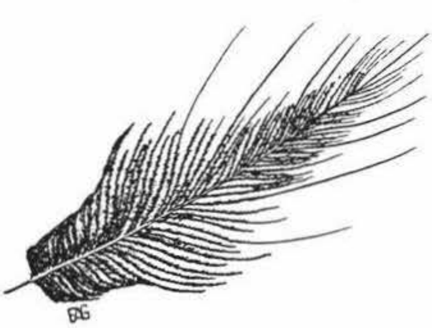
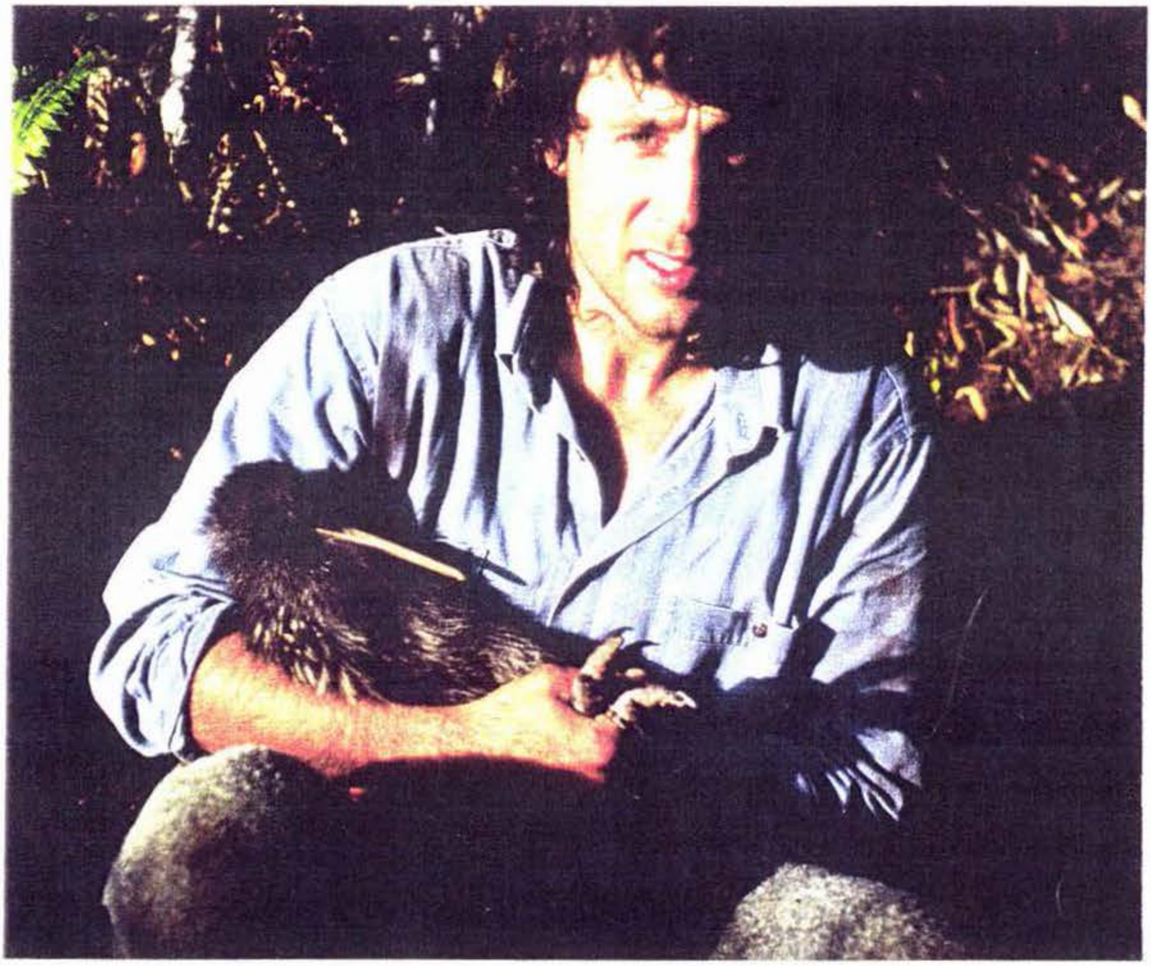
Comparative ecology of Northern brown kiwi (*Apteryx australis mantelli*) in Tongariro National Park and Tongariro Forest Park, central North Island.

Jonathan Roger Graham Miles
February 1995



A thesis presented in partial fulfilment of the requirements for the degree of Master of Science at Massey University, Palmerston North.



Frontispiece: Author holding "Tahi" (M.51) a Northern Brown kiwi male, Tongariro Forest Park, April 1994.

To my family and friends

'Like winds and sunsets,
wild things were taken for granted
until progress began to do away with them.
Now we face the question,
whether a still higher 'standard of living'
is worth its cost in things
natural, wild and free.'

- Aldo Leopold.

Acknowledgements

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This thesis will no sooner go to the binders than I will probably remember several other people who made important contributions. I apologise for any such omissions. Also, I must point out that despite the length of the list of those who assisted my efforts, I managed to make whatever mistakes all on my own.

This study was funded by Department of Conservation research contract 1489, Tongariro/Taupo Conservancy, Massey University, and my parents.

Abstract

Biological aspects of calling, range size, roost choice, feeding ecology, and potential threats faced by Northern brown kiwi (*Apteryx australis mantelli*) are described for a 14 month study in two conservation areas in central North Island, Tongariro National Park and Tongariro Forest Park.

In Tongariro Forest Park 73% of calls were made by males. The 3:1 ratio of male:female calls changed seasonally, with the proportion of female calls increasing over winter and spring. Total call rates also increased during these seasons. Between nights call rates varied irrespective of season. Temperature and rain accounted for 44% of this variation. During the night, calling behaviour was bimodal, with the majority of calls occurring in the first and last three hours of darkness. In winter and spring males called, on average, 20 minutes later than in summer and autumn. Thirty times more calls hour^{-1} were heard in Tongariro Forest Park than in Tongariro National Park. Density of kiwi was estimated to be 1 bird/km^2 in Tongariro National Park, and 4 birds/km^2 in Tongariro Forest Park. This suggests that call rates are not linearly related to the number of kiwi present in an area. Practical implications of this for the interpretation of kiwi call surveys are discussed.

Home ranges of kiwi varied from 30.8 to 91.8 ha. Range size of paired females tended to be larger than those of paired males. The range of an unpaired male was significantly larger than those of the paired males and paired females. Female home ranges overlapped more than male home ranges.

Kiwi varied considerably in their choice roost. Roost type was dependent on habitat type. Roosts associated with fallen trees and surface roots were the most frequently used type. Kiwi infrequently used one roost site more than once, those roosts that were reused were large burrows of unknown size. Male kiwi used surface vegetation more often than females, while the females favoured roosts associated with hollow logs, and/or roots. Territory size may be a consequence of habitat.

During 14 months of sampling, higher numbers and greater taxonomic diversity of invertebrates was found in Tongariro Forest Park than in Tongariro National Park with 55% of taxa common to both areas. Seasonal changes in the taxa found in faeces reflected seasonal changes in apparent invertebrate abundance. Kiwi also appeared to focus on a particular taxon, suggesting that they are selectively opportunistic feeders.

Mammalian predators pose a major threat to the long-term survival of kiwi in the central North Island. Predator surveys indicated possums, cats, dogs, and stoats were present in Tongariro Forest Park and Tongariro National Park. A ferret was caught in Tongariro National Park, and pigs were observed only in Tongariro Forest Park, but probably ferrets and pigs are present in both sites. No significant difference was found between the numbers of stoats trapped in the two study areas. Local morphometric variation appeared to occur, with adult male stoats collected in Tongariro National Park being larger, on average, than their counterparts collected in Tongariro Forest Park. There were differences between areas in the average size of prey items with the average size of prey being larger in Tongariro Forest Park than in Tongariro National Park.

Future conservation and management issues for Northern brown kiwi are discussed.

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Chapter 1

1.1 Introduction

Kiwi are part of a small family of flightless birds known as ratites. Three species of kiwi, all within the genus *Apteryx*, are extant in New Zealand today. This study deals with the Northern brown kiwi (*Apteryx australis mantelli* Bartlett).

Kiwi are unusual birds in their morphology, anatomy, physiology and behaviour (Potter, 1989). Even among the ratites they are considered peculiar (Handford and Mares, 1985). In particular, their egg to body weight ratios are extremely large (Reid, 1971a; Calder, 1978, 1979; Rowe, 1980), their 74 - 84 day incubation period is exceeded only by albatrosses, *Diomedea* spp. (Lack, 1968; Rahn and Ar, 1974; Calder et al., 1978), and relative to their size and metabolic rate kiwi lead all birds in the amount of energy invested in the egg (Reid, 1971b; Calder *et al.*, 1978).

Potter (1989) provides a bibliographic overview of early research on kiwi. Detailed discussions on early research are presented in Peat's book *Incredible Kiwi* (1990) and Fuller's *Kiwis* (1990). Knowledge of kiwi feeding habits has largely come from the study of birds in captivity, or the analysis of dead birds (Gurr, 1952; Robson, 1958; Bull, 1959; Wenzel, 1968; Reid, 1970, 1972a; Reid *et al.*, 1982; Watt, 1971; *cit.* Potter, 1989). Diet has also been studied by faecal analysis (Kleinpaste and Colbourne, 1983; Colbourne and Powlesland, 1988, Colbourne *et al.*, 1990)

The first information on kiwi spacing behaviour came from vocalisation surveys (Corbett *et al.*, 1979; Jolly, 1983, Taylor and Calder, 1983; Colbourne and Kleinpaste, 1984; Rasch and Kayes, 1985). In the early 1980's significant advances in radio telemetric techniques enabled researches to enter the world of this secretive bird (Jolly, 1983; McLennan, 1988; McLennan *et al.*, 1987, 1991; Potter, 1989, 1990; Taborsky and Taborsky, 1991, 1992). As a result of following kiwi over long periods of time, these studies highlighted that kiwi on mainland New Zealand face a collection of problems. The major threats faced are habitat loss (McLennan *et al.*, 1987; Potter, 1989, 1990), predation by dogs and mustelids (Taborsky, 1988; McLennan and Potter, 1992, 1993; J.A McLennan *pers. comm.*), and death from the incorrect use of poison baits and traps to catch possums (*Trichosurus vulpecula*; McLennan, 1987).

In this study two adjacent kiwi populations within the Tongariro/Taupo Conservancy were studied. One population is within Tongariro National Park where dogs are prohibited, and trapping is regulated. The other population is in Tongariro Forest Park where hunting for pig (*Sus scrofa*), red dear (*Cervus elaphus*), and possum is controlled, dogs have free access, and unlike Tongariro National Park has been heavily modified through logging.

Conservation of mainland kiwi must be of utmost priority not only for scientific reasons such as increasing our knowledge of their unusual behavioral and physiological characteristics (Potter, 1989), but also for ethical reasons. It will be a sad day if kiwi exist only on offshore islands, where they will be accessible to few.

1.2 Aim of the study and thesis plan

Aim

The primary aim of this study was to identify threats to the continued survival of kiwi and, where appropriate, to recommend changes to management practices that will benefit kiwi in the Tongariro Taupo Conservancy. This was tackled by call surveying, looking at home range size, habitat type and roost quality, resource availability and utilisation, and by indexing potential threats faced by kiwi in two adjoining conservation areas: Tongariro National Park and Tongariro Forest Park (location map Figure 1.1).

Thesis lay out

The thesis is presented in four primary chapters. Chapter 2 sets out firstly to use call rates as an estimate of kiwi density, and secondly to analyse the ecology of kiwi calling behaviour. Questions addressed include when kiwi call, what time of the year they call most often, and which environmental conditions influence calling. This chapter also deals with the practical implications of kiwi calls. The biological information is used to establish more precise sampling methods, and therefore, to use call surveying to accurately estimate kiwi density.

Chapter 3 compares home range size of Northern brown kiwi in central North Island with other studies, and describes the importance of habitat type with respect to daytime roosts, shelter, and range size.

Chapter 4 is concerned with the diet of kiwi in Tongariro National Park and Tongariro Forest Park. Differences between amounts of food species utilised in the two areas as judged by faecal analysis are correlated with availability of invertebrates by use of an invertebrate survey.

Chapter 5 provides an index of predators which pose a potential threat to kiwi in both study areas. The chapter also includes a detailed look at the stoat (*Mustela erminea*), which is one predator that has adjusted quickly to the variety of ecosystems available in New Zealand. Local variation between stoats collected in Tongariro National Park and Tongariro Forest Park is discussed.

Finally, results from the preceding chapters are drawn together in Chapter 6 where recommendations for future conservation and management of Northern brown kiwi are made.

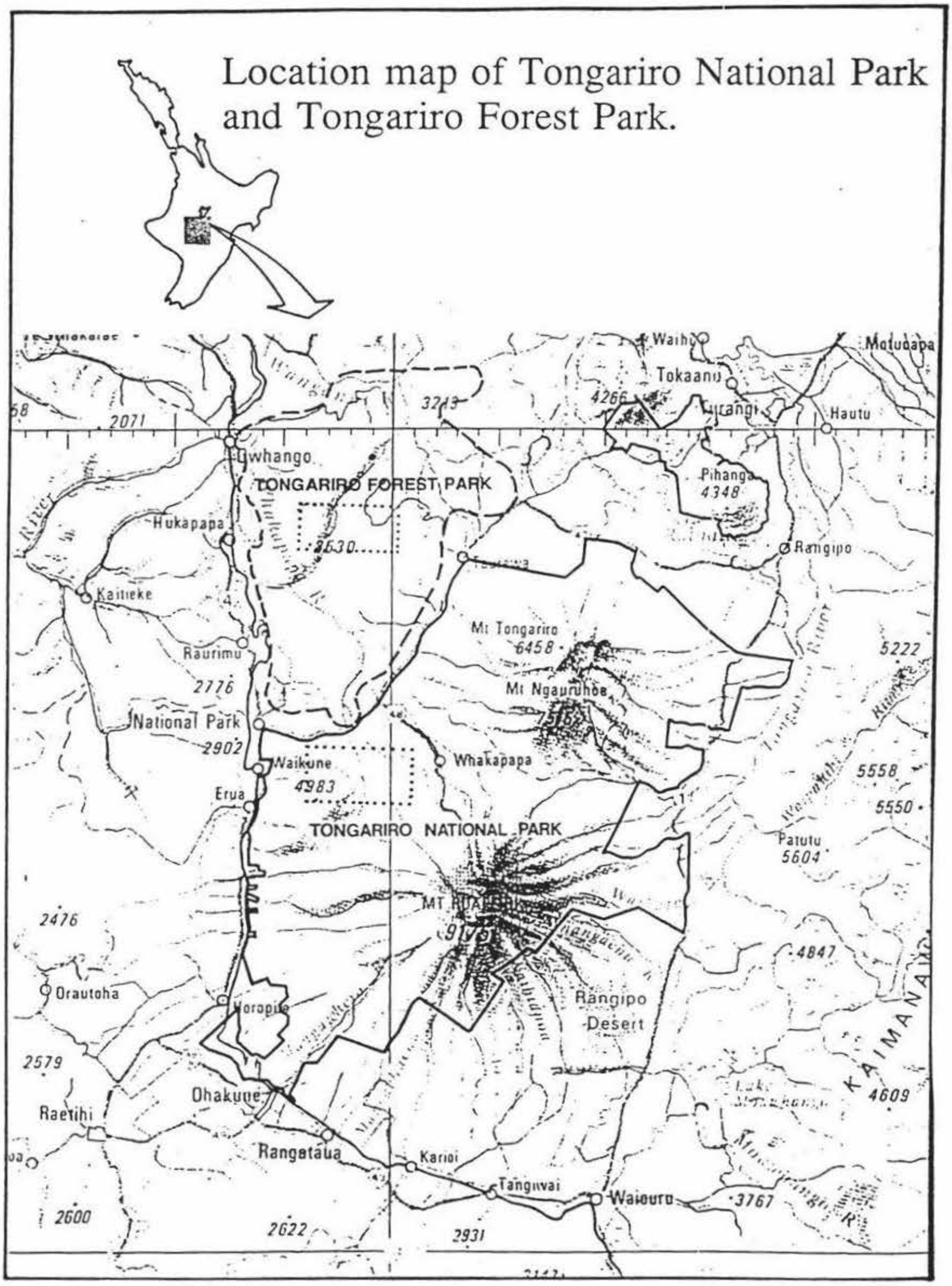


Figure 1.1 Location of Tongariro National Park and Tongariro Forest Park. The dotted areas (•••••) represent the study areas, refer to Figure 2.1 for detail.

Chapter 2

Biological aspects of calling and the practical implications in a population of Northern brown kiwi, *Apteryx australis mantelli.*

2.1 Introduction

Most techniques for censusing birds have been developed for use on diurnally active species. Few techniques are available for censusing nocturnal birds (Southern and Lowe, 1968; Cadbury, 1981; Mead, 1987). In assessing the abundance of any species an initial choice must be made between methods which seek to establish the actual number of breeding adults, and methods which seek merely to index numbers (McLennan, 1992). While counting birds can be fraught with problems (Bibby *et al.*, 1992), many of these problems can be overcome by taking adequate care and by being aware of the limitations of the method used.

Absolute counts of kiwi (*Apteryx* spp.) are difficult to obtain in the wild because the birds are nocturnal, secretive, and seldom seen. Counts of adults and juveniles are only possible with the help of dogs trained to find the birds in their daytime shelters. This census method is most useful for surveying high density populations. In low density populations it is seldom used because it is too time consuming to apply to large areas of forest. Other methods that can be used during daylight for indexing abundance of birds are not useful for extensive monitoring of kiwi, despite their obvious conveniences (McLennan, 1992).

Although kiwi are seldom seen, they make themselves known by calling at night. In doing so they reveal their sex, and sometimes their identity. Calls are audible from a kilometre or more in still conditions. This means that large areas can be surveyed from a single, well chosen position, and sparse populations of kiwi can be detected with much less effort than would be required by searching for them with trained dogs (McLennan, 1992). The technique has already been used widely, both to compare abundance of kiwi in different areas (Corbett *et al.*, 1979; Colbourne and Kleinpaste, 1984; Kayes and Rasch, 1985), and to monitor changes in population density over time (McLennan and Potter, 1992; Kayes and Rasch, 1985). The underlying assumption when using this method is that some relationship exists between call rate and local population density (McLennan, 1992), although the nature and form of it are virtually unknown (Napper, 1989).

A problem that exists when call surveying is that kiwi call less on some nights than others (Colbourne and Kleinpaste, 1984). Much of this variation appears to be unpredictable, so it is often impossible to tell in advance whether it is going to be worthwhile to survey on a particular night (McLennan, *in prep*). Some of this variation in call rate can be accounted for by season (Best, 1981; Colbourne and Kleinpaste, 1984; Kayes and Rasch, 1985; McLennan, 1992), time of sampling (Skirvin, 1981), and environmental factors (Richards, 1981; Robbins, 1981). However, variation in call rates, per se, is not a major problem, provided sufficient samples are taken from any one locality to include both the highs and lows in call rates. In practice this is often not done. Surveyors also often differ in the methodology they use for sampling call rates, making it difficult or impractical to compare results (McLennan, 1992).

My aim was to describe the calling behaviour of Northern brown kiwi (*Apteryx australis mantelli*) in two conservation areas in the Central North Island, to identify how this varies within and between nights and over season, to look at the relationship between call rate and population density, and to define procedures that should be followed when obtaining population indices from kiwi call rate samples.

2.2 **Study area**

The study was undertaken at two sites in the central North Island. The main study area was situated in Tongariro Forest Park (T.F.P.) (NZMS S19, 237367) 19 km north/west of the Tongariro National Park (T.N.P.). This site, formally a lowland-podocarp forest, has been logged and burnt from 1903 through to 1972. The landscape comprises nearly an even blend of toetoe (*Cortaderia toetoe*), with remnant stands of podocarp forest rimu (*Dacrydium cupressinum*), miro (*Prumnopitys ferruginea*), and totara (*Podocarpus hallii*). The valley floor is 500 m a.s.l. and is flanked by steep hills rising to 900 m a.s.l. The mean annual daily temperature ranged from 9 °C to 18 °C, and average rainfall in 1993 was 101.64 mm per month (Whakapapa meterological station).

The second study area in T.N.P. (NZMS S20, 240185) was situated on the western side of Mt. Ruapehu. Here the forest consists of a monotonous canopy of mountain beech (*Nothofagus solandri var cliffortioides*), with occasional emergent kaikawaka (*Librocedrus bidwillii*) and Halls totara (*Podocarpus hallii*). The understorey contains a diverse array of species: mountain beech, kaikawaka, and totara saplings, mountain toatoa (*Phyllocladus aspleniifolus*), *Coprosma* spp., mingimingi (*Leucopogon* spp., bush lawyer (*Rubus cissoides*), and many other divaricating species, all forming an extremely dense wall of vegetation. From highway 47 on the western side of Mt. Ruapehu the Mangahuia track climbs from 883 m a.s.l. to the study area at 1026 m a.s.l.. Mean annual daily temperature ranged from 2.1 °C to 11.3 °C, and the average monthly rainfall during 1993 was 169.4 mm.

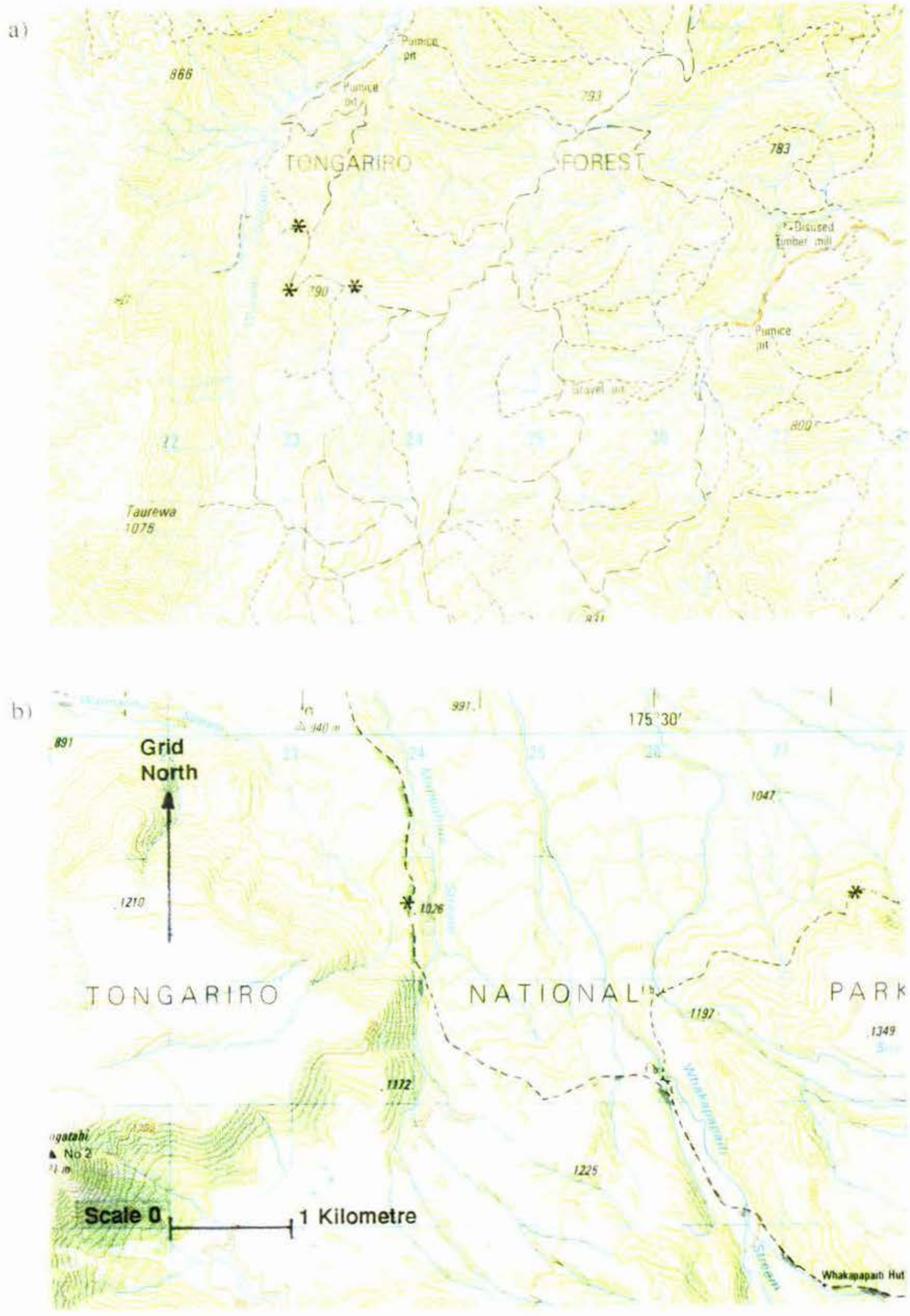


Figure 2.1 Location of listening stations (✻) in a) Tongariro Forest Park (n = 3) and b) Tongariro National Park (n = 2) used between December 1992 to December 1993.

2.3 **Methods**

Both study sites were visited once a month between November 1992 and December 1993. Each visit to T.N.P. was 4 - 5 days long, while 10 - 15 days were spent each month in T.F.P. Kiwi call rates (calls hour^{-1}) were sampled throughout the night. Three listening stations were used in T.F.P., and two in T.N.P. (Figure 2.1).

During each listening period the time of the call, the sex, approximate location (bearing in degrees using a Sunnto magnetic compass), and the approximate distance to the bird that called were recorded. Twelve environmental variables were measured (Appendix 1). Two were taken from meteorological information, temperature was recorded from the field station (wet and dry bulb thermometer), and the remaining nine variables were the subjective measures found on the standard kiwi call card scheme cards (Appendix 2). Variables such as rain and moonlight were scored by intensity.

Approximately 40% of the time spent call surveying was dedicated to testing the value of broadcasting taped male and female calls to enhance 'natural' call rates. The majority of time spent broadcasting was in the first two hours of darkness. Calls were broadcast every 10 to 15 minutes in alternately the first and second hour over consecutive nights. This gave a measure of 'natural' call rates versus 'solicited' call rates.

Calls were classified as territorial responses if they occurred within 5 minutes of either a neighbouring call or broadcast call (Appendix 4). A duet was classified as a response of paired birds to their mate within 2 minutes after that call (Appendix 5).

2.3.1 Statistical analysis

Multivariate analysis using a standardised stepwise procedure was run in SAS (SAS proc stepwise; SAS Institute, 1985) on the 12 recorded variables (Section 2.4.4; spreadsheet Appendix 3). This stepwise procedure isolated extrinsic factors affecting and not affecting calling rate. These factors were then grouped into favourable and unfavourable nights for calling (Table 2.1). These two data sets were then compared using Student's t-test. This test was also used to examine any effect of intensity of moon light on the calling behaviour of this population of kiwi (Table 2.3).

The effects of weather changes, ie: a change from wet to dry, or dry to wet, versus calling activity over periods of stable weather were tested with an analysis of variance procedure in Minitab (ANOVA; Table 2.2). This procedure was also used to test whether there was a change in male calling activity with regard to the time of first male call heard after sunset (Section 2.4.3).

A t-test was used to test for differences in means of call rates when broadcasting and not broadcasting calls (Section 2.5.2). This same test was used when comparing the effectiveness of male versus female broadcasted calls (Section 2.5.3). Differences were regarded as significant if $P \leq 0.05$. Critical values for all statistics were obtained from Zar (1984).

2.4 **Results**

The first five sections (2.4.1 - 2.4.5) focus on the higher density population of Northern brown kiwi in the study area in Tongariro Forest Park.

2.4.1 Origin of calls

Northern brown kiwi in T.F.P. lived throughout the year in territories ranging in size from 30.29 ha to 91.79 ha (Chapter 3). The sex ratio of this population was estimated to be about 1.25:1 (males:females), consisting of eight paired birds and two unpaired males. Male calls accounted for 73.5% of those heard (n = 1065), with females making up the remaining 26.5%. This ratio (3:1) did however change seasonally (Section 2.4.5).

Territorial male calls (Appendix 4) made up the main component of the overall call rate. Of the 783 calls recorded from 9 males, 24% were involved in duets (responses to their mates, or other female kiwi Appendix 5); 18% were in response to broadcasted calls (a response ≤ 5 minutes after a broadcast call; Appendix 4); and the remaining 58% were involved either in territory defence or mate location. A total of 282 calls were recorded from 7 females over the course of the study. Of these, 58% (n = 163) were involved in duets with their mates, 5% (n = 15) were in response to other bonded male calls, 3% (n = 9) were answered by other bonded males, and 17% (n = 48) were in response to broadcasted calls. Of the remaining calls (n = 47), 20 were in response to neighbouring females, while 27 calls were unaccounted for.

2.4.2 Intra-pair calling

The majority of duets (87%) were performed by members of bonded pairs. However, on 5% of occasions females of a bonded pair were answered by a male of another bonded pair, and on 6% a male of a bonded pair was answered by a female of a bonded pair. On 2% of occasions an unbonded male responded to a female of a bonded pair.

Twenty-one percent of all male calls (n = 783) and 58% of all female calls (n = 282) either preceded, or followed, a call from their mate. Both sexes initiated duets, but males usually called first (62% of occasions, n = 187). Duets were most common over the breeding season, from May through to October (Figure 2.2).

2.4.3 First calls after sunset

From September through to March kiwi began calling in the half-light of dusk. This pattern changed over the winter months when calling started later. The time to the first call after sunset was proportional to night length. Figure 2.3 shows that in summer kiwi seem to become active earlier than in winter, enabling them to maintain the same nightly length of activity throughout the year.

After removing female calls from the data set a plot showing the mean time elapsed between sunset and the first male call was constructed (Figure 2.4) The interval between sunset and the first calls by males differed significantly over the year (ANOVA, $F_{[1,57]} = 3.73$, $P = 0.017$).

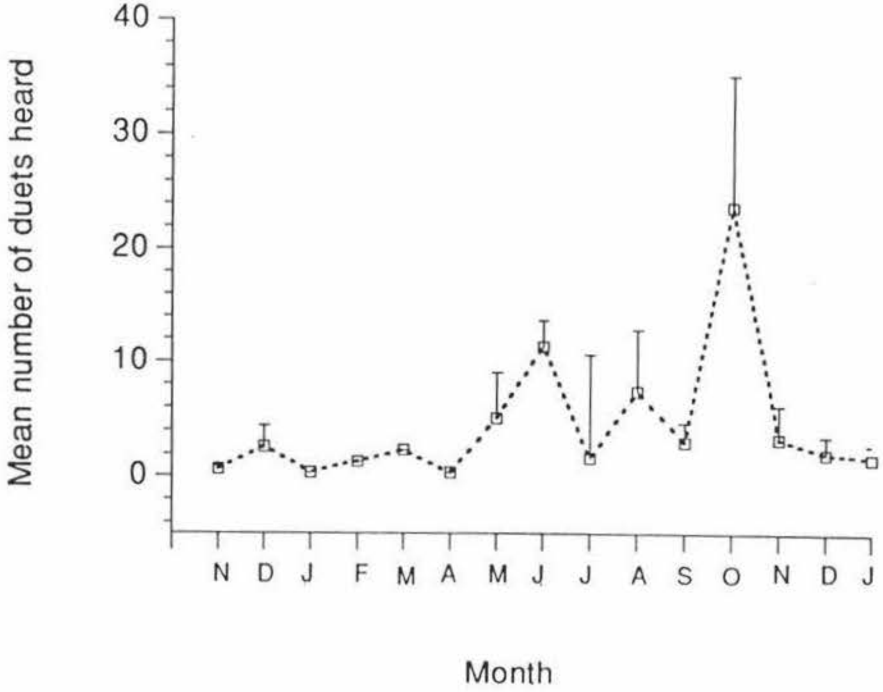


Figure 2.2 Average number of duets (± SE) heard for every 24 hours of listening, November 1992 to December 1993, in Tongariro Forest Park.

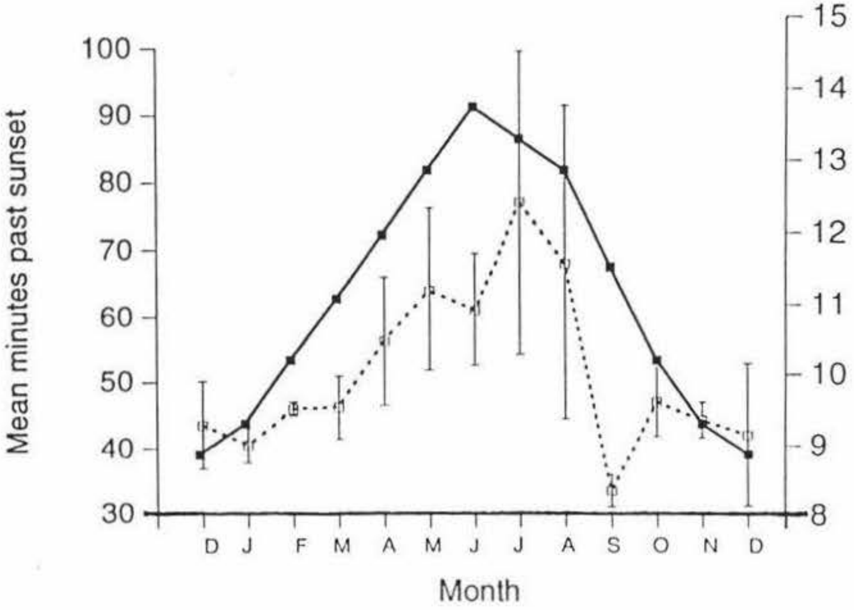


Figure 2.3 Time after sunset when the first kiwi call (-----) was heard during different months and night length (hours of darkness; ——) in Tongariro Forest Park, December 1992 to December 1993.

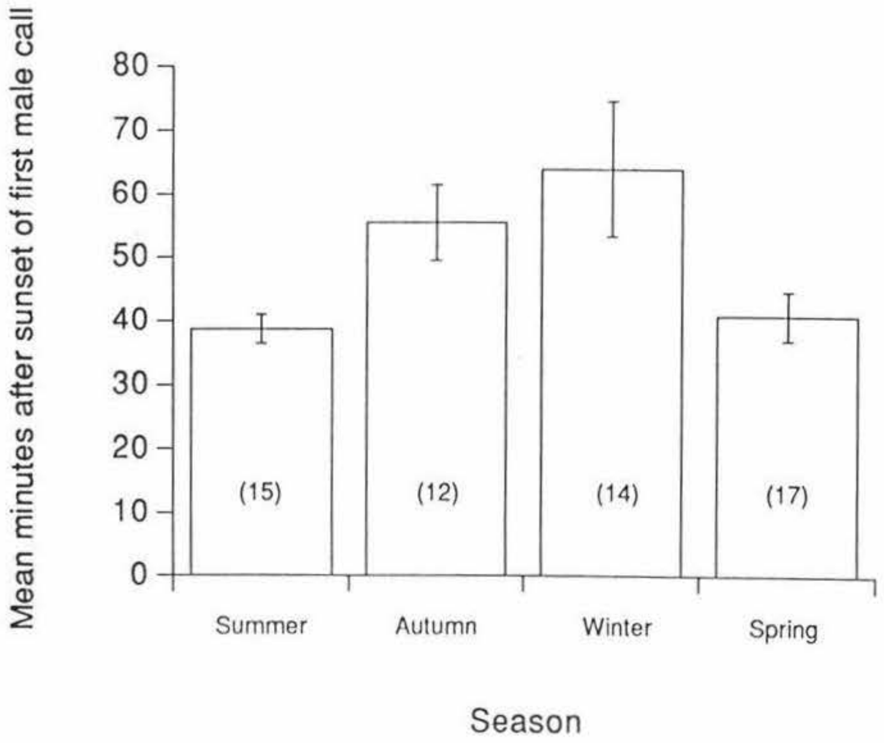


Figure 2.4 Mean time elapsed (minutes) between sunset and first male call. Sample sizes shown in brackets.

