Satellite tracking of kereru (*Hemiphaga novaeseelandiae*) in Southland, New Zealand: impacts, movements and home range

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Published on-line: 21 March 2011

Abstract: Satellite transmitters (PTTs) were attached to four kereru (New Zealand pigeon, *Hemiphaga novaeseelandiae*) in Invercargill, Southland, New Zealand, during 2005–06. The transmitters were used to monitor the birds' locations, movements and home ranges. Attachment of the transmitters affected the behaviour and body condition of one of the kereru; no other negative effects, such as skin abrasion, were noticed. Fifty-four percent of locations recorded were of Argos location classes 1, 2 or 3 (accuracy of ≤1 km), and were used to determine the birds' movements and home range areas. Three of the kereru made flights across Foveaux Strait (a minimum distance of 33 km) to Stewart Island; the other remained around Invercargill. The maximum distance between their locations ranged from 11.4 to 101.9 km. Home ranges, as determined by cluster analysis, ranged from 619 ha to 31,732 ha, 100–1000 times greater than kereru home range areas estimated in previous studies. Given the long-distance movements kereru make, often to locations distant from roads and tracks, satellite telemetry is probably the most reliable and cost-effective method of determining their locations.

Keywords: cluster analysis; minimum convex polygon; New Zealand pigeon; transmitter; weight change

Introduction

The kererū (New Zealand pigeon, *Hemiphaga novaeseelandiae*) is a 'Not Threatened' large endemic pigeon (Miskelly et al. 2008). It occurs through much of North, South and Stewart islands, on some offshore islands (Robertson et al. 2007), and in a variety of habitats, including extensive tracts of podocarp–hardwood forest, *Nothofagus* forest, forest remnants, exotic plantations, farmland, and urban parks and gardens (Heather & Robertson 2005).

Until recently, kererū were thought to be the only remaining New Zealand bird capable of dispersing large-fruited tree species (McEwen 1978; Clout & Hay 1989). However, Kelly et al. (2010) have shown that most large-fruited species produce some smaller fruit that can be swallowed by mid-sized bird species that are still widely distributed, such as tūī (*Prosthemadera novaezelandiae*). However, the effective dispersal of seeds depends not only on birds' abilities to swallow large fruits, but also on the extent and frequency of their movements. Much of New Zealand's remaining native forest occurs in relatively small fragments. Long-distance seed dispersal may be particularly important in maintaining small, isolated populations of large-seeded trees within these remnants (Purves & Dushoff 2005; Wotton 2007). In addition, the majority of gene flow among plant populations appears to occur via seed dispersal (Hamilton 1999; García et al. 2007). Restricted dispersal among populations can lead to reduced genetic diversity and may increase the risk of extinction (Shapcott 2000). The effects of inbreeding appear to be particularly severe in trees and shrubs, with complete mortality of inbred offspring prior to maturity (Scofield & Schultz 2006). Thus movements of fruit-eating bird species, such as kererū, may have significant repercussions for the maintenance of fleshy-fruited tree populations in fragmented landscapes.

While individual kererū often spend several days or weeks making only small movements within a limited geographical range (<5 ha) (Clout & Hay 1989; Bell 1996), such periods can be followed by extensive movements of several kilometres (Clout et al. 1986, 1991; Pierce & Graham 1995; Hill 2003; Schotborgh 2005; Campbell 2006; Stevens 2006). Some kererū movements can involve flights of more than 10 km (Clout et al. 1986, 1991; Harper 2003; Hill 2003) between discrete areas of their home ranges (Clout et al. 1986; Hill 2003; Stevens 2006).

Researchers have previously relied on the use of VHF transmitters attached to kererū to locate individuals at regular intervals (Clout et al. 1986, 1995; Powlesland & Willans 1997; Powlesland et al. 2003; Innes et al. 2004). Locating widely dispersed radio-tagged kererū with such transmitters is expensive and time-consuming; moreover, tracking them from a motor vehicle, light plane or helicopter is not always successful. Thus, development of satellite telemetry and smaller transmitters (≤20 g) has enabled this technology to be used on kererū (Kenward 2001; Soutullo et al. 2006). Here we report on a pilot study into the suitability of satellite telemetry to monitor the movements and home ranges of four kererū in Southland. This study was part of a 4-year study into various aspects of the ecology of kererū and tūī, particularly their foods, movements, mortality and nesting success, in urban and rural landscapes about Invercargill and New Plymouth (Powlesland et al. 2007, 2008).

