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Summer home range size and population density of great spotted kiwi (*Apteryx haastii*) in the North Branch of the Hurunui River, New Zealand

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Abstract Home range size, travel distances, and population density of the great spotted kiwi (*Apteryx haastii*) were investigated in the North Branch of the Hurunui River. Radio tracking was conducted on 10 great spotted kiwi between Dec 2007 and Apr 2008. The estimated minimum home-range sizes were determined using the concave polygon method and ranged between 19.6 ha and 35.4 ha, with a mean of 29.3 ha (± 1.6 SEM). The observed nightly distances travelled per hour varied from 7 to 433 m (n = 569). Most estimates of travel distances (73%) were clustered in the classes from 0 - 150 m/hour, and distances over 200 m/hour were seldom achieved (only *c*. 7% of distances). The kiwi population in the Mainland Island site on the western North Branch of the Hurunui River was estimated to hold around 290 birds in total. Population density for the entire North Branch area was estimated to be 2 pairs/km² and when including subadults, 5 birds/km². Our estimate of home range size is larger but with more variation than found in other studies. Differences in population density estimates between our study and those in the Hurunui and Arthurs Pass district may be due to different objectives and methods.

INTRODUCTION

All kiwi species (*Apteryx* spp.) have suffered serious population declines since human arrival and are now threatened on the New Zealand mainland (Basse *et al.* 1999; McLennan *et al.* 1996). The great spotted kiwi (*Apteryx haastii*) is considered the least known among the different kiwi species (McLennan & McCann 1991; Wilson 2004). Since the 1980's some research has investigated the ecology

of the great spotted kiwi, but there is still much to learn about their population dynamics (Holzapfel *et al.* 2008; McLennan & McCann 1991). Currently only 3 natural populations survive: Northwest Nelson, the Paparoa Range, and the Arthur's Pass-Hurunui District of the Southern Alps, although a new population was established at Nelson Lakes National Park in 2004 (Paton *et al.* 2007). The great spotted kiwi population in the Hurunui District is considered to be the smallest and most isolated. It is therefore the population most vulnerable to further declines in size and distribution. For example, a

small localised extinction in a single valley could seriously fragment the whole population (McLennan & McCann 2002). Monitoring and research are essential to understand changes in this population and to determine if it is declining (Robertson 2003).

The focus of this study was to obtain information on fundamental population parameters, such as home range sizes and the current population density of great spotted kiwi in the North Branch of the Hurunui River. Our results also provide a baseline for further monitoring, as well as important data for robust population modelling (e.g. Population Viability Analysis). Furthermore, we expect the findings of our study to enhance current knowledge on great spotted kiwi ecology and behaviour, as this information may be needed for future management (Holzapfel *et al.* 2008).

METHODS
Study area
This study was undertaken in North Canterbury at the North Branch of the Hurunui River, which extends from west of Lake Sumner to Harper Pass (42° 42′ S, 171° 58′ E). The North Branch is located in mountainous terrain; the highest peak reaches over 1670 m and the lowest part at the valley floor is about 600 m. Rainfall ranges from 1200-4000 mm per year but is dependent on location within the valley as there is a strong west–east rainfall gradient (Jane 1985). The vegetation mainly consists of beech forest (*Nothofagus* spp.) and regenerating scrubland, sub-alpine shrub-land, alpine snow tussock communities and tussock grassland in the drier eastern areas (Wardle 1984). For this study, 2 research areas were created within the Hurunui Mainland Island area of the North Branch (Fig. 1). In Area A (18.39 km²), the telemetry data from 10 birds was collected. This area follows the upper Hurunui River from about 6 km east of Harper Pass eastwards down to the Department of Conservation's No. 3 Hut. Area B (60 km²) is the North Branch Site of the Hurunui Mainland Island and includes area A. It follows the upper Hurunui River in the North Branch valley from Harper Pass passing the Department of Conservation's No. 3 Hut down to the Mainland Island stock fence, including the whole catchment area and tributaries (western North Branch). Area B in its entirety was used to estimate population density, as it is bounded by mountains and by the Mainland Island stock fence. Furthermore, prospective management actions (e.g. predator control, Operation Nest Egg) would be applied within the boundaries of Area B.