2.4.4 Changes in call rates

Call rates varied seasonally (Figure 2.5a), increasing steadily from late autumn to a peak lasting through to the end of spring. They then declined by about 62% over summer. Much of the increase in calling behaviour can be accounted for by the increase in intra-pair calling. Of the duets performed by members of bonded pairs ($n = 173$) 82% occurred over the breeding months, May to October.

Breeding behaviour accounts for some of the variation in call rates heard and appears to override any effects of other factors such as moonphase, temperature, wind, and rain. This is illustrated in Figure 2.5b which shows calling activity across seasons after duets are removed. Irrespective of season, however, kiwi did call less on some nights than others. A standardised stepwise procedure using SAS to determine which factors other than season accounted for variation in calling activity showed (Appendix 3) in step 1 rain explained 21% of the variance in call rate (R-square = 0.21), although by itself rain was not significant (Prob>F = 0.07). However, temperature and rain together (step 2) explained 44% of the variance in call rates between nights (R-square = 0.44), and the model is significant (Prob>F = 0.03). When ground condition was entered in step 3, the model remained significant (Prob>F = 0.04), but ground condition by itself was not significant (Prob>F = 0.24), and therefore did not contribute significantly to the predictor model. Beyond step 3 the model was no longer significant (Prob>F = 0.08). The best two-variable predictor model to fit a linear function to the call data is the equation:

$$Y = 1.67 + 0.09\ (\text{Temperature}) - 0.68\ (\text{Rain})$$

A total of 255 hours were spent within hearing range of five radio-tagged individuals. Their average call rate hour^{-1} was significantly lower during rain than during dry periods (Table 2.1). When low temperatures and moderate to heavy rain occurred together the call rate was further reduced (Figure 2.6). Overall kiwi were also significantly less vocal on the first wet night following a dry spell (Table 2.2). Environmental conditions accounted for 44% of the between night variation in call rates in T.F.P., leaving 56% of the variation unexplained. Call rates of these brown kiwi did not correlate with light levels (Table 2.3), nor with the phase of the moon (SAS Appendix 3 step 4; intensity of moon light entered but not significant, Prob>F = 0.61).

Table 2.1 Average call rates hr^{-1} (± SE) in T.F.P. during fine nights and during nights with rain.

Fine nights	Unfavourable nights
N Mean ± SE (53) 3.34 ± 0.24	N Mean ± SE (25) 2.27 ± 0.32

(t-test; t = 2.68, df = 50, P = 0.01)

Table 2.2 Average call rates hr^{-1} (± SE) in T.F.P. in relation to weather changes. The first column includes counts from both wet and dry nights.

No change between nights	Change from wet to dry	Change from dry to wet
N Mean ± SE (55) 3.2 ± 0.3	N Mean ± SE (11) 3.8 ± 0.6	N Mean ± SE (23) 1.6 ± 0.31

(ANOVA, $F_{[1,88]} = 7.88$, P = 0.001)

Table 2.3 Average call rates hr^{-1} (± SE) in T.F.P. in relation to the presence or absence of moonlight.

Moon full and visible	No moon
N Mean ± SE (31) 2.73 ± 0.31	N Mean ± SE (58) 2.97 ± 0.23

(t-test; t = 0.62, df = 62, P = 0.54)

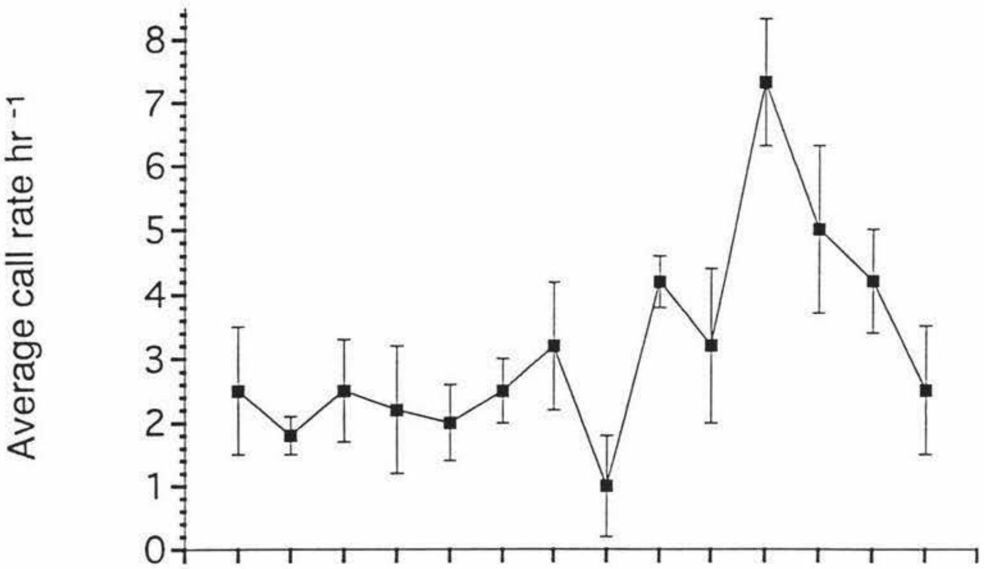


Figure 2.5a Seasonal variation in the calling rates of kiwi in Tongariro Forest Park, December 1992 to January 1994.

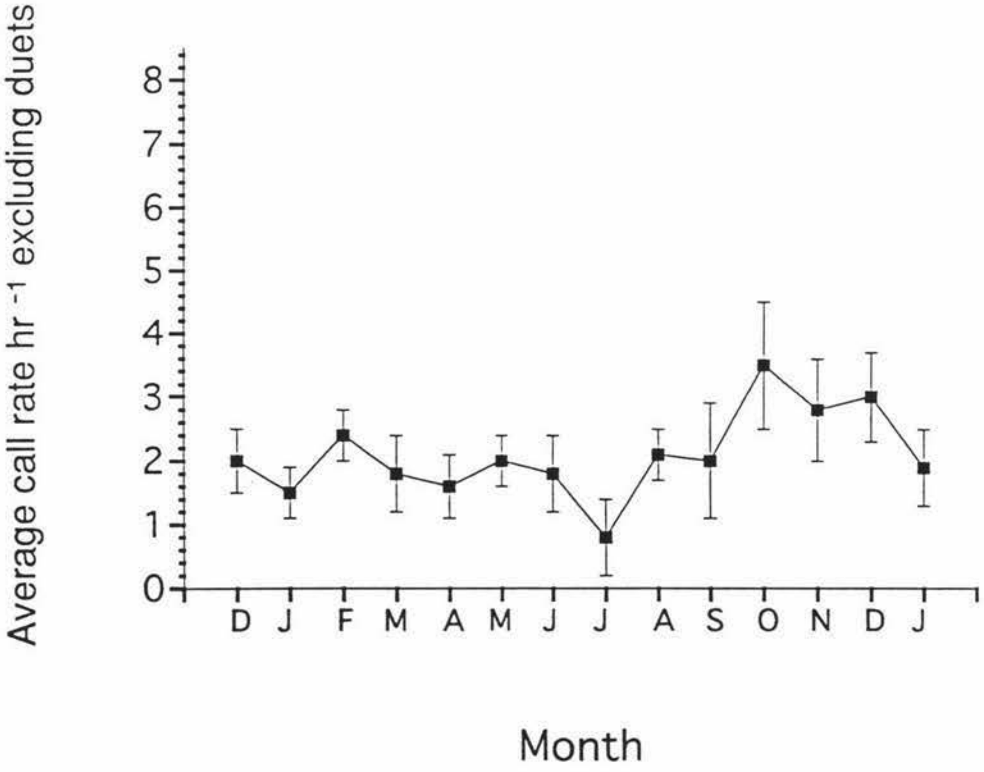


Figure 2.5b Calling rates of kiwi in Tongariro Forest Park with intra-pair calling (duets) removed.

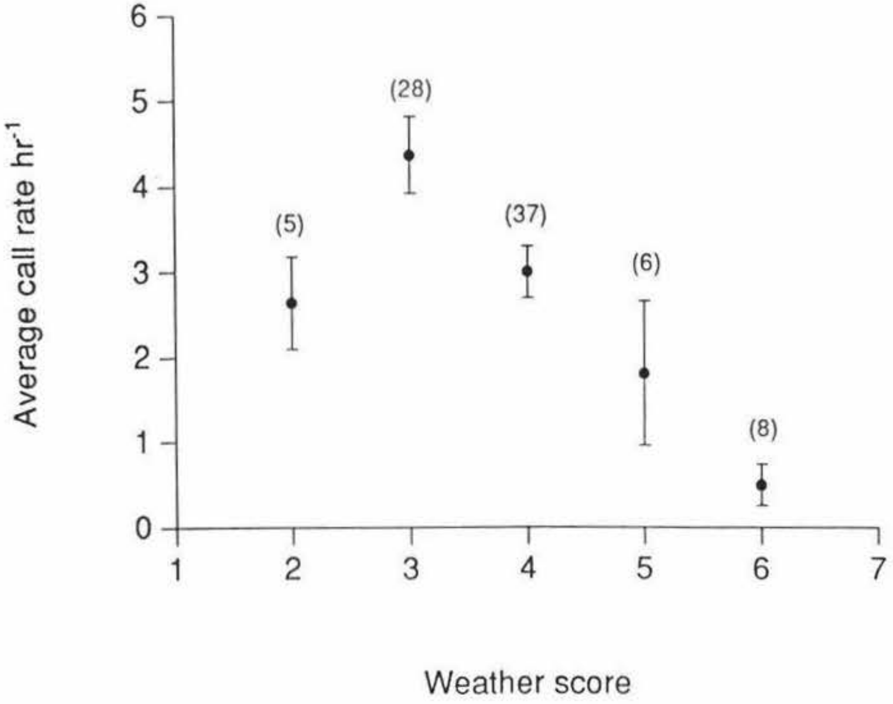


Figure 2.6 Average calling rates (± SE) of kiwi in Tongariro Forest Park in relation to weather. Rain was scored on a 1 - 3 scale, with 1 representing no rain, 2 light rain, and 3 moderate/heavy rain. Temperature was also scored on a 1 - 3 scale, with 1 representing warm temperatures, 2 mild, and 3 cold. The two scales were added together to give the weather score. Numbers in brackets refer to sample size.

2.4.5 Variation within nights

Kiwi called in two bouts during the night, and this bimodal pattern persisted throughout the year (Figure 2.7). Call rates were highest in the first two to three hours of darkness, and again during the last two to three hours of darkness. The first peak consisted mainly (75%) of male calls while the second peak comprised a more even ratio of male and female calls (65%:35%). The ratio of male to female calls making up these peaks also varied seasonally (Table 2.4).

Table 2.4 Seasonal ratio of male : female calls heard in the first and second halves of the night (hours of darkness / 2) in T.F.P. Numbers in brackets refer to number of duets heard.

Half of night	Summer	Autumn	Winter	Spring
First	4:1 (9)	3:1 (22)	2:1 (36)	4:1 (31)
Second	–	–	2:1 (25)	2:1 (53)

2.4.6 Relationship between call rates and density in Tongariro

The populations of Northern brown kiwi in T.N.P. and T.F.P. differed in size. Seven pairs, one male with an unconfirmed mate, and a satellite male in T.F.P. had territories which fell either partly or entirely within one kilometre of the listening stations. Members of four of these pairs, plus the male with an unconfirmed mate were heard only periodically, depending on where they were in their territories. From the listening stations in T.N.P. four individuals (one female and three males) were heard calling. Two of these birds were a pair. The other male apparently had a mate (her foot prints were found), but she never called. The third male may also have had a mate, but if so she never called.

A total of 14 calls were heard during the 133 hours (mean = 0.1 calls hour^{-1}) spent call surveying in T.N.P. In comparison 1065 calls were heard during 345 hours (mean = 3.0 calls hour^{-1}) in T.F.P. Radio-tagged kiwi were located on average 65.8

(range = 36 - 92; n = 5) times during the day, and radio tracked at night on average 105 (range = 17 - 179; n = 5) times, over 12 months. Using information on the positions of radio-tagged individuals and relating this to the calls heard, estimations of population density were obtained. The density of kiwi in T.N.P. was estimated to be 1 bird/km^2, while in T.F.P. it was 4 birds/km^2.

Figure 2.8a shows the average call rates versus the estimated density of Tongariro kiwi. The boxes represent standard error from the mean, while the whiskers show one standard deviation from the mean. The length of the whiskers illustrate the variance in call rates between nights, and between seasons. For example call rates in T.F.P. ranged between zero and 16 calls heard in one hour. Much of this variation is associated with time of night, time of year, and environmental conditions. When fitting a line to figure 2.8a only the standard error is required. The number of sample nights in T.N.P. was 55, and in T.F.P. it was 102 nights. The linear function represents a doubling of the call rate for every doubling of density. The data do not fit this model because with a four fold increase of kiwi density on the ground there was a 30 fold increase in call rate. This falls closer to an exponential function and this curve is fixed through 0/0 (no kiwi/no calls), and the two data points. Both Tongariro populations contain relatively low densities of kiwi. Adding information from other kiwi populations where the density of birds, and the average call rates are both known suggest that a linear function best describes the relationship between kiwi density and average call rate hour^{-1} over a large range of densities (Figure 2.8b).

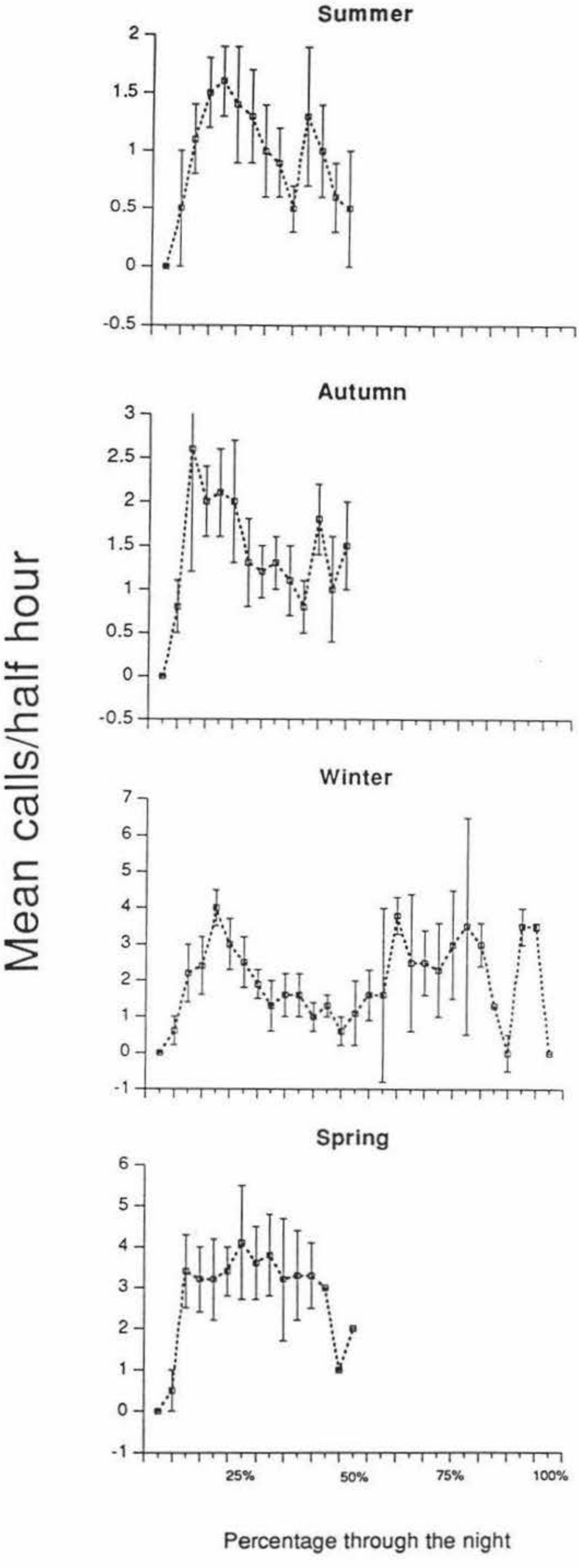


Figure 2.7 Average calling rates (± SE) per season of kiwi in Tongariro Forest Park in relation to the percentage of the night which had elapsed when the calls were heard. Midnight = 50%, and sunrise = 100%.

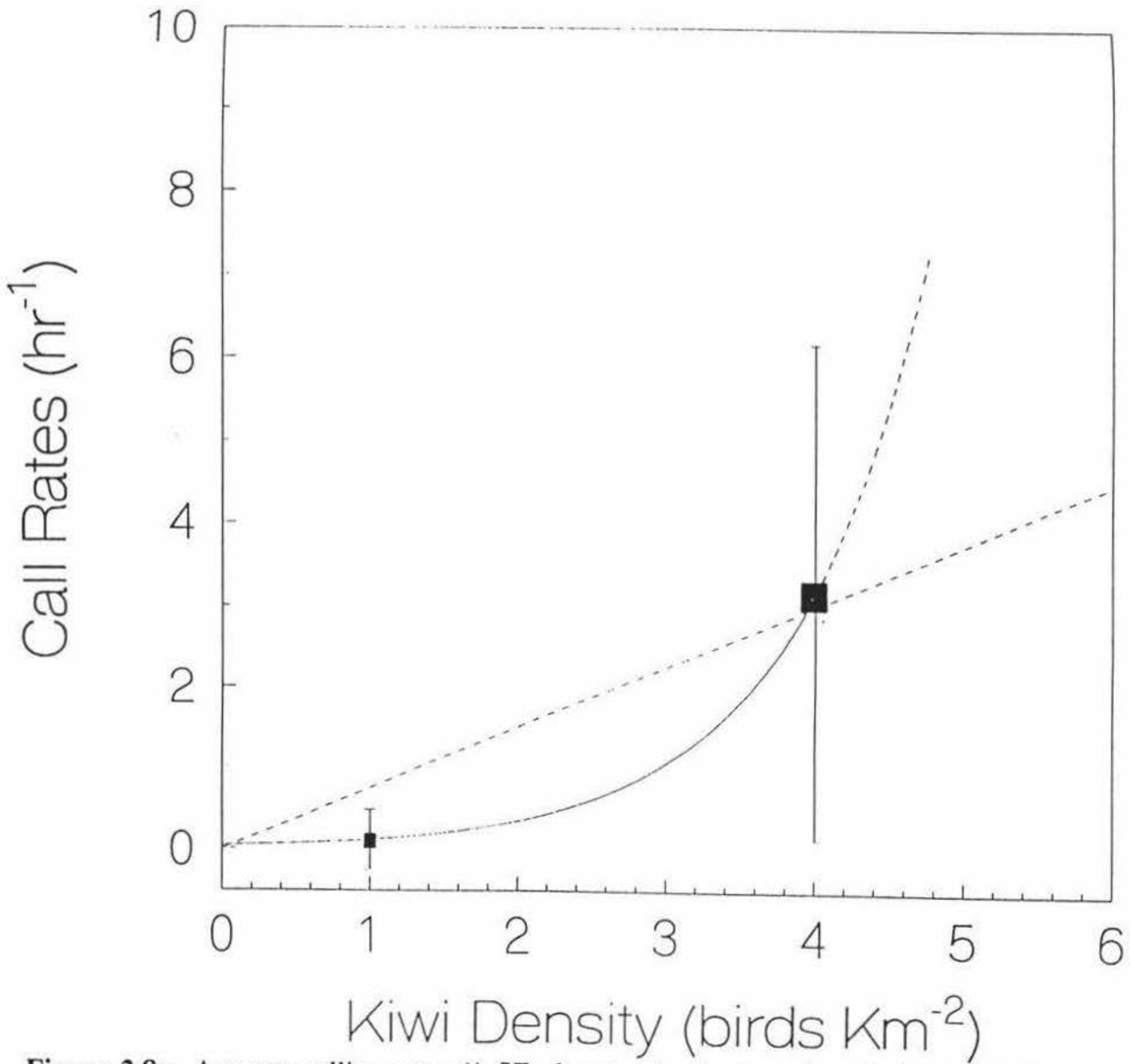


Figure 2.8a Average calling rates (± SE, denoted by the box size; ± single SD from the mean) of kiwi in Tongariro National Park (n = 55), and Tongariro Forest Park (n = 102). The dashed line represents a linear function, the curve is fixed at 0/0 and is fitted to the two points, and forms the density call rate curve for Tongariro kiwi. The dotted line represents the continuation of the exponential function.

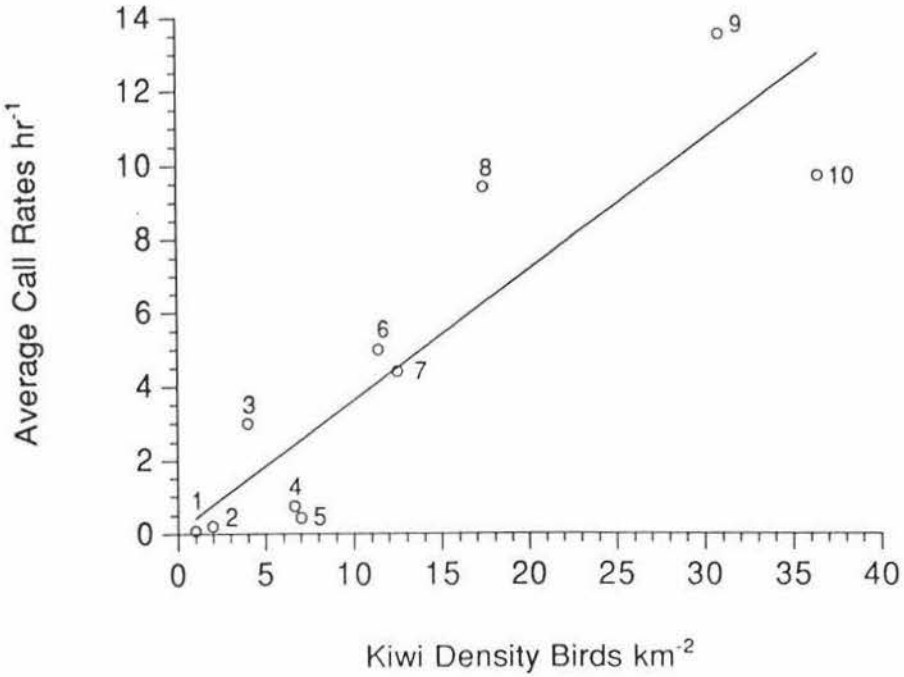


Figure 2.8b Call rate versus kiwi density; 1 and 2 represent Tongariro National Park and Tongariro Forest Park respectively. The other references for birds per km^2: 3, Okarito (Lyall *pers. comm*); 4, Kaweka Range (McLennan *pers. comm.*); 5, Fiordland: Junction Burn (Colbourne, 1987 and 1988; *cit.* Napper, 1989); 6, Stewart Island: Scollays Flat (Colbourne and Powlesland, 1988); 7, Fiordland: Camelot River (Colbourne, 1987 and 1988; *cit.* Napper, 1989); 8, NW Nelson: Gouland Downs (McLennan, *pers. comm.*); 9, Waitangi (Kayes and Rasch, 1985); 10, Stewart Island: Masons Bay (Colbourne, 1988; *cit.* Napper, 1989).

2.5 **Practical implications**

2.5.1 Analysis of the first calling peak

Eighty-one hours was spent surveying during the first four hours after sunset in T.F.P. (Figure 2.9). Histograms represent the total number of calls heard in these hours. The line represents the percentage probability of no calls being heard in that particular hour. Percentage probability was obtained by dividing the number of times no calls were heard in each of the four hours by the number of hours spent listening (n = 81). Significantly more calls were heard in the third hour of darkness than in the first and fourth hours ($X^2 = 16.67$; df = 3, $P<0.001$). There is also a greater chance of hearing calls in this hour (Figure 2.9).

2.5.2 Broadcasting calls in areas with different kiwi densities

Over 61 nights in T.F.P. 226 calls were heard when broadcasting calls in either the first or second hours, and 150 calls were heard when not broadcasting calls in the alternate hours. Thus there were significantly more calls heard in the hours when calls were broadcast (Table 2.5).

Broadcasting calls only elicited responses from kiwi in the higher density population. In T.N.P. over 45 nights were spent broadcasting and listening in alternately the first or second hour. A total of 7 calls were heard when passively listening, and 7 were heard in the hour when broadcasting. Only 5 of these 7 calls were in response to the broadcast calls. A response was deemed to be any call heard within 5 minutes of a broadcast call (Appendix 4). There was no significant increase in call rates when broadcasting calls in this population (density 1 bird/km^2; Section 2.4.6).

When comparing between consecutive nights there was no difference in call rate if broadcasting in the first hour and not broadcasting in the first hour (Table 2.6). This was also the case for the second hour (Table 2.7).

Table 2.5 Change in average call rate hr^{-1} (± SE) in response to broadcast calls, December 1992 to November 1993. Calls heard in the absence of broadcasting comprise the "natural" call rate.

Hour when broadcasting	Hour when not broadcasting
N Mean ± SE (61) 3.41 ± 0.33	N Mean ± SE (61) 2.46 ± 0.30

(t-test; $t = 2.12$, $df = 119$, $P = 0.036$)

Table 2.6 Change in average call rate hr^{-1} (± SE) in response to broadcast calls in the first hour of darkness.

Broadcasting in first hour	Not Broadcasting in first hour
N Mean ± SE (27) 3.30 ± 0.45	N Mean ± SE (37) 2.95 ± 0.43

(t-test; $t = 0.56$, $df = 59$; $P = 0.58$)

Table 2.7 Change in average call rate hr^{-1} (± SE) in response to broadcast calls in the second hour of darkness.

Broadcasting in second hour	Not broadcasting in second hour
N Mean ± SE (24) 2.96 ± 0.58	N Mean ± SE (24) 3.21 ± 0.57

(t-test; $t = 0.31$, $df = 45$, $P = 0.76$)

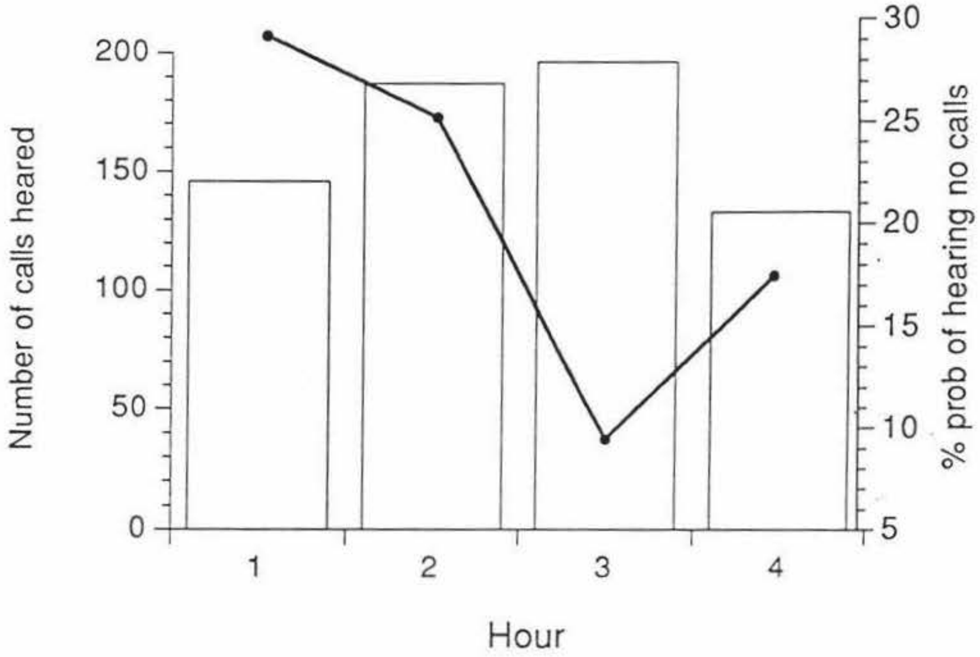


Figure 2.9 Total number of calls heard in the first four hours of darkness (histograms). The line represents the percentage probability of no calls occurring in that particular hour.

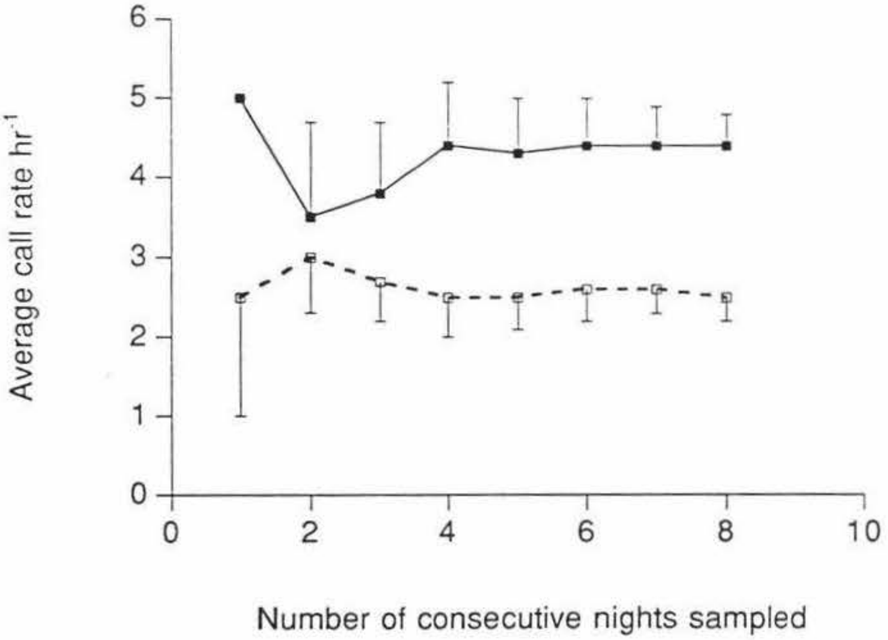


Figure 2.10 Effects of increasing sample size on estimates of average calling rate (± SE) - -□- = Tongariro Forest Park in March 1993; —■— = Tongariro Forest Park in October/November 1993.

2.5.3 Which calls elicit the greatest response

Kiwi calls are sexually dimorphic so that a broadcaster has the choice of playing a male or female taped call. In T.F.P. females responded more to a taped female call than to a taped male call (Table 2.8), but the difference was not statistically significant. For males, however, there was a significantly higher response to a broadcast female call (Table 2.9). Overall, taped calls of either sex induced significantly more responses from males than from females (Table 2.10).

2.5.4 Length of sampling needed

As shown in sections 2.4.1 to 2.4.6 there is great variation in call rates from one night to the next. In the most extreme case recorded in T.F.P., call rates varied from 0 calls hour^{-1} to 16 calls hour^{-1} over two consecutive nights. Figure 2.10 shows that irrespective of season about 4 to 5 consecutive nights of data are needed to accurately estimate average call rates. Even then the standard error of the mean is still high (at about 16% to 18% of the mean), but this reduces by about half if sampling continues for a further 2 to 3 nights.

2.5.5 Territory mapping

To map all 16 individual kiwi in a 1 km radius from listening stations using individual identification from calls took eight consecutive nights, totalling 32 hours. This estimate of density provided an accurate assessment of the actual density of birds on the ground (Section 2.4.6).

Table 2.8 Change in average call rate hr^{-1} (± SE) of female kiwi in response to a taped male or taped female call.

Broadcast male call	Broadcast female call
N Mean ± SE (18) 1.44 ± 0.17	N Mean ± SE (15) 2.0 ± 0.32

(t-test; t = 1.53, df = 21, P = 0.14)

Table 2.9 Change in average call rate hr^{-1} (± SE) of male kiwi in response to a taped male or taped female call.

Broadcast male call	Broadcast female call
N Mean ± SE (34) 2.32 ± 0.25	N Mean ± SE (17) 3.94 ± 0.29

(t-test; t = 4.26, df = 37, P = 0.0001)

Table 2.10 Average call rate hr^{-1} (± SE) of male and female kiwi in response to taped calls.

Taped male		Taped female	
Male response	Female response	Male response	Female response
N Mean ± SE (34) 2.32 ± 0.25	N Mean ± SE (18) 1.44 ± 0.17	N Mean ± SE (17) 3.94 ± 0.29	N Mean ± SE (15) 2.0 ± 0.32

(t-test; t = 2.97, df = 49, P = 0.0046)   (t-test; t = 4.46, df = 29, P = 0.0001)

2.6 **Discussion**

2.6.1 Function of calls

Avian vocalisations have traditionally been divided into song and calls, though this distinction is somewhat arbitrary (Bibby *et al.*, 1992). The term "song" is usually reserved for loud and sustained vocalisations delivered seasonally by males in possession of a territory (Nottebohm, 1975). Song can also be triggered by a variety of social stimuli, particularly auditory ones, and is therefore density-related.

The long distance calls of Northern brown kiwi undoubtedly signal occupancy of an area and contribute towards territorial defence (Chapter 3). The calls are audible up to a kilometre away, a distance twice the average diameter of their territories. Neighbours sometimes replied to each others calls, especially when they were near a common boundary; both sexes reacted to imitation whistles, or taped calls.

Though the visual aspect of territorial behaviour has been rarely recorded in kiwi (Rowe, 1974; Reid and Williams, 1975) "vocal duels" between males appears to be more important (Colbourne and Kleinpaste, 1983). Song therefore advertises the presence of a paired or unpaired male in breeding condition, as well as the existence of a defended territory (Smith, 1959). Males usually respond more quickly, and aggressively, to either simulated or real intruders than do females (McLennan *et al.*, 1987; Taborsky and Taborsky, 1991). Of the male calls recorded in T.F.P. 58% were involved in territory defence or mate location, and 18% were responses to broadcast calls. One fight was witnessed between neighbouring males, one of which was unpaired. Piles of feathers were also found, mostly at edges of territories indicating other fights had taken place. Of the female calls heard in T.F.P. only 16% were involved in territory defence, or mate location, and 17% were responses to broadcast calls. Call rates of the female Great spotted kiwi are 2 - 3 times greater than those of female brown kiwi (McLennan, *in prep.*), perhaps implying a greater role in territorial defence. The calling sex ratio for Northern brown kiwi in the T.F.P. averaged 3:1 (male:female), although this ratio varied seasonally. The ratio for Great spotted kiwi calls was 1:1 in the Saxon, NW Nelson (J.A. McLennan, *pers.comm.*).

Apart from territory defence, some calls of the Tongariro brown kiwi were directed at mates. Calls are, presumably, the only means by which members of pairs can keep in contact with each other (McLennan, *in prep.*). Duets were apparently performed to indicate the whereabouts of the caller and the respondent. In T.F.P. duets were performed mostly by members of bonded pairs, and initiated by males, but proportionally more female calls were involved in intra-pair calling activity. This was also noted in Waitangi, where males initiated most calls, and females responded almost exclusively to calls of their partners (Taborsky and Taborsky, 1992). In T.F.P. duets were most often heard over the breeding season, increasing from May through to October. The sex ratio of male to female calls also changed, with the male dominance reducing over the breeding season as more females were heard, particularly over the second half of the night. McLennan (*in prep.*) suggests that Great spotted kiwi vocalisations involve contact calls in the hour before dawn, as members of bonded pairs converge on daytime shelters. Calls made earlier in the night presumably involve a mixture of contact and territorial calls. This may also be the case with the Tongariro brown kiwi.

2.6.2 Factors affecting calling

In T.F.P. Northern brown kiwi call rates showed a seasonal peak between May and November. Colbourne and Kleinpaste (1984) found call rates of Northern brown kiwi in Waitangi State Forest peaked between July and November (1981 - 1982), while in 1985 they peaked between May and September (Kayes and Rasch, 1985). These differences result from variations between years in weather conditions (Best, 1981). Potter and Cockrem (1992) found that when calling rates increase in autumn (1 - 2 months before laying) the levels of testosterone in Northern brown kiwi also rise. Testosterone has been widely linked to male aggression, territorial defence, singing, courtship, and increased mate guarding by paired males (Moore, 1984; Ramenofsky, 1984; Wingfield *et al.*, 1987). Generally Northern brown kiwi call rates peak in mid-winter, at the on-set of breeding.