Methods

Kererū capture, handling, transmitter attachment, and sexing

Three kererū were captured in mist-nets erected using aluminium poles (Dilks et al. 1995), with two of these kererū being recaptured the same way. A fourth bird was tagged with a satellite transmitter while in captivity recuperating from injury sustained after flying into a window. We used satellite transmitters (platform transmitter terminals; PTT-100, Microwave Telemetry Inc., Columbia, MD, USA) that weighed 20 g, were battery-powered, and had a transmission life of 400 h – just 17 days (more details at http://microwavetelemetry.com). To extend the potential field life of the transmitters, the following duty cycles were used: 6 h on, 48 h off (148 days of field life); 5 h on, 72 h off (257 days), and 4 h on, 84 h off (367 days) (Table 1). The *on* or *transmission period* of the duty cycle is when the transmitter is signalling to satellites. The satellite transmitters were attached to the birds using a back-mounted harness (c. 3.5 g) developed by Karl and Clout (1987). Satellite transmitter signals were picked up by Argos® satellites that use the Doppler Effect to determine the transmitter's location (Nicholls & Robertson 2007). The location information is relayed to a central computer in France, which the researcher can download via the Internet. Thus signals from satellite transmitters could not be tracked to their source by a person on foot with a receiver and antenna.

Because kererū sometimes suffer post-handling shock (become grounded and unable to fly) following transmitter attachment (Clout et al. 1995; Powlesland et al. 2003), two additional procedures were carried out. The first was the attachment on three of the four birds of a 3.8-g VHF two-stage transmitter (Sirtrack, Havelock North, NZ) to the top of the satellite transmitter with a piece of adhesive tape so that the kererū could be located daily for the first week after release. One of the VHF transmitters remained attached for 10 weeks; the fate of the other transmitters is unknown. The weight of the complete package (satellite transmitter, VHF transmitter and harness) was c. 27.3 g. Thus the package represents c. 4% of a Southland kererū's bodyweight (mean = 686 g, SD = 51.9, range = 585–790, n = 33). The second procedure involved administering 20 ml of Hartmann's solution or 20 ml of a glucose solution (1 teaspoon of glucose dissolved in distilled water) directly into the bird's crop. This was done in an effort to provide an easily assimilated energy supplement and liquid to assist a shocked bird through the first few hours after its release. Following release, each kererū with a VHF transmitter was located and checked twice daily for the first two days, and then once daily for another five.

At the initial capture of each kererū, a few dislodged feathers were collected from the weighing bag. These were submitted to the Equine Blood Typing & Research Centre, Massey University, Palmerston North, for gender determination by DNA (Griffiths et al. 1998).

Locations from Argos

The number of days that satellite transmitters were active (i.e. provided location data) ranged from 42 to 305 (mean = 155) (Table 1). The number of locations per transmitter ranged from 99 to 339 (mean = 221), as a result of both duty cycle and actual transmitter field life. Locations provided by the Argos system were divided into different classes (labelled Z, B, A, 0, 1, 2, 3 in ascending order of accuracy). Only location classes 1, 2 and 3 were used in analyses because they provide reasonably accurate estimates of locations, 1 km, 350 m and 150 m respectively. These high-quality locations (LC 1–3) represented 54.6% of our total data set. During transmitter transmission periods a mean of 2.2 high-quality locations were obtained (Table 2), which is a similar rate to that found in two other studies (Hake et al. 2001; Jourdain et al. 2008).

Estimation of movement distance and home range area

Movement distance was estimated using the statistical programme R (version 2.8.0; R Development Core Team 2008) using package 'adehabitat' (version 1.8.0; Calenge 2006).

Table 1. Details for each adult kererū that was fitted with a PTT (platform terminal transmitter) transmitter in Southland, New Zealand: sex, period when PTT was active, duty cycle, kererū percentage weight change between capture and recapture, and location information.