Radio-tagging
A total of 5 male and 6 female kiwi were caught and radio-tagged between Mar and Jul 2007 by Department of Conservation staff and contractors using trained kiwi dogs following the Best Practice Manual (Robertson & Colbourne 2003). Individual bird names in this paper follow the database set up by the Department of Conservation. They are used in all reports (Wylie 2007; Wylie & Yong 2008) for easier recognition and to emphasise the individuality of each bird. Unfortunately, limited information was obtained from 1 male kiwi whose transmitter failed after a couple of months. The final study group (*n* = 10) contained 3 kiwi pairs with both partners tagged, 2 adult birds where the partners were not tagged, and 2 subadult birds where no partner was either heard or captured.

During the fitting of radio tags, bill length and weight of the birds were taken as they are important for the identification of gender and age (Wylie 2007). These measurements were taken again during a transmitter change between Feb and Apr 2008. In addition, 18 new birds were captured, banded and radio tagged within Area A after the radio-tracking sessions between May and Jul 2008 for Operation Nest Egg. These 18 birds were used to estimate the occupancy rate for any available territories in Area A. As subsequent measurement data was lacking for the 18 additional kiwi, gender and age were not certain. However, at least 2 birds are thought to be subadults.

"Egg-Timers," originally developed for Haast tokoeka kiwi (*A. australis lawryi*) and rowi kiwi (*A. rowi*) by Wildtech Ltd, were used as VHF transmitters. For our research, the Haast tokoeka adult version was selected as it was the most comparable species to great spotted kiwi (Wylie 2007). Egg-Timers have been specifically designed to detect the start and end of the incubation period (Wildtech Ltd 2007). However, it is also possible to use the Egg-Timers as normal location VHF devices. The battery has an approximate life span of 1 year.

The telemetry data collection was conducted between Dec 2007 and Apr 2008. Throughout the monitoring sessions, tagged kiwi were relocated using 2 ground-based techniques: triangulation during nights (Mech 1983) and homing (Kenward 2001) during the day time. For both techniques, hand-held TR-4 receivers (Telonics™) together with 3-element folding Yagi antennas (Sirtrack Ltd) were used to locate birds and hand-held GPS devices (Garmin 60CSx) were used for marking telemetry base points for the radio-tagged birds. We started triangulation 1 hour before sunset, continuing throughout the night until the birds retreated to their day shelters. Two telemetry bearings were taken simultaneously by 2 teams at fixed telemetry base points. During the night, kiwi calls were also recorded in order to estimate the occupancy of available territories. Homing of
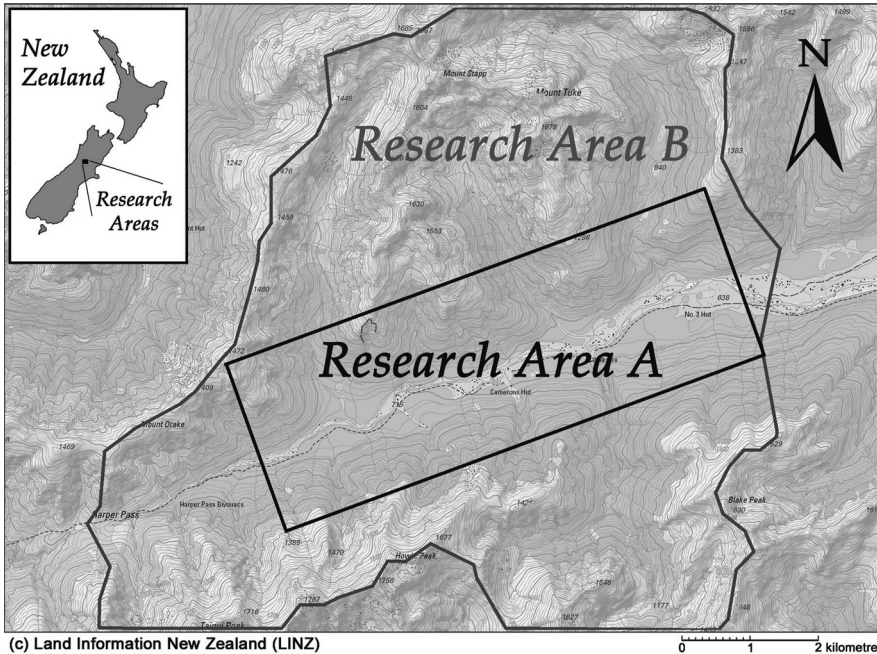
Fig. 1. Location of the 2 research areas in the Hurunui North Branch, Research areas A and B.