Tongariro brown kiwi called less on some nights than others, irrespective of season. Weather contributed to this variation. Rain and temperature were the two major variables influencing call rate in T.F.P. When moderate to heavy rain and low temperatures occurred together call rates decreased markedly. McLennan (*in prep.*) reports similar results with Great spotted kiwi in NW Nelson, however, here wind and rain independently suppressed call rates at Saxon, but their effects were most pronounced when the two factors acted in concert. These two variables explained 43% of nightly variation in call rates in the Great spotted kiwi, while in T.F.P. rain and temperature explained 44% of nightly variation. Garson *et al.* (1979) and Higgins (1979) report extremes in weather, whether cold or hot, inhibit song and may affect counts. Colbourne and Kleinpaste (1984), and Kayes and Rasch (1985) also found Waitangi brown kiwi call rates fluctuated both seasonally and nightly. However, they found that moon brightness had the greatest effect on calling rates, but at Tongariro brown kiwi were not significantly affected by moonphase, or light levels. McLennan (*in prep.*) found that Great spotted kiwi call rates were similarly not affected by moon light.

The Tongariro brown kiwi called in two bouts within a night. Vocalisations peaked in the first 2 - 3 hours of darkness. Later, the calling frequency tended to drop to occasional and irregular bursts of vocal activity and remain low until a few hours before dawn, when vocalisations increased sporadically. Kleinpaste (1990) similarly found in Waitangi kiwi that, after the initial wake up-calls, calling lagged until a spasmodic increase later on in the night. In Tongariro, nightly calling showed this bimodal pattern in all seasons. Diurnal species also exhibit a bimodal calling pattern, with activity and detection of most bird species being greatest at dawn, decreasing to a diurnal minimum at mid-day, and increasing in the late afternoon (Grue *et al.*, 1981; Robbins, 1981; Skirvin, 1981).

Tongariro brown kiwi usually began calling 45 - 50 minutes after sunset (except in summer when some birds called earlier) and finished at dawn, just as the first diurnal birds began to stir. This activity period changed over winter when kiwi first called later in the night, and finished before the first diurnal birds began singing. Activity period appeared to remain constant throughout the year. Male kiwi, however, gradually called significantly later in the night through the breeding season. This may be a function of incubation, because males spend longer on the nest the closer the egg is to hatching (McLennan *et al.*, 1988; Potter, 1989). McLennan (1988) and Potter (1989) also showed that the activity period of incubating males was significantly shorter than the activity period of non-incubating kiwi.

2.6.3 Density, call rates, and mapping

Densities of Northern brown kiwi in T.F.P. and T.N.P. were different, and this was reflected by the average calling rates. Determining the relationship of call rate to density of kiwi on the ground has been attempted before. Corbett *et al.* (1979) attempted to estimate population size and distribution of kiwi in Waitangi State Forest based on calls. Again in Waitangi Colbourne and Kleinpaste (1984) employed the census methods of Corbett *et al.* (1979) and found no significant differences in call rates. Four years later Kayes and Rasch (1985) repeated this, and again found no significant change. Colbourne and Kleinpaste (1984) suggested that monitoring call rates (calls hour^{-1}) was the most effective method of detecting changes in kiwi populations. McLennan (*in prep.*) agrees, stating that it is feasible to index abundance of Great spotted kiwi by counting their calls. However, using call counts for census work selectively samples territorial adults only, and ignores the non-calling or infrequent calling component of the population. Thus populations with similar call rates could potentially contain different densities of kiwi.

Many techniques are available to map densities of birds but most are time consuming, requiring well trained and experienced observers, and the final results are often highly subjective (O'Conner, 1981b; Oelke, 1981a; Svensson, 1981). "The ideal way to determine the size of a kiwi population is to band as many birds as possible until no unmarked kiwi are caught or seen then territory boundaries can be calculated" (Colbourne and Kleinpaste, 1984). However, Taborsky and Taborsky (1992) suggest that kiwi spacing systems do not depend strongly on density. McLennan *et al.* (1987) investigated a population of eight birds in Hawke's Bay living in an area of 770 ha. Territory sizes were six to eight times larger than those of kiwi in Waitangi (6 ha/pair; Colbourne and Kleinpaste 1983). Nevertheless, both populations consisted primarily of paired kiwi defending territories with little or no overlap. The spacing system in Paerata was quite different to that in Waitangi. This population was even denser (40 - 45 birds/km^2) than that of Waitangi (33 birds/km^2). Range sizes in Paerata equalled those of the Hawke's Bay population, but overlapped extensively (Potter, 1989). The interpretation of call rates in relation to density is therefore the most difficult aspect of a vocalisation census. When territory sizes and boundaries are not known, it is hard to judge whether a bird that calls one night is the same individual heard a short distance away the night before. These boundaries cannot be just assumed, since the populations with the highest kiwi densities studied exhibited divergent spacing systems.

Functionally the majority of kiwi calls are territorial. Therefore one would predict as kiwi density (birds/km^2) increases so call rate (calls hour^{-1}) will increase. It is the shape of this relationship (density vs call rate) that is important when using call rates as an estimate of kiwi on the ground. Data suggest a linear relationship exists between call rate and density. However, at low densities (<1 bird/km^2), or very high densities (>40 birds/km^2), the relationship may break down (Figure 2.8b).

In the next section (2.7) the practical implications of kiwi calling behaviour are considered and recommendations are made on survey methodology that will allow a more accurate approach to surveying kiwi.

2.7 **Practical Implications**

2.7.1 Deriving an accurate estimate or index

Precision improves with increasing sample size. However, precision also has to be balanced against the time available. For kiwi, call rates are so variable that averages based on one or two nights of sampling are often of little value (McLennan, *in prep.*). The results from T.F.P. suggest that, irrespective of season, it generally takes four to five nights of sampling for the mean call count to stabilise. McLennan and McCann (1991) also found this when sampling Great spotted kiwi. Precision of the density estimate can also be improved by counting in more than one site, and each should be randomly located (Bibby *et al.*, 1992). McLennan (*in prep.*) suggests that samples of call rates from a population should be taken from 3 - 5 different sites. Random positioning of sites is, in the majority of cases, logistically unrealistic but if random sites are impossible, they should at least be 1 km apart on hill tops or promontories (McLennan, 1992).

Census methods that are free of bias are usually impossible to achieve but bias can be minimised, for instance by careful census design (Bibby *et al.*, 1992). Kiwi counts should be restricted to the peak calling months - winter in the case of the Northern brown kiwi. Counts should be made in the first three hours of darkness, over a period of 4 - 5 consecutive days. Censusing should be suspended if wind is too strong, if it is raining heavily, or if temperatures are low. Though moon phase was not a significant factor in Tongariro, it was important in Waitangi (Kayes and Rasch, 1985). Ideally, therefore, counts should not be made within 5 days of full moon.

2.7.2 Territory mapping

Kiwi are territorial all year round (Chapter 3). The mapping of individual calls provides a minimum estimation of occupants in a specified area, and can "fine-tune" the density estimate given on the density call rate curve (Figure.8b). In T.F.P. mapping of all known individuals in a 1 km radius of listening stations took eight consecutive nights listening in the first four hours of each night. This also provided a good estimate of the average call rate for that population.

Territory mapping is valuable as an index method when populations are sparse (McLennan, *in prep.*), as in T.F.P. ($\leq$ 3 pairs/km^2). If individuals are spread widely and if neighbours called within a few minutes of each other, it was usually possible to determine, in any one hour, the maximum number of different birds calling. In such situations there is little room for confusion. At higher densities observer bias greatly reduces minimum density estimates. In these densities call counts alone are the best method of indexing the size of populations.

If samples are taken over long periods it becomes increasingly difficult to determine whether each successive call indicates a 'new' bird, or one that has already called before (McLennan, *in prep.*). To increase the chance of 'finding' birds a surveyor should broadcast tape recordings of kiwi calls. Broadcast calls increase individual call rates in T.F.P. Male kiwi respond significantly more to either a broadcast male or female call than do females, however, a female call elicits a greater response from male and female birds. This method also allows a better estimation of sex ratios in populations of Northern brown kiwi where female kiwi call about one third as often as males (J.A. McLennan *pers. comm.*).

Chapter 3

Range size and roost choice of Northern brown kiwi (*Apteryx australis mantelli*) in the central North Island.

3.1 Introduction

A territory is an area of exclusive use by an animal and is maintained by mutual avoidance (Kaufmann, 1983). A home range is the area, usually around a "home site" (or "core area", Samuel *et al.*, 1985), over which the animal normally travels in search of food (Burt, 1943). Issues of territoriality and home range are complex and their components too variable to expect unanimous agreement on single definitions (Kaufmann, 1983). Use of space by kiwi appears to fall between these definitions. The majority of time individuals are found exclusively in certain areas of the total habitat available to them and these areas do seem to be maintained by mutual avoidance (McLennan *et al.*, 1987; Taborsky and Taborsky, 1992).

For an animal to maintain or to require a "mutually exclusive area", that area must enable that animal priority access to competed-for resources. This can be any physical or social commodity that increases fitness (Kaufmann, 1983), and may include food, water, shelter, and space. Taborsky and Taborsky (1992) suggest kiwi territoriality cannot be explained by the distribution and availability of food and shelter sites, but instead serves mainly a reproductive function.

Only three enclaves of Northern brown kiwi remain in the North Island: Northland, Taranaki - King Country, and Hawke's Bay (Bull *et al.*, 1985; *cit.* Potter, 1990). If management of these fragmented populations is to be effective, requirements of the species need to be understood. McLennan *et al.* (1987) discussed implications for minimum size and design of kiwi reserves while Potter (1990) addressed movements of kiwi between forest remnants, and the implications of this for reserve design. This chapter compares home range size of Northern brown kiwi in central North Island with comparative work by McLennan *et al.* (1987) and Potter (1990), and describes the importance of habitat type with respect to daytime roosts and shelter.

3.2 **Methods**

3.2.1 Capture of kiwi

Kiwi were caught by using either a whistle, or taped calls, to bring the birds in closer. They were then spotlighted and run down. Following capture each kiwi was banded (New Zealand National Banding Scheme size 'R' bands), fitted with a radio transmitter, weighed and measured (bill length, tarsus width, breadth and length, and toe length; Appendix 6), and then released.

3.2.2 Telemetry

Radio telemetric techniques and transmitter design were similar to those described in McLennan *et al.* (1987), and Potter (1990). All radio transmitters were of the internal loop design and operated around 160 MHz. Transmitters were powered by a 750 - 900 mA-h lithium cell battery, which gave an average field life of 10 months. A CE 12 receiver (Custom electronics of Urbana Inc.) and a three element hand-held Yagi aerial were used in tracking. Signals could be detected at distances of 10 - 1500 m when kiwi were in their daytime shelters. The battery, transmitter and loop aerial were encased in epoxy resin. The average weight of the transmitter package was 26 g (less than 2 % of body weight), and measured approximately 30 x 25 x 25 mm. They were attached to the tibiotarsus, above the tarsometatarsal joint with two plastic straps (child-size hospital identification bands) and a couple of loops of electrician insulation tape. The bands could break naturally after a few months (McLennan *et al.*, 1987; Potter, 1990; Taborsky and Taborsky, 1991).

During the day kiwi were either tracked to their roost, or their location was determined using cross bearings. At night kiwi were also tracked, but these data were not included in range estimates because of the difficulties in obtaining accurate location estimates. Location records were obtained each day from 10 tracking stations (Figure 3.1), transcribed into co-ordinates, and recorded on a NZMS map. The habitat at each point was assigned to one of the following categories: 1 toetoe (site 1); 2 Leptospermum/scrub; 3 logged (site 3); 4 unlogged (site 4); 5 swamp/bog (site 5); 6

broadleaf/scrub (site 2; refer to site descriptions in Chapter 4). This provided a picture of which habitats kiwi preferred or avoided.

Day-time roosts of radio tagged kiwi were also located by following the path of increasing signal strength until the type of shelter being used was seen. This also allowed a check on the accuracy of the triangulation (accurate to approximately 10 - 15 m^2 of the actual location). Located roost sites were classed as either surface vegetation, excavated, or associated with hollow logs and/or tree roots.

3.2.3 Birds captured and tracking period

In Tongariro National Park (T.N.P.) only one male (M.58) was caught and radio tagged. This was radio tracked discontinuously for 40 weeks between January 1993 to December 1993 (Table 3.1). Here data are presented on his territory size only. In Tongariro Forest Park (T.F.P.), five kiwi (3 males, and 2 females) were caught and radio tagged between December 1992 and December 1993, and tracked for periods ranging from two days (for male M.54, whose transmitter failed immediately), to 58 weeks. The two males were radio tracked discontinuously for 58 weeks, and the two females (F.53, and F.57) discontinuously for 26 and 49 weeks respectively.

3.2.4 Frequency of tracking and handling

In T.N.P. M.58 was located on 44 days between January 1993 and December 1993. In T.F.P. kiwi were located on 93 days between December 1992 and December 1993. A total of 904 location records were collected, comprising 377 day-time, and 527 night-time fixes.

Radio tagged kiwi were recaptured on average every three months for weighing and measuring, and to check on and change damaged straps and transmitters with old batteries.

3.2.5 Estimation of range size

The term "home range" describes two aspects of animal movement. The first comprises a basic map of locations produced from radio tracking an animal. The second refers to the numerical estimate of area used by the animal. Lance and Watson (1980) reviewed publications from the first 10 years of radio tagging. They concluded that the technique was rarely used to its full potential. A particular problem was the choice of an appropriate method to represent an animals home range. Six methods are available (MacDonald *et al.*, 1980; Voight *et al.*, 1980; Worton, 1987; White and Garrot, 1990, Harris *et al.*, 1990). There are also many different ways of using home range and other location data to investigate sociality and habitat use (White and Garrot, 1990).

In this chapter three of the six methods are used to estimate range size, the convex polygon method (CP; Mohr, 1947), the field-worker method (FW; Macdonald *et al.*, 1980), and the adaptive kernal method (AK; Taborsky and Taborsky 1992).

The CP is the oldest and most common method of estimating home range. The minimum area polygon is constructed by connecting the outer locations to form a convex polygon and then calculating the area of this polygon. The advantages of CP are: i) simplicity, ii) flexibility of shape, and iii) ease of calculation. The disadvantage is the home range increases as the number of locations increase.

McLennan *et al.* (1987) felt that the FW method was the most accurate estimate of the kiwi home range. MacDonald *et al.* (1980) considered the method to be the most biologically meaningful. The FW method estimates home range size and shape by drawing a shape that takes into account radio fixes, topography, and general knowledge of the bird's movements when moving about its home range.

Both these methods were used by McLennan *et al.* (1987) and Potter (1990), thus allowing comparison of home ranges of kiwi in the central North Island to home range estimates of kiwi from Hawke's Bay and Northland. For consistency in habitat analysis, only the convex polygon estimate of home range size was used. The third method used, the AK, is described in Taborsky and Taborsky (1992).

McLennan *et al.* (1987), and Potter (1990) also used the Grid Cell method, a non-parametric test, to estimate home range size and habitat use. This test requires ≥ 100 fixes per individual for home range stabilisation (Kenward, 1992) so was not attempted because the sample size in the present study is too small.

3.2.6 Daytime roost and habitat description

In both T.N.P. and T.F.P. roosts include burrows excavated by kiwi, surface vegetation, and burrows associated with hollow logs and/or roots. Where possible the length of roosts, and the habitat in which they were located were recorded. Habitat type was assigned a number: 1 - 6 (refer to section 3.2.2). "Logged" refers to areas which had been selectively logged, while "unlogged" refers to areas where logging did not occur. "Leptospermum/scrub" were areas covered in *Leptospermum* spp., heather (*Calluna vulgaris*), and in part toetoe (*Cortedaria toetoe*). This was the only habitat type not surveyed in the invertebrate survey (Chapter 4).

3.2.7 Amount of available habitat

Determining the amount of a particular habitat type found within each home range involved tracing the outline of each habitat type on to paper from a large scale (1:3500) aerial photograph (N.Z. Aerial Mapping Ltd., Hastings). These tracings were then cut out and weighed (Mettler AE 200, accurate to 0.0001 g), and the weight converted to area (ha).

3.2.8 Habitat analysis:

a Availability: Availability was calculated as the apparent amount of area of each habitat type within the bounds of each kiwis' home range estimated by the convex polygon method.

b Utilisation: The daytime location of each kiwi was classified according to the habitat type, and percentage of time each kiwi roosted in a particular habitat type within their home range was calculated. All locations were assumed to be independent (taken 24 hours apart).

c Preference: Preference refers to whether kiwi select some habitat types over others, and therefore spends more time in these habitats (less time in the remaining habitats) than would be expected based on the availability of each habitat type.

A standard approach to testing the hypotheses of preference has been presented by Neu *et al.* (1974). The two null hypotheses tested by the Chi-square test (described by Alldredge and Ratti, 1986) are: H_{o1}: usage occurs in proportion to availability, considering all habitats simultaneously, and; H_{o2}: usage occurs in proportion to availability, considering each habitat separately. The areas of each habitat type and the proportion of each home range contained in each habitat (availability) are given in Table 3.2.

Nue *et al.* (1974) used a statistical technique evaluating preference or avoidance of a given habitat, given that the Chi-square test rejects the null hypothesis for all habitat types considered together. Confidence intervals for the proportion of times an animal used each habitat type were calculated as:

$$\hat{p}_i - z_{\alpha/2k}\left[\frac{\hat{p}_i(1 - \hat{p}_i)}{n}\right]^{1/2} \leq p_i \leq \hat{p}_i + z_{\alpha/2k}\left[\frac{\hat{p}_i(1 - \hat{p}_i)}{n}\right]^{1/2}$$

where p_i is the proportion of locations in habitat type i, and $z_{\alpha/2k}$ is the upper standard normal variate corresponding to a probability tail area of $\alpha/2k$.

k = the number of habitat types.

α = level of significance (in this case 0.10).

n = the sample size, in this case number of locations.

z = standard deviations from the mean using the standard normal distribution.

Critical values are found in Zar (1984; Appendix, Table B.2).

To determine whether habitat is avoided or preferred, the confidence interval is checked for overlap with the availability proportion of the corresponding habitat (Table 3.2). If the confidence interval includes the availability proportion the hypotheses of no preference or avoidance of this habitat type cannot be rejected. However, if the lower bound of the interval exceeds the availability proportion, then the animal has shown preference for this habitat type, and we can reject H_{o2} for that habitat type. In contrast, if the upper bound for a habitat type exceeds the expected, H_{o2} for that habitat type cannot be rejected (White and Garrot, 1990).

3.2.9 Statistical analyses

Chi-square analyses were used to compare home range size and overlap, utilised habitat to available habitat type, day-time roost selection, and roost choice by male and female kiwi. In the case of habitat preference the G-statistic (Sokal and Rolf, 1981) was also calculated for the observed frequencies, to emphasise the size and direction of deviation from the expected. Confidence intervals adopted from Nue *et al.* (1974) were constructed for the proportion of times kiwi roosted in each habitat type, and are discussed further in the results. Differences were regarded as significant if $P \leq 0.05$. Critical values for all statistics were obtained from Zar (1984).

3.3 **Results**

3.3.1 Home range estimation

Home range estimates determined by the three chosen techniques are shown in Table 3.1. The convex polygon estimate of ranges of the five radio-tracked kiwi varied from 30.8 to 91.8 ha. Field worker estimates were approximately 8 - 23 % smaller ranging between 26.1 to 82.6 ha, and the adaptive kernal estimate ranged from 28.2 to 74.8 ha.

Mean range size of paired females tended to be larger than that of paired males in all three estimates although the difference was not significant (CP, Chi-square = 1.11;

FW, Chi-square = 0.94; AK, Chi-square = 0.95; df = 1; Critical value $X^2_{0.05} = 3.84$; all $P > 0.05$). M.52 was an unpaired male. His range was significantly larger than that of the paired males and paired females ($P<0.001$, Table 3.1).

The four kiwi in T.F.P had closely connected ranges, with one or more mutual boundaries (Figure 3.1). Female home ranges showed more overlap than male home ranges, but this difference was not significant (Chi-square = 1.38; df = 1; $0.75<P<0.50$). F.57 shared 45% of her home range with her neighbours. Females were found intruding 52 times (38.24 % of 136 locations) and males 18 times (11.46 % of 157 locations) into neighbouring territories. M.52, the unpaired male, entered the range of M.51, a paired male more often than the paired male enter M.52's range, however, this was not significant (Chi-square = 0.53; df = 1; $0.90<P<0.75$).

Table 3.1 Range size (ha) of kiwi in T.F.P. and T.N.P. Estimates were calculated by the convex polygon method, field worker method, and the adaptive kernal method (see text for explanations).

Bird	T.F.P		Range size (ha)		
	Radio fixes	Weeks tracked	Convex polygon	Field worker	90% Adaptive kernal
M.51	65	58	30.29	26.14	28.43
M.52	92	58	91.79	82.58	74.83
M.54	2	1	-	-	-
F.57	82	49	34.18	29.49	28.22
F.53	54	26	52.79	44.21	52.75
Bird	T.N.P		Range size (ha)		
M.58	36	40	38.16	31.79	47.70
Mean	65.8	46.2	49.44	42.84	46.39
Total	329	231			
mean male	50.5	49	34.23	28.97	38.07
mean female	68	37.5	43.49	36.85	40.49

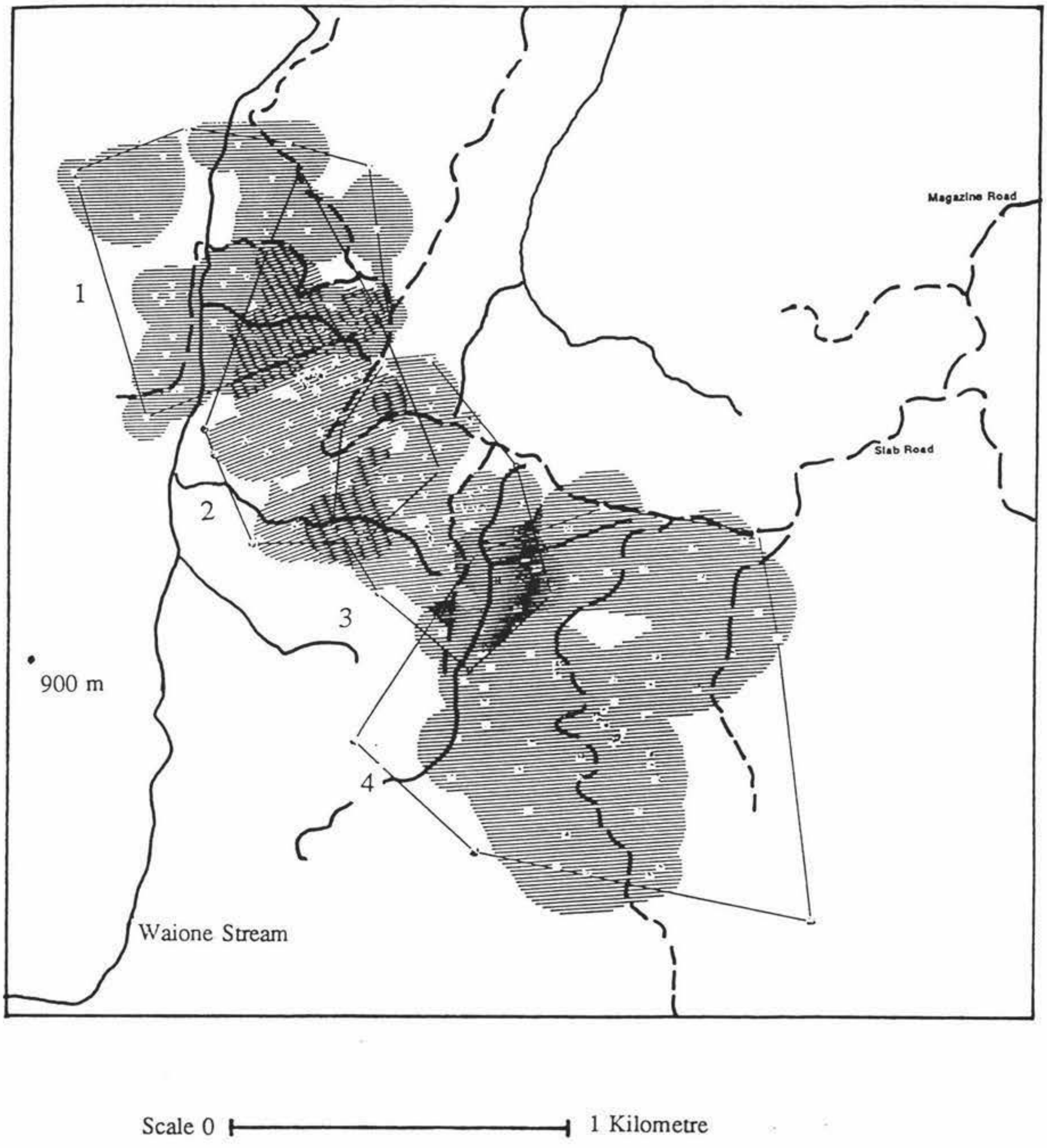


Figure 3.1 Spatial distribution of kiwi in T.F.P. Ranges 1 to 4 depict F.53, F.57, M.51, and M.52 respectively.

3.3.2 Preference

The four kiwi tagged in T.F.P. were tracked over an average of 48 weeks (Table 3.1). The proportion of time kiwi spent in each habitat type (utilisation) is shown in Table 3.3.

The Chi-square table for each kiwi is shown in Table 3.4. The expected number of locations in each habitat type, if no preference or avoidance is shown by kiwi, is the proportion of locations that fell in the habitat type, assuming that locations were picked at random. From Table 3.4, M.51 seemed to show little preference (and hence no avoidance) of any habitat type (Chi-square = 5.45; df = 3; $0.25<P<0.01$). The Chi-square and G calculation of expected frequencies show the size and direction of deviation from the expected. Both suggest that M.51 preferred habitats 4 and 6 (both show greatest deviation to random), although he made use of all other habitats as well. In contrast M.51 and F.57 showed little preference for one or other habitat type. The home ranges of these kiwi were dominated by habitat types 3 and 4, possibly reducing habitat 1, 2 and 6's contribution to the Chi-square statistic.

M.52 apparently did prefer some habitats, since the probability of observing such a large Chi-square statistic (17.12) is $P < 0.001$; df = 2. Although F.57 exhibited little preference for any habitat type (Chi-square = 4.64; df = 3; $0.50<P<0.25$), both she and F.53 (Chi-square = 16.2; df = 3; $0.005<P<0.001$) utilise the unlogged area within their range, and in the case of F.53, the broadleaf/scrub more than expected (G-statistic, Table 3.4).

Because of animal variability, different animals will prefer and/or avoid different habitats. A summary of habitat preference/avoidance for the four kiwi is presented in Table 3.6. The overall result is that habitat 1 was avoided, while habitats 4 and 6 were preferred, indicating that kiwi prefer to roost in forest habitat. Territory size may be a consequence of habitat type.

Table 3.2 Habitat area and proportion of the total home range (availability), for each of six habitat types.

*	M.51		M.52		F.57		F.53	
Habitat type	Area (ha)	Proportion	Area (ha)	Proportion	Area (ha)	Proportion	Area (ha)	Proportion
(1) Toetoe	4.47	0.1477	46	0.5011	4.61	0.1350	7.70	0.1459
(2) Leptospermum/scrub	0.98	0.0325	3.39	0.369	0.34	0.01	1.53	0.0289
(3) Selectively logged	8.02	0.2649	21.16	0.2305	5.66	0.1655	11.28	0.2136
(4) Unlogged	11.32	0.3736	0	0	19.91	0.5824	27.22	0.5157
(5) Swamp/bog	0.82	0.0271	1.98	0.216	0.49	0.0143	1.07	0.0203
(6) Broadleaf/scrub	4.67	0.1542	19.27	0.2099	3.17	0.0928	3.99	0.0756
Total	30.29	1	91.79	1	34.18	1	52.79	1

Table 3.3 Numbers and percentages of radio-tracking locations in each habitat type (utilisation) for kiwi within their home range, as determined by the convex polygon method. (1 toetoe, 2 Leptospermum/scrub, 3 selectively logged, 4 unlogged, 5 swamp/bog, and 6 broadleaf/scrub).

*	M.51		M.52		F.57		F.53	
Habitat type	Number	Percent	Number	Percent	Number	Percent	Number	Percent
1	7	10.77	30	32.61	6	7.32	4	7.4
2	0	0	0	0	0	0	1	1.9
3	14	21.54	29	31.52	11	13.41	22	40.7
4	28	43.08	0	0	57	69.51	19	35.2
5	0	0	0	0	1	1.22	0	0
6	16	24.62	33	35.87	7	8.54	8	14.8
Total	65	100.00	91	100.00	82	100.00	54	100.00

Table 3.4 Calculation of the Chi-square statistic (test of preference) for all four kiwi (1 toetoe, 2 Leptospermum/scrub, 3 selectively logged, 4 unlogged, 5 swamp/bog, and 6 broadleaf scrub. For the G-statistic +ve = obs > expec, and -ve = Obs < expec.

•	M.51				M.52				F.57				F.53			
Habitat type	Obs	Exp	X^2	G-stat	Obs	Exp	X^2	G-stat	Obs	Exp	X^2	G-stat	Obs	Exp	X^2	G-stat
1	7	9.60	0.71	-2.21	30	46.10	5.62	-12.89	6	11.07	2.32	-3.67	4	7.88	1.91	-2.71
2	0	2.11	0	0	0	3.40	0	0	0	0.82	0	0	1	1.56		-0.44
3	14	17.22	0.60	-2.90	29	21.21	2.87	9.08	11	13.57	0.47	-2.31	22	11.53	9.51	14.21
4	28	23.28	0.57	3.99	0	0	0	0	57	47.76	1.79	10.08	19	27.85	2.81	-7.27
5	0	1.76	0	0	0	2.00	0	0	1	1.17		-0.16	0	1.1	0	0
6	16	10.02	3.57	7.49	33	19.31	9.71	17.68	7	7.61	0.04	-0.52	8	4.1	1.97	5.35
Total	65	65	5.45	6.37	92	92	18.19	13.87	82	82	4.62	3.36	54	54	16.20	9.14

Table 3.5 Confidence intervals for the proportion of time each kiwi spent in each habitat type (1 toetoe, 2 Leptospermum/scrub, 3 selectively logged, 4 unlogged, 5 swamp/bog, and 6 broadleaf/scrub).

•	M.51			M.52			F.57			F.53		
Habitat type	no. locations	p	Confidence interval	no. locations	P	Confidence interval	no. locations	P	Confidence intervals	no. locations	P	Confidence intervals
1	7	0.1077	0.023<P<0.192	30	0.5011	0.223<P<0.429	6	0.1350	0.007<P<0.139	4	0.1459	-0.008<P<0.156
2	0	0	0	0	0	0	0	0	0	1	0.0289	-0.024<P<0.062
3	14	0.2154	0.103<p<0.328	29	0.2305	0.213<P<0.417	11	0.1655	0.048<P<0.221	22	0.2136	0.253<P<0.561
4	28	0.4308	0.296<P<0.566	0	0	0	57	0.5824	0.578<P<0.812	19	0.5157	0.203<P<0.501
5	0	0	0	0	0	0	1	0.0143	-0.016<P<0.040	0	0	0
6	16	0.2462	0.129<P<0.364	33	0.2099	0.254<P<0.464	7	0.0928	0.014<P<0.156	8	0.0756	0.037<P<0.259
Total	65	1		92	1		82	1		54	1	

Table 3.6 Conclusions on preference and/or avoidance by the four kiwi towards the six habitat types.

•				Habitat type					
Kiwi	X^2	df	Probability	toetoe	Lepto/scr	selec logd	unlogged	swa/bg	brdlf/scr
M.51	5.45	3	$0.025<P<0.01$	x	-	x	x	-	x
M.52	18.19	2	$P<0.001$	Avoided	-	x	-	-	Preferred
F.57	4.64	3	$0.50<P<0.25$	x	-	x	x	x	x
F.53	16.20	3	$0.005<P<0.001$	x	x	Preferred	Avoided	-	x
Combined	44.48	11	$P<0.001$	Avoided	x	x	Preferred	x	Preferred

3.3.3 Daytime roost selection

Kiwi were highly variable in the types of roosts they used, but roost type was highly dependant on habitat type, since the probability of observing such a large Chi-square statistic ($X^2 = 20.03$, df = 3) is $P<0.001$ (Figure 3.2). Roosts associated with fallen trees and surface roots were the most frequently used roost type (40.86%), followed by excavated cavities (32.26%), and finally surface vegetation (26.88%; n = 93 comprising 53 records for 2 males, and 40 records for 2 females). Surface vegetation tended to be used in summer, excavated roosts in winter and spring, and roosts associated with logs and roots in autumn and winter (Chi-square = 26.22, df = 3, $P<0.001$).

On only one occasion was a pair found together. The roost was approximately 2 - 3 m in length, the entrance 120 mm radius and 150 - 200 mm off the ground. The chamber itself was L shaped.

Kiwi infrequently used one roost site more than once. However, one male (M.52), located 29 times over an 11 month period, used 21 different roosts. He used one site 8 times over a 3 month period, and 11 other radio fixes put him in the same area during the same period of time. This roost was excavated on an angle of approximately 35°, with an entrance of 230 mm diameter and length of 2.5 m. This attachment to one secure (or "safe") site was also recorded in a female (F.57). She was located 27 times over a 12 month period. She used 22 different roosts once, and one roost five times over consecutive days. The roost was a network of tunnels of unknown size, with multiple entrances and exits. These "safe sites" seem to be large burrows of unknown size, and possibly were used and enlarged by successive generations of kiwi. All had a distinctive "kiwi smell" associated with them.

Other types of roosts used by kiwi were either excavated short tunnels, no longer than one metre in length, or vegetation, such as toetoe or fern fronds, where kiwi simply nestled underneath.

Males and females differed in the types of roosts they used. Males used surface vegetation more often than expected, while females favoured roosts associated with hollow logs, and/or roots (Chi-square = 10.27; df = 2, 0.01<P<0.005). Both sexes made similar use of excavated roosts.

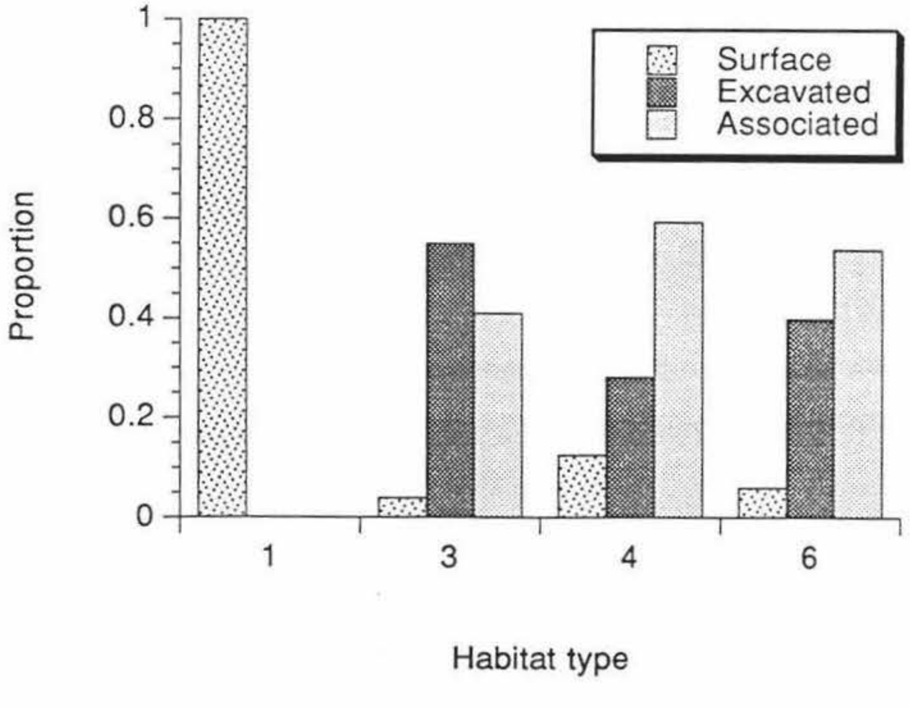


Figure 3.2 Proportion of roost types found in the four main habitat types (1 toetoe, 3 selectively logged, 4 unlogged, and 6 broadleaf/scrub) within kiwi ranges in Tongariro Forest Park.