Band no.	Sex	PTT active period (days active)	PTT duty cycle	Weight change (%)	Locations (n)	LC 3, 2 or 1 locations (%)	LC 3, 2 or 1 locations per transmission period[1] (n)
K-14403	Male	26 January 2005 to 05 May 2005 (100)	5 h on, 72 h off	+4.7	108	50.0	54/34 = 1.6
K-14403 (recapture)	Male	28 November 2005 to 08 January 2006 (42)	6 h on, 48 h off	+1.3	99	53.5	53/17 = 3.1
S-80578	Female	02 December 2005 to 18 April 2006 (138)	6 h on, 48 h off	-13.5	339	66.4	225/53 = 4.2
K-12304	Female	21 December 2005 to 28 June 2006 (190)	6 h on, 48 h off	-	263	39.9	105/88 = 1.2
S-80580	Female	13 January 2006 to 13 November 2006 (305)	4 h on, 84 h off	-	298	56.4	166/80 = 2.1

[1]Transmission or 'on' period of the duty cycle is when the transmitter is signalling to satellites.

Table 2. Distance moved (km) and home range (ha) estimations using cluster analysis and 95% minimum convex polygons for four satellite-tagged kererū in Southland, New Zealand.

Bird ID	K-14403 (1)	K-14403 (2)	S-80578	K-12304	S-80580
Mean distance between locations	10.0 (± 22.8)	5.1 (± 10.3)	1.0 (± 1.8)	2.1 (± 5.5)	1.3 (± 1.2)
Maximum distance between locations	101.9	63.7	31.9	68.7	11.4
Home range by 95% MCP	94453	49040	12461	86641	2263
Home range by cluster analysis	31732	5439	619	1608	1605

In addition, the same package was used to estimate home range area using both cluster analysis (Kenward 2001) and minimum convex polygons (MCP). A 95% threshold was used to exclude outliers from home range calculations for both methods. Previous studies have identified that kererū home ranges often include two or more discrete areas separated by several kilometres (Clout et al. 1986; Hill 2003; Stevens 2006). Cluster analysis of nearest-neighbour distances between locations enables multiple high-usage areas to be distinguished within home ranges (Kenward 2001) and therefore is the most appropriate method for estimating kererū home ranges. We included MCP results to allow comparison with results from earlier studies of kererū home range, and to illustrate how this method can provide a misleading home range estimate when kererū core areas are separated by extensive unused areas.

Results

Impacts of transmitters on weight and feathering

Satellite transmitters, their harnesses and the attached VHF transmitters represented 3.0 – 4.7% of the four birds' capture weights. The two birds (K-14403, K-12304) that had been carrying VHF transmitters before being deployed with satellite transmitters showed no ill effects of the capture and handling procedures. Similarly, S-80580, the bird that had recuperated from window strike, flew off strongly when released and appeared to behave normally during the following week. In contrast, S-80578 was found on the ground in a weakened state on the fourth day after transmitter attachment. She was taken into captivity, the transmitter was detached then reattached 2 weeks later, and she was then re-released a further two weeks later. This bird behaved normally thereafter.

Two of the kererū were recaptured after about a year of carrying a satellite transmitter. The weight of K-14403 had increased by 4.7% over the 10-month period he carried his first transmitter, and by a further 1.3% during the 12-month period that he carried the second transmitter (Table 1). In contrast, S-80578 had lost 13.5% of her bodyweight when the transmitter was removed, but had gained 8.7% following her release from captivity.

On none of the three occasions that the above two birds were recaptured did they show any evidence of skin abrasion or callusing as a result of carrying satellite transmitters. The feathers under and adjacent to where the transmitters were positioned on the birds' backs were ruffled, but no skin was exposed.

Movements

The satellite-tagged kererū spent variable time resident in a relatively small area, interspersed with movements to new locations, occasionally of many kilometres. For example for the first 47 days after being radio-tagged, K-12304 remained within 2 km of the capture site near Invercargill. Subsequently she was located near Bluff, and then 2 days later, having crossed Foveaux Strait, was located in northern Stewart Island where she remained for more than 4 months (Fig. 1). Similarly, within 4 days of being radio-tagged, K-14403 flew from Invercargill to Greenpoint near Bluff, and then 3 days later, when further data were received, the bird was near Port William, Stewart Island (Fig. 2). K-14403 remained in the Port William area and then near Horseshoe Bay, Stewart Island, for 6 weeks. However, during the next 7.5 weeks he made at least four crossings of Foveaux Strait, and flew more than 480 km during a 100-day period. In contrast, S-80580 remained within c. 5 km of her release site throughout the 305-day period her transmitter provided location data (Fig. 1). Overall, the mean distance between locations of the four kererū varied from 1.0 to 10.0 km, and the maximum distance 11.4 to 101.9 km (Table 2).