inactive birds during daytime was used to verify accuracy levels of night-time triangulation data (see Keye 2008).

Radio tracking errors
Location accuracy was estimated using the "modified beacon" test (Millspaugh & Marzluff 2001). For this test, the animal locations gained from fixed telemetry points by triangulation in the inactive phase of the birds were compared with the locations gained by homing. The mean distances between actual and estimated bird locations (i.e., linear error) were calculated (Garrott *et al.* 1986). The arithmetic mean of 30.8 m ($n = 42$, range = 1 – 95 m) along with the 95% confidence interval of ± 6.6 m indicate that 95% of the location fixes were presumed to be within 37.4 m (30.8 ± 6.6) of the true location. The standard deviation of 21.1 m indicates that there was considerable variation in the error associated with the location fixes obtained and reflects the difficulties of radio telemetry in steep and rugged mountainous terrain.

To identify unrealistic location fixes (e.g., signal bounce) the radio-tracking teams stayed in contact throughout the night via VHF radios. Location fixes were plotted and evaluated on the spot as recommended by Kenward (2001). Data from movement analysis were used to estimate if travelled distances between subsequent kiwi locations seemed plausible (White & Garrot 1990), with unrealistic fixes omitted. Poor individual location fixes could not be identified arithmetically, as 2 bearings allowed only the "error polygon

method" (Heezen & Tester 1967), which is not recommended as a basis to omit location fixes (Nams & Boutin 1991). By application of multiple regression techniques, the calculated linear error can be related to various explanatory variables (e.g., distance from receiver to transmitter, geometry of bearing intersections; Millspaugh & Marzluff 2001). However, since the largest error source for triangulation in our study was likely to be the steep terrain, we did not attempt to quantify how much of the error was attributed to the other variables.

To avoid autocorrelation of the location data (Kenward 2001), sampling intervals for location fixes were calculated using Ranges 6 v1.2214 (Anatrack Ltd). Results showed that 6 of 10 kiwi reached independence at 60 minutes and the remaining 4 birds at 30 minutes. Therefore, a sampling interval of 1 hour between individual fixes was deemed appropriate.

Home range analysis
There are many home range estimators which can be applied for an estimation of range size and shape. Moreover there is no consensus of which method performs best and all techniques seem to have some drawbacks (Kenward 2001; Kernohan *et al.* 2001). As the aim of this study was to gain a better understanding of home range size and shape, the concave polygon method was chosen (Stickel 1954). To enable comparison with other studies, home range sizes were also calculated with the minimum

Table 1. Radio tagged birds, giving their sex (M = male, F = female with index 1, 2 and 3 for bonded pairs) and the age classification (A = adult, SA = subadult). The home range sizes, using minimum convex and concave polygon methods, range span (for concave method), number of homing locations and total number of locations (triangulation and homing data) are given.

| Bird | Sex | Age | Home range area (ha) | | Range span (m) | n Locations |
			Concave 100%	Convex 100%		
Asterix	M1	A	26.85	27.63	932	109
Scabby	F1	A	32.67	36.74	1069	101
Taihau	F	SA	25.65	35.05	887	107
Rooster	M2	A	33.25	36.98	953	80
Stooge	F2	A	19.59	20.75	659	88
Bow	F	SA	35.41	36.81	1340	60
Carrhart	M	A	30.39	31.85	874	72
Percy	M3	A	31.03	31.98	861	102
Clarabelle	F3	A	32.27	39.50	992	105
Fiona	F	A	28.36	35.67	914	92