3.4 **Discussion**

The average range size of Northern brown kiwi in T.F.P. was estimated at 49.4 ha (CP). This compares with 45.8 ha in Hawke's Bay (McLennan *et al.*,1987), 40.5 ha in Paerata (Potter, 1990), and 6 ha in Waitangi State Forest (Taborsky and Taborsky, 1992). The population in Hawke's Bay had a density of about one kiwi/km^2, the Paerata population was approximately 43 kiwi/km^2, Waitangi 33 kiwi/km^2, and T.F.P. had three kiwi/km^2. Spacing behaviour of kiwi therefore does not seem to be density dependant, as range size varies little. However, Potter (1990) found the degree of overlap of ranges increases as density increases, to the extent that some birds held no ranges at all.

Range size in T.F.P. appears to be consistent with other studies of brown kiwi that suggest an optimal range size of approximately 45 ha (CP) per pair. Differences in the size of kiwi ranges, both within and between regions, probably reflect differences in food supply and intruder pressure (McLennan *et al.*, 1987). Other studies have indicated that territories tend to be smaller where food is denser or more nutritious, or where cost of defence is high (Krebs and Davies, 1987). In the Tongariro area range size appears to vary with habitat type, and quality roost sites. Kiwi in the Tongariro area preferred to roost in un-logged, unmodified areas (habitat type: 4) and/or dense broadleaf/scrub (habitat type 6; Table 3.6). Kendeigh (1961) found there were advantageous thermal qualities in holes associated with very dense vegetation. In T.F.P. high "quality roosts" were mainly found in habitat types 3 (selectively logged), 4 and 6 (Figure 3.3). The range of the unpaired male M.52 (91.79 ha; CP) was considerably larger than the other kiwi ranges (Table 3.1) although proportionally this range contained very little of habitats 3, 4 and 6 (Table 3.2) in relation to its size.

Tongariro kiwi, like Paerata kiwi (Potter, 1989), appeared to reuse particular roost sites. A paired female (F.57) was located on five consecutive days in a roost consisting of a labyrinth of chambers that smelt very strongly of "kiwi." The second reused roost was used on a more regular basis by the unpaired male (M.52). This roost consisted of a long, steep-angled chamber. Curiously the repeated use of this roost by M.52 coincided with M.51, a paired male, as he got into the routine of egg incubation. Potter (1989) found the extent of competition for some roosts in Paerata suggested that quality roosts may have been at a premium in the reserve. The density of kiwi in

Tongariro was 10% less than that in Paerata, with far less territorial overlap. Competition for the same roost site was therefore less in Tongariro, though kiwi still showed preference for some roost types over others.

There may be two key behaviours kiwi use in "territory" maintenance. One is calling, which is dealt with in Chapter 2. The other is scent marking. In this respect olfaction plays an important role (Johnson, 1973). Unlike most birds, kiwi have a highly developed sense of smell (Wenzel, 1968). McLennan *et al.* (1987) notes, "it is noteworthy that when birds intruded into their neighbours ranges, they often sheltered in burrows that had been used a few days beforehand by the residents." Marker posts may be used to indicate boundaries and to drive away neighbours. The resident therefore does not have to spend time and energy actively maintaining borders, which may be impossible to defend physically (Harper, 1991).

Some roosts in T.F.P. smelled more strongly of kiwi than others, particularly those that were located at the edge/overlap with other home ranges. Many species communicate by scent marking, either to advertise condition, or "ownership" of a particular area (Harper, 1991). They do this by leaving glandular secretions, sometimes mixed within the urine, and/or strategically placed faecal piles (Barrette *et al.*, 1980; Gosling, 1987; Smith *et al.*, 1989). The smell in these "marker post" roosts, which were distinctly shorter than the larger "safe site" type roost, seemed to be from faecal piles built up over long periods of time. A large faecal pile was also identified 4 m from a roost entrance. The size of the pile suggested regular patronage.

With the failure of a transmitter on the mate (M.54) of a radio-tagged female, ranges of pair members were unattainable. However comparing neighbouring birds in similar habitat (M.51, and F.57) the home range of the paired female was 10.4% larger than that of the paired male. Taborsky and Taborsky (1992) found kiwi in Waitangi maintained territories of 6.7 ha if female, and 5.5 ha if male. McLennan *et al.* (1987) also found female kiwi maintained larger ranges. Tongariro female/female ranges had greater overlap than did female/male and male/male ranges. The male/male overlap occurred between a paired (M.51) and an unpaired male (M.52). M.52 entered the range of M.51 more often than M.51 entered M.52's range. M.52's range was also twice the size of paired males ranges. Taborsky and Taborsky (1992), and McLennan *et al.* (1987) calculated home ranges of unpaired birds, and similarly found their ranges were at least twice as large as paired birds. These ranges extensively overlapped the ranges of paired kiwi, which I suspect is also the case with the unpaired male in T.F.P.

In Waitangi (Taborsky and Taborsky, 1992) the density of kiwi was about 33 birds/km^2 and like the kiwi in Hawke's Bay and T.F.P. this population consisted of kiwi defending ranges with little or no overlap. Within these ranges are mutually exclusive areas, better known as "home sites" (Burt, 1943) or "core areas" (Taborsky and Taborsky, 1992). In T.F.P. core areas (50% adaptive kernal) were not contiguous but broken, distributed centrally over the entire range (Appendix 7). The marked preference for individuals to concentrate their activity in clearly defined core areas suggests such locations contain resources of high quality. Advantages for occupying such sites could include higher availability of food, shelter, and protection. The distribution of core areas may define the minimum area kiwi need to defend, to maintain a certain proportion of these quality habitat areas. This seems consistent when comparing range size to core area size. The more wide ranging the kiwi, the more widely are core areas distributed within its range. This is highlighted when comparing M.52's range and M.51's range size, and core area distribution. Similar results have been reported in the dunnock (*Prunella modularis*), with range sizes of the female dunnocks all containing about the same feeding area of thick cover and dense bushes (Davies *et al.* 1984). Clutton-Brock *et al.* (1982) found that core areas were closely related to home range size.

Ranges were defended in T.F.P. On two occasions fights were seen, and "aggressive" calling was also heard at close quarters from radio-tagged neighbours. Aggressive responses could also be induced by whistling calls within birds ranges. Taborsky and Taborsky (1992) reported that after about half of the Waitangi kiwi population was eradicated by a single dog (Taborsky, 1988), some of the remaining neighbours expanded their ranges into the vacant areas. McLennan (*in draft*) also noted that after the disappearance of a pair of Great spotted kiwi (*Apteryx haastii*) in the Saxon, neighbouring kiwi seemed to expand their ranges.

In T.F.P. the range of the unpaired male (M.52) was twice that of the paired males, even though he did not have to compete for food with a partner. Food availability, therefore, does not seem to be the primary cause of "territoriality" in kiwi (Taborsky and Taborsky, 1992). Spatial organisation of male and female kiwi currently suggests that range size has some reproductive function, which is suggested by the spatial organisation of males and females, because the ranges of pair partners match to some extent (Taborsky and Taborsky, 1991). The evidence presented here strongly suggests that territory size may also be an artifact of habitat quality, in regard to secure roost sites with kiwi appearing to prefer to roost in unlogged forest and tight broadleaf/scrub areas.

What ever the situation, large areas are required to maintain populations of kiwi at the "minimum viable population" size. Gilpin and Soule' (1986) calculated that most populations need to contain between 500 - 1000 breeding individuals. "While there is no magic number" Potter (1990), McLennan *et al.* (1987) estimated reserves would need to be between 7,500 - 15,000 ha each to meet this requirement for brown kiwi. Potter (1990) showed that kiwi are versatile and can utilise small remnants of forest as "stepping stones" between larger areas. These remnants may contain core areas. It is therefore important to recognise the range of requirements, other than size of an area alone, that kiwi may have.

If size of an area was the only criterion judged important for populations of kiwi to thrive, the Tongariro kiwi should be secure. Potentially T.F.P. (approximately 20,000 ha) could hold 444 paired kiwi plus an unknown quantity of unpaired birds or floaters. Results from my study area in T.F.P. suggest density of birds in T.F.P. (4 kiwi/km^2; Chapter 2) to be less than 400 pairs, with few floaters, and little to no recruitment due to predation (Chapter 5). Transect surveys undertaken recently (Erua field-trip survey, 1994, and Conservancy call surveys 1994; C. Speedy *pers. comm.*) in T.F.P. suggest that there is an unusually high number of kiwi in the study area, and the density of kiwi is considerably less in other parts of T.F.P., and the conservancy generally (Call surveys undertaken in the Conservancy up to 1992). Land clearance has stopped in T.F.P., and the habitat appears to be expanding. Theoretically therefore kiwi numbers also should be increasing. However, the complete opposite appears to be happening: the older resident population is slowly disappearing, and with little or no apparent recruitment the kiwi population in central North Island is on the decline. Geographically this population of Northern brown kiwi is of importance, and if it is to survive predators need to be controlled.

Chapter 4

Food availability and diet of Northern brown kiwi (*Apteryx australis mantelli*) in two adjoining conservation areas in the central North Island.

4.1 Introduction

A consequence of kiwi nocturnal behaviour is that studies of diet focus on invertebrate surveys and faecal analysis. The majority of information on kiwi diet comes from the examination of dead birds (Buller, 1888; Gurr, 1952; Bull, 1959; Watt, 1971; Reid *et al.*, 1982) and more recently faecal analysis in conjunction with invertebrate surveys (Colbourne and Kleinpaste, 1984; Colbourne and Powlesand, 1988; Colbourne *et al.*, 1990; Kleinpaste, 1990). The earlier papers suggest kiwi are opportunistic feeders, while the more recent papers suggest kiwi may actively select particular prey species.

Kiwi live at different densities in two conservation areas in central North Island: Tongariro Forest Park (T.F.P.) and Tongariro National Park (T.N.P.; Chapter 2). The aims of this chapter are to establish whether food is a limiting resource for kiwi in T.N.P. thereby restricting the density of kiwi in this area, and to provide new information on the feeding ecology of Northern brown kiwi.

4.2 Study areas

4.2.1 Tongariro National Park

The area in which the invertebrates were sampled was selected after extensive call surveys (Chapter 2), and ground surveillance (looking for kiwi sign) to identify where kiwi were living. The site selected was situated 5 km up from the Mangahuia Camp Site (refer to Figure 2.1, Chapter 2), just off state highway 47, on the northern slopes of Ruapehu (NZMS, S20; 240185). At 1026 m a.s.l the vegetation canopy was predominantly mountain beech (*Nothofagus solandri var. cliffortiodes*), kaikawaka (*Libocedrus bidwillii*), and Hall's totara (*Podocarpus hallii*). The understorey consisted of a single layer of undergrowth containing a diverse array of species: sapling mountain beech, kaikawaka, totara, mountain toatoa (*Phyllocladus aspleniifolus var. alpinus*), stinkwood (*Coprosma foetidissima*), creeping coprosma (*Coprosma pumila*), horopito (*Pseudowintera colorata*), mingimingi (*Leucopogon sauveoleris*), prickly mingimingi (*Cyathodes juniperina*), and many more divaricating species.

Five sites, 100 m apart and running in a north-east direction from the Mangahuia track down to the Mangahuia stream, were selected. The vegetation at each site was similar in composition average litter depth was 15 mm. Soil at all sites was a mix of podzolised yellow-brown pumice, and recent soils related to yellow brown pumice soils: Ngaurahoe sand (Rijkse, *in press*). The soil remained moist all year. Mean daily temperature ranged from 2.1 °C to 11.3 °C and average rainfall per month was 169.4 mm during the study (December 1992 to January 1994).

4.2.2 Tongariro Forest Park

Tongariro Forest Park (approximately 20,000 ha) is situated to the north-west of Tongariro National Park. The vegetation of the area is a mix of virgin and cut-over indigenous forest. The landscape includes Taurewa Ridge and the headwaters and tributaries of the Whanganui River (DoC discussion paper, 1992).

The study site was located 10 km north-west of Kapoors Road off state highway 47 (NZMS, S19; 237367). Although this area was heavily logged between 1903 and 1978, it still contains forest remnants dominated by a variety of podocarps. Within these refugia kiwi were found (Chapter 3), and the invertebrate surveys were made. Five sample sites within the Waione Valley were chosen. These were spaced at 100 m intervals from a ridge (700 m a.s.l.), down to the Waione Stream (510 m a.s.l.). Unlike T.N.P. each site fell within a different vegetation type.

4.2.3 Invertebrate survey sites in T.F.P.

The vegetation found at site 1 was dominated by toetoe (*Cortaderia fulvida*). The canopy consisted of *Buddleia*, rangiora (*Brachyglottis repanda*), and cabbage tree (*Cordyline banksii*). Excluding toetoe, ground cover was sparse, consisting mainly of putaputaweta (*Carpodetus serata*) and *Hebe* spp. seedlings.

At site 2 rimu (*Dacrydium cupressinum*) and tawa (*Beilschmeidia tawa*) were emergent, with a tangled understorey of putaputaweta, raurekau (*Coprosma grandifolia*), tawa, heketara (*Oleria rani*), wineberry (*Aristotelia serrata*), lancewood (*Pseudopanax crassifolius*), mahoe (*Melicytus ramiflorus*), black maire (*Nestegis cunninghamii*), rangiora, and horopeto (*Pseudowintera colorata*). The ground cover contained crown fern (*Blechnum discolor*), wheki-ponga (*Dicksonia fibrosa*), filmy fern (*Hymenophyllum flabellatum*), *Asplenium flaccidum* and the occasional podocarp seedling.

Site 3 was dominated by wheki-ponga, with the odd emergent rimu, lancewood, putaputaweta and mahoe. No subcanopy existed but there was a shrub layer of horopito, hangehange (*Geniostoma rupestre*), broad leaf (*Griselinia littoralis*), lancewood and pate (*Schefflera digitata*). The ground cover was a mosaic of umbrella moss, giant moss (*Dawsonia superba)*, crown fern, panakenake (*Pratia angulata*) and forest rice grass (*Microleana avinacea*). This area still showed evidence of selective logging.

Site 4 was situated in an un-logged area 60 m up from the Waione Stream. Here the canopy was dominated by rimu, while the subcanopy was made up of sapling rimu, broad leaf, wheki-ponga, tawa, black maire, putaputaweta, lancewood and miro (*Phyllocladus ferrugineus*). The understorey comprised putaputaweta, broadleaf, rimu, totara (*Podocarpus hallii*), wheki-ponga, horopito, miro, kamahi (*Weinmannia racemosa*), raurekau and heketara. Ground cover was sparse with some kawakawa, putaputaweta, ferns (weki-ponga and Asplenium spp.), rimu and other podocarp seedlings.

Site 5 (10 m above Waione Stream) like site 1, mainly comprised toetoe, with some putaputaweta, and panakenake. An array of mosses and liverworts covered the ground. Surrounding the perimeter were rimu, lance wood, broad leaf, *Hebe stricta*, and horopito. This area was permanently boggy.

The average litter depth ranged from 10 mm at sites 1 and 5, to 35 mm in sites 2, 3 and 4. Soils varied from integrades between central yellow-brown loam and yellow-brown pumice soils (Rijkse, *In press*). Mean daily temperature ranged from 9 °C to 18 °C, and average rainfall per month was 101.64 mm during the study.

4.3 **Methods**

The techniques used to sample invertebrates were similar to those of Moeed and Meads (1985, 1986, 1987). Each site had five pitfall traps arranged to cover an area of approximately 100 m^2. Each trap comprised an open-ended plastic container 100 mm in diameter and 120 mm deep, with a 250 mm sheet of galvanized iron set 20 mm above the trap to act as the lid preventing excessive amounts of litter falling into the trap. A combination of anti-freeze (ethylene-glycol) and salt (M. Meads *pers. comm.*) was used as a preservative. Two other 100 m^2 grids at each site were used alternately for litter and soil sample collection. A litter sample of 400 mm^2 was taken from one of these grids, the invertebrates within this sample were later extracted using Tullgren funnels as described by Moeed and Meads (1986). From the second grid a core of soil 150 mm in diameter and 150 mm deep was extracted, and the invertebrates were sorted on site. Each site was sampled on average every 45 days from December 1992 to January 1994. The nine sample dates were then arranged into the four seasons, summer (December-February) autumn (March-May), winter (June-August), and spring (September-November).

Work by Colbourne *et al.* (1990) compared mandibles and other chitinous remains within little spotted kiwi (*Apteryx owenii*) faeces to whole specimens and indicated that the minimum size of food items eaten by these kiwi was about 8 mm. This was used here as a conservative estimate of the minimum size of food brown kiwi are likely to consume. Invertebrates less than this length were not counted, and invertebrates smaller than 5 mm were discarded.

Brown kiwi faeces were collected over 14 months and stored individually in 75% alcohol. Samples were then washed with detergent in hot water to dissolve mucus, then washed through a gradation of four sieve sizes: 1mm gauze and 500 µm gauze to collect the larger invertebrates, and 250 µm and 125 µm gauze to collect smaller invertebrate fragments and worm chaetae. Apart from earthworms, all invertebrate food items (numbers of individuals) within the faeces were counted under a X 10 binocular microscope. All invertebrates were identified to family, and some to genus, by comparing fragments to whole specimens collected over the 14 month invertebrate survey of both areas. The number of species of each taxon in a dropping were determined by counting the most conspicuous remains; ie, the fore-tibias of cicada nymphs, head parts of adult beetles, and chelicerae of spiders. Thirteen non-annelid taxa were identified as common in faeces collected in both areas. Ten examples of each taxon were selected from invertebrate sampled material and weighed to give an estimation of individual biomass. Analyses were carried out on these 13 taxa only.

Earthworm chaetae in faeces were counted but the numbers of earthworms consumed was not attempted as chaetae give an unreliable indication of the number of earthworms eaten because the number of chaetae per earthworm differs between species and between different sized earthworms of the same species (Wroot, 1985).

The presence of identifiable plant remains, ie; seeds and fruit, was recorded. Identification of plant fragments by their cuticle patterns was not attempted as these particles have been thought to be ingested incidentally by kiwi (Kleinpaste, 1990).

4.3.1 Statistical analysis

Variances between T.N.P. and T.F.P.; seasonal variation of invertebrate availability; differences between numbers of individuals caught annually using the three sampling techniques; and inter site relationships within each area, were analysed using ANOVA (SAS Institute, 1985).

Chi-square analyses were used to determine whether there were any significant differences in the frequency with which invertebrates were eaten and their apparent availability. The G-statistic was also calculated (Sokal and Rolf, 1981) to emphasise the direction of deviation from the expected. Confidence intervals were constructed to examine several comparisons between estimated and expected occurrence of invertebrates in faeces in order to detect preference or under-utilisation (avoidance) of forage species (refer to Chapter 3, Section 3.2.8 for description). The Mann-Whitney test was used to test whether kiwi favoured larger taxa over smaller taxa. All differences were regarded as significant if $P \leq 0.05$, critical values were taken from Zar (1984).

4.4 **Results**

4.4.1 Food distribution

Over 14 months of field work a total of 12594 surface, litter, and soil dwelling invertebrates > 5 mm were caught in pitfall traps, litter samples, and soil samples in both study areas. Higher numbers of invertebrates were caught in T.F.P. (n = 7725), a highly modified lowland podocarp forest, than T.N.P. (n = 4869), a montane beech forest. Similarly, taxonomic diversity was also greater in T.F.P. (n = 189) than T.N.P. (n = 156).

4.4.2 Differences in numbers of invertebrates and taxonomic diversity between areas

Tables 4.1 and 4.2 show that both the total number of invertebrates caught and their diversity varies significantly with season, the specific location of the pitfall traps, and between T.F.P. and T.N.P. The effect of season was similar in both areas (area * season). Taxonomic diversity of litter dwelling invertebrates did not vary through season, however, absolute numbers did differ between locations with more caught in T.F.P. Specific locations of litter samples also varied between areas. Total numbers of soil dwelling invertebrates caught and their diversity varied significantly with season and specific location of sample sites. However, taxonomic diversity did not vary between area.

4.4.3 Differences in invertebrate abundance and taxonomic diversity within areas

Section 4.4.2 highlighted significant variation between sampling sites within each area (Tables 4.1 & 4.2). This section looks at this apparent variation (Tables 4.3 & 4.4).

Both the total number of invertebrates caught (Table 4.3) in pitfall traps and their taxonomic diversity (Table 4.4) varies significantly with season between sampling sites in T.F.P. This was not the case between sites in T.N.P. where no significant variation was evident in total numbers of invertebrates caught or taxonomic diversity.

Within T.F.P. there was significant seasonal variation in the numbers of litter dwelling invertebrates caught between sites, however season did not influence their diversity. Similarly in T.N.P. there was significant variation in numbers of litter dwelling invertebrates caught, but no seasonal or site effect on taxonomic diversity was evident.

There was a seasonal effect but no site effect on the numbers of soil dwelling invertebrates caught in T.F.P.. While taxonomic diversity varied significantly both seasonally as well as between sites. Both the total number of soil dwelling invertebrates caught and their diversity varied significantly with season, and the location of sampling sites within T.N.P.

Table 4.1 Analysis of variance table for total number of individual invertebrates > 5 mm caught in either pitfall traps, litter samples, or soil samples in T.F.P. and T.N.P.

	Source of variation	df	MS[1]	F	P > F
Pitfall traps	Total model	449	12.66	32.84	0.0001
	Season	8	16.73	43.39	0.0001
	Area	1	62.66	162.51	0.0001
	Site(area)	8	14.47	37.53	0.0001
	Area*season	8	0.54	1.39	0.1979
Litter samples	Total model	89	1.85	5.26	0.0001
	Season	8	1.79	5.10	0.0001
	Area	1	0.51	1.45	0.2334
	Site(area)	8	2.97	8.46	0.0001
	Area*season	8	0.95	2.71	0.0124
Soil samples	Total model	89	1.25	4.78	0.0001
	Season	8	2.63	10.07	0.0001
	Area	1	0.12	0.46	0.5002
	Site(area)	8	0.91	3.49	0.0021
	Area*season	8	0.35	1.33	0.2431

Table 4.2 Analysis of variance table comparing taxonomic diversity of invertebrate taxa caught in pitfall traps, litter samples, and soil samples in both T.F.P. and T.N.P.

	Source of variation	df	MS	F	P > F
Pitfall traps	Total model	449	225.11	21.58	0.0001
	Season	8	383.40	36.75	0.0001
	Area	1	904.54	86.71	0.0001
	Site(area)	8	192.85	18.49	0.0001
	Area*season	8	14.14	1.36	0.2142
Litter samples	Total model	89	39.52	2.89	0.0003
	Season	8	28.39	2.08	0.0512
	Area	1	16.90	1.24	0.27
	Site(area)	8	76.82	5.62	0.0001
	Area*season	8	16.18	1.18	0.32
Soil samples	Total model	89	4.27	4.16	0.0001
	Season	8	7.94	7.74	0.0001
	Area	1	0.28	0.27	0.6047
	Site(area)	8	3.19	3.11	0.0050
	Area*season	8	2.18	2.12	0.0463

Table 4.3 Zonal differences in invertebrate numbers

	Source of variation	df	MS	F	P > F
T.F.P. Pitfall traps	Total model	224	2287.66	6.67	0.0001
	Season	8	6330.89	18.47	0.0001
	Site	4	6907.86	20.15	0.0001
	Site*season	32	699.33	2.04	0.0019
T.N.P Pitfall traps	Total model	224	304.78	3.05	0.0001
	Season	8	1080.87	10.82	0.0001
	Site	4	86.63	0.87	0.4848
	Site*season	32	138.03	1.32	0.0975
T.F.P Litter samples	Total model	44	7736.86	3.54	0.0021
	Season	8	5832.55	2.67	0.0228
	Site(area)	4	11545.47	5.28	0.0022
T.N.P Litter samples	Total model	44	7111.87	8.06	0.0001
	Season	8	5594.42	6.34	0.0001
	Site(area)	4	10146.76	11.50	0.0001
T.F.P Soil samples	Total model	44	15.56	4.22	0.0005
	Season	8	18.60	5.04	0.0004
	Site(area)	4	9.48	2.57	0.0568
T.N.P Soil samples	Total model	44	12.85	3.36	0.0031
	Season	8	14.15	3.69	0.0037
	Site(area)	4	10.26	2.68	0.0494

Table 4.4 Intersite difference in zonal taxonomic diversity.

Source of variation		df	MS	F	P > F
T.F.P Pitfall traps	Total model	224	84.64	6.13	0.0001
	Season	8	200.89	14.55	0.0001
	Site	4	375.12	27.16	0.0001
	Site*season	32	19.27	1.40	0.0910
T.N.P Pitfall traps	Total model	224	41.45	6.71	0.0001
	Season	8	196.65	31.82	0.0001
	Site	4	10.58	1.71	0.1491
	Site*season	32	6.50	1.05	0.4004
T.F.P. Litter samples	Total model	44	57.82	3.31	0.0034
	Season	8	22.72	1.30	0.2784
	Site(area)	4	128.02	7.33	0.0003
T.N.P.Litter samples	Total model	44	23.10	2.34	0.0274
	Season	8	21.84	2.21	0.0531
	Site(area)	4	25.61	2.59	0.0550
T.F.P. Soil samples	Total model	44	3.99	3.27	0.0037
	Season	8	3.92	3.21	0.0086
	Site(area)	4	4.13	3.39	0.0203
T.N.P. Soil samples	Total model	44	4.88	5.87	0.0001
	Season	8	6.20	7.45	0.0001
	Site(area)	4	2.24	2.70	0.0482

4.4.4 Faecal analysis

A total of 40 faeces were found and analysed. Four of the twenty-six faeces found in T.F.P. consisted only of rimu arils and seed. Invertebrates identified in faecal material were compared to captured specimens. Only invertebrates ≥ 10 mm body length were found in faeces. Annelid chaetae were identified in 83% of faeces. Annelids were available all year round to kiwi, with the largest number caught in pitfall traps and litter samples in summer (Figure 4.1). This was reflected in chaetae counts (Figure 4.2). Thirteen non-annelid invertebrate groups were found commonly to occur in faeces found in T.F.P. and T.N.P. (Table 4.5). These 13 taxa accounted for 28% of all invertebrates caught in the invertebrate survey in T.N.P., and 19% in T.F.P. The

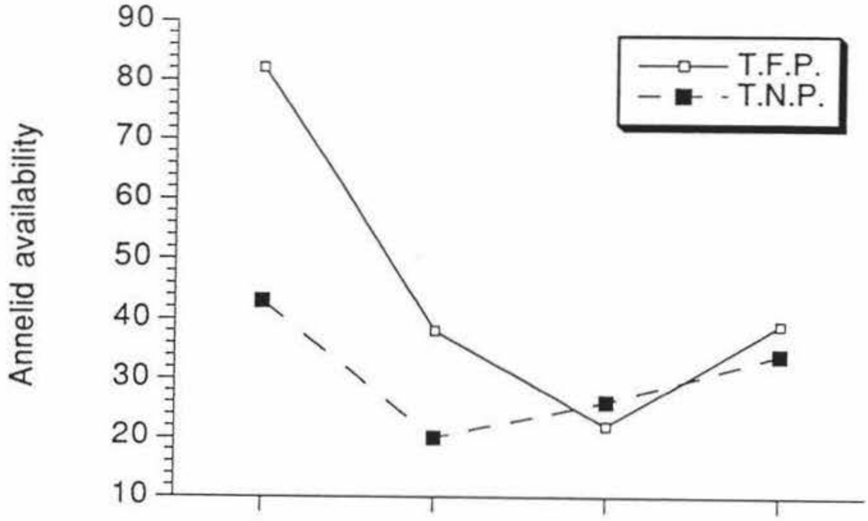


Figure 4.1 Availability of annelids in Tongariro Forest Park and Tongariro National Park.

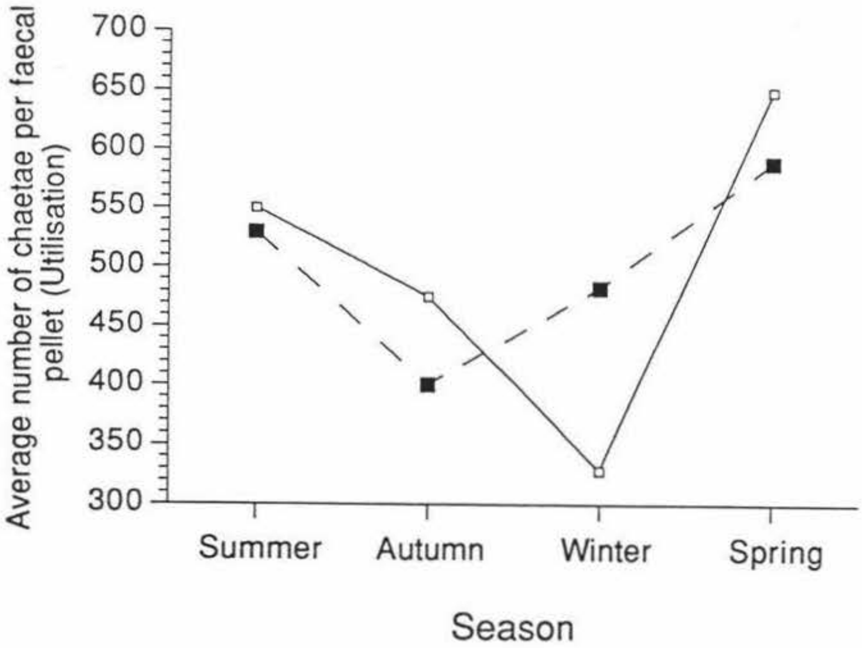


Figure 4.2 Utilisation of annelids by kiwi, reflected by average number of chaetae per faecal pellet collected in Tongariro Forest Park and Tongariro National Park.

Table 4.5 Average weights of taxa, their zone of capture, and their weight contribution in proportion to availability and utilisation in T.F.P. and T.N.P.

Taxonomic group	Weight ± SE (g)	Zone of capture	Weight in proportion to availability in T.F.P.	Weight in proportion to utilisation in T.F.P.	Weight in proportion to availability in T.N.P.	Weight in proportion to utilisation in T.N.P.
Arachnida	1.4 ± 0.2	Surface	0.22	1.78	0.31	2.60
Orthoptera	1.3 ± 0.2	"	0.14	1.24	0.12	1.48
Carabidae adult	1.1 ± 0.3	"	1.19	1.55	0.13	1.18
Scarabaeidae adult	0.6 ± 0.2	"	0.01	0.74	0.01	0.3
Curculionidae adult	0.09 ± 0.01	"	0.004	0.02	0.007	0.05
Tenebrionid adult	0.07 ± 0.02	"	0.002	0.02	0.004	0.04
Diplopoda	0.4 ± 0.2	Litter	0.04	0.18	0.04	0.43
Lepidoptera larvae	0.3 ± 0.06	"	0.02	0.08	0.009	0.09
Tipulidae larvae	0.2 ± 0.05	"	0.03	0.07	0.04	0.10
Elateridae larvae	0.003 ± 0.002	"	0.0002	0.0007	0.0002	0.002
Cicadidae nymph	0.4 ± 0.07	Soil	0.01	0.87	0.004	0.29
Scarabaeidae larvae	0.3 ± 0.03	"	0.006	0.48	0.006	0.24
Carabidae larvae	0.04 ± 0.01	"	0.002	0.03	0.002	0.04

average number of invertebrates recorded per dropping found in T.N.P. (mean = 10.5. ± 0.03) and T.F.P. (mean = 10.52 ± 2.69) was similar.

4.4.5 Availability of taxa ȧnd their occurrence in kiwi diet

Seasonal availability of each zonal grouping of invertebrate (Table 4.5) either pitfall trapped - surface dwelling, litter sampled - litter dwelling, and soil sampled - soil dwelling is shown in Table 4.6. The proportion of each zonal category within each area and the number of each category within faeces were determined (Table 4.7), and the following hypothesis was tested by the Chi-square technique: kiwi utilise each "feeding zone" in exact proportion to availability of invertebrates found in that feeding zone. Table 4.8 shows that the expected occurrence of each zonal category differed significantly from the observed occurrence of invertebrates each season within both study areas. Thus the null hypothesis of no difference is rejected.

4.4.6 Seasonal preference or "avoidance" of feeding zones

To detect a seasonal preference or avoidance of feeding zones by kiwi individual confidence intervals were constructed to detect whether expected values lay within the magnitude of significant effect (Table 4.9). This table shows there were significant differences between estimated and hypothesised seasonal use of each feeding zone by kiwi. Table 4.10 shows faeces found in T.F.P. over summer had lower numbers of surface dwelling taxa than expected, an even amount of litter dwelling taxa, and a higher amount of soil dwelling taxa. In T.F.P. higher numbers of soil dwelling taxa occurred in faeces than were caught in the invertebrate survey except in spring, when utilisation matched availability. In autumn, winter and spring surface dwelling invertebrates occurred in similar proportions in the diet to their availability, while litter dwelling invertebrates occurred less in the diet than their availability suggested. Figure 4.3a illustrates percentage availability and utilisation of the 13 taxa common in faeces in T.F.P. In T.N.P. seasonal utilisation of the three feeding zones was within the confidence intervals (Table 4.9) indicating invertebrates occurred in similar proportions in the diet to what was available to them in these zones. Only in spring were soil dwelling invertebrates found in higher proportion in the diet than expected from their apparent availability (Table 4.10). Figure 4.3b shows fairly uniform percent availability vs utilisation curves.

4.4.7 Preference or "avoidance" of taxa

In both T.F.P. and T.N.P. in spring kiwi appeared to over-utilise soil dwelling taxa (Table 4.10). Comparisons between estimated and expected occurrence of taxa in the diet were made in order to detect preference or avoidance of individual forage species.

If preference is shown to exist by kiwi choosing to feed in one zone over another it would be expected that taxa occurring in that zone would be significantly preferred to taxa occurring in other zones. Table 4.11 lists the 13 taxa common in faeces of kiwi in both areas, and shows kiwi in T.F.P. to prefer Cicadidae nymphs living in the soil column. Kiwi in T.N.P. also consumed significantly more soil dwelling invertebrates than availability suggests, particularly in spring, however, no preference towards these invertebrates was apparent.

4.4.8 Biomass contribution of taxa

Arachnida, Orthopteran, Carabidae and Scarabaeidae adults contribute more to the biomass of faeces than soil dwelling taxa (Table 4.5). In terms of weight consumed Arachnida, Orthopteran, Carabidae adults, and Cicadidae nymphs were very important components in the diet of kiwi.

Arachnida contributed 25.21%, Carabidae adults 21.95%, Orthoptera 17.56%, and Cicadidae nymphs 12.32% to the average "wet" weight (7.06 g) of the faeces found ($n = 22$) in T.F.P. In T.N.P. Arachnida contributed 38.01%, Orthoptera 21.64%, Carabidae adults 17.25%, and Cicadidae nymphs 4.24% to the average "wet" weight (6.84 g) of the faeces found ($n = 14$).

When comparing biomass of invertebrates utilised with their apparent available biomass (Table 4.5), kiwi do not take invertebrates in proportion to what would be expected, if weight was an important "consideration" when feeding (Mann-Whitney; T.F.P., $0.01 < P < 0.025$; T.N.P, $P = 0.005$).

