant results as such results have been found in the rock pigeon. Johnston (1992) found that the body plumage of adult rock pigeon looks similar in relation to sexes determined by the human eye, except for a noticeable decrease in neck iridescence in the female. Johnston (1992) believes that this region of the pigeon's plumage may play a role in the courtship 'bow-coo' behaviour predominately displayed by the male, where the male inflates his crop and consequently displays his iridescent neck feathers directly at his con-specifics. The almost significant differences in Crown colouration, and significant differences for the Breast could potentially indicate that Kereru use their plumage in this fashion. Another study that investigated similar plumage regions to those examined on the Kereru (forehead, nape, throat, under tail coverts, tail feathers (dark brown), primaries (dark brown), crown, back, breast, tail feathers (white), primaries (white) and wing stripe), on the monochromatic Picui dove, found that they are indeed a dichromatic species and that males are brighter, in regards to reflectance, in most regions than females (Mahler & Kempenaers, 2002).

Analysis of any condition dependence involving mass, wing and/or tarsus length showed that plumage and bare part colourations were not governed by condition. However, this may be dependent on the time of year that the birds are sampled. My samples, of 41 adults, are from throughout the year, encompassing all seasons although individual birds were not assessed for seasonal variation. Due to this, seasonal variations such as moult and breeding plumage, and factors that affect these are not accounted for. Also, this sample involves birds that have been involved in collisions with vehicles and infrastructure windows so it is not known whether the bird may have gone through a period of starvation due to injuries prior to collection. This is not to say there are no condition-dependent colourations, in particular carotenoids, in Kereru, as other studies have found that yellow carotenoids in great tits showed that varying levels of carotenoid in the diet will ultimately affect the display of yellow chroma (Eeva et al., 2009), potentially reducing the quality of the individual. Areas such as the bare parts in Kereru are governed by carotenoids. Estep (2006) found that the quality of the red breast feathers of male Red Fodys (*Foudia madagascariensis*) deceased with limited availability of carotenoids and this consequently determined the mate choice of the females and indirectly the clutch size.

In respect to age, six parameters (across all regions) showed significant differences (Table 5.4). However, these results may be biased due to the small sample size of juveniles potentially skewing the results. As can be seen from these results, plumage colouration does not feature highly for identification of age; instead bare parts, especially the Foot, show these differences. Adults appear brighter in all aspects for those regions mentioned in Table 5.4. Even within juveniles there does not appear to be any condition dependence. Based on these findings the above parameters could cautiously be used as a means of aging young sub-adult Kereru; if there were no gold fleck feathers remaining on the plumage and where other morphometrics possibly suggest an adult.

5.5 Conclusion

In this study it was found that Kereru exhibit UV signals in all eight regions (plumage and bare parts), however, it is not known to what extent these signals are used for determining sexual dimorphism, mate quality, body condition/health and consequently immunity. It appears that bare part UV signalling plays an important role in age determination, as opposed to that of the plumage. However, even with the use of light spectrometry it is still extremely difficult to accurately determine sex of an adult Kereru. This is because there is a lot of variation when assessing overall reflectance curves and that of individual parameters within regions. Even with a large amount of input there is no clear answer or region that can determine sex. It appears that the entirety of a bird's body is more important for sexual colouration than individual plumage components. However, the effect of condensation (use of frozen specimens) was not assessed due to time constraints. Whether this had an impact on the final reflectance obtained is unknown.

In regards to condition-dependence there appears to be only one regional parameter that is correlated with mass, suggesting that the condition of the birds sampled has little influence on the state, quality and appearance of feather colouration. The exception is in the orange chroma of the Crown which may indicate that this area influences the choice of potential mates, as carotenoids are diet dependant. In all respects, further study using multiple-angle spectrometry would be beneficial due to evidence that single-angle spectrometry does not depict the full extent of reflectance for some plumage types. This may be the case for Kereru due to the high presence of multiple feather colouration factors, structural, melanins and carotenoids and also the presence of iridescence. All of these factors will have a bearing on the final outcome for reflectance; this study has only touched the tip of the iceberg for trying to explain Kereru colouration in the terms of human and avian perspectives.