Home range

Home range was estimated using two methods (Table 2). Cluster analysis gave home ranges varying from 619 ha to 31

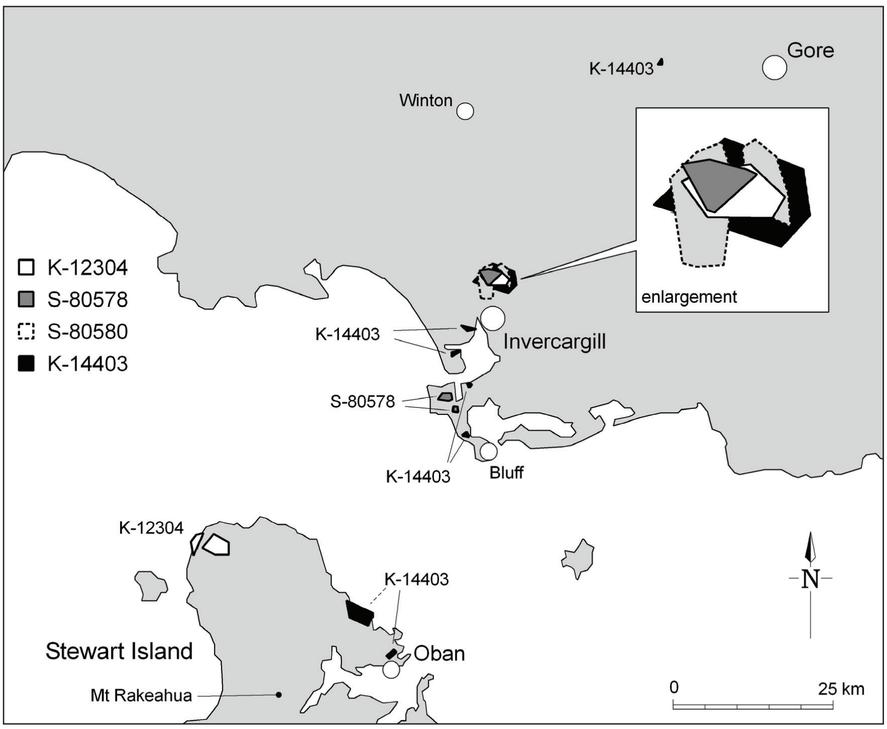

Figure 1. Home ranges of four satellite-tagged kererū in Southland and Stewart Island, New Zealand, as determined by cluster analysis for locations obtained during 2005–06.

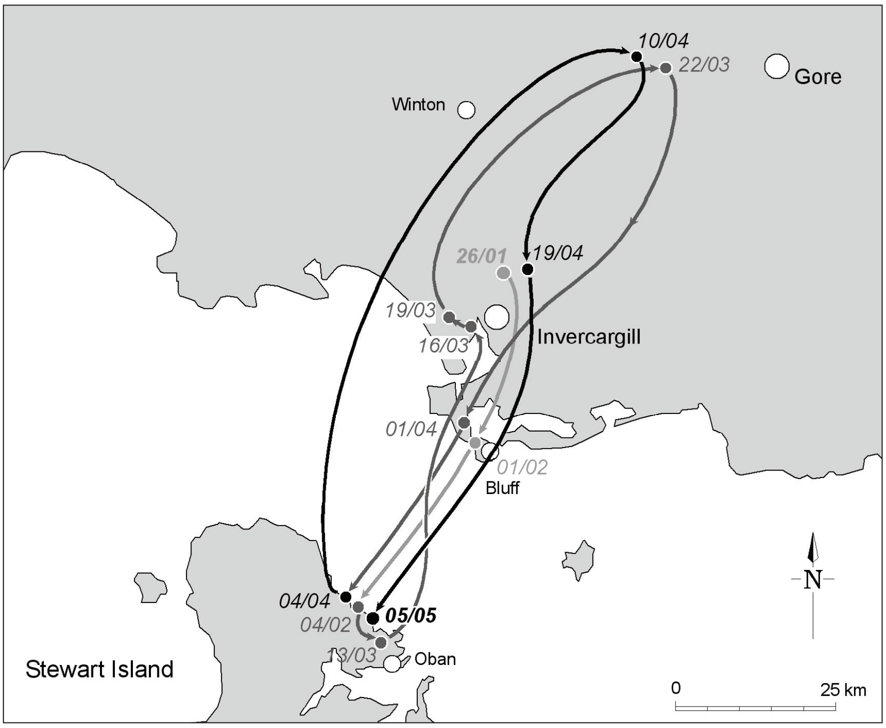

Figure 2. Movements of K-14403, an adult male kererū, from 26 January to 5 May 2005 in Southland and Stewart Island, New Zealand.