Table 4.6 Availability of taxa in the three feeding zones

	Season	Summer			Autumn			Winter			Spring		
	Zone	#	Prop.	%	#	Prop.	%	#	Prop.	%	#	Prop.	%
T.F.P	Surface	278	0.69	68.98	127	0.59	58.53	59	0.26	26.34	92	0.42	42.40
	Litter	98	0.24	24.32	65	0.30	29.95	146	0.65	65.18	90	0.41	41.47
	Soil	27	0.07	6.7	25	0.12	11.52	19	0.08	8.48	35	0.16	16.13
	Total	403	1	100	217	1	100	224	1	100	217	1	100
T.N.P.	Surface	251	0.69	68.58	105	0.50	50.24	34	0.30	29.82	122	0.61	60.70
	Litter	90	0.25	24.59	75	0.36	35.89	80	0.70	70.18	67	0.33	33.33
	Soil	25	0.07	6.83	29	0.14	13.86	0	0	0	12	0.06	5.97
	Total	366	1	100	209	1	100	114	1	100	201	1	100

Table 4.7 Utilisation of the three feeding zones by kiwi

•	Zone	Summer	Percent	Autumn	Percent	Winter	Percent	Spring	Percent
T.F.P.	Surface	44	48.89	31	53.45	7	25	34	51.52
	Litter	8	8.89	5	8.62	6	21.43	10	15.15
	Soil	38	42.22	22	37.93	15	53.57	22	33.33
	Total	90	100	58	100	28	100	66	100
T.N.P.	Surface	28	53.85	19	46.34	5	45.45	26	60.47
	Litter	9	17.31	8	19.51	6	54.54	10	23.26
	Soil	15	28.85	14	34.15	0	0	7	16.28
	Total	52	100	41	100	11	100	43	100

Table 4.8 Calculation of the Chi-square statistic (test of preference) of feeding zones in T.F.P. and T.N.P.

T.F.P.	Summer				Autumn				Winter				Spring			
Zone	Observed	Expected	X^2	G stat	Observed	Expected	X^2	G stat	Observed	Expected	X^2	G stat	Observed	Expected	X^2	G stat
Surface	44	62.1	5.28	-15.16	31	34.22	0.30	-3.06	7	7.28	0.01	-0.27	34	27.72	1.42	6.94
Litter	8	21.6	8.56	-7.95	5	17.40	8.84	-6.24	6	18.20	8.19	-6.66	10	27.06	10.76	-9.95
Soil	38	6.3	159.51	68.29	22	6.96	32.50	25.32	15	2.24	72.69	28.52	22	10.56	12.39	16.15
Total	90	90	73.35	75.50	58	58	41.64	16.02	28	28	80.89	21.59	66	66	24.57	13.14
T.N.P	Summer				Autumn				Winter				Spring			
Zone	Observed	Expected	X^2	G stat	Observed	Expected	X^2	G stat	Observed	Expected	X^2	G stat	Observed	Expected	X^2	G stat
Surface	28	35.88	1.73	-6.94	19	20.50	0.11	-1.44	5	3.3	0.88	2.08	26	26.23	0.002	-0.23
Litter	9	13	1.23	-3.31	8	14.76	3.10	-4.99	6	7.7	0.38	-1.50	10	14.19	1.24	-3.50
Soil	15	3.64	35.45	21.24	14	5.74	11.89	12.48	0	0	0	0	7	2.58	7.57	6.99
Total	52	52	38.41	10.99	41	41	15.10	6.05	11	11	1.26	0.58	43	43	8.812	3.26

Table 4.9 Confidence intervals for the proportion spent feeding in each feeding zone in T.F.P. and T.N.P.

T.F.P.	Summer			Autumn			Winter			Spring		
Zone	# eaten	P	Confidence int.	# eaten	P	Confidence int.	# eaten	P	Confidence int.	# eaten	P	Confidence int.
Surface	44	0.69	0.33<P<0.65	31	0.59	0.35<P<0.72	7	0.26	-0.09<P<0.59	34	0.42	0.34<P<0.70
Litter	8	0.24	0.12<P<0.30	5	0.30	-0.18<P<0.35	6	0.65	-0.14<P<0.57	10	0.41	-0.09<P<0.39
Soil	38	0.07	0.25<P<0.59	22	0.12	0.16<P<0.60	15	0.08	0.27<P<0.81	22	0.16	0.12<P<0.54
Total	90	1		58	1		28	1		66	1	
T.N.P.	# eaten	P	Confidence int.	# eaten	P	Confidence int	# eaten	P	Confidence int.	# eaten	P	Confidence int.
Surface	28	0.69	0.34<P<0.74	19	0.50	0.22<P<0.70	5	0.30	-0.01<P<0.92	26	0.61	0.40<P<0.81
Litter	9	0.25	-0.09<P<0.44	8	0.36	-0.01<P<0.49	6	0.70	0.12<P<0.97	10	0.33	-0.05<P<0.51
Soil	15	0.07	0.04<P<0.53	14	0.14	0.08<P<0.61	0	0	0	7	0.06	-0.13<P<0.46
Total	52	1		41	1		11	1		43	1	

Table 4.10 Conclusions on preference (+) or under-utilisation (-) of feeding zones by kiwi in T.F.P. and T.N.P. (* = neither preferred nor "avoided").

T.F.P.				Zone		
Season	X^2	df	Probability	Surface	Litter	Soil
Summer	173.35	2	$P<0.001$	-	*	+
Autumn	41.64	2	$P<0.001$	*	*	+
Winter	80.89	2	$P<0.001$	*	-	+
Spring	24.57	2	$P<0.001$	*	-	*
Combined	320.45	8	$P<0.001$	*	*	+
T.N.P.				Zone		
Season	X^2	df	Probability	Surface	Litter	Soil
Summer	38.41	2	$P<0.001$	*	*	*
Autumn	15.10	2	$P<0.001$	*	*	*
Winter	1.26	1	$0.50<P<0.25$	*	*	
Spring	8.812	2	$0.025<P<0.01$	*	*	+
Combined	63.582	7	$P<0.001$	*	*	*

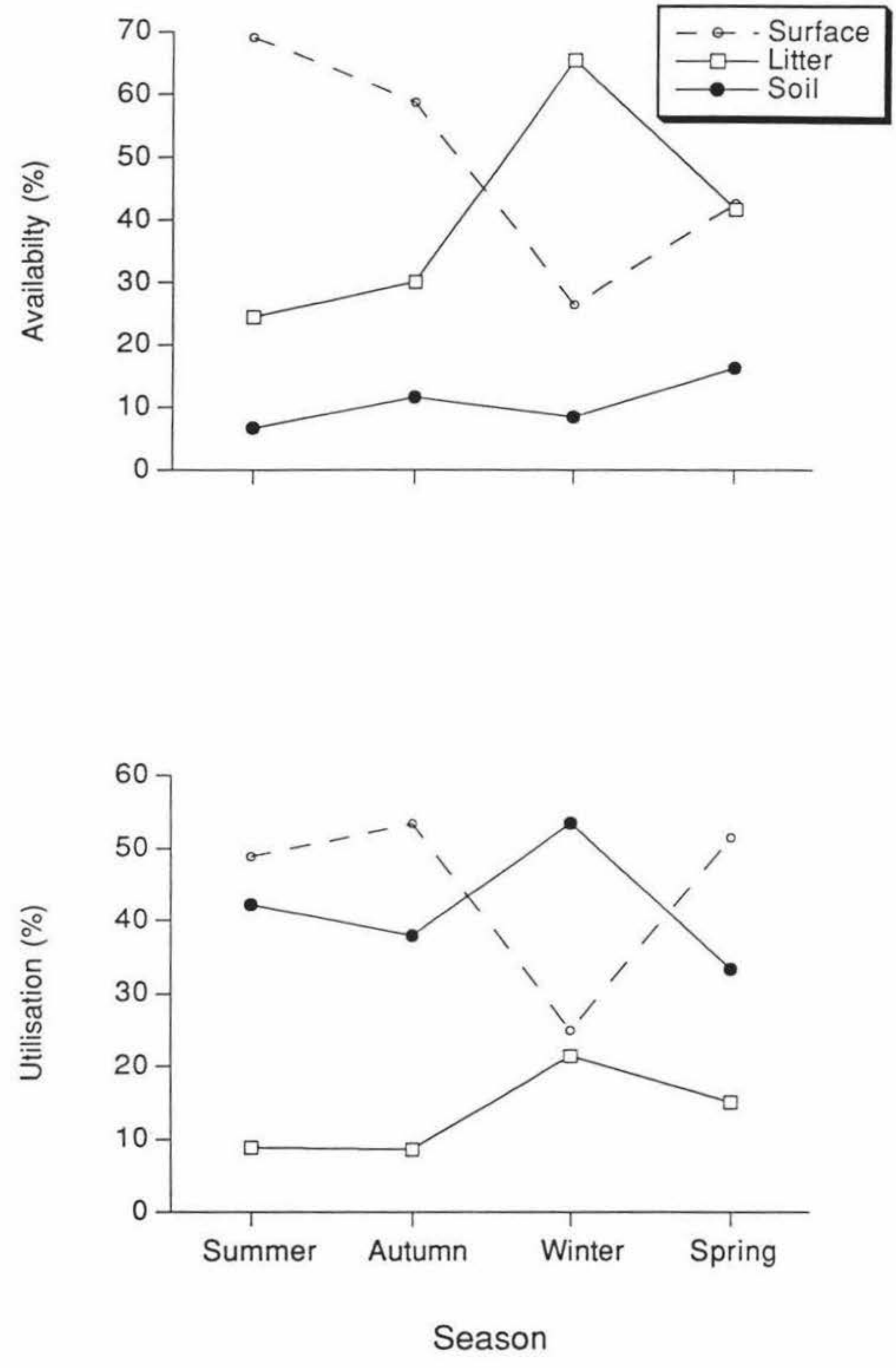


Figure 4.3a Availability and utilisation by kiwi, of surface, litter, and soil dwelling invertebrates in Tongariro Forest Park.

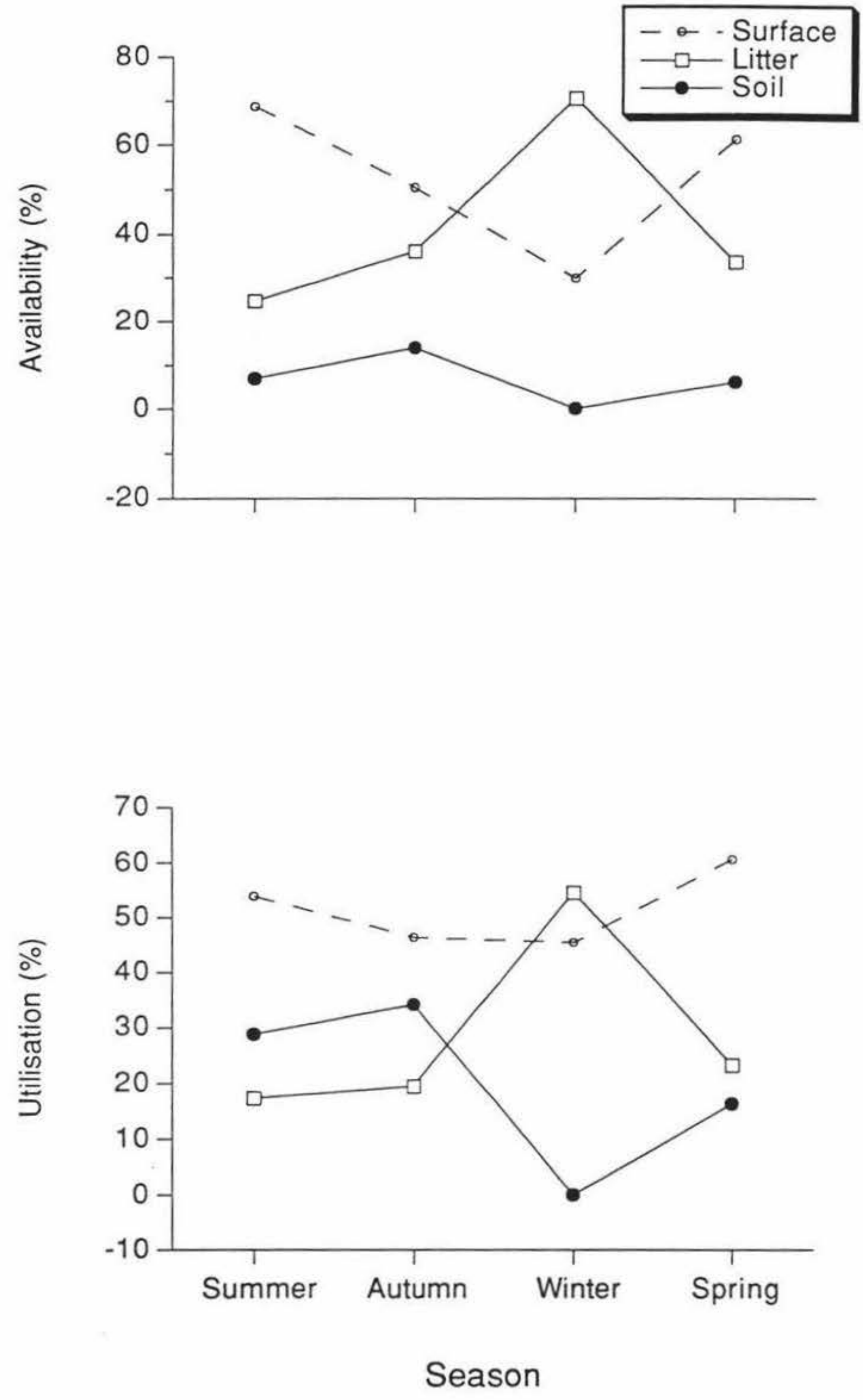


Figure 4.3b Availability and utilisation by kiwi, of surface, litter, and soil dwelling invertebrates in Tongariro National Park.

Table 4.11 Preference of particular taxa by kiwi in T.F.P. and T.N.P.

	Taxonomic group	Proportion of total caught	Number in faeces	Expected number in faeces	Proportion identified	Confidence interval on proportion of occurrence
Tongariro Forest Park	Arachnida	0.16	28	38.72	0.1157	$-0.041<P<0.273$
	Orthoptera	0.11	21	26.62	0.0868	$-0.073<P<0.247$
	Carabidae adult	0.17	31	41.14	0.1281	$-0.028<P<0.284$
	Scarabaeidae adult	0.02	27	4.84	0.1116	$-0.044<P<0.276$
	Curculionidae adult	0.04	4	9.68	0.0165	$-0.149<P<0.182$
	Tenebrionidae adult	0.03	5	7.26	0.0207	$-0.145<P<0.186$
	Diplopoda	0.11	10	26.62	0.0413	$-0.122<P<0.205$
	Lepidoptera larvae	0.05	6	12.10	0.0248	$-0.140<P<0.190$
	Tipulidae larvae	0.15	8	36.30	0.0331	$-0.131<P<0.198$
	Elateridae larvae	0.06	5	14.52	0.0207	$-0.145<P<0.186$
	Cicadidae nymph	0.03	48	7.26	0.1983	$0.049<P<0.348$
	Scarabaeidae larvae	0.02	35	4.84	0.1446	$-0.010<P<0.299$
	Carabidae larvae	0.05	14	12.10	0.0579	$-0.104<P<0.220$
Total		1	242	242	1	
Tongariro National Park	Arachnida	0.22	26	32.34	0.1769	$-0.018<P<0.371$
	Orthoptera	0.09	16	13.23	0.1088	$-0.018<P<0.371$
	Carabidae adult	0.12	15	17.64	0.1020	$-0.101<P<0.305$
	Scarabaeidae adult	0.02	7	2.94	0.0476	$-0.162<P<0.257$
	Curculionidae adult	0.08	7	11.76	0.0476	$-0.162<P<0.257$
	Tenebrionidae adult	0.05	7	7.35	0.0476	$-0.162<P<0.257$
	Diplopoda	0.09	15	13.23	0.1020	$-0.101<P<0.305$
	Lepidoptera larvae	0.03	4	4.41	0.0272	$-0.184<P<0.239$
	Tipulidae larvae	0.19	7	27.93	0.0476	$-0.162<P<0.257$
	Elateridae larvae	0.04	7	5.88	0.0476	$-0.162<P<0.257$
	Cicadidae nymph	0.01	10	1.47	0.0680	$-0.139<P<0.275$
	Scarabaeidae larvae	0.02	11	2.94	0.0748	$-0.131<P<0.281$
	Carabidae larvae	0.04	15	5.88	0.1020	$-0.101<P<0.305$
Total		1	147	147	1	

4.5 **Discussion**

4.5.1 Seasonal availability of invertebrates

Results indicate that although invertebrates vary in abundance and in the numbers of taxonomic groups represented in the three feeding zones of kiwi there was always some food available to kiwi in both T.N.P. and T.F.P. Kiwi also appeared to change their feeding behaviour to compensate for these seasonal changes in the food supply (Figure 4.3a & b).

Higher numbers of surface and soil dwelling invertebrates and greater taxonomic diversity were seen in T.F.P. than T.N.P. Invertebrates were most abundant in summer, autumn, and spring in both T.N.P. and T.F.P. which coincides with the end of the breeding season. In this period kiwi require large amounts of food to replenish reserves in preparation for the next breeding season. McLennan (1988) found both sexes of brown kiwi in Hawke's Bay reached their heaviest weight for the year before the onset of breeding. Recently fledged chicks that are around at this time also require large volumes of food to maintain their rapid growth rate. Invertebrates whose abundance peaked in these months were Arachnida, Orthoptera, Carabidae adults, Curculionidae adults, Tenebrionidae adults, Scarabaeidae adults and larvae, and Lepidoptera larvae (Appendix 8). Cicada nymphs which featured so much in the kiwi diet in T.F.P. were not as abundant during the autumn months as in other months, although they still were eaten in amounts proportional to other invertebrates available at this time.

Over the winter and spring months the majority of invertebrates collected were larval forms found in the litter layer and soil column (Appendix 8). Invertebrates available at this time of year included Lepidoptera larvae, Tipulidae larvae, Elateridae larvae, Cicadidae nymphs, and Carabidae larvae. Annelid and Diplopoda were found throughout the year, with earthworm numbers peaking in summer in both T.N.P. and T.F.P. (Figure 4.1), and millepede numbers peaking in T.N.P. in spring and summer, and summer and winter in T.F.P. (Appendix 8).

4.5.2 Occurrence of taxa in kiwi diet

Although a wide range of invertebrates were recorded in the kiwi faeces some groups were recorded in higher proportions than other groups. Cicadidae nymphs and Scarabaeidae larvae were the only two taxa found consistently in higher proportions in faeces than were caught in the invertebrate survey in both T.F.P. and T.N.P. (Appendix 9). Whether considered as a percentage of the total non-annelid invertebrates eaten (27%), or on the basis of how many faeces contained fragments of both Cicadidae nymphs and Scarabaeidae larvae appeared to be important food items in the kiwi diet (75% in the National Park and 81% in the Forest Park). Other studies on kiwi diet have also identified high numbers of these particular taxa present in either kiwi faecal material (Gurr, 1952; Colbourne and Kleinpaste, 1984; Colbourne *et al.*, 1990; Kleinpaste, 1990) or gizzard contents (Bull, 1959; Watt, 1971; Reid *et al.*, 1982).

This high occurrence of cicada nymphs and scarabaeid larvae in faeces of kiwi in both T.F.P. and T.N.P., and their contribution to overall numbers of "food" invertebrates collected (Appendix 9) suggest both are preferentially selected foods. Colbourne *et al.* (1990) found on Kapiti Island scarabaeid larvae represent the most important non-annelid food item of Little spotted kiwi diet in one site (Te Kahu), and the second most important item after spiders in the other (Te Rere). Eight times more larvae were caught in Te Kahu than Te Rere suggesting that in Te Rere kiwi actively prefer scarabaeid larvae. "It seems highly probable that the probing capacity of the bill is fully utilized" (Reid *et.al.*, 1982). This also seems to apply in T.F.P., as 40.10% of the kiwi's diet was extracted from soil, while kiwi in T.N.P. obtained only 24.50% of their food from the soil.

Few Cicadidae nymphs or scarabaeid larvae were caught in the National Park in the invertebrate survey, indicating low or patchy availability (Appendix 9). These particular life stages adopt what are known as internal distribution patterns (Odum, 1983). That is, they are irregularly or non-randomly clumped, meaning that the likelihood of collecting (in the case of the invertebrate survey) or capturing them (in the case of the kiwi) is low, unless they are actively searched for. Many groups of invertebrates show this type of clumping which seems to be associated with predator avoidance (Krebs and Davies, 1987). To combat this, kiwi appear to switch their foraging behaviour. In T.N.P. kiwi have switched to feeding from the forest surface (Table 4.7). Kleinpaste (1990) showed that kiwi in Waitangi Forest Park switch to alternative food groups instead of searching for the favoured food group when its availability is low. Here kiwi switched to feeding in swampy areas because of drought which makes probing elsewhere difficult. Associated with these swampy areas were Scirtid beetle larvae which were found throughout the year.

4.5.3 Habitat diversity, invertebrate abundance and taxonomic diversity

Large home ranges with a variety of habitat types permit kiwi to switch to alternative food sources. Home range size differed widely in T.F.P. (Chapter 3). Range size of the single kiwi captured in T.N.P. was 38.16 ha while in T.F.P. range size varied from 30.29 to 91.79 ha (Table 3.1, Chapter 3). The uniform habitat type T.N.P. (Section 4.2.1), was reflected in little inter-site variation in the numbers and taxonomic diversity of invertebrates caught. By comparison in T.F.P. diverse habitats rendered significant differences between sites (Section 4.2.3). Perhaps larger range sizes in T.F.P. compensated for habitat diversity, particularly in the case of the "favoured" soil dwelling taxa (Appendix 10).

Odum (1983) suggests that when food (in this case preferred "food" species) are scarce, larger areas of habitat are required to provide alternate food items. Optimisation can therefore, be achieved in two ways: (1) minimising search time by searching efficiently, or (2) maximising net energy by selecting large food items or easily converted energy sources (Odum, 1983). Results here indicate that kiwi appear to adopt the second approach. Fordham (1961) found a large male weta (*Hemideina megacephala*) and two snails (*Wainuia* spp.), 25 mm in diameter in the gizzard of a dead kiwi. However, this irregular clumping of preferred food groups increases the likelihood of kiwi opportunistically picking up other less "preferred" invertebrates. Consumption also appears to be synchronised with seasonal increases of the alternate invertebrate food groups (Figure 4.3a & b), which in turn results in the emergence of a pseudo opportunistic feeding pattern. Schoener (1971), Cody (1974) and Pyke *et.al.* (1977), in reviewing how energy partitioning and optimisation can be analysed, suggested that the problem is similar to the cost benefit approach used in economic theory. The partitioning of behaviour, such as selecting for more nutritious foods, may mean that other available food groups are collected resulting in an energy surplus. This energy surplus is probably channelled into reproduction (Calder, 1977).

4.5.4 Relative importance of taxa to diet in terms of biomass and availability

When considering the relative importance of taxa in terms of biomass ("live" weight), surface dwelling Arachnida, Orthoptera, Carabidae and Scarabaeidae adults contribute more as biomass than soil dwelling taxa (Table 4.5). However, kiwi appear not to utilise invertebrates in proportion to their weight. For example, Arachnida and Orthoptera occurred proportionally more frequently in faeces found in T.N.P. than in T.F.P., even though significantly higher numbers of Orthoptera were available to kiwi in T.F.P. Colbourne *et al.* (1990) and Kleinpaste (1990) both showed that cicada nymphs and scarabaeid larvae contained the highest ratios of soft tissue to dry matter of all the invertebrate taxa and effectively were "high protein packages." These taxa contributed proportionally only 7.75% to the total biomass of an average faecal pellet found in T.N.P., as opposed to 19.12% in T.F.P., lending support to the idea that kiwi seem to be compensating for the low availability of Cicadidae nymphs and Scarabaeidae larvae in T.N.P. by taking Arachnida and Orthoptera as alternatives.

Kiwi in T.F.P. also exhibit a change in diet, when these same favoured taxa are scarce, that appears to be seasonally driven (Figure 4.3a). As Cicadidae nymphs and Scarabaeidae larva's availability in the soil column decreases over summer kiwi take more surface dwelling invertebrates. During these months much of the other taxa are at their numerical peak. Over this period Kleinpaste (1990) also found that adult Coleoptera beetles were eaten quite frequently. The three most frequently encountered families in the Waitangi kiwi diet were Scarabaeidae, Elateridae and Carabidae beetles. Colbourne *et al.* (1990) similarly found that Scarabaeidae and Carabidae beetles were seasonally important in the diet of Little spotted kiwi.

Coleoptera, Lepidoptera and Diptera larvae were available throughout the year in both T.F.P. and T.N.P., but were most available in spring and summer (Appendix 8). Larvae in both areas were eaten in relative proportions to their availability, and presumably were more important to the diet of kiwi in T.N.P. than kiwi in T.F.P. Reid *et al.* (1982), Colbourne and Powesland (1988), Colbourne *et al.* (1990), and Kleinpaste (1990) all found these larval forms in kiwi faeces or gizzards, but in low numbers that contributed little to overall diet.

Tipulidae larvae were mostly associated with decomposing organic material in the litter layer in both T.N.P. and T.F.P., and were the most abundant larval food group associated with these layers. Kleinpaste (1990) similarly found Tipulidae to be the main food species associated with these layers in Waitangi. Numerically Lepidoptera larvae featured little in faeces in both T.F.P. and T.N.P. This may, however, be misleading as both Colbourne *et al.* (1990) and Kleinpaste (1990) determined relative biomass of each prey item, and found that larger soft bodied invertebrates such as Annelida, Cicadidae nymphs and Scarabaeidae larvae had the highest biomass ratings. Large Lepidoptera such as porina and noctuid larvae, were both identified in faeces from T.N.P. and T.F.P., and fell into this category.

Diplopoda were found in reasonable numbers in all strata throughout the year, but they contributed only about 4.13% to the diet of kiwi in T.F.P. and 20% to the diet of kiwi in T.N.P. Colbourne *et al.* (1990) suggested that the Little spotted kiwi may have ~~been~~ avoided some invertebrates, including staphylinid beetles and millipedes, which secrete a defensive chemical (Barns, 1968; Richards and Davis, 1977). The inverse was suggested by Kleinpaste (1990) who found kiwi in Waitangi picked up millipedes and centipedes from the forest floor, and suggested "the strong smell makes prey easier to locate for kiwi." Carabidae adults also secrete a strong smelling chemical, and were identified in faeces in relative to their apparent availability in both T.N.P. and T.F.P. (Table 4.11).

Annelids were apparently eaten in large numbers both in T.F.P. and T.N.P. with most droppings having high counts of chaetae (Figure 4.2). The numbers of chaetae peaked in spring and summer when the majority of earthworms were caught in pitfall traps. Chaetae counts give an unreliable indication of the number of earthworms eaten (Wroot, 1985). Colbourne and Kleinpaste (1984) found that faeces in the recta of kiwi contained about one-eighth of the chaetae that were present in the gizzard. In this study the overall arthropod component in the diet could be determined, but overall feeding preferences remain unclear because the earthworm component of the diet could not be measured.

4.5.5 Vegetative component to diet

The size and type of the seeds identified in faeces found in T.N.P. and T.F.P., and their abundance in particular faeces, indicates that fruits were selectively eaten when available, and make up a component of the kiwi diet. *Coprosma* spp. seed were identified in faeces found in T.N.P., while 4 faeces in T.F.P. consisted entirely of rimu seed and arils. Associated with both of these items is a soft fleshy fruit. Reid *et al.* (1982) found vegetable matter in 40 of the 50 gizzards analysed. Much of this vegetation is attributed to incidental ingestion (Kleinpaste, 1990) although some browsing or selective feeding may occur (Shorland *et al.*, 1961). Buller (1888) suggested that fruit with hard endodermis act like pebbles and grit, and are useful for grinding food in the gizzard, and Kleinpaste (1990) mentions kiwi feasting on large numbers of hard kernelled berries such as tawa.

4.5.6 Food as a limiting resource

Similar numbers of litter and soil dwelling invertebrates were available to kiwi in both T.N.P. and T.F.P., while higher numbers of surface dwelling invertebrates were available in T.F.P. More invertebrates were available for consumption in summer than in other seasons. However, in both T.N.P. and T.F.P. all taxa appeared in the faeces in proportion to their availability.

Over 61% of the invertebrates caught were from T.F.P.. This may reflect the greater diversity of vegetation in this lowland podocarp forest compared with the more structurally uniform montane forest in T.N.P.. Differences in the numbers of taxonomic groups caught in T.N.P. and T.F.P. supports the view that habitat type plays an important role in resource diversity, and suggests that historically the two areas may have had different kiwi carrying capacities. However, only a small proportion of this taxonomic diversity seem to be targeted by kiwi, and at current densities kiwi are unlikely to be food limited at either site. The differences in kiwi densities in T.N.P. and T.F.P. at present appear to be effected by predation, and possibly human activities (chiefly in T.F.P.). These issues are addressed in Chapter 5.

Chapter 5

Index of predators: potential threats to the survival of Northern brown kiwi (*Apteryx australis mantelli*) in the central North Island.

5.1 Introduction

Kiwi mortality can be affected by a range of factors, including predation. Little is known about the impact of predators on the majority of contemporary New Zealand fauna (C.M. King *pers. comm.*). It is indisputable, however, that mammalian predators are hastening the extinction of particular species, including kiwi. Of the introduced carnivores, feral dogs are probably the greatest threat to kiwi (McLennan and Potter, 1992) because a single dog can decimate an otherwise viable population of kiwi (Taborsky, 1988). McLennan and Potter (1992) speculate that predation by cats (*Felis catus*) and stoats (*Mustela erminea*) on juveniles is probably contributing to the decline, because chicks known to have fledged seldom reappear as breeding adults (McLennan, 1988). A comparison of juvenile to adult ratios in mainland versus predator free offshore island populations of kiwi suggests that introduced predators may kill over 90% of juvenile kiwi on the mainland (McLennan and Potter, 1993). Recently ferrets (*Mustela putorius*) and possums (*Trichosurus vulpecula*) have been identified killing adult kiwi at Lake Waikaremoana, Urewera National Park (J.A. McLennan *pers. comm.*). Feral pigs (*Sus scrofa*) also kill kiwi, and possums occasionally eat kiwi eggs (McLennan, 1988). Additionally kiwi fall victim to poison and traps, set to catch possums (McLennan, 1987; McLennan and Potter, 1992).

There are different densities of kiwi in Tongariro National Park (T.N.P.) and Tongariro Forest Park (T.F.P.; Chapter 2). It might be expected that the different management regimes operating in the two areas would provide greater protection to kiwi residing in T.N.P. Yet T.N.P. appears to support a kiwi population at a density only 25% of that found in T.F.P. These two areas have fundamental differences in vegetation, and in food availability, which historically may have influenced density of kiwi (Chapter 4). Both areas appear to be able to support more kiwi than present numbers suggest (historical records in *A History of the birds of New Zealand*; Buller 1888). Therefore can this difference in density be accounted for by present assemblages and densities of predators ?

The aim of this chapter is to address this question, by determining whether there were significant differences in the mammalian predators in the two areas that may help account for the observed difference in kiwi density. A further aim is to compare samples of stoats collected in the study area with those analysed by King and Moody (1982 b & c).

5.2 **Methods**

5.2.1 Study sites: see Chapter 2, section 2.2.

5.2.2 Indexing mammalian predators

The presence of mammalian predators in each site was determined by establishing and monitoring a trap-line; by noting any other predators seen; and by recording data from the Department of Conservation (Whakapapa) Pest Control Diary system (Appendix 11).

5.2.3 Trap layout

Twelve trapping tunnels spaced at 500 m intervals and placed 5 - 10 m from the main access ways were set along 6 km transects down both Mangahuia track in T.N.P. and Slabb road in T.F.P. Traps were set for 14 consecutive days each month from July to September 1993, and provided a total of 504 trap nights.

5.2.4 Trapping tunnels

Mark IV Fenn Humane Traps were used to trap stoats. The Fenn trap is designed to operate in a tunnel only a little wider than the trap. The traps jaws close across the stoats back, killing it almost instantly (O'Donnell *et al.*, 1992). Each trapping tunnel was 600 mm long with a cross section 180 mm high x 150 mm wide. Two 300 mm lengths of 150 mm diameter Nova pipe, were fastened to each end of the main tunnel by two vertical wire bars. Two other wire bars were placed horizontally at the end of each tunnel, 50 mm from the base to reduce the risk of non-target species entering the traps. Two Fenn traps were also fastened to these bars. The Fenn traps were set near the centre of each tunnel with the bait between them. This ensured that a stoat had to cross a trap to reach a bait. Dilks *et al.* (1992) compared various bait types and found that stoats appeared to have a significant preference for traps baited only with eggs. Accordingly two hen eggs were used per trapping tunnel, one whole, and one punctured. Traps were checked and reset every second day, and all dead animals were collected for autopsy.

5.2.5 Biological preparation of specimens: refer to methods in King and Moody (1982c).

5.2.6 Morphological measures (King and Moody, 1982c)

Whole body weight was measured using a Mettler PJ 3600 Delta Range balance. Length was measured by stretching the carcass, supine, along a ruler. Head length was measured from nose to anus. Tail length was measured from the anus to the tip of the last caudal vertebra. The length of the right hind foot was measured from the posterior edge of the tarsal bone to the tip of the phalange, excluding the claw. Measurements of skulls were taken to the nearest 0.01 mm with vernier callipers. In order to determine general variation in size and age with locality the condylobasal length was also measured (King, 1989).

5.2.7 Age determination

The age of stoats collected was determined following King and Moody (1982c). Four age classes are identifiable but only three were applicable in this study:

a Young: either sex collected in November to February inclusive. As trapping in this study occurred between July and September, this class was not filled.

b Subadult: immature males with a baculum[1] weight less than 38.0 mg, collected between March and August inclusive.

c Adult: All stoats other than young collected in November to February, and males other than subadults collected between March and April.

d Unclassified (Nominal adults): all females collected from March to April, and all stoats of both sexes collected between September and October.

The term 'adult' used in general terms includes nominal adults (unclassified, Table 5.2).

1: Male mustelids have one other character very useful for age determination - the baculum - which is distinctly smaller in first year males than in older ones. Fitzgerald (1964; *cit. in* King and Moody, 1982c), found 38.0 mg was the minimum baculum weight for adults.

5.2.8 Diet analysis (King and Moody, 1982b)

The stomach and intestine of each stoat was removed and stored in 75% ethanol. Before analysis the material was washed through a four-tier sieve system (1 mm; and 500, 250, and 125 μm) and then sorted under a X 10 binocular microscope into the following groups:

1 Feathers: identification went no further than bird.

2 Eggshells: most fragments were probably hens eggs (bait), since the eggs of most species targeted by stoats would not have been available over the trapping period.

3 Hairs: guard hairs were picked out and identified alongside hairs from known animals, ie rat, mouse, possum, rabbit, and hare.

4 Invertebrate exoskeleton: fragments of invertebrates were identified to family, and some to genus, by comparing fragments to whole specimens collected over the 14 month invertebrate survey of both areas (Chapter 4). The number of species of each taxon found in the stomach or upper intestine were determined by counting the most conspicuous remains, ie; head parts of beetles or weta, and chelicerae of spiders.

5 Unidentified items: these were unidentifiable remains, the majority consisting of invertebrate fragments. Chunks of flesh were identified according to which guard hairs were present. If no hair was present the flesh then came under the banner of unidentified food.

The results of the gut analysis were recorded as the minimum number of identifiable specimens in the gut of each stoat. Each prey item was recorded as being present or absent. Percentages were calculated from the number of stoats in a particular age category with that food group present.

The composition of the diet by weight was estimated by expressing the numerical occurrence of each prey category as a proportion of the total diet. Weights or estimators of prey biomass were taken from King and Moody (1982b; Appendix 1). Here each prey category is assigned a weight value. A single meal was taken to weigh 10 g, and all types of prey were assumed to remain in the gut for equal periods. The contribution of small items (< 1 per meal) to the diet was estimated by multiplying the minimum number found by their approximate mean weight: small prey items and wetas 3 g, other insects 1 g, bird eggs 7 g. Medium sized prey items (mice and birds) were treated as 10 g each. Large prey items (possums and rats) were treated as 20 g each.

5.2.9 Data analysis

The results were analysed following King and Moody (1982 b & c). No statistical analysis was applicable because the sample sizes were too small (stoats $n = 13$, ferret $n = 1$, and rats $n = 2$).

5.3 **Results**

5.3.1 Mammalian predators identified in each site

Mammalian predators present in each site and considered to be detrimental to kiwi survival in T.N.P., and T.F.P are shown in Table 5.1. Appendix 11 lists occurrences of some of these particular predators in both T.N.P. and T.F.P.