The effect that light has on feather colouration and signalling is another avenue that needs to be investigated because varying levels of light within different habitats ultimately has a bearing on how signals are developed, produced and received by con-specifics and non con-specifics. Endler (1993) assessed how variation in light environments affects the communication among animals, plants and other organisms.

He suggests that ambient light could affect the conspicuousness of an animals' colour and/or patterns against background colours and patterns, which either makes the bird appear cryptic within its habitat or stand out. The combinations of light reflection from the environment and animal adjust the visual signal that is received by a viewer. Each level of forest light intensity would produce a different colour signal, ultimately suggesting that within habitat variables play a significant role in colour visualisation for birds. It has been found in the White-throated Manakin (*Corapipio gutturalis*) that the male uses the sun spots on fallen logs as a part of his courtship display, where in the light the males bluish-black back and flanks and white chest appear brighter and of higher quality in the light than in the dark (Thery, 1990). It is possible that the stalling display swoops of Kereru uses light in this fashion, whereby the whites of the chest and iridescences of the breast and crown are at their maximum in direct sunlight than under the shade of the forest canopy. This is because these visual colours are a result of structural mechanisms and therefore, the effect of light is greatest on these regions (Endler, 1997).

In terms of using light spectrometry as a means for Kereru sexing in preparation for management decisions, at this time it would not be warranted, due to limitations of accurate sexing. It may be possible with multiple-angle spectrometry to gain a better understanding of Kereru sexual colouration, but until this time the use of DNA sexing is best for management decisions. This ultimately means at the expense of capturing, stressing and drawing blood or feather samples from Kereru this remains the best method. Because of this, methods of reducing stress which Kereru undergo during these procedures is a necessity and management decisions need to be unfortunately governed by the time and expense of waiting for DNA results.

Chapter Six - Summary

6.1 Impact injuries

Kereru come into frequent contact with humans and man-made structures, because of modifications to habitat and development of residential areas. It is inevitable that they will sustain injuries caused by collisions with infrastructure; such as windows in buildings, vehicles and fences. Little information had been documented about the types and extent of injuries that Kereru sustained in relation to collisions; the only knowledge came from bird rehabilitators, wildlife reserves and Massey Wildlife Ward; all of it unpublished. However, from indepth investigation of over 100 deceased Kereru it was found that impact injuries can be classified into three types of injuries:

1. Skeletal damage in the form of bone fractures and dislocations;
2. Soft tissue damage in the form of haemorrhaging/bruising to organs, muscles and skin, laceration to intestines and crop, and trauma to the head;
3. Injuries that involve soft tissue and skeletal damage with some fractures causing damage to organs (laceration to the heart and liver by coracoids).

Of these injuries, fractures to the extremities (wings/legs) occurred most often in those individuals that collided with vehicles as opposed to stationary windows (buildings). Survival probability for birds depended on the extent of damage, internal and/or external, and the prognosis of adequate rehabilitation after surgery. However, the number of fractures that a bird received did not clearly indicate probable survival. Survival ultimately depends on force of impact, time from impact to first care and extent of both internal and external injuries. These factors did not, however, closely relate to overall time spent in rehabilitation. Collisions occurred throughout the year, although the majority occurred leading up to spring and during the breeding season (Aug – Mar).

6.2 Morphometrics, body condition, organ masses and crop contents

As in other morphometric studies on Kereru there were no substantial properties that distinguished males and females. The only difference found was in the head and bill lengths (females longer than males); however, this variation was slight. Therefore, morphometrics are not an adequate and accurate means of determining sex in Kereru.