Table 2. Results of overlap analysis carried out for the 3 studied kiwi pairs and for 1 pair and their neighbouring female kiwi.

| | Bonded pairs | | | Neighbours | |
	Rooster/Stooge	Percy/Clarabelle	Asterix/Scabby	Fiona/Clarabelle	Fiona/Percy
Mean overlap (%)	59.25%	76.96%	88.00%	2.34%	2.95%

convex polygon method using all fixes obtained (Mohr 1947). For the concave polygon method, 100% of the location data gained were used and the edge restriction was set to 0.4 (proportion of the maximum range width). It is assumed that use of 100% of the location data causes inaccuracies as outlier values may be included (Kenward 2001). However, in this study, no notably isolated locations inside other kiwi territories were gained. To determine the point in time when a satisfactory amount of location data was sampled for an accurate estimation of home range for each bird, results of the incremental area analysis were examined. Overlap analysis was also carried out for each pair and 1 neighbouring kiwi. All home range and overlap calculations were estimated using Ranges version 6.

Movement
Mobility was estimated using Ranges to calculate straight distances between consecutive fixes gained within an hour of movement. These hourly estimates were also summed for an entire night. The results

were used as indicators of the total movement for that individual bird per night (Laundre et al. 1987). The values were calculated for each bird and give the minimum distances moved per night and per hour as a straight-line between consecutive radio locations. Movement data were also used mainly to evaluate triangulation results and to identify unrealistic location fixes (see above), as being flightless, kiwi are expected to have a strong physical limitation of speed and therefore moving distance in a certain time frame.

RESULTS
Home range area
Home range sizes calculated with the concave polygon method ranged from 19.6 ha to 35.4 ha. The computed mean size for all 10 birds was 29.5 ha (± 1.4 SEM). As 2 of the 10 birds were subadults and may not have fixed home ranges, the mean home range size was also calculated only for the 8 adult birds, resulting in a similar estimate of 29.3 ha (± 1.6 SEM).

Table 3. Results of population density estimation for great spotted kiwi in different areas, South I, New Zealand. In addition the methods used in the different studies are stated below (radio-telemetry = R, call counts = C).

Area	n birds	Population density		Method used	Reference
		pairs/km²	birds/km²		
Hurunui North Branch	10	2	5	R (C)	This study
Saxon area	22	4	-	R	McLennan & McCann (1991)
Kahurangi Point	9	3	-	R	McLennan & McCann (1991)
Paparoa Range	-	1.5	-	C	McLennan & McCann (2002)
Southern Northwest Nelson	-	1	-	C	McLennan & McCann (2002)
Arthur's Pass-Hurunui district	-	-	2-3	C	McLennan & McCann (2002)
Taramakau Valley/Hokitika	9	-	10	R	Eastwood (2002)

Table 1 shows that the calculated home range sizes for all birds were relatively similar, with the exception of Stooge who had a small home range compared to the other birds. In addition, nearly all birds, except for Bow, had more than 50% of their day shelters located at or close to their territory boundaries (i.e., ≤ 50 m). This tendency increased as more homing fixes were gained, suggesting that the birds tended to establish most of their day shelters at the boundaries of their territories or close to them.

Overlap of ranges
Overlap analysis indicated an overlap of < 3% for neighbouring adult kiwi territories. However, during this study there were only 3 radio-tagged neighbouring kiwi; 1 pair sharing territory borders with another adult female kiwi (Fig. 2). Her partner was caught only at the end of this study and therefore home range data of this bird were not included in overlap analysis. For the pairs, the level of range overlap varied considerably with the lowest overlap for Rooster and Stooge, and the highest for Asterix and Scabby (Table 2).

Movement
The distances travelled by kiwi varied from 7-433 m/hour (n = 569). Most values (73%) are clustered from 0-150 m/hour, while distances over 200 m/hour were rare (c. 7%; Fig. 3). The birds were capable of travelling a total distance of up to 1701 m/night; in comparison the lowest observed distance travelled in one night was 488 m.