Table 5.1 Mammalian predators present in T.N.P. and T.F.P.

	Predators present					
	Possum	Cat	Dog[2]	Pig	Ferret	Stoat
T.N.P	Yes	Yes[1]	Yes	?	Yes	Yes
T.F.P	Yes	Yes	Yes	Yes	?	Yes

1: records of a cat in the T.N.P were obtained from the exotic pest diary, Whakapapa.

2: Dog tracks were seen along the Mangahuia, and Whakapapiti tracks in T.N.P. (*pers. obs.*, 1993) and I caught an unattended dog within the National Park boundary. Dogs are regularly used in T.F.P., particularly for pig hunting (*pers. obs.*). On three separate occasions I observed dogs that had been left in the Forest Park and retrieved later.

Excluding personal trapping information (Appendix 11), the majority of stoats (85.3%; n = 48) were recorded around residential areas and huts in T.N.P. and T.F.P. between August through to May (95.8%). The next highest occurring predator the cat (n = 11) was also recorded mostly around residential areas (72.7%) from July through to February (90.9%).

5.3.2 Central North Island stoats

Table 5.2 gives the combined numbers of male and female stoats in each age class collected over the three months of trapping. In 504 trap nights 8 stoats were caught in T.F.P, and 5 stoats in T.N.P.. There was no significant difference in the numbers of stoats trapped in the two study areas.

Table 5.2 Details of the age ratios of the total stoat sample (n = 13) by month.

Month	Age class	n	Males % of subtotal	n	Females % of subtotal	subtotal
July	Adult	-	_	1	50%	1
	Adult	1	50%	-	_	1
August	Subadult	2	33%	-	_	2
	Adult	3	50%	1	17%	4
September	Subadult	-	_	-	_	_
	Adult	5	100%	-	_	5

Measurements of subadult and 'adult' stoats were compared with King and Moody (1982c). Body weights and morphometric data are presented in Appendix 12.

5.3.3 Geographic variation in size with change in habitat type

Mean body and skull measurements of adult male stoats caught in T.F.P. (n = 4) and T.N.P. (n = 5) are presented in Figures 5.1 - 5.4. Plots of head and body lengths against tail length of adult male stoats caught in T.F.P. and T.N.P. (Figure 5.1) suggest that there may be a direct relationship between altitude and tail length, with tail length being shorter at higher altitude.

The distributions of condylobasal lengths, and head and body lengths clearly separate the two groups (Figure 5.2), with the mean condylobasal lengths of samples from the T.F.P. 0.3% smaller than those from the T.N.P. (T.F.P., mean = 51.55 ± 0.59; T.N.P., mean = 51.78 ± 0.38).

The mean body weights of adult male stoats collected in the two areas did not overlap. The body lengths in T.F.P. also appeared to be shorter (T.F.P., mean = 267.83 ± 5.15; T.N.P., mean = 279.60 ± 2.34; Figure 5.3).

The mean hind foot lengths of adult male stoats collected at both altitudes showed broadly similar patterns (Figure 5.4).

5.3.4 Sexual dimorphism

Moors (1980) suggests the pronounced sexual dimorphism in small mustelids is one of the most important features of their biology. Because only one adult female stoat and 9 adult males were caught, comparison is severely curtailed. The data are presented in Table 5.3.

Table 5.3 Comparison between morphometric measures (mm) of adult male (mean ± SE) and female stoats (mean ± SE) collected in both T.N.P. and T.F.P. 1993.

n	Sex	Length	Tail length	Hind Foot	Weight(g)	Cb[1]
9	Male	274.3 ± 5.4	105.8 ± 1.2	21.5 ± 0.3	385.3 ± 17	51.7 ± 0.7
1	Female	257	8.8	20.4	249.45	45.1

1: Condylobasal length

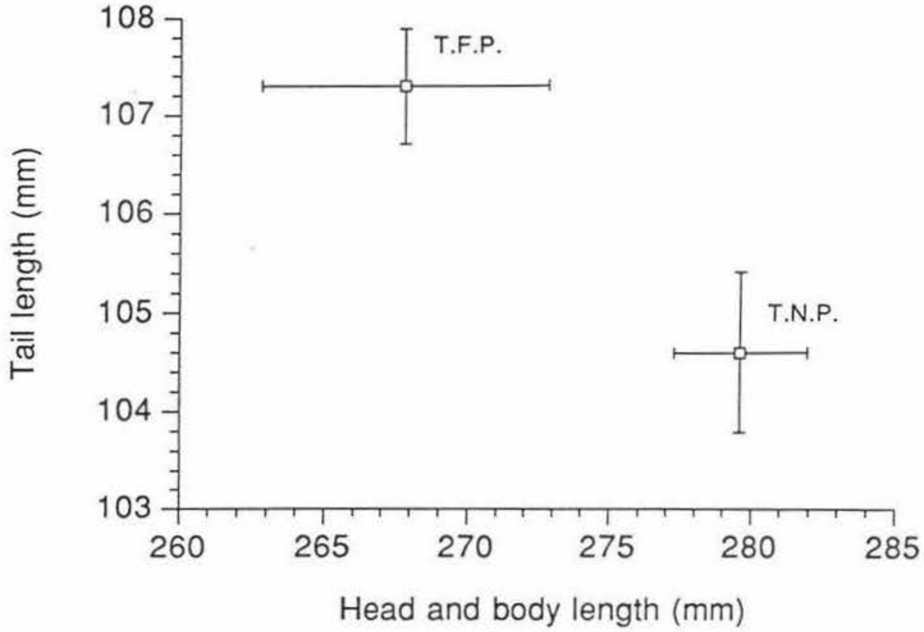


Figure 5.1 Tail lengths (± SE) of adult male stoats in Tongariro Forest Park (n = 4) and Tongariro National Park (n = 50) plotted against mean head and body length (± SE).

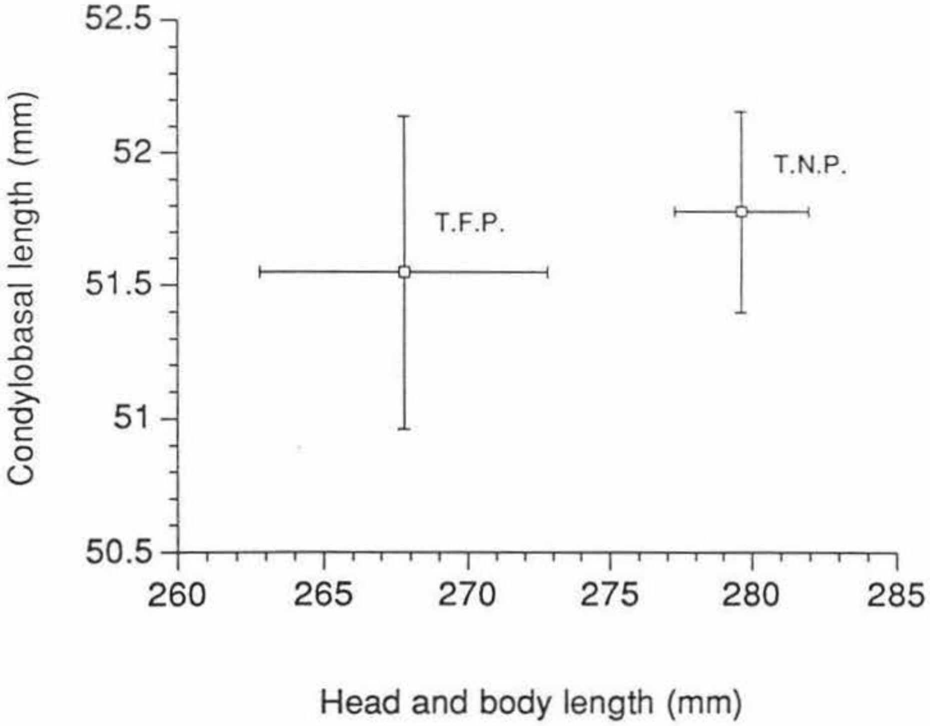


Figure 5.2 Condylobasal lengths (± SE) of adult male stoats in Tongariro Forest Park (n = 4) and Tongariro National Park (n = 50) plotted against mean head and body length (± SE).

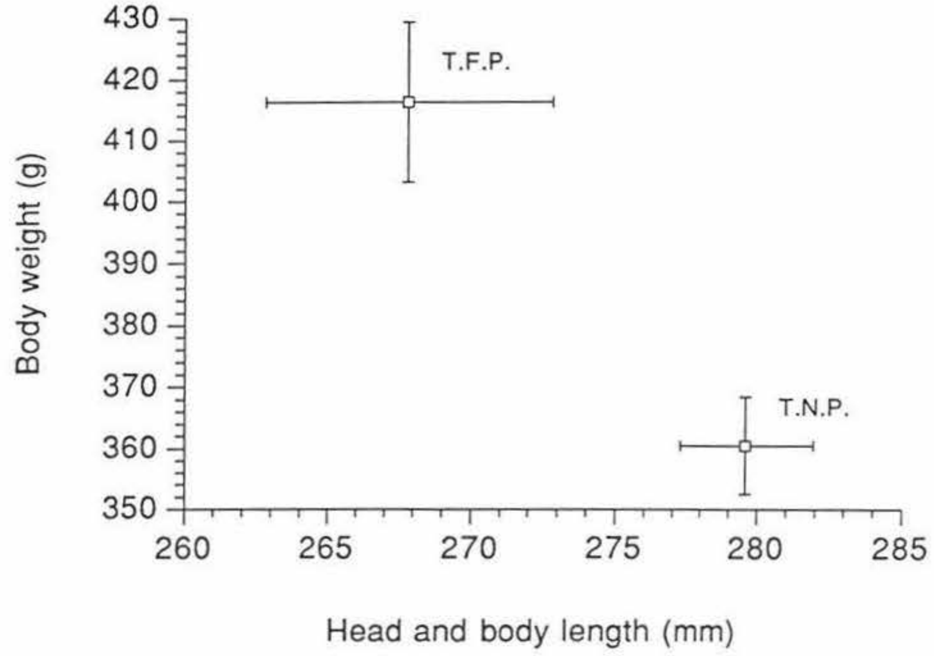


Figure 5.3 Body weights (± SE) of adult male stoats in Tongariro Forest Park (n = 4) and Tongariro National Park (n = 50) plotted against mean head and body length (± SE).

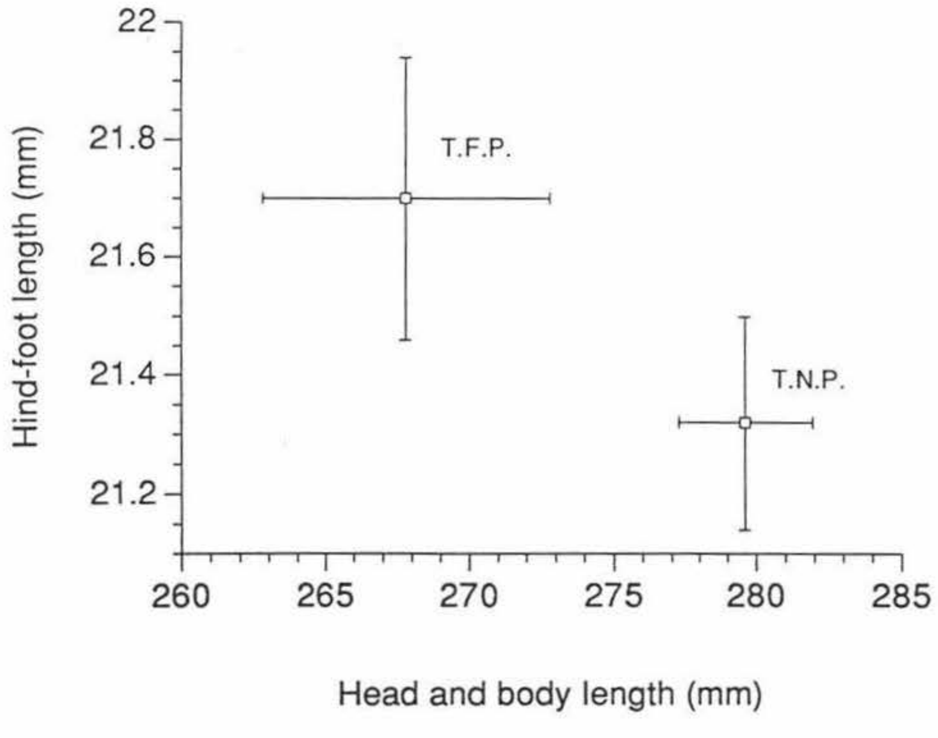


Figure 5.4 Hind foot lengths (± SE) of adult male stoats in Tongariro Forest Park (n = 4) and Tongariro National Park (n = 50) plotted against mean head and body length (± SE).

5.3.5 Diet

Thirteen stoat stomachs were analysed, and surprisingly all contained food. Table 5.4 shows the distribution of the 33 identified prey items. Table 5.5 shows the comparison and percentage frequency of the samples with respect to age, sex and habitat.

Table 5.4 Prey identified in stoat stomachs (n = 13)

Prey items	no. of occurrences	frequency of occurrence (%)
Possum	3	9.1
Rat	4	12.1
Mouse	2	6.1
Bird	5	15.2
Birds egg	2	6.1
Tree weta	8	24.2
Carabid beetle	2	6.1
Spider	1	3.0
Stream invertebrate	1	3.0
Other Arthropods	2	6.1
Unidentified food	3	9.1

Of the identified prey items (n = 10), 60% are active mainly at night, although both night and day active prey could have been caught when at rest. The adult female had 7 tree weta (*Hemideina* spp.) in her gut, suggesting that local concentrations of prey are heavily exploited. The stream invertebrate (*Megaloptera* spp.) was identified in the stomach of an adult male stoat collected in T.N.P. (Table 5.4). There was also a high occurrence of bird remains identified in gut content of adult stoats collected in both sites (Table 5.5).

Table 5.5 Number and percentage frequency of occurrence (in brackets) of prey in stoat stomachs (ad.M = adult male, Sa.M = subadult male, ad.F = adult female, and Sa.F = subadult female).

Prey	T.F.P ad.M	T.F.P Sa.M	T.F.P ad.F	T.F.P Sa.F	T.N.P ad.M
Possum	3 (75)	–	–	–	–
Rat	3 (75)	1 (50)	–	–	–
Mouse	–	–	–	–	2 (40)
Bird	2 (50)	–	1 (100)	–	2 (40)
Bird egg	1 (25)	1 (50)	-	-	–
Tree weta	1 (25)	2 (100)	1 (100)	1 (100)	3 (60)
Carabid beetle	–	1 (50)	–	1 (100)	–
Spider	–	1 (50)	–	–	–
Stream invert.	–	–	–	–	1 (20)
Other Arth.	–	–	1 (100)	–	1 (20)
Unident. food	2 (50)	–	–	1 (100)	–
No. of stoats	4	2	1	1	5

Table 5.6 shows the pooled percentage contribution of identified prey items to the diet of all stoats collected. Night active species contribute most to the diet.
In T.F.P. subadult male stoats appear to focus on low weight prey such as birds eggs, ground weta, carabid beetles and other arthropods. Using the weight categories given in Table 5.6, rats accounted for 54% of the diet while small prey items accounted for 43%. This compares with 70 % of large prey items and 30 % of small prey items in adult male diet. The adult female stoat stomach contained similar prey items to those in the subadult male stomachs, with all items falling into the medium to small weight class. The subadult females stomach contained only arthropods.

Comparison of adult males collected in T.N.P. and T.F.P. (Table 5.5) shows no difference in the selection of small prey items, but no possum or rat remains were found in stoats collected in T.N.P, and no mice were identified in stoats caught in T.F.P.

Table 5.6 Contribution of identified prey items to the diet of stoats collected in both study areas.

Prey	no. of occurrences	Weight[1] (g)	Weight contribution(g)	% Contribution
Possum	3	20	60	23.44
Rat	4	20	80	31.25
Mouse	2	10	20	7.81
Bird	5	10	50	19.53
Birds egg	2	7	14	5.47
Tree weta	8	3	24	9.38
Carabid	2	1	2	0.78
Spider	1	3	3	1.17
Stream invert.	1	1	1	0.39
Other Arth.	2	1	2	0.78
Unident. food	3	20	60	-

1: refer to methods for weight categories.

5.4 **Discussion**

5.4.1 Predator assemblages

Kiwi in the central North Island face a suite of threats similar to those faced by kiwi, and other native fauna throughout the country. All three mustelid groups are found in this region with stoats and ferrets occurring throughout the forests, and weasels and ferrets on the fringes of bush and pasture land (Appendix 11). Cats are also present in T.N.P. and T.F.P. In T.F.P. a cat was seen prowling about the entrance of a kiwi nest, and 45 minutes later a stoat was seen at the nest (*pers. obs.*). The egg subsequently was found to be broken. The damage was consistent with nest predation (J.A. McLennan, *pers. comm.*). Dogs pose an additional threat to kiwi. On three separate occasions I encountered lone dogs left in T.F.P. by pig hunters who had lost one out of their pack. One hunter commented that "the dog had scented a pig, and wouldn't break off the chase." Possums are a continuous problem in both areas, and also pose a threat to kiwi. J.A. McLennan (*pers. comm.*) recently found an adult kiwi killed by a possum at Lake Waikaremoana. Possum in search of daytime shelters can also disturb and possibly displace kiwi (video evidence from Okarito, 1993; West Coast Conservancy, DoC).

It is difficult to identify which predators are killing selected age classes or sexes of native species. The rates of removal of native species by predators needs to be understood so that the question of whether predators are "cropping" native species or "exterminating" them can be answered.

5.4.2 Predator density

Over 504 trap nights between July and September 1993 8 stoats were collected in T.F.P., and 5 stoats, and 1 ferret in T.N.P. All stoats caught were either adult or subadult stoats, most were male. Though there were no significant differences in numbers of stoats caught in both areas, the numbers of stoats captured for this time of the year were high compared to other trapping efforts elsewhere over the same period (King and Moody, 1982a; King, 1989).

5.4.3 Morphometric variation

Introduced mammals are adjusting quickly to exploiting the variety of ecosystems available in New Zealand. Stoats have been remarkably successful in adjusting to a new range of prey species. New Zealand stoats differ from the British stock originally released here (King and Moody, 1982c). The new environment encountered by stoats in New Zealand with more large, and fewer small prey, than Britain, is thought by King (1991) to have induced an increase in stoat body size. Different habitats have different prey species. For instance mice are more common than ship rats in beech forest (*Nothofagus* spp.), while the reverse is true in podocarp forest. Rabbits are more common on grasslands but rare in damp podocarp forests, while possums are distributed the other way round (King, 1991). This was reflected in the diet of stoats collected in

T.F.P. - a podocarp forest, and T.N.P - a beech forest. There were differences between the areas particularly in the frequency of medium to large sized prey. Stoats ate more possums and rats in T.F.P. than those living in T.N.P. King and Moody (1982b) also found this, however they suggested that large mammalian prey are available to all forest stoats in New Zealand, and these prey items are the staple diet of stoats living in all forests. In this study there was no evidence of possum predation by stoats in T.N.P., even though possums were present in the area.

Female stoats are smaller than males (Table 5.3), and therefore generally take smaller-sized prey (Table 5.5). King (1991) found that when prey categories are grouped and classified as small, medium or large, males ate more large prey, and females ate more small prey. Females take small rodents and insect more often than do males, but they take birds and rats as often as males (King, 1982b). The high prevalence of weta in the stomach of the female stoat and their contribution to overall biomass of the diet (Table 5.6), suggests that invertebrate prey are important in the diet. Unfortunately there is no detailed knowledge of the feeding behaviour of stoats in New Zealand (King, 1991).

Local morphometric variation in stoats is also consistently related to habitat. King (1989) showed that adult male stoats collected in the 1970's from podocarp or mixed forest habitats, which are mostly at lower altitudes, were smaller than those collected from higher altitude beech forest by about 3% in skull length (condylobasal length), and 4% in head and body length. Though the sample size here was not as large as King and Moody's (1982a; n = 394), adult male stoats did appear to exhibit this dimorphism. Adult male stoats collected in T.N.P. were on average larger than their counterparts collected in T.F.P., but stoats caught in T.F.P. had longer tails (Figure 5.2), and were inexplicably heavier (Figure 5.4). Tail length differences are thought to be associated with a change of altitude in a similar way to other morphometric differences. This difference in size of male stoats in samples collected from two kinds of forest within a short distance of each other, is recognised to occur in other parts of New Zealand. King and Moody (1982c) found morphometric differences in samples from the Main Divide, Southern Alps. There stoats from podocarp forests on the western side were smaller than neighbouring animals less than 20 km distant in beech forests on the eastern side. This link with altitude is probably a consequence of other correlations between habitat, body size and climate (King, 1991).

5.4.4 Influence of predator assemblages and density on kiwi in central North Island

Results in this study suggest that introduced mammalian predators are adapting to suit the available ecosystems. Predator surveys indicated possums, cats, dogs and stoats were present in both T.F.P. and T.N.P. One ferret was caught in T.N.P., and pigs were observed only in T.F.P. It is probable, however, that ferrets and pigs occur in both sites. No significant difference was found between the numbers of stoats trapped in the two study areas. Differences in predator density therefore do not appear to be the primary reason for the observed differences in kiwi density between T.F.P. and T.N.P. However, compelling evidence now exists which highlights the detrimental impact of introduced predators on kiwi survival and recruitment rates (Taborsky, 1988; McLennan and Potter, 1992; McLennan and Potter, 1993). Predation pressure has almost certainly been a major contributing factor in producing the current patchy, fragmented distribution of kiwi in the forests that comprise T.N.P. and T.F.P.

The development of cost-effective methodology for predator control applicable on a large scale must be a high priority if we are to enable the continued survival of kiwi in the central North Island, and elsewhere on the mainland.

Chapter 6

General summary and recommendations for future conservation and management of Northern brown kiwi (*Apteryx australis mantelli*).

6.1 Introduction

The aim of this study was to identify threats to the continued survival of kiwi in Tongariro/Taupo Conservancy and, where appropriate, to recommend changes to management practices so as to benefit kiwi. Two adjacent kiwi populations in the conservancy were studied, one within Tongariro National Park (T.N.P.). Here hunting, dogs, and trapping is strictly regulated by a permit system (National Parks Act 1980), and extermination of introduced flora and fauna in the park is pursued in accordance with the National Parks Act 1980, and the Wild Animal Control Plan, 1988. The other population was in Tongariro Forest Park (T.F.P.), where hunting, dogs, and trapping are harder to control. The comparative study of kiwi in these two areas was designed to help determine whether current management practices adversely affected kiwi in T.F.P.. To achieve this aim calls were surveyed, and home range size, habitat use, roost quality, resource availability and its utilisation were measured. Finally potential threats to kiwi were indexed. This chapter comprises two sections. The first summarises major findings of the study (Section 6.2). The second recommends options for local and nationwide management of kiwi (Section 6.3).

6.2 General summary

6.2.1 Study sites and general methodology

The study was undertaken between November 1992 and January 1994. Call surveys were used to determine the comparative densities of kiwi in each area. A total of 14 calls were heard during the 133 hours (mean = 0.1 calls hour^{-1}) spent surveying in T.N.P., compared with 1065 calls heard during 345 hours (mean = 3.0 calls hour^{-1}) in T.F.P. Six kiwi (4 males and 2 females) were caught, fitted with transmitters, and tracked for up to 58 weeks. A total of 904 location records were collected, comprising 377 day-time, and 527 night-time fixes. This enabled home range, habitat use, and roost choice to be assessed. Radio-tagged kiwi were recaptured every 2.5 - 3 months for weighing, and to check transmitters and transmitter bands. Call surveying coupled with radio-telemetry indicated that T.N.P. contained one kiwi/km^2, while the density in T.F.P. was estimated to be four kiwi/km^2. Density in T.F.P. was comparable to the density of kiwi in Hawke's Bay (McLennan *et al.*, 1987), kiwi in Urewera National Park (J.A. McLennan *pers. comm.*), and Okarito (J. Lyall *pers. comm.*), but ten times less than in Northland (Corbett *et al.*, 1979; Colbourne and Kleinpaste, 1983; Kayes and Rasch, 1985; Potter, 1989, 1990; Taborsky and Taborsky, 1991, 1992).

Because different management regimes operated in the two study areas higher numbers of kiwi were expected in T.N.P., yet this population appeared to exist at only 25% of the density in T.F.P. In an attempt to account for this two additional objectives were added. The first was to compare the diversity and seasonal abundance of the potential invertebrate food resource in each area. Invertebrate availability was estimated by pitfall trapping, litter sampling, and soil sampling. Kiwi faeces were also analysed to determine the relationship between kiwi diet and apparent invertebrate availability. The second objective was to compile an index of mammalian predators (chiefly mustelids) at each site. Each trap line consisted of 12 trapping tunnels spaced at 500 m intervals set up along 6 km transects in both T.N.P. and T.F.P.

6.2.2 Biological aspects of calling and the practical implications

1. Both study sites were visited once a month between November 1992 and December 1993. Three listening stations were used in T.F.P., and two in T.N.P. (Figure 2.1). During each listening period the time of the call, the sex, approximate location, and the approximate distance to the bird that called were recorded. The majority (1065) of calls were heard in T.F.P., while only 14 calls were heard in T.N.P.

2. In T.F.P. male calls accounted for 73.5% of all calls heard, the majority being territorially based. However, this ratio (3:1) changed seasonally with more female calls heard in the winter and spring months. Males and females often called together, the majority of these duets (87%) were performed by members of bonded pairs. Calling started later over the winter months and the time to the first call appeared to be

proportional to night length. Kiwi called in two bouts during the night, call rates were highest in the first 2 - 3 hours of darkness, and the second peak occurring shortly before dawn. This bimodal pattern persisted throughout the year.

3. Breeding behaviour accounted for some variation in call rates, with calls increasing steadily from autumn to a peak lasting through to the end of spring. However, irrespective of season, kiwi called less on some nights than others. To account for additional variation in call rates 12 environmental variables were measured. Nine of these were the subjective measures found on the standard kiwi call card scheme cards. Environmental conditions accounted for 44% of the between night variation. When low temperature and moderate to heavy rain occurred together call rate was further reduced. Kiwi were also less vocal on the first wet night following a dry spell. Reduced call rates did not correlate with light levels, or with the phase of the moon.

4. Approximately 40% of the time spent call surveying was dedicated to testing the value of broadcasting taped male and female calls to enhance 'natural' call rates. Significantly more calls were heard when calls were broadcast. However, broadcasting appeared to elicit responses only from kiwi in the higher density population in T.F.P.. There was no difference in call rate as a result of either broadcasting in the first hour or not doing so. This was also the case for the second hour. Females responded more to a taped female call as did males. Overall, taped calls of either sex induced significantly more responses from males than from females.

5. Irrespective of season about 4 to 5 consecutive nights of data are needed to accurately estimate average call rates in an area. Mapping individual calling kiwi over an equivalent period will also provide an accurate assessment of the density of kiwi on the ground.

6. The relationship between density of kiwi, and average call rates is best described by a linear function (Figure 2.8a).

6.2.3 **Range size and roost choice**

1. Home range sizes were determined by three methods: convex polygon, field worker, and adaptive kernal. The convex polygon estimate of ranges varied from 30.8 to 91.8 ha. Field worker estimates were approximately 8 - 23% smaller ranging between 26.1 to 82.6 ha, and the adaptive kernal estimate ranged from 28.2 to 74.8 ha.

2. Mean range size of paired females tended to be larger than that of paired males. The unpaired male home range was significantly larger than that of both paired males and paired females. Home range size of kiwi in T.N.P. and T.F.P. were remarkably similar to those of Hawke's Bay kiwi (McLennan *et al.*, 1987) and Paerata kiwi (Potter, 1989). Home ranges of females showed more overlap than male home ranges.

3. There appeared to be significant habitat selection for the location of roost sites. Toetoe was "avoided", while unlogged and broadleaf/scrub habitats were preferred, indicating that kiwi prefer to roost in forest habitat. Territory size, therefore, may be a consequence of habitat type.

4. Kiwi varied greatly in the types of roosts they used and the roost site was highly dependent on habitat. Roosts associated with fallen trees and surface roots were used most frequently. Surface vegetation tended to be used in summer, excavated roosts in winter and spring, and roosts associated with logs and roots in autumn and winter. Male kiwi used surface vegetation more than expected, while females favoured roosts associated with hollow logs, and/or roots. Both sexes made similar use of excavated roosts. On only one occasion was a pair found roosting together. Kiwi infrequently used any roost site more than once.

6.2.4 **Feeding ecology**

1. Over 14 months of field work 12594 surface, litter, and soil dwelling invertebrates were caught. Higher numbers of invertebrates and greater taxonomic diversity was found in T.F.P. (n = 7725; no. of taxa = 189) than in T.N.P. (n = 4869;

no. of taxa = 156), with 122 taxa common to both areas. Invertebrate availability and taxonomic diversity varied with season. Invertebrates were least abundant in winter.

2. There was significant seasonal variation in the numbers of invertebrates caught between sampling sites located in T.F.P., while in T.N.P. little variation was evident. This appeared to relate to the relatively uniform habitat in T.N.P., compared with the diverse array of habitat types in T.F.P.

3. Although a wide range of invertebrates were recorded in kiwi faeces some groups were recorded more often than other groups. Cicadidae nymphs and Scarabaeidae larvae were the only two taxa consistently found in faeces in higher numbers than in invertebrate surveys in T.F.P. and T.N.P. This suggest both are preferentially selected food items.

4. In both T.F.P. and T.N.P. kiwi appeared to over utilise soil dwelling taxa, though only in T.F.P. was any preference shown for a particular taxonomic group. Few Cicadidae nymphs or Scarabaeidae larvae were caught in T.N.P., indicating low or patchy availability. Kiwi appeared to switch their foraging to other species thereby partly overcoming this.

5. Kiwi appeared not to utilise invertebrates in proportion to what would be expected if invertebrate weight was an "important consideration" when feeding.

6. Size and type of seeds identified in faeces found in T.N.P. and T.F.P., and their abundance in particular faeces, indicates they were selectively eaten when available, and are a component of kiwi diet. Associated with these seeds (rimu; *Dacrydium cupressinum*, and *Coprosma* spp.) are fleshy fruits.

7. Similar numbers of litter and soil dwelling invertebrates were available to kiwi in both T.N.P. and T.F.P., while higher numbers of surface dwelling invertebrates were available to kiwi in T.F.P. Differences in numbers and in taxonomic diversity of invertebrates seems to suggest that the two areas have different carrying capacities for

kiwi. However, only a small proportion of this taxonomic diversity seem to be targeted by kiwi, and at current densities neither site is likely to be food limiting.

6.2.5 **Potential threats: predator indexing**

1. Predator surveys indicated possums, cats, dogs, and stoats were present in T.F.P. and T.N.P. One ferret was caught in T.N.P., and pigs were only observed in T.F.P. It is probable, however that ferrets and pigs occur in both areas.

2. Excluding personal trapping information, the majority of stoats were recorded in the Whakapapa Pest Control Diary between August through to May around residential areas/huts in T.N.P. and T.F.P. , and cats from July through to February.

3. To determine patterns of morphometric variation between stoats caught in T.F.P. and T.N.P., mean body and skull measures were taken. These measurements suggest that a morphological difference exists between stoats in each area, with stoats in T.N.P. being generally larger than their counterparts in T.F.P. This may be habitat and temperature related.

4. Thirteen stoat stomachs were analysed. Of the identified prey species 60% are active mainly at night. There was also a high occurrence of bird remains identified in gut content of adult stoats collected in both sites.

5. There were differences between the areas in the occurrence of medium to large sized prey. Stoats in T.F.P. ate more possums and rats and fewer mice than those in T.N.P..

6. Predator pressure has almost certainly been a major contributing factor in producing the current fragmented distribution of kiwi in the forests that make up T.N.P. and T.F.P. These predators pose a major threat to the long-term survival of kiwi in the conservancy. The development of cost effective methods of predator control applicable on a large scale should be a high priority.

6.3 Management recommendations

1. Continue annual call surveys of kiwi in T.F.P. Incorporate recommended changes (Chapter 2) to national monitoring programmes. Keep monitoring methods as consistent as possible. More populations should be monitored so that population trends can be determined.

2. Park status means that kiwi in T.N.P. and T.F.P. are secure so far as their habitat is protected. However areas elsewhere with high kiwi numbers need to be identified nationally and protection and expansion of these habitats needs to be undertaken.

3. Continue to monitor the well-being of radio-tagged kiwi in T.F.P. Radio-tag kiwi elsewhere, to enable potential problems faced by individual birds in designated areas to be identified.

4. Maintain the predator control scheme started in 1994 in T.F.P. The benefits of this can be assessed by: monitoring the radio-tagged birds, and by annual call surveys. Nationally, quantify the threat mammalian predators (chiefly mustelids) pose to the native fauna, and develop cost-effective, coordinated, wide scale methods of control.

5. Form a multidisciplinary group to specifically work on mammalian predators.

6. Erect signs at main accesses to hunting areas indicating the presence of kiwi, and highlighting the vulnerability of kiwi to uncontrolled dogs.

7. When issuing hunting permits for these areas containing kiwi highlight the need for hunters using dogs to maintain tighter control over them.

References

Alldredge, J.R.; Ratti, J.T. 1986 Comparison of some statistical techniques for analysis of resource selection. *Journal of Wildlife Management* 50: 157 - 165.

Barnes, R.D. 1968 *Invertebrate Zoology* (2nd.Ed) W.B. Saunders Company, London.

Barrette, C.; Messier, F. 1980 Scent-marking in free-ranging coyotes, *Canis latrans*. *Animal Behaviour* 28: 814 - 819.

Best, L.B. 1981 Seasonal changes in detection of individual bird species. *Studies in Avian Biology* No.6, pp 252 - 261.

Bibby, C.J.; Burges, N.D.; Hill, D.A. 1992 *Bird Census Techniques*. Academic Press, London.

Bull, P.C. 1959 Stomach contents of a North Island kiwi (*Apteryx australis mantelli*) from the Raetihi district. *Notornis* 8: 143 - 145.

Bull, P.C.; Gaze, P.D.; Robertson, C.J.R. 1985. *The atlas of bird distribution in New Zealand*. Ornithological Society of New Zealand Inc.. Wellington, New Zealand.

Buller, W.L. 1888 *A History of the birds of New Zealand*. Second edition. Volume 2. The author, London, pp 318 - 319.

Burt, W.H. 1943 Territoriality and home-range concepts as applied to mammals. *Journal of Mammalogy* 24: 346 - 352.

Calder, W.A.,III; Rowe, B. 1977 Body mass changes and energetics of kiwi's egg cycle. *Notornis* 24: 129 - 135.

Calder, W.A.,III. 1978 The kiwi. *Scientific American* 239: 102 - 110.

Calder, W.A.,III; Parr, C.R.; Karl, D.P. 1978 Energy content of eggs of the brown kiwi *Apteryx australis*; an extreme in avian evolution. *Comparative Biochemistry and Physiology* 60A: 177 - 179.

Calder, W.A., III. 1979 The kiwi and egg design: Evolution as a package deal. *Bio Science* 29: 461 - 467.

Cadbury, C.J. 1981 Nightjar census methods. *Bird Study* 28: 1 - 4.

Clutton Brock, T.H.; Guinness, F.E.; Albon, S.D. 1982 *Red Deer: The behavior and ecology of two sexes*. Chicago University Press, Chicago.

Cochran, W.W.; Lord, R.D. 1963 A radio-tracking system for wild animals. *Journal of Wildlife Management* 27: 9 - 24.

Cody, M.I. 1974 Optimisation in ecology. *Science* 183: 1156 - 1164.

Colbourne, R.M.; Kleinpaste, R.H. 1983 A banding study of North Island brown kiwis in an exotic forest. *Notornis* 30: 109 - 124.

Colbourne, R.; Kleinpaste, R. 1984 North Island brown kiwi vocalisations and their use in censusing populations. *Notornis* 31: 191 - 201.

Colbourne, R.M.; Kleinpaste, R. 1984 A study of kiwis in an exotic forest. Unpublished report in the New Zealand Forest Service library. Auckland, New Zealand.