Assessment of Kereru body condition found that there was a close relationship between fat score and body condition score, which is to be expected as they are both forms of condition scores. Seasonal analysis depicted a slight trend of increasing fat stores leading into autumn and winter, indicating preparation for leaner months in relation to food supplies and cooler climates. Fat stores then reduced when progressing out of winter. No caeca were found in any of the 50 Kereru studied. This observation is similar to that noted in other pigeon species, but due to their size and being herbivorous this is an interesting finding. In respect to internal organ masses and intestinal length there was no difference between the sexes or age. Intestines were shorter than those in species of birds of similar size, despite the latter group having caeca. The digestive strategy of Kereru seems to be to process a very large amount of vegetation very slowly rather than to have a large gut *per se*. Organ masses were significantly related to body mass, but the gizzard was just as strongly related to body size (tarsus length). This suggests that different organ sizes reflect different factors, with the gizzard potentially being less variable over time than the liver and intestine.

The types of food consumed varied greatly and included native (Puriri, Tawa, Karaka, Kowhai) and introduced materials, fruit and vegetables which indicated a period of time in rehabilitation/captivity. Kereru tended to show a preference for native material throughout the year and possibly resorted to consuming introduced material when preferred native material was less available. There were no incidents where there were combinations of food types suggesting that they focus on one type at a time. The type of material consumed (foliage, fruit or flowers) related closely to the time of year and at any one time there could be upwards of 40g of consumed material in the crop. Because of this large consumption of material the predicted retention time of 16hrs from other studies is understandable. There was no difference in the amount of material consumed between sexes. With up to 84g of food contained in the crop, gizzard and intestine, the mass of a Kereru that has recently consumed food will vary greatly from one that has not, meaning the assessment of mass as a statistical measurement is not very informative.

6.3 Moult

Few people have investigated adult Kereru moult in depth and how this may impact on flight and their breeding cycle. This study found that Kereru do not moult in a conventional fashion and because of this they do not moult in a symmetrical style. This was supported by the relationships between moult scores and the presence of multiple moult loci. Their moult cycle takes approximately nine months with a ceased or halted period during winter and unlike the majority of bird species Kereru continue a limited form of moult (tail feathers only) during their breeding season. This may be possible due to the long and continual moult that they exhibit thereby reducing energy expenditure for both activities, especially by forgoing moult of wing feathers during this time. Even with the high degree of moult variation there were no regularly occurring sequences that would suggest a pattern by which Kereru moult. This suggested that moult by an individual was in relation to minimising wing gaps, response to the environment, individual health and reproductive status. By not following a conventional moult they would reduce energy expenditure by moulting a feather that is less costly to produce at particular times of the year and reduce the likelihood of developing large gaps in the wings which would have an impact on flight performance.

However, due to Kereru seldom moulting several adjacent feathers at once, and their large mass, the loss of a particular feather did not have a substantial effect on either wing area or wing loading. This effect was reduced even further by the inner primary feathers having a large degree of overlap and all the primary feathers occupying a similar area due to their shape and size. The greatest impact on flight performance would arguably come from the loss of outer primaries, which extend out at the tip of the wing and show little overlap with other feathers.. The impact that the loss of several feathers had on loading constituted no more than what an individual meal (~

80g) would have on Kereru. It may be because of this that Kereru are able to adapt to changes in moult as they regularly have large changes in mass due to excessive consumption.

6.4 Light spectrometry

Using light spectrometry little difference in plumage colouration between sexes of Kereru was found. Adults appeared brighter than juveniles for all regions investigated, with the most variation being in the foot and crown, which may be used as age-related communication. The occurrence of UV signals in all regions indicated that this was a means of communication that we as humans are not able to detect. The strength of UV signal was greatest in the bare parts regions suggesting that those regions are more important for communication than the plumage. This may be because bare parts may continuously reflect an individual's state, unlike plumage, which is replaced only periodically. Differences within the bare parts in relation to UV signal may be because they were more readily visible when perching or sitting in a nest and that UV signals are more readily received than 'regular' chroma. Kereru show a high level of iridescence on the breast and this may play a role in sexual communication, and the subtle non-significant differences viewed between sexes on the plumage may be enough for con-specific identification. Lack of condition-dependent variables affecting plumage colouration is potentially associated with an array of individuals from across all seasons and at different stages of moult. In all, Kereru are a highly cryptic species to humans, but this cannot be the case for Kereru themselves.