Population estimation
The size of Area A was estimated to be around 18.39 km². As no kiwi were observed in the river bed or above the tree line (c. 1200 m) these areas were excluded from the population estimation, thus an effective habitat area size of 16.32 km² was

used. Area B (including area A) was estimated to be around 60 km². Again, excluding the riverbed and areas above the tree line (20.5 km² = 34% of area B) this leaves a total effective habitat area size of 39.5 km² (Fig. 1).

Mean home range size of the adult kiwi was calculated to be 29.3 ha (± 4.5 SEM). Accordingly, there was habitat for approximately 28 kiwi adjacent to the river bed, with 56 possible territories estimated for all of Area A. For the 28 theoretical territories adjacent to the river bed, 24 of these 28 theoretical territories were subsequently found to be occupied by at least 1 bird, collaborated either by kiwi call-count data or through the 18 additionally-caught birds in 2008. For the remaining 4 territories, occupancy could not be assessed due to a lack of data. Given that all 8 adult birds radio-tagged in 2007 had partners, we can assume that nearly all territories in Area A could be occupied by at least 2 birds, plus an unknown number of sub-adult birds and chicks. That would mean this area could be inhabited by c. 56 kiwi pairs.

Whilst we have not factored in sub-adult or juvenile birds, during 2007-2008, a minimum of 2-4 sub-adult birds (as it was difficult to reliably age kiwi) were captured from a total of 29 radio-tagged birds, which would give a sub-adult proportion of c. 7%. If the lowest number of sub-adult kiwi would be applied, a further 8 sub-adults could possibly live in Area A. Taking these sub-adults into account would give a population density of c. 7 birds/km² or c. 3 pairs/km² for all of Area A. Using the same estimation techniques there is room for 135 kiwi territories in Area B. In other words, up to 135 pairs and additionally at least 19 sub-adults could reside in Area B (western North Branch). Consequently the great spotted kiwi density for the total Area B (60 km²) is estimated to be c. 5 birds/km² (including sub-adults), or c. 2 pairs/km².

Table 4. Estimated home range sizes for great spotted kiwi for each research areas, South I, New Zealand.

Area	Home range size (ha)		Reference
	Minimum-Maximum	Mean	
Hurunui North Branch	20-35	29	This study
Saxon area	10-42	23	McLennan & McCann (1991)
Kahurangi Point	8-25	-	McLennan & McCann (1991)
Gouland Downs	12-26	-	Marchant & Higgins (1990)
Taramakau Valley/Hokitika	-	20	Eastwood (2002)

Fig. 2. Maps of 2 sections of the Research area A with estimated home ranges for the 10 radio tracked kiwi. Ranges estimated using the concave polygon method. Overlapping ranges are indicating the 3 pairs within this study.
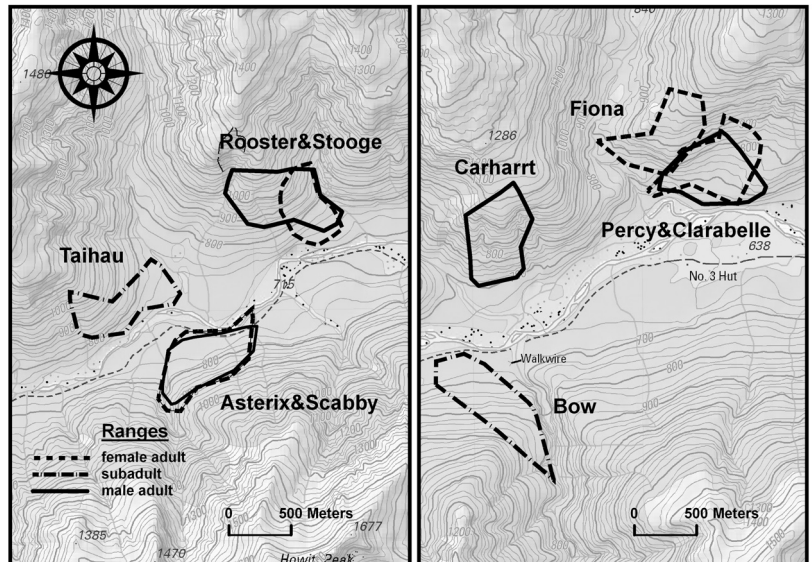
Finally, all 8 radio-tracked adult kiwi within this study seemed to have bred in the season 2007/2008 (Wylie & Yong 2008), with eggshells or chicks detected (generally only eggshells were seen). Two of these eggs were removed for captive rearing and 1 chick was captured and radio tagged, but found dead after a couple of days (Wylie & Yong 2008). Given that not much is known regarding chick survival, further information is required before we can include likely chick numbers in this population estimate.