Colbourne, R.M.; Powesland, R.G. 1988 Diet of the Stewart Island brown kiwi (*Apteryx australis lawryi*) at Scollay's Flat, southern Stewart Island. *New Zealand Journal of Ecology* 11: 99 - 104.

Colbourne, R.M.; Baird, K.; Jolly, J. 1990 Relationship between invertebrates eaten by little spotted kiwi, *Apteryx owenii*, and their availability on Kapiti Island, New Zealand. *New Zealand Journal of Zoology* 17: 533 - 542.

Corbett, H.; Thode, P.; Reid, B. 1979 A survey of kiwis within an exotic forest. *New Zealand Forestry Service, unpublished report.* Auckland, New Zealand.

Davies, N.B.; Landberg, A. 1984 Food distribution and variable mating system in the dunnock. *Journal of Animal Ecology* 53: 895 - 912.

Department of Conservation 1992 Discussion paper, Tongariro Forest, a conservation park proposal. Tongariro Taupo Conservancy. Turangi, New Zealand.

Dilks, P.; O'Donnell, C.; Elliott, G. 1992 Predator trapping in the Eglinton Valley, Fiordland, 1990 - 1991. *Science and Research Internal Report No. 114*. Department of Conservation. Te Anau, New Zealand.

Fordham, R.A. 1961 Distribution of birds in the south-east Kaweka Range. *Notornis* 9: 113 - 119.

Fuller, E. 1990 Editor of *A monograph of the family Apterygidae: Kiwis.* Seto publishing, New Zealand.

Garson, P.J.; Hunter, M.L. 1979 Effects of temperature and time of year on the singing behaviour of wrens *Troglodytes troglodytes* and great tits *Parus major*. *Ibis* 121: 481 - 487.

Gilpin, M.E.; Soule', M.E. 1986 Minimum viable populations: Processes of species extinction. In: *Conservation Biology: The science of scarcity and diversity*. Edited by M.E.Soule', Sinauer Associates, Inc Publishers, Sunderland, Massachusetts.

Gosling, L.M. 1987 Scent marking in an antelope lek territory. *Animal Behaviour* 35: 620 - 622.

Grue, C.E.; Balda, R.P.; Johnson, C.D. 1981 Diurnal activity patterns and population estimates of breeding birds within a disturbed and undisturbed desert-scrub community. *Studies in Avian Biology* No.6: 287 - 291.

Gurr, L. 1952 Some food of the North Island kiwi. *Notornis* 4: 209 - 210.

Handford, P.; Mares, M.A. 1985 The mating systems of ratites and tinamous: an evolutionary perspective. *Biological Journal of the Linnaean Society* 25: 77 - 104.

Harper, D.G.C,. 1991 Communication. In: *Behavioural Ecology: An evolutionary approach.* 3rd edition. Editors J.R.Krebs and N.B.Davies, Blackwell Scientific Publications. pp 374 - 397.

Harris, S.; Cresswell, W.J.; Forde, P.G.; Trewhella, W.J.; Woollard, T.; Wray, S. 1990 Home-range analysis using radio-tracking data: A review of problems and techniques particularly as applied to the study of mammals. *Mammel Review* 20: 97 - 123.

Higgins, R.M. 1979 Temperature-related variation in the duration of morning song of the song thrush (*Turdus ericetorum*). *Ibis* 121: 333 - 335.

Johnson, R.P 1973 Scent-marking in mammals. *Animal Behaviour* 21: 521 - 535.

Jolly, J. 1983 Little spotted kiwi research on Kapiti Island; 1980 - 82. *Wildlife - A Review* 12: 33 - 39. Department of Internal Affairs, Wellington, New Zealand.

Kaufmann, J.H. 1983 On the definitions and functions of dominance and territoriality. *Biological Review* 58: 1 - 20.

Kayes, P.; Rasch, G. 1985 The second survey of the brown kiwi in Waitangi State forest. *New Zealand Forest Service unpublished report.*

Kendeigh, S. 1961 Energy of birds conserved by roosting in cavities. *Wilson Bulletin* 73: 140 - 146.

Kenwood, R.E. 1992 Quality versus quantity: programmed collection and analysis of radio-tracking data. In: *Wildlife Telemetry: Remote monitoring and tracking of animals.* Published by Ellis Horwood Limited. pp 231 - 247.

King, C.M.; Moody, J.E. 1982a The biology of the stoat (*Mustela erminea*) in the National Parks of New Zealand, I. General introduction. *New Zealand Journal of Zoology* 9: 49 - 56.

King, C.M.; Moody, J.E. 1982b The biology of the stoat (*Mustela erminea*) in the National Parks of New Zealand, II. Food habits. *New Zealand Journal of Zoology* 9: 57 - 80.

King, C.M.; Moody, J.E. 1982c The biology of the stoat (*Mustela erminea*) in the National Parks of New Zealand, III. Morphometric variation in relation to growth, geographic distribution, and colonisation. *New Zealand Journal of Zoology* 9: 81 - 102.

King, C.M. 1989 *The natural history of weasles and stoats*. Comstock Publishing Associates. London.

King, C.M. 1991 Body size relationships in European stoats *Mustela erminea*: a test case. *Holartic Ecology* 14: 173 - 185.

Kleinpaste, R.H. 1990 Kiwis in a pine forest habitat. *In Kiwi*, Ed. Errol Fuller. Saeto Publishing Ltd. New Zealand, pp 97 - 138.

Krebs, J.R.; Davies, N.B. 1987 *An introduction to Behavioral Ecology* 2nd Edition, Blackwell Scientific Publications, Oxford. pp 102 -110.

Lack, D. 1968 *Ecological Adaptions for Breeding in Birds*. Methuen & Co Ltd, London.

Lance, A.N.; Watson, A. 1980 A comment on the use of radio tracking in ecological research. In: Amlaner, C.J and Macdonald, D.W. (eds). *A Handbook on Biotelemetry and radio Tracking*. Perganon Press, Oxford. pp 355 - 359.

Macdonald, D.W.: Ball, F.G.; Hough, N.G. 1980 The evaluation of Home Range size and configuration using radio tracking data. In: Amlaner, C.J and Macdonald, D.W. (eds). *A Handbook on Biotelemetry and radio Tracking*. Pergamon Press, Oxford. pp 405 - 424.

McLennan, J.A.; Rudge, M.R.; Potter, M.A. 1987 Range size and denning behaviour of brown kiwi, *Apteryx australis mantelli*, in Hawke's Bay, New Zealand. *New Zealand Journal of Ecology* 10: 97 - 107.

McLennan, J.A. 1987 Opossum hunting and kiwis - A reply to Brian Reids Article in Fur Facts 7 (27). *Fur Facts* 8 (29).

McLennan, J.A. 1988 Breeding of North Island brown kiwi, *Apteryx australis mantelli*, in Hawke's Bay, New Zealand. *New Zealand Journal of Ecology* 11: 89 - 97.

McLennan, J.A.; McCann, A.J. 1991 Ecology of great spotted kiwi *Apteryx haastii*. *D.S.I.R Land Resources contract report No. 91/48 to the Department of Conservation.* Wellington, New Zealand.

McLennan, J.A.; McCann, A.J. *in prep*. Vocalisation in great spotted kiwi.

McLennan, J.A. 1992 Nationwide monitoring of kiwi populations. *D.S.I.R land resources Contract Report No. 92/21*. Wellington, New Zealand.

McLennan, J.A.; Potter, M.A. 1992 Distribution, population changes and management of brown kiwi in Hawke's Bay. *New Zealand Journal of Ecology* 16: 91 - 102.

McLennan, J.A.; Potter, M.A. 1993 Juveniles in mainland populations of kiwi. *Notornis* 40: 294 - 297.

Mead, C. 1987 *Owls*. Whittet Books, London.

Meterological Data, care of Department of Conservation, Tongariro/Taupo Conservancy, Whakapapa field station, New Zealand.

Moeed, A.; Meads, M.J. 1985 Seasonality of pitfall trapped invertebrates in three types of native forest, Orongorongo Valley, New Zealand. *New Zealand Journal of Zoology* 12: 17 - 53.

Moeed, A.; Meads, M.J. 1986 Seasonality of litter inhabiting invertebrates in two native forest communities of Orongorongo Valley, New Zealand. *New Zealand Journal of Zoology* 13: 45 - 63.

Moeed, A.; Meads, M.J. 1987 Invertebrate survey of offshore islands in relation to potential food sources for the little spotted kiwi (*Apteryx owenii*). *New Zealand Entomologist* 10: 50 - 64.

Mohr, C.O. 1947 Table of equivalent populations of North American small mammals. *American Midland Naturalist* 37: 223 - 249.

Moore, M.C. 1984 Changes in territorial defence produced by changes in circulating levels of testosterone: A possible hormonal basis for mateguarding behaviour in white-crowned sparrows. *Behaviour* 88: 215 - 226.

Moors, P.J. 1980 Sexual dimorphism in the body size of mustelids (Mammalia: Carnivora): the roles of food habits and breeding systems. *Oikos* 34: 147 - 158.

Napper, J.L. 1989 Department of Conservation, *Science Progress Reports*, 1988/1989: 49 - 56.

Neu, C.W.; Byers, C.R.; Peck, J.M.; Boy, V. 1974 A technique for analysis of utilization - availability data. *Journal of Wildlife Management* 38: 541 - 545.

Nottebohm, F. 1975 Vocal Behaviour in Birds. *Avian Biology* Volume V. Edited by Farner, D.S.; King, J.R.; Parkes, K.C., Academic Press, London.

O'Conner, R.J. 1981b The influence of observer and analyst efficiency in mapping method censuses. *Studies in Avian Biology* No.6: 372 - 376.

O'Donnell, C.F.J.; Dilks, P.J.; Elliot, G.P. 1993 Control of a stoat population irruption to enhance yellowhead breeding success. *Science and Research internal report No. 124*, Department of Conservation. Wellington, New Zealand.

Odum, E.P. 1983 *Basic Ecology*. CBS College Publishing, New York.

Oelke, H. 1981a Limitations of estimating bird populations because of vegetation structure and composition. *Studies in Avian Biology* No.6: 316 - 321.

Peat, N. 1990 *The incredible kiwi*. Random Century New Zealand Ltd.. Auckland, New Zealand.

Potter, M.A. 1989 Ecology and reproductive biology of the North Island brown kiwi (*Apteryx australis mantelli*). *Ph.D thesis*. Massey University, Palmerston North, New Zealand.

Potter, M.A. 1990 Movement of North Island brown kiwi (*Apteryx australis mantelli*) between forest remnants. *New Zealand Journal of Ecology* 14: 17 - 24.

Potter, M.A.; Cockrem, J.F. 1992 Plasma levels of sex steroids in the North Island brown kiwi (*Apteryx australis mantelli*) in relation to time of year and stages of breeding. *General and Comparative Endocrinology* 87: 416 - 424.

Pyke, G.H.; Pulliam, H.R.; Charnov, E.L. 1977 Optimal foraging: A selective review of theory and tests. *Quarterly Review in Biology* 52: 137 - 154.

Rahn, H.; Ar, A. 1974 The avian egg: incubation time and water loss. *Condor* 76: 147 - 152.

Ramenofsky, M. 1984 Agonistic behaviour and endogenous plasma hormones in male Japanese quail. *Animal Behaviour* 32: 698 - 708.

Richards, D.G. 1981b Environmental acoustics and censuses of singing birds. *Studies in Avian Biology* No.6, pp 297 - 300.

Rijkse, W.C. *In press*: Soil Map of Taupo County, *Soil Bureau, D.S.I.R.*. Rotorua, New Zealand.

Reid, B. 1970 Feeding kiwis in captivity. *Wildlife - A review* 2: 26 - 30.

Reid, B. 1971a The weight of the kiwi and its egg. *Notornis* 18: 245 - 249.

Reid, B. 1971b Composition of a kiwi egg. *Notornis* 18: 245 - 249.

Reid, B. 1972a North Island brown kiwi Apteryx australis mantelli. Measurements and weights of a young chick. *Notornis* 19: 261 - 266.

Reid, B.; Williams, G.R. 1975 The kiwi. In: *Biogeography and Ecology in New Zealand.* W. Junk. The Hague, pp 301 - 330.

Reid, B.; Ordish, R.G.; Harrison, M. 1982 An analysis of the gizzard contents of 50 North Island brown kiwis (*Apteryx australis mantelli*) and notes on feeding observations. *New Zealand Journal of Ecology* 5: 76 - 85.

Richards, O.W.; Davies, R.G. 1977 *Imm's general textbook of entomology* (10th. Ed.) Vol.II. Chapman & Hall, London.

Robbins, C.S. 1981 Bird activity levels related to weather. *Studies in Avian biology* No.6, 301 - 310.

Rowe, B.E. 1980 The kiwi *Apteryx australis*: an extreme in egg size. *Internatioal Zoo Yearbook* 20: 196 - 197.

Samuel, M.D; Garton, E.O. 1985 Home-range: A weighted normal estimate and tests of underlying assumptions. *Journal of Wildlife Management* 49: 513 - 519.

SAS Institute. 1985 *SAS User's Guide*: Statistics 1985 edition, Cary, North Carolina.

Schoener, T.W. 1971 Theory of feeding strategies. *Annual Review of Ecological Systems* 2: 369 - 404.

Shorland, F.B.; Gass, J.P. 1961 Fatty acid composition of the depot fats of kiwi (*Apteryx austrlis mantelli*). *Journal of the Science of Food and Agriculture* 12: 174 - 177.

Skirvin, A.A. 1981 Effect of time of day and of season on the number of observations and density estimates of breeding birds. *Studies of Avian Biology* No.6, 271 - 274.

Smith, J.L.D.; McDougal, C.; Miquelle, D. 1989 Scent marking in free-ranging tigers, *Panthera tigris*. *Animal Behaviour* 37: 1 - 10.

Smith, R.L. 1959 The songs of the Grasshopper Sparrow. *Wilson Bulletin* 71: 141 - 152.

Sokal, R.R.; Rohlf, F.J. 1981 *Biometry - The principles and practice of statistics in biological research.* 2nd Ed. W.H. Freeman and Company, San Francisco.

Southern, H.N.; Lowe, V.P.W. 1968 Pattern of distribution of prey and predation in Twany Owls. *Journal of Animal Ecology* 37: 75 - 97.

Svensson, S.E. 1981 Do transect counts monitor abundance trends in the same way as territory mapping in study plots. *Studies in Avian Biology* No.6: 209 - 214.

Taborsky, M. 1988 Kiwis and dog predation: observations in Waitangi State Forest. *Notornis* 35: 197 - 202.

Taborsky, B.; Taborsky, M. 1991 Spatial organisation of North Island brown kiwi: sex, pairing status and territoriality. *Ethology* 89: 47 - 62.

Taborsky, B.; Taborsky, M. 1992 Spatial organization of the North Island brown kiwi, *Apteryx australis mantelli*: sex, pairing status and territoriality. *Ibis* 134: 1 - 10.

Taylor, G.; Calder, B. 1983 Rotorua survey shows that kiwis prefer unmodified forest. *Forest and Bird* 229; 24 - 34.

Voight, D.R.; Tinline, R.R. 1980 Strategies for analysing radio tracking data. In: Amlaner, C.J. and Macdonald, D.W. (eds). *A Handbook on Biotelemetry and radio Tracking*. Perganon Press, Oxford. pp 387 - 404.

Watt, J.C. 1971 The North Island kiwi: a predator of pasture insects. *New Zealand Entomologist* 5: 25 - 27.

Wenzel, B.M. 1968 Olfactory prowess in the kiwi. *Nature* 220: 1133 - 1134.

White, G.C.; Garrott, R.A. 1990 *Analysis of Wildlife Radio-Tracking Data*, Published by Academic Press Inc, San Deiago, California.

Wingfield, J.C.; Bull, G.F.; Dutly, A.M.; Hegner, R.E.; and Ramenofsky, M. 1987 Testosterone and aggression in birds *American Scientist* 75: 602 - 608.

Worton, B.J. 1987 A review of models of home-range for animal movement. *Ecological Modelling* 23: 277 - 298.

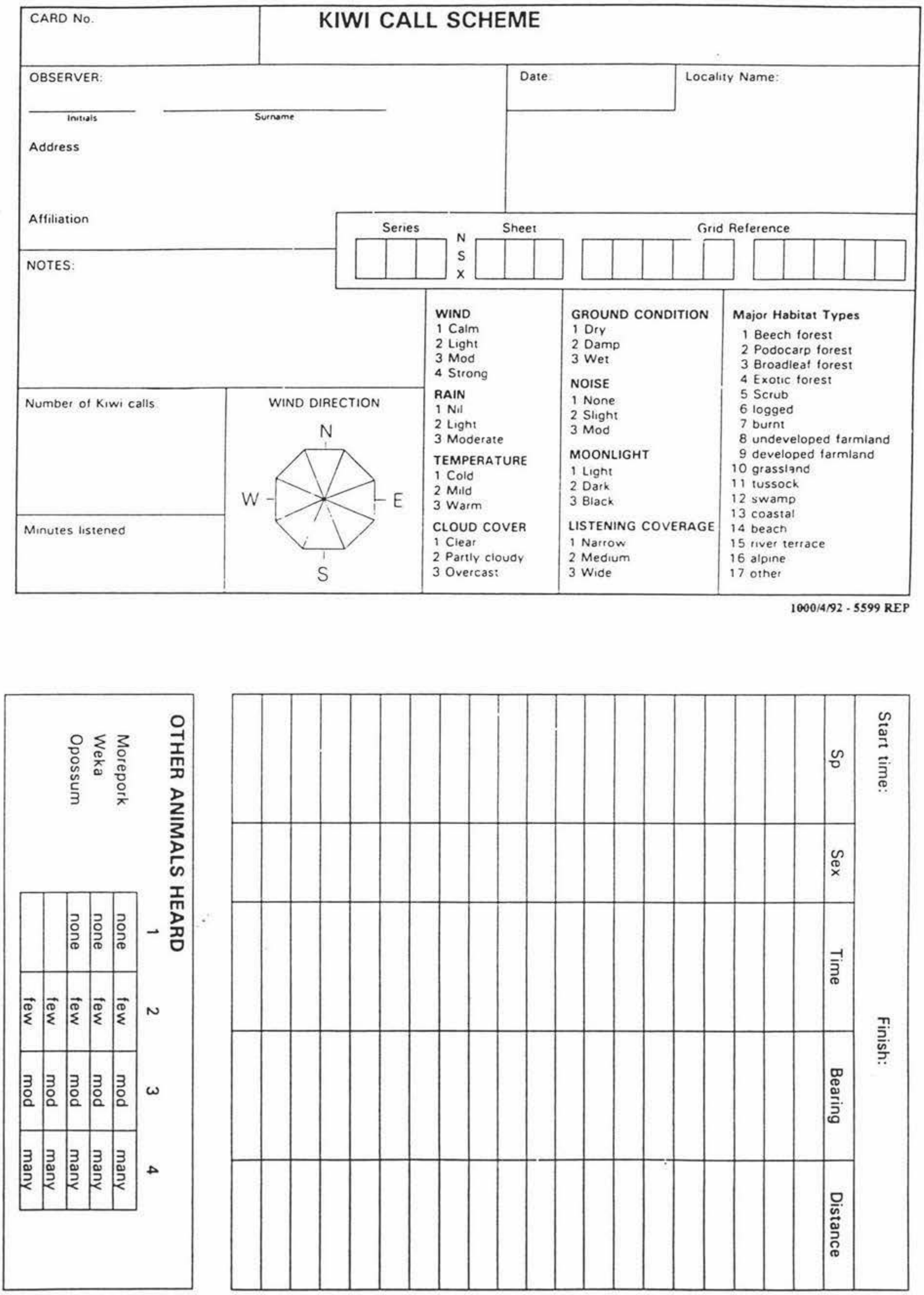
Wroot, A.J. 1985 A Quantitative method for estimating the amount of earthworm (*Lumbricus terrestris*) in animal diets. *Oikos* 44: 239 - 242.

Zar, J.H. 1984 *Biostatistical Analysis* 2nd Edition. Pretence Hall, Englewood Cliffs, New Jersey.

Appendix 1 The influence of environmental variables on kiwi calling activity in the Tongariro Forest Park November 1992 to December 1993. Column one lists the twelve environmental variables measured in a night when call surveying. Column two explains how these mesures were recorded. Column three shows the significance of each variable related to call rates for a best fie two variable linear function.

Variables	Measures	Significance (P≤0.05)
Moon phase	Met. station	no
Hours of darkness	"	no
Temperature	Field station	yes
Wind	Subjective	no
Rain	"	yes
Estimated Temperature	"	no
Cloud cover	"	no
Ground conditions	"	no
Background noise	"	no
Moonlight	"	no
Morepork calls	"	no
Possum calls	"	no

Appendix 2 Kiwi Call Scheme card.



CARD No.

KIWI CALL SCHEME

OBSERVER:

Initials
Surname

Address

Affiliation

NOTES:

Date:

Locality Name:

Series N S X Sheet Grid Reference

Number of Kiwi calls

Minutes listened

WIND DIRECTION

WIND
1 Calm
2 Light
3 Mod
4 Strong

RAIN
1 Nil
2 Light
3 Moderate

TEMPERATURE
1 Cold
2 Mild
3 Warm

CLOUD COVER
1 Clear
2 Partly cloudy
3 Overcast

GROUND CONDITION
1 Dry
2 Damp
3 Wet

NOISE
1 None
2 Slight
3 Mod

MOONLIGHT
1 Light
2 Dark
3 Black

LISTENING COVERAGE
1 Narrow
2 Medium
3 Wide

Major Habitat Types
1 Beech forest
2 Podocarp forest
3 Broadleaf forest
4 Exotic forest
5 Scrub
6 logged
7 burnt
8 undeveloped farmland
9 developed farmland
10 grassland
11 tussock
12 swamp
13 coastal
14 beach
15 river terrace
16 alpine
17 other

1000/4/92 - 5599 REP

Start time: Finish:

Sp	Sex	Time	Bearing	Distance

OTHER ANIMALS HEARD

	1	2	3	4
Morepork	none	few	mod	many
Weka	none	few	mod	many
Opossum	none	few	mod	many
		few	mod	many
		few	mod	many