6.5 Recommendations and further research

Results from these investigations will provide valuable information for wildlife rehabilitators, conservation workers and researchers alike, while at the same time improving the knowledge and awareness of the public in regards to Kereru injuries. The studies contained within this thesis have answered questions, and at the same time more have arisen requiring further research. All of this will help improve our understanding of Kereru biology and subsequently Kereru conservation. The following are recommendations for future research topics:

- Increase public awareness of the plight of Kereru and suggest ways that they can help if they ever find an injured Kereru. Compile lists of wildlife carers for each region so that the public know who to contact.

- Development of future residential properties may need to take into account installing tinted windows to prevent incidents of bird, and owners need to think carefully about the placement of bird feeders (five meters or more away from windows).

- In areas with high prevalence of Kereru strikes the development and implementation of bird deterrents at windows should be investigated (use of hanging reflective objects, predator silhouettes, use of ultraviolet images).

- Further assessment of moult in relation to the initial onset, moult during breeding, energy requirements and how it affects flight performance in regards to loss of outer primaries.

- Assess how quantity of consumed materials affects body condition, moult and flight performance.

- Single-angle light spectrometry is not an accurate means of sexing adult Kereru so reassessment of Kereru plumage and bare parts using multiple-angle light spectrometry, and investigation of the occurrence of iridescence on the crown and breast is needed.

Appendices

Appendix One

Kereru Window Collision Questionnaire

Contact

Name:-- *Phone:*-----------------------------------

Impact

Date:--- *Time:*---

Location (area, region, locality):--

Site description (Infrastructure)

Type of building (single or double storey, tower):--

Location of building (residential, rural, town/city):---

Site of window- what direction does it face? (N,E,S,W):---

Is there another window on the other side of the building? (can you see through one window to the other?):--

Site description (Environment)

Weather (sunny, cloudy, overcast, showers, raining, stormy):---

How far is it to the nearest large tree? (from location of impact)---

What is the species and approximate height of the nearest large tree?-------------------------------------

How far is it to the nearest known feeding tree?(from location of impact)----------------------------------

What is the species and approximate height of the nearest known feeding tree?

Bird description

From what direction did the bird fly from into window, if known? (N,E,S,W):-----------------------------

What happened to the bird after impact? (bird died, immediately flew away, stunned and then flew away or taken into care, other):--

Have Kereru struck this house/window before? If so, how many times?------------------------------------

Diagram of surrounding environment (infrastructure, pigeon movements, trees/bushes):

N

Appendix Two

Table 1 Locations of Kereru collisions and the number of birds analysed from each area, from three sources of information: clinical files, my collection, and necropsy database.

	Location	Number of Kereru
Clinical Files	Central N.I	13
	New Plymouth	9
	Palmerston North	30
	Wellington	12
	Unknown	12
My Collection	Hawkes Bay	1
	Kapiti	14
	New Plymouth	6
	Opotiki	5
	Palmerston North	4
	Wairarapa	5
	Wellington	14
	Unknown	1
Necropsy Database	Nelson	2
	New Plymouth	1
	Palmerston North	10
	Rotorua	1
	Wellington	1
	Unknown	5
Total		**146**

Appendix Three

Table 2 Body Condition Score (1-9) based on extent of muscle around the keel.

Health status	Body Condition Score (BCS)	Number of birds
	1	4
Unhealthy	2	1
	3	2
	4	2
	5	10
Healthy	6	5
	7	10
	8	13
	9	2
Total	-	49

Appendix Four

Table 3 Type of organic material found within 32 Kereru crops and the mass (g) of material found within each one.