732 ha for the four birds (Fig. 1), while the minimum convex polygon method gave areas from 2263 ha to 94 453 ha (Fig. 3). While the two methodologies gave similar-sized home ranges for female S-80580, they gave quite different results for the other three kererū, with the MCP method giving home ranges 3–54 times greater than cluster analysis (Table 2).

Each of the satellite-tagged kererū centred its movements within more than one area during the study. K-14403 spent most time in three areas, but also stayed briefly (<4 days duration) at five other areas. The two females that flew to Stewart Island occupied three areas, while S-80580, which remained about Invercargill, occupied two.

Discussion

Impacts of capture and transmitter attachment

Of the four kererū used in this study, the one that had never been handled before responded negatively to handling and transmitter attachment. Even though most kererū coped well with handling and weight of transmitters and harness, appearing to behave normally and three making long-distance movements across Foveaux Strait, we think it advisable to reduce package weight in accord with the recommendation that back-mounted transmitters attached to flighted birds should be ≤3% of bodyweight (Kenward 2001; Redfern & Clark 2001). Now that 9.5-g and 12-g solar-powered satellite transmitters are available, such transmitters plus harness and VHF transmitters would constitute c. 2% of a Southland kererū's bodyweight and may be a better option for monitoring kererū movements. We recommend that if satellite transmitters are attached to kererū small VHF transmitters continue to be attached as well so the tagged kererū can be readily located and their well-being checked daily for about a week after release.

Movements

Kererū occasionally make long-distance movements (>1.5 km) in between weeks or months of fairly sedentary behaviour (Clout et al. 1986, 1991; Hill 2003; Schotborgh 2005; Campbell 2006; Stevens 2006). These long-distance movements may involve sea crossings, for example between Cape Rodney and Little Barrier Island (21.5 km) (L. Whitwell & S. McInnes, Department of Conservation, pers. comm.) and between Southland and Stewart Island (c. 33 km) (Harper 2003). Thus, the general behaviour of the four satellite-tagged kererū and the extent of their movements were not unusual. However, the frequency of the long-distance movements, including repeated traverses of Foveaux Strait, undertaken by K-14403 was unexpected. It is possible that he was unpaired and that his movements involved attempts to find a mate as he was never regularly seen roosting closely with another kererū while in Invercargill. Bell (1996) found that unpaired immature kererū had significantly larger home ranges than adults and made more long-distance movements.

The three satellite-tagged kererū that moved from Invercargill to Stewart Island did so during December–March. The timing of these movements related well to the start of the main nesting season of kererū in Southland. While a few eggs were laid during August–November of the three breeding seasons covered by the study (2003/04, 2004/05, 2005/06), the majority were laid during December–March (RGP & LRM unpubl. data). Even though none of the satellite-tagged kererū could be located and observed when on Stewart Island, the timing of their departures suggests that they were going there to breed. Similarly, some kererū at Whirinaki Forest Park (Hill 2003) and Pelorus Bridge Scenic Reserve (Clout et al. 1991) made long-distance movements during late spring – early summer between wintering and breeding sites.