Appendix 3 Maximum R-square Improvement for the dependent variable Call Rate excluding Duets (SAS proc stepwise, SAS Institute, 1985). Abbreviations: RA - rain, TE - temperature, GR - ground conditions, MO - moonlight, PO - possum calls, NO - background noise, ESTM - estimated temperature, CL - cloud cover, WI - wind, MP - morepork calls, PH - moonphase.

```
         Maximum R-square Improvement for Dependent Variable MA

Step 1   Variable RA Entered        R-square = 0.21099105   C(p) = -2.94375594

                DF        Sum of Squares      Mean Square          F   Prob>F

Regression       1            2.14670204       2.14670204       3.74   0.0735
Error           14            8.02767296       0.57340521
Total           15           10.17437500

                 Parameter        Standard          Type II
Variable          Estimate           Error   Sum of Squares          F   Prob>F

INTERCEP        1.79937107      0.39379163      11.97209449      20.88   0.0004
RA             -0.46477987      0.24021064       2.14670204       3.74   0.0735

Bounds on condition number:             1,              1

The above model is the best  1-variable model found.

Step 2   Variable TE Entered        R-square = 0.43091538   C(p) = -3.46804723

                DF        Sum of Squares      Mean Square          F   Prob>F

Regression       2            4.38429467       2.19214733       4.92   0.0256
Error           13            5.79008033       0.44539079
Total           15           10.17437500

                 Parameter        Standard          Type II
Variable          Estimate           Error   Sum of Squares          F   Prob>F

INTERCEP        1.66696091      0.35205315       9.98563319      22.42   0.0004
TE              0.09217695      0.04112467       2.23759262       5.02   0.0431
RA             -0.68206240      0.23284468       3.82170197       8.58   0.0117

Bounds on condition number:      1.209675,       4.838698

The above model is the best  2-variable model found.
```

```
Step 3   Variable GR Entered        R-square = 0.49595751   C(p) = -2.21460072

                  DF         Sum of Squares       Mean Square           F    Prob>F

Regression         3             5.04605767        1.68201922        3.94    0.0362
Error             12             5.12831733        0.42735978
Total             15            10.17437500

                Parameter          Standard           Type II
Variable         Estimate             Error    Sum of Squares           F    Prob>F

INTERCEP       1.31679282        0.44509445        3.74045285        8.75    0.0120
TE             0.09048633        0.04030654        2.15381600        5.04    0.0444
RA            -0.88724470        0.28144159        4.24721198        9.94    0.0083
GR             0.31673934        0.25453504        0.66176300        1.55    0.2371

Bounds on condition number:       1.841874,       14.13318
                                       SAS    14:35 Wednesday, July 6, 1994  15


The above model is the best  3-variable model found.

Step 4   Variable MO Entered        R-square = 0.50815439   C(p) = -0.35459653

                  DF         Sum of Squares       Mean Square           F    Prob>F

Regression         4             5.17015333        1.29253833        2.84    0.0766
Error             11             5.00422167        0.45492924
Total             15            10.17437500

                Parameter          Standard           Type II
Variable         Estimate             Error    Sum of Squares           F    Prob>F

INTERCEP       1.46573476        0.54056802        3.34467502        7.35    0.0202
TE             0.08791682        0.04187633        2.00516701        4.41    0.0597
RA            -0.77628934        0.35979324        2.11780071        4.66    0.0539
GR             0.32630853        0.26325526        0.69895078        1.54    0.2409
MO            -0.15788941        0.30230592        0.12409566        0.27    0.6118

Bounds on condition number:       2.827739,       30.92321

The above model is the best  4-variable model found.

Step 5   Variable PO Entered        R-square = 0.56006672   C(p) =  1.04955375

                  DF         Sum of Squares       Mean Square           F    Prob>F

Regression         5             5.69832888        1.13966578        2.55    0.0978
Error             10             4.47604612        0.44760461
Total             15            10.17437500

                Parameter          Standard           Type II
```

```
Variable          Estimate           Error   Sum of Squares          F   Prob>F

INTERCEP        0.72200477      0.86963496       0.30853235       0.69   0.4258
TE              0.10580292      0.04468226       2.50968777       5.61   0.0394
RA             -0.63940671      0.37847796       1.27752010       2.85   0.1220
GR              0.41200908      0.27278509       1.02109669       2.28   0.1619
MO             -0.42268465      0.38644274       0.53549719       1.20   0.2997
PO              0.52063606      0.47928338       0.52817556       1.18   0.3028

Bounds on condition number:       3.336382,       58.88322


The above model is the best  5-variable model found.

Step 6   Variable NO Entered        R-square = 0.58984727   C(p) =  2.70773265

                    DF       Sum of Squares      Mean Square          F   Prob>F

Regression           6           6.00132734       1.00022122       2.16   0.1443
Error                9           4.17304766       0.46367196
Total               15          10.17437500

                 Parameter         Standard          Type II
                                        SAS   14:35 Wednesday, July 6, 1994  16

Variable          Estimate           Error   Sum of Squares          F   Prob>F

INTERCEP        0.32587890      1.01169995       0.04810828       0.10   0.7547
TE              0.10758276      0.04553042       2.58876727       5.58   0.0424
RA             -0.53296028      0.40709568       0.79470791       1.71   0.2229
GR              0.32305134      0.29865137       0.54253143       1.17   0.3075
NO              0.26021370      0.32189584       0.30299846       0.65   0.4397
MO             -0.58827227      0.44346113       0.81593671       1.76   0.2173
PO              0.66703260      0.52034146       0.76195283       1.64   0.2319

Bounds on condition number:       4.241313,       92.45073


The above model is the best  6-variable model found.

Step 7   Variable ESTM Entered      R-square = 0.60172879   C(p) =  4.57135663

                    DF       Sum of Squares      Mean Square          F   Prob>F

Regression           7           6.12221433       0.87460205       1.73   0.2302
Error                8           4.05216067       0.50652008
Total               15          10.17437500

                 Parameter         Standard          Type II
Variable          Estimate           Error   Sum of Squares          F   Prob>F

INTERCEP       -0.21978230      1.53807914       0.01034248       0.02   0.8899
TE              0.07405956      0.08350667       0.39839756       0.79   0.4010
RA             -0.73593594      0.59469935       0.77567853       1.53   0.2510
ESTM            0.35921057      0.73528832       0.12088699       0.24   0.6383
GR              0.42181161      0.37189086       0.65163249       1.29   0.2895
NO              0.31590357      0.35522812       0.40058167       0.79   0.3998
MO             -0.56747577      0.46544942       0.75291566       1.49   0.2575
PO              0.76214158      0.57764840       0.88174060       1.74   0.2235

Bounds on condition number:       8.272187,       220.1295


Step 8   Variable TE Removed        R-square = 0.62866566   C(p) =  4.26217522
         Variable CL Entered
```

```
                 DF        Sum of Squares      Mean Square          F   Prob>F

Regression        7            6.39628018       0.91375431       1.93   0.1874
Error             8            3.77809482       0.47226185
Total            15           10.17437500

              Parameter          Standard          Type II
Variable       Estimate             Error   Sum of Squares          F   Prob>F

INTERCEP    -0.62790541        1.33259615       0.10485139       0.22   0.6501
RA          -1.34219927        0.56475700       2.66743362       5.65   0.0448
ESTM         0.83910130        0.40730790       2.00431501       4.24   0.0733
CL           0.56154219        0.47058654       0.67246341       1.42   0.2669
GR           0.50445227        0.32869315       1.11235070       2.36   0.1634
NO           0.28569159        0.34461994       0.32456146       0.69   0.4311
MO          -0.55740893        0.44604156       0.73753064       1.56   0.2467
PO           0.69772929        0.56301983       0.72528616       1.54   0.2504
                                      SAS   14:35 Wednesday, July 6, 1994  17

Bounds on condition number:      6.711468,     176.6032


The above model is the best  7-variable model found.

Step 9   Variable WI Entered        R-square = 0.64109646   C(p) =  6.11949450

                 DF        Sum of Squares      Mean Square          F   Prob>F

Regression        8            6.52275581       0.81534448       1.56   0.2848
Error             7            3.65161919       0.52165988
Total            15           10.17437500

              Parameter          Standard          Type II
Variable       Estimate             Error   Sum of Squares          F   Prob>F

INTERCEP    -1.39133126        2.08936566       0.23132343       0.44   0.5268
WI          -0.19379276        0.39357531       0.12647563       0.24   0.6375
RA          -1.43794381        0.62459786       2.76484186       5.30   0.0548
ESTM         1.03268602        0.58122438       1.64678309       3.16   0.1189
CL           0.65964565        0.53320868       0.79838877       1.53   0.2559
GR           0.52606799        0.34823430       1.19049647       2.28   0.1746
NO           0.49325230        0.55576849       0.41090161       0.79   0.4043
MO          -0.56023563        0.46882437       0.74491814       1.43   0.2710
PO           1.00982493        0.86712073       0.70749028       1.36   0.2823

Bounds on condition number:      7.431743,     330.2114


The above model is the best  8-variable model found.

Step10   Variable MP Entered        R-square = 0.64482669   C(p) =  8.07667897

                 DF        Sum of Squares      Mean Square          F   Prob>F

Regression        9            6.56070853       0.72896761       1.21   0.4225
Error             6            3.61366647       0.60227775
Total            15           10.17437500

              Parameter          Standard          Type II
Variable       Estimate             Error   Sum of Squares          F   Prob>F

INTERCEP    -1.24780718        2.31667460       0.17472768       0.29   0.6095
WI          -0.16467460        0.43851466       0.08493404       0.14   0.7202
RA          -1.70700250        1.26460335       1.09737856       1.82   0.2258
ESTM         1.12641480        0.72762695       1.44336429       2.40   0.1726
CL           0.83954275        0.91750875       0.50426870       0.84   0.3955
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GR             0.56558306      0.40593918       1.16914305       1.94    0.2130
NO             0.41510770      0.67343843       0.22883508       0.38    0.5603
MO            -0.49332750      0.56991688       0.45127828       0.75    0.4200
MP            -0.18970177      0.75569810       0.03795272       0.06    0.8102
PO             0.99523357      0.93352889       0.68452816       1.14    0.3274

Bounds on condition number:     26.38694,     712.1872

                                SAS     14:35 Wednesday, July 6, 1994  18

Step11   Variable WI Removed         R-square = 0.64499223   C(p) =  8.07477882
         Variable TE Entered

                 DF          Sum of Squares      Mean Square          F    Prob>F

Regression        9              6.56239287       0.72915476       1.21    0.4222
Error             6              3.61198213       0.60199702
Total            15             10.17437500

                Parameter        Standard          Type II
Variable         Estimate           Error   Sum of Squares          F    Prob>F

INTERCEP      -1.06624978      1.96662232       0.17695805       0.29    0.6072
TE            -0.07634700      0.20127236       0.08661838       0.14    0.7175
RA            -2.39552129      2.14435234       0.75128051       1.25    0.3067
ESTM           1.58634970      1.65483965       0.55319770       0.92    0.3748
CL             1.32322250      1.58429592       0.41994024       0.70    0.4356
GR             0.69022025      0.52457519       1.04220762       1.73    0.2363
NO             0.20027763      0.43204392       0.12936102       0.21    0.6593
MO            -0.40145177      0.58867765       0.27996646       0.47    0.5207
MP            -0.36116161      0.77165420       0.13187184       0.22    0.6563
PO             0.72854475      0.64875255       0.75918680       1.26    0.3044

Bounds on condition number:     75.90582,     1744.291


The above model is the best  9-variable model found.

Step12   Variable WI Entered         R-square = 0.65021335   C(p) = 10.01485088

                 DF          Sum of Squares      Mean Square          F    Prob>F

Regression       10              6.61551444       0.66155144       0.93    0.5711
Error             5              3.55886056       0.71177211
Total            15             10.17437500

                Parameter        Standard          Type II
Variable         Estimate           Error   Sum of Squares          F    Prob>F

INTERCEP      -1.51475998      2.69596250       0.22469889       0.32    0.5985
TE            -0.06236754      0.22475813       0.05480591       0.08    0.7925
WI            -0.13374549      0.48956928       0.05312157       0.07    0.7956
RA            -2.25007303      2.39169425       0.62997436       0.89    0.3900
ESTM           1.57504265      1.79988221       0.54505137       0.77    0.4216
CL             1.23864898      1.75029512       0.35646337       0.50    0.5108
GR             0.66830841      0.57601361       0.95814078       1.35    0.2983
NO             0.36225578      0.75646986       0.16322563       0.23    0.6522
MO            -0.43633543      0.65271623       0.31807761       0.45    0.5334
MP            -0.28254388      0.88704389       0.07221419       0.10    0.7630
PO             0.93616781      1.03692817       0.58016434       0.82    0.4080

Bounds on condition number:     79.86334,     2157.813


The above model is the best 10-variable model found.
                                SAS     14:35 Wednesday, July 6, 1994  19
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Step13   Variable PH Entered        R-square = 0.65150720   C(p) = 12.00000000

                 DF        Sum of Squares      Mean Square          F      Prob>F

Regression       11            6.62867861       0.60260715       0.68      0.7237
Error             4            3.54569639       0.88642410
Total            15           10.17437500

                 Parameter        Standard          Type II
Variable          Estimate           Error   Sum of Squares          F      Prob>F

INTERCEP       -1.68489457      3.31673886       0.22875176       0.26      0.6382
PH              0.16999813      1.39498043       0.01316417       0.01      0.9089
TE             -0.07636738      0.27587910       0.06792346       0.08      0.7956
WI             -0.09037507      0.65203384       0.01702937       0.02      0.8965
RA             -2.47196938      3.23099012       0.51886750       0.59      0.4869
ESTM            1.69917255      2.25211481       0.50458631       0.57      0.4925
CL              1.36792596      2.22274792       0.33572703       0.38      0.5716
GR              0.69568677      0.68093974       0.92523422       1.04      0.3647
NO              0.31964439      0.91374317       0.10847445       0.12      0.7441
MO             -0.34575092      1.04072484       0.09783549       0.11      0.7564
MP             -0.35811785      1.16812049       0.08331404       0.09      0.7745
PO              0.89758316      1.19970905       0.49617980       0.56      0.4959

Bounds on condition number:      117.0326,      3267.127

The above model is the best 11-variable model found.

No further improvement in R-square is possible.
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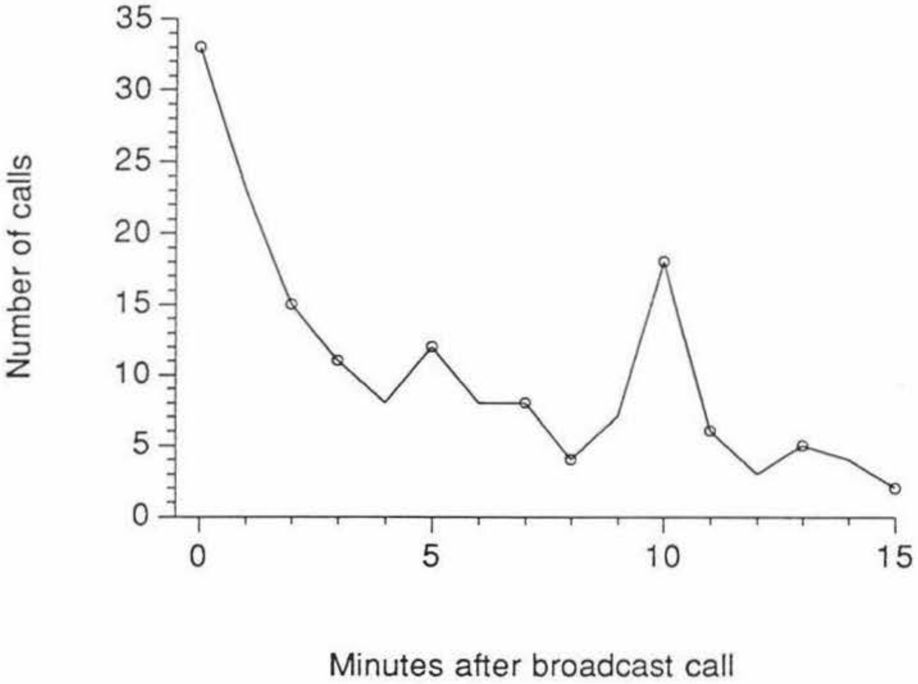
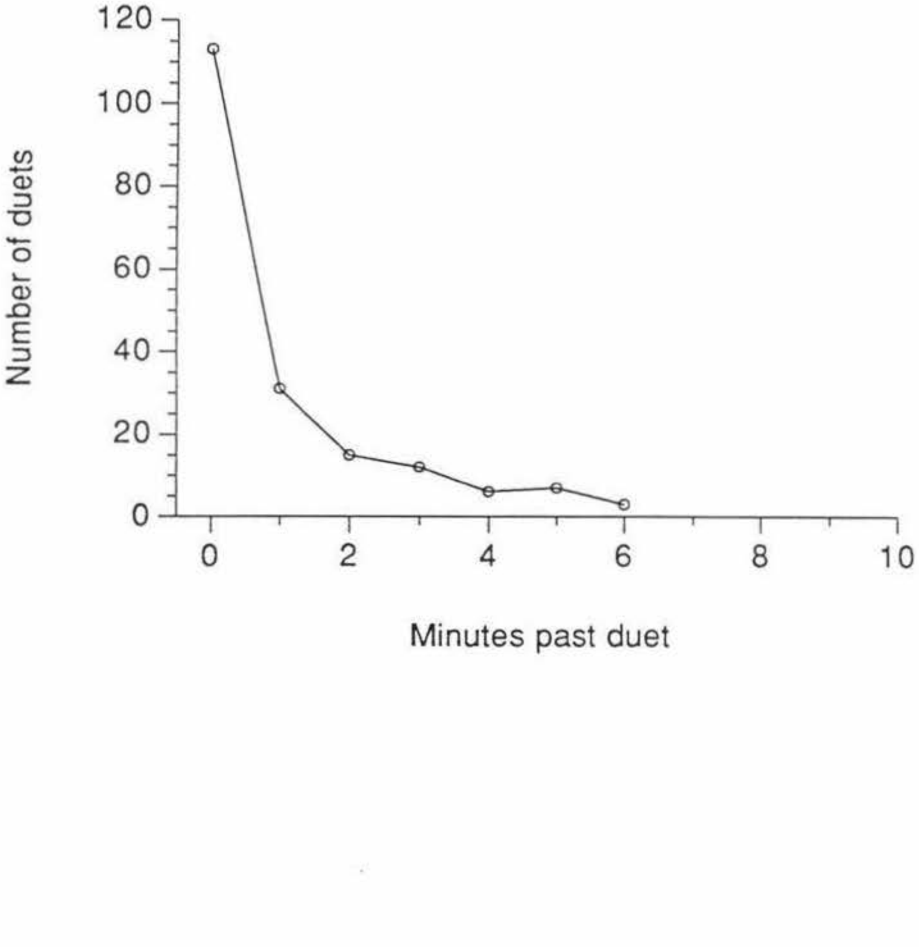
Appendix 4 Number of calls heard (n = 169) in the 15 minute interval between broadcasting calls (0: includes calls within the first minute after the call was broadcasted). 60% of calls occur within 5 minutes of broadcasting a call (x = 4.76 min, SD = 4.32). Calls were classified as responses to a broadcasted call, or territorial responses to neighbouring calls if they fell into this time interval.



Appendix 5 Response interval of mate after one of the pair called. 77% of responses fell within the 2 minute range. A duet was classified as one of the partners from a bonded pair responded within this 2 minute time-frame.



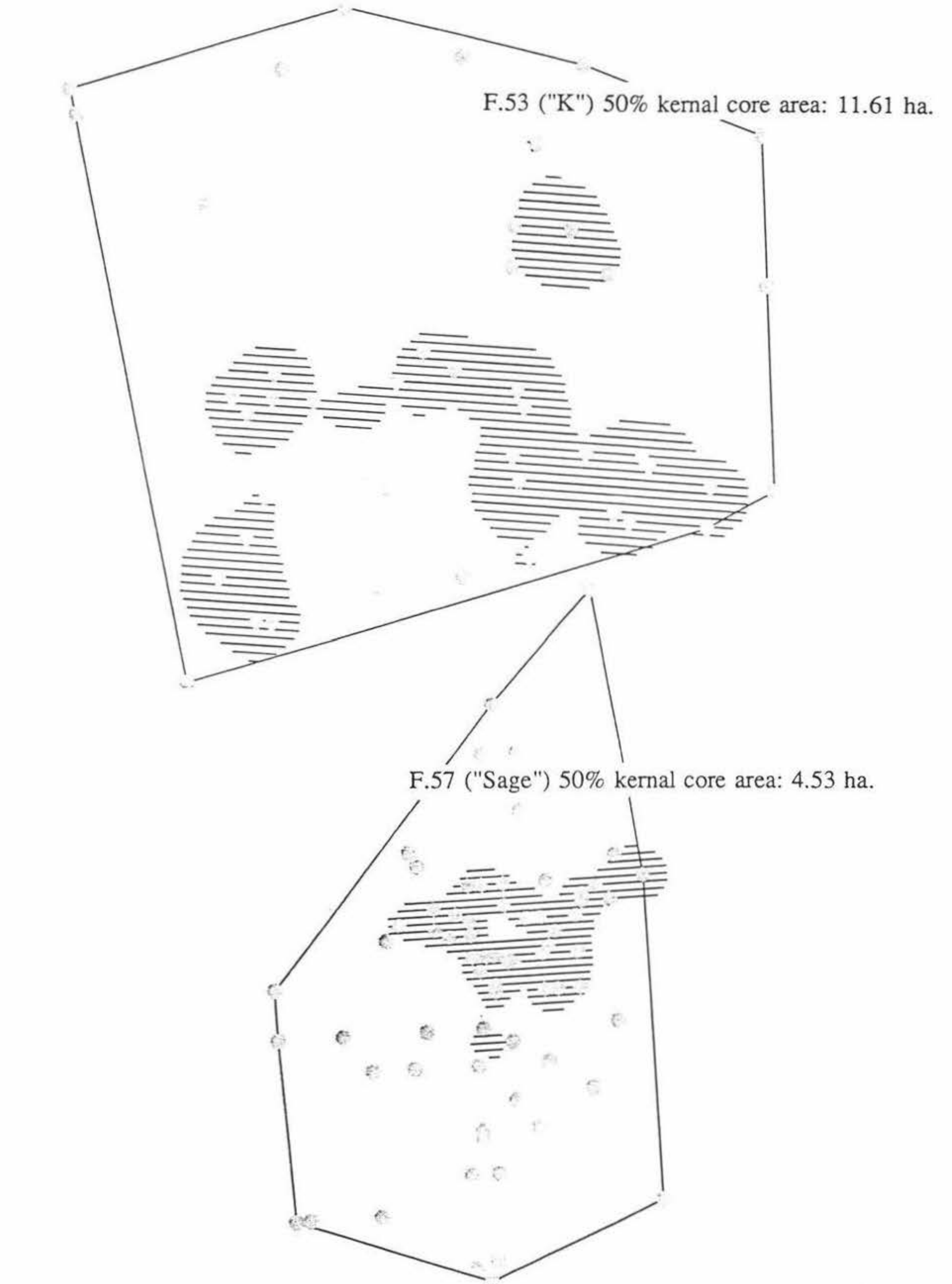
Appendix 6 Measurements of Tongariro kiwi.

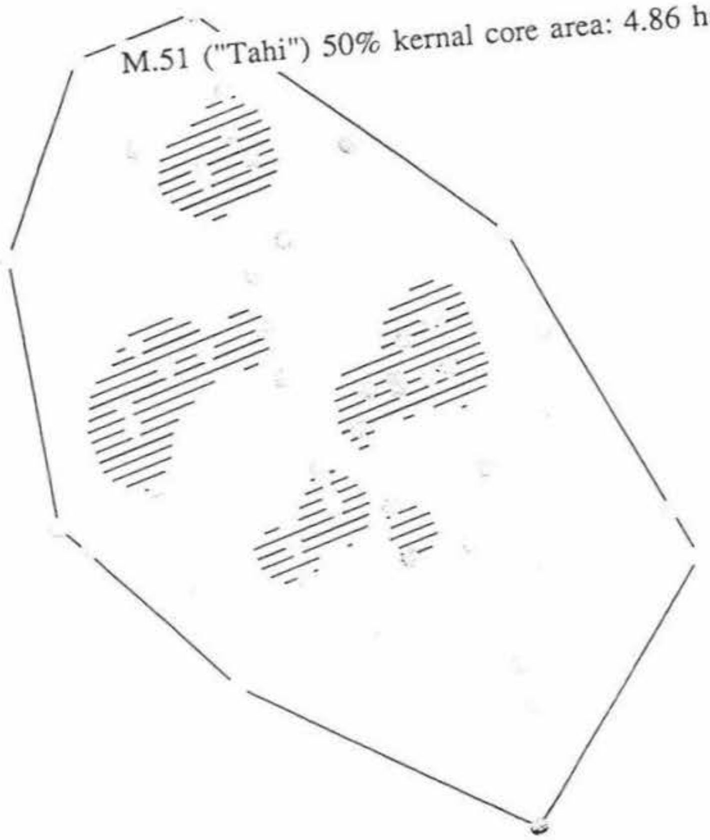
					Right middle toe (mm)				Tarsus (mm)			Bill (mm)		
Bird	Band #	Date	Weight kg	Length mm	Nail	Pad	Width	Depth	Length	Depth	Breadth	Cere	Gape	Width
M.51	R-46251	15.12.92	1.80	755	40.7	48.7	10.5	13.9	86.4	17.4	11.1	99.6	122.0	23.4
		21.2.93	1.90									98.8		
		11.5.93	2.10	740	40.0	47.0	10.2	13.6	85.2	15.1	11.2	97.3	123.4	24.3
		19.2.94	2.00	750	41.6	47.6	9.4	14.4	86.7	18.0	10.8	98.7	124.4	25.7
		1.4.94	2.05	747	42.7	47.4	9.7	14.1	86.3	15.4	11.9	99.1	121.0	26.6
M.52	R-46252	17.12.92	2.75	689	45.6	46.0	9.3	14.3	86.7	17.0	12.0	99.7	125.0	22.2
		21.3.93	2.60	-	45.6	48.1	9.7	14.7	87.3	16.4	12.4	99.2	125.1	-
		22.4.93	2.68									-		
		27.11.93	2.60									99.1		
F.57	R-46257	11.2.93	2.80	883	50.4	53.0	12.3	16.8	102.0	13.6	18.5	132.9	151.7	28.3
		20.3.93	2.60									132.3		
		21.4.93	2.70	883	51.4	55.0	12.0	17.0	101.0	14.0	18.8	132.8	153.5	29.4
		8.8.93	2.50									131.9		
		26.11.93	2.90									131.5		
		3.1.93	2.50									131.6		
		20.1.94	2.55	880	50.8	54.1	11.7	16.2	101.8	13.8	17.7	132.8	156.0	-
		1.4.94	2.60	895	50.1	53.6	12.0	17.6	100.9	14.1	17.8	133.7	153.4	27.5

Appendix 6 continued ...

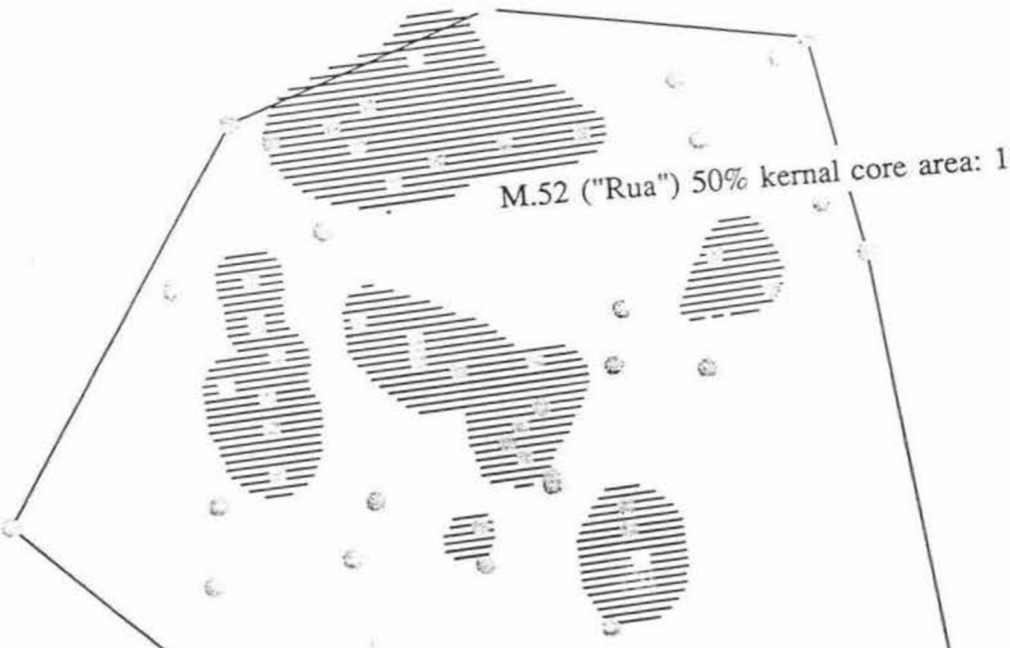
					Right middle toe (mm)				Tarsus (mm)			Bill (mm)		
Bird	Band #	Date	Weight kg	Length mm	Nail	Pad	Width	Depth	Length	Depth	Breadth	Cere	Gape	Width
M.58	R-46258	23.2.93	2.10	745	44.7	51.0	10.2	15.7	90.3	13.5	17.8	98.6	115.7	23.1
		18.5.93	2.17	743	45.2	49.4	11.4	15.6	92.9	12.5	16.9	97.4	115.3	23.7
F.53	R-46253	2.6.93	2.50	847	47.5	52.0	10.5	15.7	93.0	13.2	17.8	125.8	147.4	27.5
		3.7.93	2.50	-	-	-	-	-	-	-	-	126.3	-	-
		6.8.93	2.50	-	-	-	-	-	-	-	-	126.1	-	-
		16.10.93	2.55	-	-	-	-	-	-	-	-	126.1	-	-
M.54	R-46254	17.11.93	1.90	734	43.6	47.6	9.8	13.0	85.0	12.7	13.0	96.3	115.3	24.9
		1.4.94	1.95	736	43.6	46.7	10.0	13.8	86.3	11.9	14.2	95.6	116.1	25.7

Appendix 7 Range size estimation (CP), with 50% adaptive kernal core areas within.



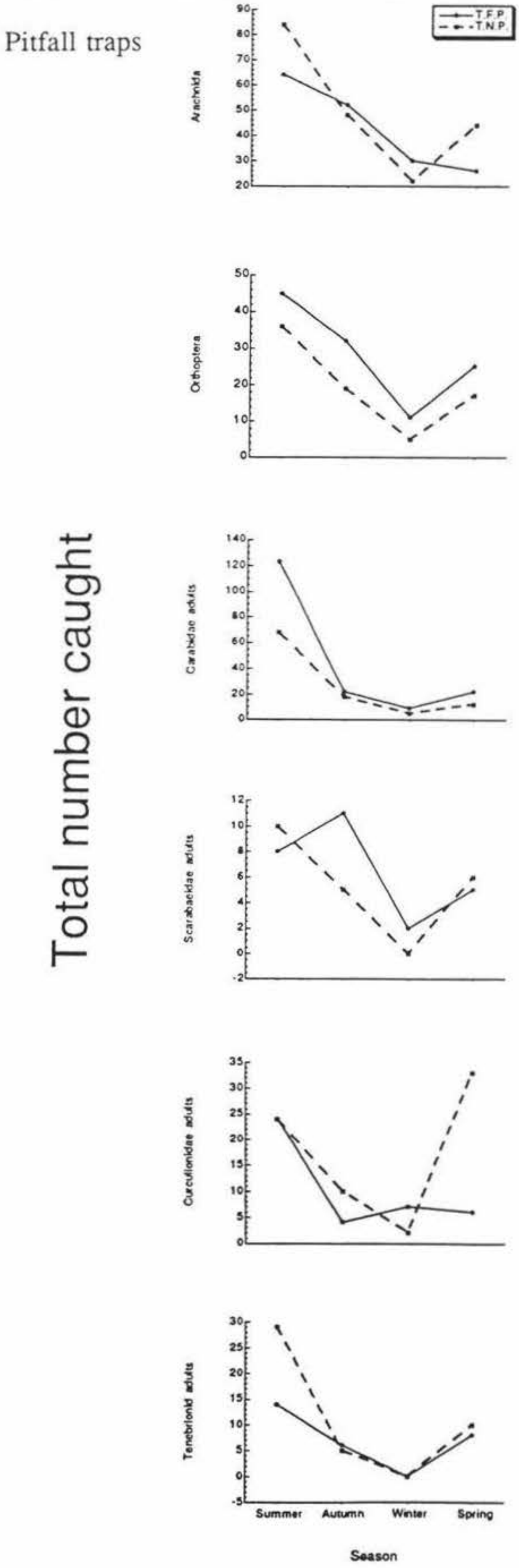


M.51 ("Tahi") 50% kernal core area: 4.86 ha.

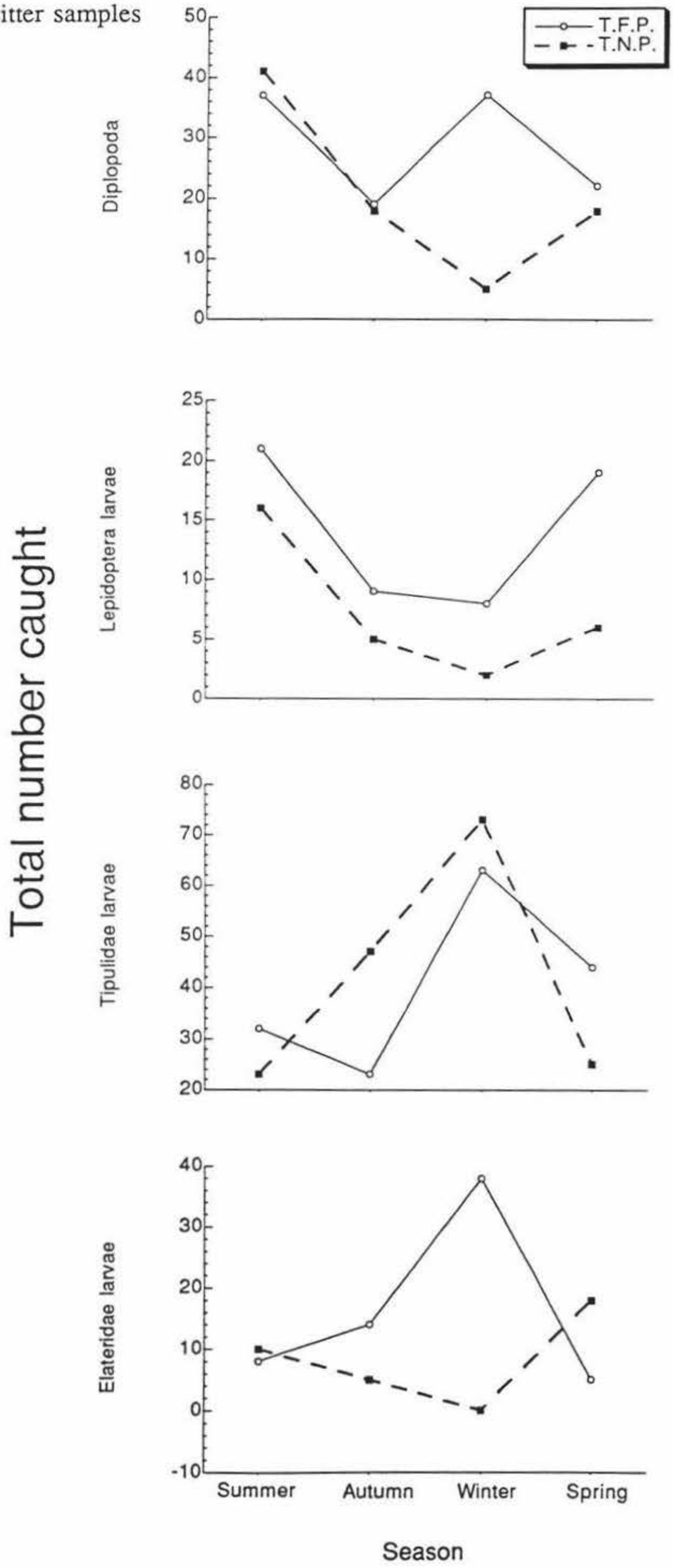


M.52 ("Rua") 50% kernal core area: 18.55 ha.

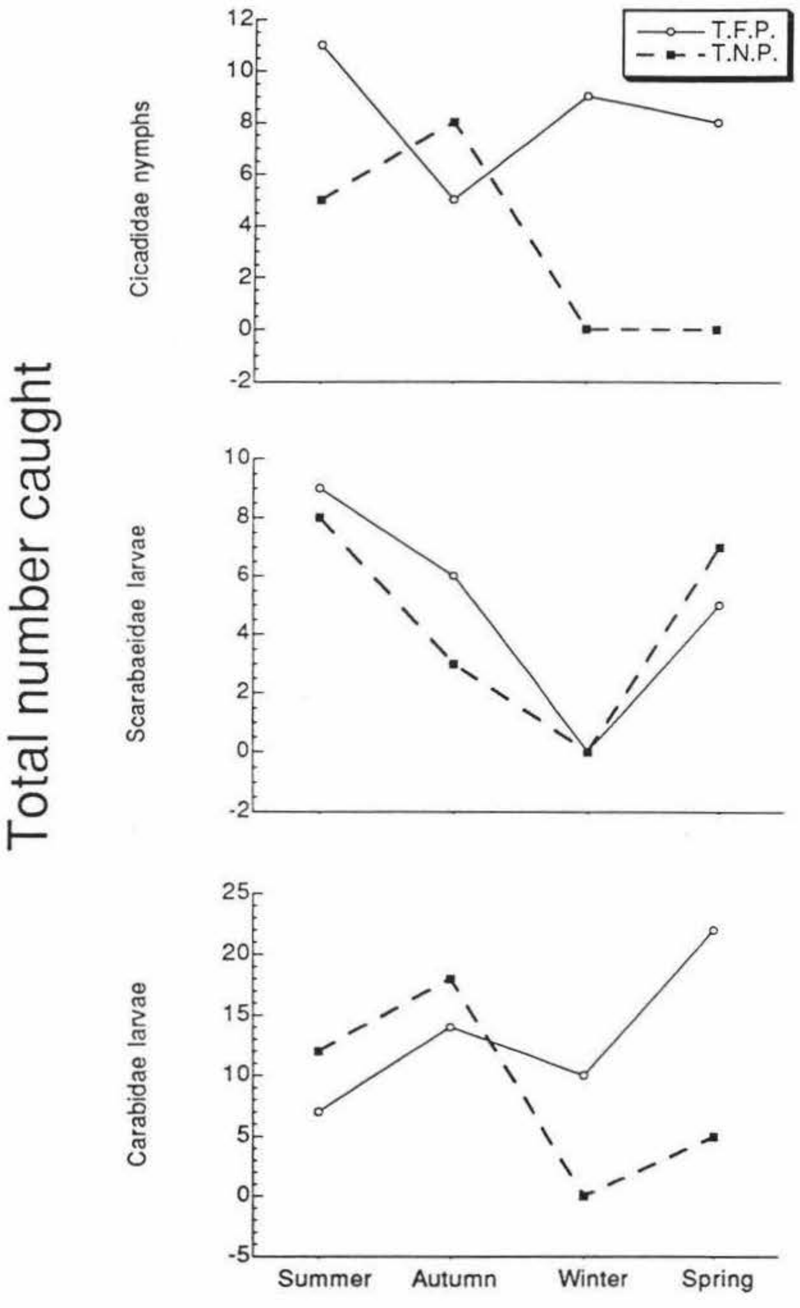
Appendix 8 Seasonality of the 13 taxonomic groups found in faeces caught in either pitfall traps, litter samples, and soil samples in T.F.P. and T.N.P.



Litter samples



Soil samples



Season

Appendix 9 Availability and utilisation by kiwi of the 13 non-annelid food invertebrates in T.F.P. and T.N.P.

Taxon	Number caught	Percent	Number utilised	Percent	Expected	X^2	G-statistic
Arachnida	172	16.21	28	11.57	38.72	2.97	-9.08
Orthoptera	113	10.65	21	8.68	26.62	1.19	-4.98
Carabidae adult	176	16.59	31	12.87	41.14	2.50	-8.77
Scarabaeidae adult	26	2.45	27	11.16	4.84	101.46	46.41
Curculionidae adult	41	3.86	4	1.65	9.68	1.14	-3.54
Tenebrionid adult	28	2.64	5	2.07	7.26	0.70	-1.86
Diplopoda	115	10.84	10	4.13	26.62	10.38	-9.79
Lepidoptera larvae	57	5.37	6	2.48	12.10	3.08	-4.21
Tipulidae larvae	162	15.27	8	3.31	36.30	22.06	-12.10
Elateridae larvae	65	6.13	5	2.07	14.52	6.24	-5.33
Cicadidae nymph	33	3.11	48	19.83	7.26	228.62	90.66
Scrabaeidae larvae	20	1.89	35	14.46	4.84	187.94	94.96
Carabidae larvae	53	4.99	14	5.79	12.10	0.30	2.04
Total	1061	100	242	100	242	568.58	174.41
T.N.P.							
Arachnida	198	22.25	26	17.69	32.34	1.24	-5.67
Orthoptera	77	8.65	16	10.88	13.23	0.58	3.04
Carabidae adult	103	11.57	15	10.20	17.64	0.40	-2.43
Scarabaeidae adult	21	2.36	7	4.76	2.94	5.61	6.07
Curculionidae adult	69	7.75	7	4.76	11.76	1.93	-3.63
Tenebrionidae adult	44	4.94	7	4.76	7.35	0.02	-0.36
Diplopoda	82	9.21	15	10.20	13.23	0.24	1.88
Lepidoptera larvae	29	3.26	4	2.72	4.41	0.04	-0.39
Tipulidae larvae	168	18.88	7	4.76	27.93	15.68	-9.69
Elateridae larvae	33	3.71	7	4.76	5.88	0.21	1.22
Cicadidae nymph	13	1.46	10	6.80	1.47	49.50	19.17
Scarabaeidae larvae	18	2.02	11	7.48	2.94	22.10	14.51
Carabidae larvae	35	3.93	15	10.20	5.88	14.15	14.04
Total	890	100	147	100	147	111.70	37.76

Appendix 10 Averages of taxonomic diversity and total numbers of individuals in the three feeding zones sampled in each of the four home ranges of kiwi in T.F.P.

		Bird and home range size (ha)			
Average taxonomic diversity	Feeding zone	M.51 (30.29)	M.52 (91.72)	F.57 (34.18)	F.53 (52.79)
	Surface	7.8566	8.8744	7.7932	7.6741
	Litter	11.2148	13.1862	9.2502	10.4280
•	Soil	1.7858	1.6616	1.8112	1.7743
	Total	20.8572	23.7222	18.8546	19.8764
Average number of individuals	Feeding zone	M.51 (30.29)	M.52 (91.72)	F.57 (34.18)	F.53 (52.79)
	Surface	23.6986	28.4351	21.5654	21.7660
	Litter	56.0071	72.1471	44.1664	46.3722
•	Soil	2.9014	3.0117	2.9701	2.9075
	Total	82.6071	103.5939	68.7019	71.0457

Appendix 11 Stoats, Ferrets, Weasels, Cats and Dogs recorded in, and in the vicinity of T.N.P and T.F.P.

Date	Animal	Description
8.1.85	1 M stoat	Ticket kiosk hut. Wk
15.7.85	1 cat	Motor camp. Wk
27.10.85	1 F stoat	Lodge clearing. Wk
27.11.85	1 cat	Golf course. Wk
5.2.86	1 cat	Mahuia Rapids Rd bridge. Wk
15.3.86	1 F stoat	Motor camp. Wk
5.9.86	1 cat	Wainene flats. Wk
15.10.86	1 cat	Wk
5.11.86	1 cat	Hepi Terrace. Wk
10.2.87	1 stoat	Hepi Terrace. Wk
14.2.87	1 stoat	Park H.Q. Wk
15.5.87	1 stoat	Motor camp. Wk
2.7.87	1 cat	Bottom of Ridge Track. Wk
9.8.87	1 M stoat	Hepi Terrace. Wk
23.10.87	1 M stoat	Visitors Centre. Wk
30.10.87	1 M stoat	Hepi Terrace. Wk
30.10.87	1 M stoat	Hepi Terrace. Wk
6.12.87	1 M stoat	Tama Flat. Wk
5.1.88	1 ferret	Mangatepopo. Wk
6.1.88	1 stoat	Whakapapaiti Hut. Wk
17.1.88	1 stoat	Tama Flat. Wk
18.1.88	1 stoat	T.H.C behind Chateau. Wk
20.1.88	1 stoat	Ridge Track. Wk
20.1.88	1 stoat	Chairmans Lodge. Wk
20.1.88	1 stoat	Chairmans Lodge. Wk
20.1.88	1 stoat	Chairmans Lodge. Wk
23.1.88	1 stoat	Hepi Terrace. Wk
28.1.88	1 weasel	Two mile corner. Wk
10.1.88	1 cat	Chateau. Wk
10.2.88	1 stoat	Golf course. Wk
3.3.88	1 stoat	Visitors Centre. Wk
5.5.88	1 F cat	Visitors Centre. Wk
20.5.88	1 weasel	Chairmans Lodge. Wk
1.7.88	1 stoat	Golf course. Wk

6.7.88	1 stoat	Golf course. Wk
7.7.88	1 stoat	Sewage plant. Wk
15.7.88	1 stoat	Sewage plant. Wk
29.8.88	1 stoat	Golf course. Wk
8.9.88	1 F stoat	Golf course. Wk
4.1.89	1 cat	Whakaehaere Lodge. Wk
10.8.89	1 stoat	Workshop. Wk
17.11.89	1 F stoat	Chairmans Lodge. Wk
28.11.89	1 F stoat	Motor camp. Wk
28.11.89	5 stoats	Motor camp. Wk
29.11.89	1 M & 1 F stoat	Chairmans Lodge. Wk
7.12.89	2 stoats	Chairmans Lodge. Wk
19.12.89	1 stoat	Chairmans Lodge. Wk
11.1.90	1 M stoat	Chairmans Lodge. Wk
14.2.90	1 stoat	Tama Flat. Wk
19.3.90	1 stoat	Tama Flat. Wk
Date	Animal	Personal records
26.8.92	dog tracks	Whakapapiti Track. Wk
21.8.92	1 dog (unattended)	Tongariro Forest Park
11.1.93	1 stoat	Tongariro Forest Park
9.2.93	1 stoat	Carls Camp. T.F.P
18.3.93	1 weasel	Nicks Hut. T.F.P
14.7.93	1 F stoat	Tongariro Forest Park
14.7.93	1 M stoat	Hidden Hut. T.F.P
26.7.93	1 dog (unattended)	S.H. 47 in T.N.P boundary
5.8.93	1 M stoat	Tongariro Forest Park
5.8.93	1 M stoat	Tongariro Forest Park
7.8.93	1 M stoat	Tongariro Forest Park
9.8.93	1 M stoat	Tongariro Forest Park
21.8.93	1 M stoat	Tongariro Forest Park
21.8.93	1 M stoat	Tongariro Forest Park
21.8.93	1 F stoat	Tongariro Forest Park
23.8.93	1 dog	Tongariro Forest Park
26.8.93	dog tracks	Whakapapaiti track. T.N.P
1.9.93	1 M stoat	Mangahuia Track. T.N.P
1.9.93	1 M stoat	Mangahuia Track. T.N.P
1.9.93	1 M stoat	Mangahuia Track. T.N.P
1.9.93	1 M stoat	Mangahuia Track. T.N.P
5.9.93	1 M stoat	Mangahuia Track. T.N.P

5.9.93	1 M ferret	Mangahuia Track. T.N.P
10.10.93	1 dog (unattended)	Tongariro Forest Park
11.10.93	1 stoat	Nicks Hut T.F.P
8.12.93	1 cat	Tongariro Forest Park
8.12.93	1 stoat	Tongariro Forest Park
29.1.94	1 dog (unattended)	Tongariro Forest Park
19.1.94	1 stoat	Tongariro Forest Park

* Information unavailable for 1990 to 1993.
Wk. Whakapapa, Tongariro National Park (T.N.P)
T.F.P Tongariro Forest Park

Appendix 12 Body and skull measurements of stoats collected in T.N.P. and T.F.P. from July to September 1993.

Stoat #	Date caught	Where caught	Sex	Age class	Weight (g)	Length (mm)	Tail length	Hind foot	Cb^1. lgth	Baculum (mg)
1	14.7.93	T.F.P	Female	Unclassed	143.69	107.1	83	15.7	42.1	–
2	14.7.93	T.F.P	Male	Adult	395.11	282.3	104	21.3	49.3	60
3	5.8.93	T.F.P	Male	Adult	470.4	283	107	23	54.6	53
4	5.8.93	T.F.P	Male	Adult	446.33	239	109	20.7	50.2	62
5	7.8.93	T.F.P	Male	Subadult	262.51	240	94	17.8	44.1	23
6	9.8.93	T.F.P	Male	Subadult	170.09	229	101	15.5	40.2	20
7	21.8.93	T.F.P	Male	Adult	353.50	267	109	21.8	52.1	66
8	21.8.93	T.F.P	Female	Adult	249.45	257	88	20.4	45.1	–
9	1.9.93	T.N.P	Male	Adult	315.7	267	99	20.5	50.3	53
10	1.9.93	T.N.P	Male	Adult	358.33	273	107	21.6	51.2	64
11	1.9.93	T.N.P	Male	Adult	327.5	285	102	22.2	55.1	69
12	1.9.93	T.N.P	Male	Adult	406.08	297	106	20.2	51.3	37
13	5.9.93	T.N.P	Male	Adult	394.89	276	109	22.1	51.0	62

1: Condylobasal length.