DISCUSSION
Home range
Estimated summer home-range sizes for 10 great spotted kiwi in the North Branch varied between 19.6 ha and 35.4 ha, with a calculated mean of 29.3 ($\pm$ SE) ha for adult birds. Great spotted kiwi territories estimated at Saxon River (northern Northwest Nelson) ranged from *c.* 10-42 ha with a mean home range size of 23 ha (McLennan & McCann 1991). Furthermore, McLennan and McCann observed that territories in the Gouland Downs (Northwest Nelson) ranged between 12-26 ha and at Kahurangi Point (western Northwest Nelson) territory sizes ranged from 8-25 ha (as cited in Marchant & Higgins 1990). For the Taramakau Valley (Hokitika area), the mean territory size was estimated to be *c.* 20 ha (Eastwood 2002).

Compared to the findings of other studies, the mean home range size of great spotted kiwi in the North Branch seems to be rather large, and the variation relatively low (see Table 4). McLennan and McCann (1991) suggest that mean size and variation of home ranges may provide a sensitive indicator for population health. They suggested that both values would increase as habitat supply and demand become equalised. Still, reasons for mean territory size and variation found in the North Branch remain unknown. Therefore, it is difficult from the data we collected to conclude whether
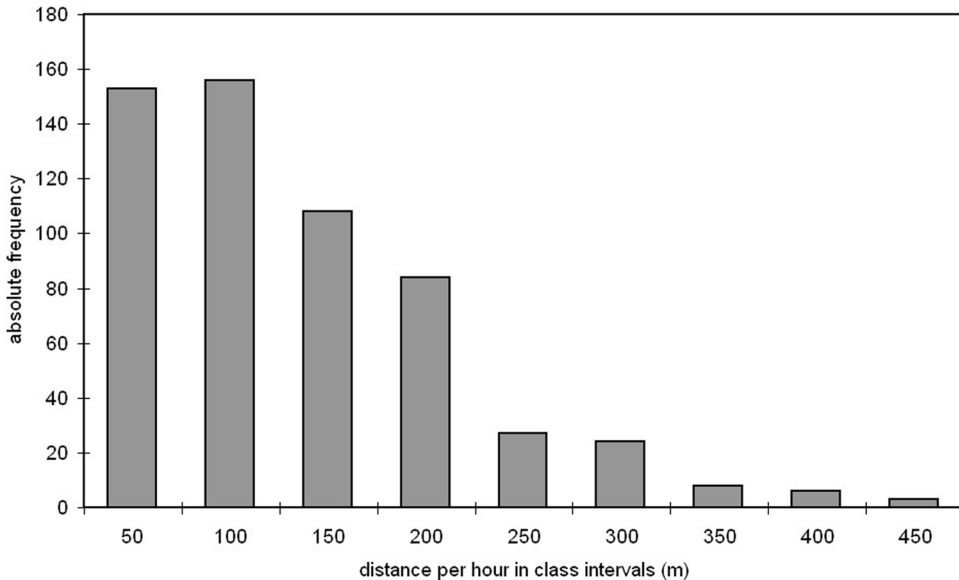
Fig. 3. Frequency of distances moved (*n* = 569) per hour (m) for all observed birds during research.

the population is healthy. Habitat studies that are supplemented by feeding surveys are needed for further interpretation.

The methods employed for estimating home-range sizes are often not explained in the literature and this makes it difficult to compare results between studies. For example, not all studies describe the home range estimators used, the settings selected, or which software was used. Furthermore, location error and the number of locations is often not reported. For this reason little can be said about the quality of the results of other studies or whether they are comparable with our findings. As the number of people currently working with kiwi is increasing, it is essential to establish a protocol of how to report results of home-range studies following the recommendations given by Laver and Kelly (2008). Additionally, most of the other studies do not report the season for which the home range was estimated. Home-range sizes can be subject to changes during the year or in between years (Kenward 2001).