Organic material	Month	Mass	Organic material	Month	Mass
Unknown Exotic broadleaf	Sept	0.13	Kowhai (leaves/flowers)	?	9.63
	Apr	0.2	(*Sophora tetraptera*)	Sept	30.58
	Oct	1.55		?	6.7
	Mar	7.43		?	14.8
Fruit/vegetables	Aug	38.67		June	38.5
(Pea/bean/corn/carrot/sultana	Oct	9.98	Tree Lucerne (leaves/flowers)	Aug	8.64
apple/banana)	Aug	3.22	(*Chamaecytisus palmensis*)	Sept	0.89
	Mar	11.21		July	1.4
	Aug	16.13		Nov	11.85
	Aug	58.15	Lacebark (leaves)	Sept	0.84
	Aug	67.51	(*Hoheria populnea*)	Mar	7.18
	May	14.35	Puriri (fruits)	Mar	15.66
	Apr	25.73	(*Vitex lucens*)	Jan	17.86
	Jan	4.02	Karaka (fruits) (*Corynocarpus laevigatus*)	Feb	6.67
	May	6.48	Tawa (fruits) (*Beilschmiedia tawa*)	Mar	5.41
	?	2.81	? (fruits)	?	36

Appendix Five

Table 4 Mass of bird (pre-necropsy), total wet mass of consumed material in crop, gizzard and intestine, and the proportion that this mass constitutes in Kereru mass.

Mass of bird (g)	Mass of consumed materials (g)	Percent of Kereru mass
423	2.79	0.66
425	12.44	2.93
434	58.15	13.40
442	10.4	2.35
451	17.36	3.85
468	12.23	2.61
527	3.22	0.61
531	28.87	5.44
545	25.4	4.66
552	14.6	2.64
602	41.38	6.87
612	25.73	4.20
643	38.67	6.01
646	15.53	2.40
687	3.74	0.54
727	0.89	0.12
736	20	2.72
750	40.87	5.45
767	2.81	0.37

Appendix Six

Table 5 Number of primary feather moult loci in relation to time of year.

Months	One moult locus	Two moult loci	Three moult loci	Four moult loci	**Total**
Jan	9	5	2	0	**16**
Feb	19	13	5	1	**38**
Mar	11	1	0	0	**12**
Apr	6	4	0	0	**10**
May	2	2	0	0	**4**
June	1	0	0	0	**1**
July	8	3	0	0	**11**
Aug	14	1	1	0	**16**
Sept	9	4	0	0	**13**
Oct	7	0	0	0	**7**
Nov	6	4	0	0	**10**
Dec	8	4	1	0	**13**
Total	**100**	**41**	**9**	**1**	**151**

Appendix Seven

Table 6 Comparison of a conventional moult from Bar-tailed Godwits to the moult of Kereru with the same or similar moult score.

Godwit (conventional)	Moult score	Kereru	Moult score
0000000000	0	0000000000	0
1100000000	2	2000000000	2
1110000000	3	0000000003	3
2211000000	6	4000000002	6
2221000000	7	5200000000	7
3321000000	9	0500005000	10
4432100000	14	5530000000	13
5543100000	18	5054103000	18
5554210000	22	5554000003	22
5554310000	23	5554000040	23
5555420000	26	5555400000	24
5555421000	27	5555500000	25
5555431000	28	5555530000	28
5555531000	29	5552200550	29
5555542000	31	1555554000	30
5555554100	35	5555554000	34
5555554210	37	5444455500	36
5555554310	38	5555554211	38
5555555420	41	1045555555	40
5555555421	42	1515555555	42
5555555431	43	5555522555	44
5555555543	47	5555555255	47
5555555554	49	5555555554	49
5555555555	50	5555555555	50

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