Home range area

Our results show that cluster analysis is more appropriate

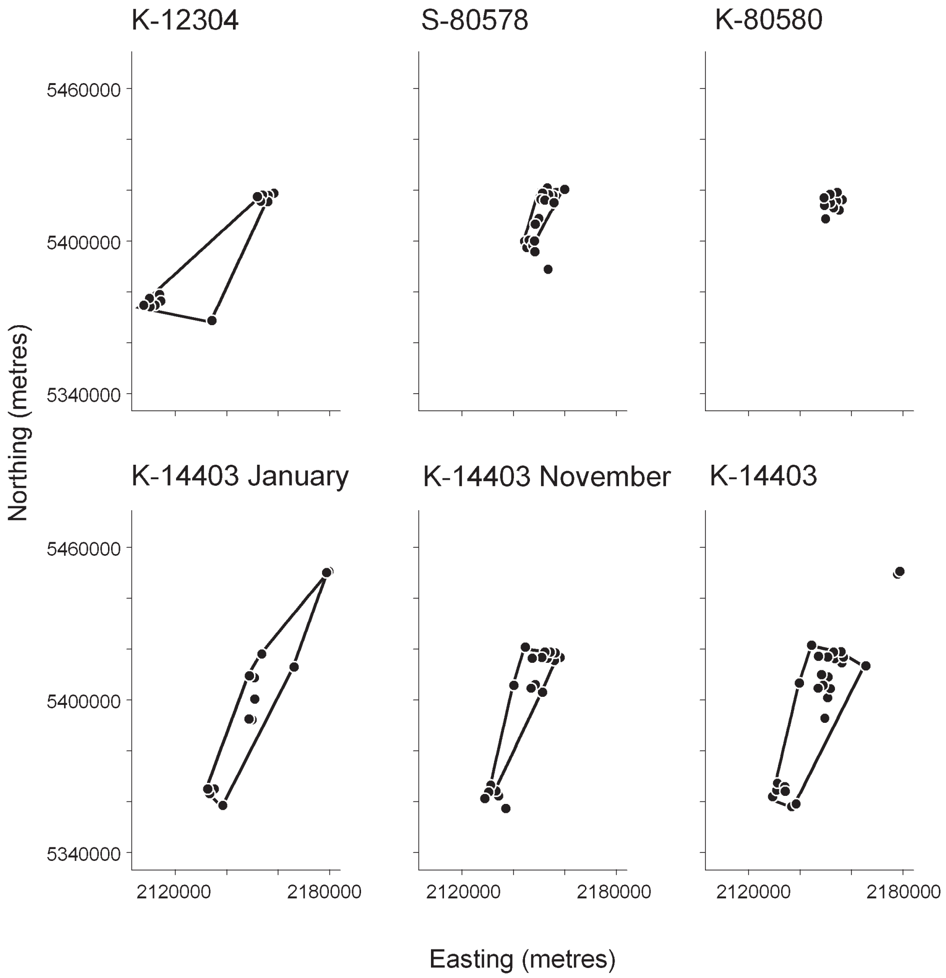

Figure 3. Home ranges of four satellite-tagged kererū in Southland and Stewart Island, New Zealand, as determined by the 95% Minimum Convex Polygon method (outliers removed) for locations obtained during 2005–06.

for estimating kererū home range size than the minimum convex polygon approach, especially when discrete areas of an individual's home range are separated by large areas of unused habitat. This is illustrated by the three kererū that had home range core areas in both mainland Southland and Stewart Island. Minimum convex polygon analysis included Foveaux Strait, obviously unusable habitat, within the home range areas of these kererū.

Home range areas were far larger for the four kererū monitored during our study than those previously recorded (Table 3). Even the cluster analysis results were still 100–1000 times greater than those obtained from other studies. Possible reasons for this difference includes habitat quality and that all four of the kererū in our study had home ranges that included two or more disparate areas. Compared with regions further north and especially compared with the North Island, Southland kererū habitat is of lesser quality, has fewer native plant species producing fruit >10 mm in diameter, and fleshy-fruited plants comprise a lesser proportion of the woody basal area (Kelly et al. 2010). For example, at Maungatapere, near Whangarei (Pierce & Graham 1995), at Wenderholm, near Auckland (Bell 1996), and at Hinewai Reserve on Banks Peninsula (Campbell 2006), suitable food sources appeared to be available year round within relatively small areas. Consequently, kererū did not move more than a few kilometres.

The ability of satellite transmitters to collect kererū location data at widely separated sites may also have contributed to the larger estimates of home range size in this study compared with previous studies using radio transmitters. Several authors have reported the 'disappearance' of tagged kererū during radio-tracking studies (Pierce & Graham 1995; Bell 1996; Schotborgh 2005; Campbell 2006). Thus home range estimates for some kererū carrying VHF transmitters are likely to be underestimates of home range size.

Conclusions

In most studies that have involved radio-tagging kererū the occasional bird has suffered from post-capture trauma, with some kererū becoming grounded within a few days of having a transmitter attached. With appropriate care in captivity they generally recuperate within a week. Retagging a bird while it is still in captivity enables it to be monitored closely before being released. However, given the possible deleterious reaction to manipulations, it is essential that each radio-tagged kererū is checked daily for a week after release or until such time that it is feeding and flying readily.