The data given for the range overlap analysis for this study are limited, especially in case of neighbouring birds. Only one pair, Percy and Clarabelle, with their adjacent neighbour, Fiona, were radio tracked. Furthermore, the mean location error was 30.8 m for the triangulation data gained; hence the calculated overlap with these adjacent neighbours could be a result of the location error. Therefore, the results of the overlap analysis for neighbouring territories should be treated with caution and requires further investigation. The overlap analysis for bonded pairs shows

diverse results ranging from 59% to 88% overlap. The behaviour of Rooster and Stooge was quite inconsistent and it is possible that this couple separated as Rooster was found sharing his shelter with another adult female kiwi during the study. Accordingly, their range overlap of about 59% may not be characteristic for great spotted kiwi pairs and may more likely lie between 77% and 88%. It is also possible that the overlap value may increase with observation time or vary in other seasons.

Population estimation

The kiwi population in the Hurunui North Branch was estimated to be around 290 birds. The density for the whole area monitored by the Department of Conservation in the North Branch was estimated to be 2.25 pairs per km² plus subadults or 4.83 birds per km². These density estimates are much higher than results of earlier studies in the Arthurs Pass/Hurunui district. There is considerable variation in the estimates of great spotted kiwi population densities, ranging between 2 and 10 birds/km² (see Table 3). Perhaps the most comparable is the Taramakau study area, as it is located only 15 km west of the North Branch. The vegetation only differs slightly from the North Branch, consisting mainly of mixed beech and podocarp forest (Eastwood 2002). However, it is surprising that the estimated density of great spotted kiwi in the Taramakau research area was calculated to be 2 times higher than our estimated value for the western North Branch. An explanation might be that the Taramakau study was set up as a breeding study in an area assumed to already hold a high density

of great spotted kiwi (Eastwood 2002). Eastwood (2002) also noticed (on the basis of unpublished call-count data) that the adjacent valley floor sites up and downstream of the research area appeared to have much lower densities and he speculated that the densities fell off higher up the mountain slopes. Given this information, it is likely that an estimate of 10 birds/km² for the whole Taramakau valley is rather high.

McLennan and McCann (2002) estimated the overall density for the whole great spotted kiwi Arthur's Pass–Hurunui population to be *c.* 2-3 birds/km². This lower population density is based on the observation that a great extend of this mountainous region might be unsuitable for great spotted kiwi, since much of the land is above the tree line, steep and unstable (McLennan & McCann 2002). Indeed, the estimated tree line/ home range limit of *c.* 1200 m for great spotted kiwi in the North Branch strongly constricts the area of suitable habitat. In fact, the proportion of unfavourable habitat for kiwi might be much greater for the whole Arthur's Pass–Hurunui area than the 34% estimated for the North Branch. This could explain the slightly higher population density estimation for Area B (5 birds/km²); however, it is still not known in great detail what is favourable kiwi habitat below the tree line. Moreover, only a conservative number of sub-adults was applied when calculating population density and chicks were omitted due to lack of survival data. Therefore, the overall kiwi population size may still be underestimated.

In conclusion, although we have been able to estimate the current population size of great spotted kiwi we cannot predict whether the Hurunui North Branch population is stable or declining and we recommend repeating this study again in 5 years to learn more about possible territory shifts and to obtain an indication of population health. In addition, it would be worthwhile to extend this study to other valleys in the Southern Alps where great spotted kiwi occur, to explore where population densities differ and for what reasons. Our estimated population size is one important input variable needed to run a population model. With additional data about population dispersal and fragmentation, as well as survival rates of all kiwi age cohorts, population trends of the North Branch great spotted kiwi (sub-) population and for the whole Arthur's Pass-Hurunui (meta-) population could be modelled and a management action plan could be developed to ensure their long-term survival.

ACKNOWLEDGEMENTS

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