Given the long-distance movements made by kererū during several radio-tracking studies (Clout et al. 1986, 1991; Harper 2003; Hill 2003; Stevens 2006), and the disappearance of some tagged kererū in others (Pierce & Graham 1995; Bell 1996; Schotborgh 2005; Campbell 2006), satellite telemetry is presently the most reliable method for determining the locations of individuals. Although light fixed-wing aircraft have been used to locate VHF radio-tagged animals (Seddon & Maloney 2004), for those that can move tens of kilometres in a day, such as kererū, satellite telemetry is probably the

Table 3. Comparison of home range estimates for kererū during six studies as determined by minimum convex polygon and cluster analysis methods.

Source	Location	Period of study	Habitat type	Mean home range (ha), range and *n*	
				Minimum convex polygon	Cluster analysis
Pierce & Graham 1995	Maungatapere, Northland	May 1992 – August 1993	Farmland, exotic plantations, and podocarp–hardwood forest remnants.	242, 80–402, 6	
Bell 1996	Wenderholm, Auckland	October 1994 – September 1995	Coastal broadleaved forest remnants	45, 8–110, 6	3[1], 1–9, 5
Hill 2003	Whirinaki Forest Park, central North Island	November 1998 – May 2001	Podocarp–hardwood forest.	163, 14–704, 18	7, 1–27, 18
Scotborgh 2005	Lyttelton Harbour, Banks Peninsula	February 2004 – March 2005	Urban–rural habitats, mixed hardwood forest patches.	1355, 26–10638, 14	8, 2–22, 14
Campbell 2006	Hinewai Reserve, Banks Peninsula	February 2005 – February 2006	Beech forest, second–growth.	144, 20–499, 12	16, 2–40, 12
This study	Southland and Stewart Island	January 2005 – November 2006	Urban–rural habitats, podocarp–hardwood forest.	48972, 2263–94453, 5	8200, 619–31732, 5

[1]Determined by peeled polygon.

only cost-effective method of obtaining daily locations to fully detail movements, home range and habitat use.

One drawback observed during our study was the limited transmission life of the satellite transmitters. Even with a duty cycle incorporating much time off (4 h on, 84 h off), transmission life was only one year. Given that kererū occasionally travel several kilometres in a day, and that timing of movements and locations of individuals can differ between years as a result of food availability (Clout et al. 1991), transmission life needs to be at least 2 years. Solar-powered transmitters have the potential to provide the increased transmission life needed and should be trialled on kererū.

Native forest in New Zealand has become fragmented because much has been converted to pasture and exotic plantations, especially in the lowlands. The ability of kererū to make long-distance flights (McEwen 1978; Clout et al. 1991; Pierce & Graham 1995; Karan 2000; Schotborgh 2005; Campbell 2006; Powlesland et al. 2008) has enabled them to cope with the fragmented landscape as they are able to reach seasonal food sources at widely separated sites (Heather & Robertson 2005; Powlesland et al. 2008). Kererū may not be essential for seed dispersal of most large-fruited (fruit >14 mm in diameter) tree species (Kelly et al. 2010). However, as a long-distance disperser of such fruit, they are probably important for maintaining the diversity of medium- to large-fruited tree species in fragmented native forest ecosystems. Kererū home range data collected during this study help demonstrate the potential for this mechanism.

Acknowledgements

We thank Gloria Harris, John Henderson and Kirsty Moran for assistance with capture and tagging of kererū; Mary and Mark Hosie, Des and Brenda Quayle, and Gary and Suzette Morgan for access to their properties to capture and monitor kererū; May and Russell Evans for the rehabilitation of S-80578; Clément Calenge for assistance with using the Adehabitat package; Peter Hiemstra and Chris Edkins for preparation of the figures; Lynette Clelland, Department of Conservation, for editing of the manuscript; and Kirsten Campbell, Mick Clout, John Innes, Isabel Castro and two anonymous referees for comments that improved the manuscript. This project was funded by the Department of Conservation (investigation 3579), and was carried out with Department of Conservation Animal Ethics Committee approval (AEC 117).

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Editorial Board member: Isabel Castro
Received 19 April 2010; accepted 22 October 2010

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