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Post-translocation dispersal and home range establishment of roroa (great spotted kiwi, *Apteryx haastii*): need for long-term monitoring and a flexible management strategy

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Abstract: Between 2010 and 2016, the community group Friends of Flora Inc., in partnership with the Department of Conservation, translocated 44 roroa (*Apteryx haastii*) to the Flora Stream area in Kahurangi National Park, New Zealand. Each kiwi was fitted with a VHF transmitter and their subsequent locations were monitored for two to eight years by radio-telemetry. Monitoring showed that short to medium term translocation goals relating to survival and home range establishment were met. Dispersal occurred for 9 to 878 days prior to home ranges being established. This post-translocation monitoring was used to inform management decisions to extend predator control from 5,000 to 9,000 ha and to retrieve four of the kiwi that dispersed outside the project area. At the end of the study, 68% of the translocated kiwi were known to have home ranges within the trapped area. The study illustrates the benefit of long-term post-translocation monitoring and a flexible approach to deal with unforeseen dispersal.

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Key Words: roroa, great spotted kiwi, *Apteryx haastii*, translocation, dispersal, home range, community group

INTRODUCTION

Kiwi are endemic to New Zealand. Roroa (great spotted kiwi, *Apteryx haastii*) are classified as Vulnerable by the IUCN (BirdLife International 2020) and nationally Vulnerable by the Department of Conservation (DOC) (Robertson *et al.* 2017). Kiwi of all ages are vulnerable to predation by non-native ferrets (*Mustela putorius furo*) and dogs (*Canis familiaris*) (Robertson *et al.* 2011) and young kiwi and kiwi eggs are vulnerable to predation by other mustelids (McLennan *et al.* 1996). Translocations have been used as a conservation tool for kiwi to supplement long-term predator management. They can be used for range re-establishment, genetic management, and advocacy (Germano *et al.* 2018).

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Effective post-release monitoring is necessary to determine both short- and long-term success of translocations and reasons for failure (Parker *et al.* 2013; IUCN/SSC 2013). Roroa pose particular challenges for intensive monitoring; they are nocturnal, sensitive to disturbance, and live at low density in mainly remote, mountainous terrain (McLennan & McCann 2002; Heather & Robertson 2015). Miskelly & Powlesland (2013) reported 62 kiwi conservation translocations, excluding reinforcements. Only four of these were of roroa: to Te Hauturu-o-Toi in 1915; Rotoiti, Nelson Lakes National Park in 2004 and again in 2006; and the Flora Stream area, Kahurangi National Park. In addition, there were roroa translocations to the Nina Valley, Lewis Pass between 2011 and 2015 (S. Yong *pers. comm.*).

There are anecdotal reports of kiwi from the project area dating back to the 1970s and 1980s. Sub-fossil remains of large kiwi have been found in cave systems at Hodge Creek in the Flora area (Worthy 1997), but the bones of roroa and 'brown' kiwi, which were also present historically, overlap in size (Worthy & Holdaway 2002). Roroa were still present on Mt Arthur in 1994 (Worthy & Holdaway 1994), although McLennan & McCann (2002) suggest reports may have related to a single female translocated from Karamea. Roroa are found in the adjacent Cobb Valley albeit with low call rates (Toy *et al. in prep*.). However, in a 2011 survey of the area between the Flora and the Cobb, no kiwi were detected in 1,579 hours of acoustic recording (Friends of Flora, *unpubl. data*). It was assumed that predation by dogs and non-native stoats (*Mustela erminea*) caused the loss of roroa from the project area and that habitat conditions are otherwise suitable for roroa.

Roroa were translocated in accordance with the long-term goal of the Kiwi Recovery Plan 'to restore and, wherever possible, enhance the current abundance, distribution and genetic diversity of all kiwi taxa' (Holzapfel *et al.* 2008). The project area was chosen because it has more intensive predator control than much of the roroa range, it was recently occupied by roroa, and it has comparatively easy access, enabling monitoring and public engagement. Between 2010 and 2016, four wild-to-wild translocations of adult and sub-adult kiwi were performed. Forty-four kiwi were translocated, meeting the recommendation of more than 40 founders when establishing a new kiwi population (Sporle 2013; DOC translocation proposal 2016). The project is a partnership between DOC and Friends of Flora and aims to achieve a sustainable population of roroa. Each translocation and its follow-up monitoring were approved by the Kiwi Recovery Group and DOC and were undertaken in accordance with best practice at that time (Robertson & Colbourne 2003). Post-translocation fieldwork was performed by Friends of Flora volunteers working with two part-time, contracted ecologists accredited to handle kiwi. Operational targets included successful transfer and establishment, defined as more than 50% of the transferred kiwi establishing home ranges within the project area within 12 months of release. Longer-term conservation goals included: a self-sustaining population be established with roroa successfully breeding and young birds forming new pairs within the protected area within 10 years; roroa are common within the Flora Stream area, and juvenile kiwi moving into adjacent areas within 50 years (DOC translocation proposals 2010, 2013, 2016).

Here, we summarise eight years of post-translocation monitoring of dispersal, home-range establishment, and pairing. Breeding success, the long-term measure of a sustainable population will be discussed separately (Toy & Toy *in prep*.).

METHODS

The Flora Stream lies to the north of Tu Ao Wharepapa (Mt Arthur) in the Upper Takaka River catchment, (41°10′S, 172°41′E; Fig. 1). The project area covers approximately 10,000 ha ranging from 700 to 1,500 m altitude. Rainfall for the Mt Arthur Ecological District is between 1,500 and 4,000 mm/annum, wetter towards the west (McEwan 1987). Silver beech (*Lophozonia menziesii*) is the predominant canopy species with red beech (*Fuscospora fusca*) at lower altitudes and mountain beech (*Fuscospora cliffortioides*) at higher altitudes. Above the tree line there are areas of *Olearia*, *Dracophyllum* and *Hebe* spp. shrubland and extensive *Chionochloa* spp. grasslands (Toy 2016). The geology is predominantly sedimentary with areas of tertiary limestone and igneous rock, with marble mainly in the south (Rattenbury *et al.* 1998).

The area was gazetted as part of Kahurangi National Park in 1996. It is managed by the community group Friends of Flora Inc. and DOC with the aim of restoring and enhancing the biodiversity values of the area. Stoat trapping was started in 2001 and the network of traps has been expanded to cover about 9,000 ha by 2020 (Fig. 1). Traplines are spaced approximately 1 km apart with double set DOC150 traps at 100 m intervals along the lines. Traps are serviced approximately monthly. The area adjoins the Cobb Valley in which the community group Friends of Cobb have trapped stoats since 2006. The project area is on the edge of a much larger block that has received four aerial applications of sodium fluoroacetate (1080) for control of rats (*Rattus* spp.) or brushtail possums (*Trichosurus vulpecula*). Secondary poisoning of mustelids occurs from such applications (Parliamentary Commissioner for the Environment 2011). The threat from dogs has declined since a permit is required to bring a dog into a National Park.

In the Flora, roroa daytime roosts are most commonly underground 'burrows' which are naturally occurring cavities, or occasionally above ground 'shelters' in hollow logs or under ferns or overhangs. For the purpose of this paper, 'burrow' is used to refer to both underground burrows and above ground shelters.

Translocation

Forty one adult and three sub-adult kiwi were translocated into the Flora from four separate source sites in NW Nelson: Clark River (40°56′S, 172°32′E); New Creek (41°48′S, 171°55′E); Upper Roaring Lion

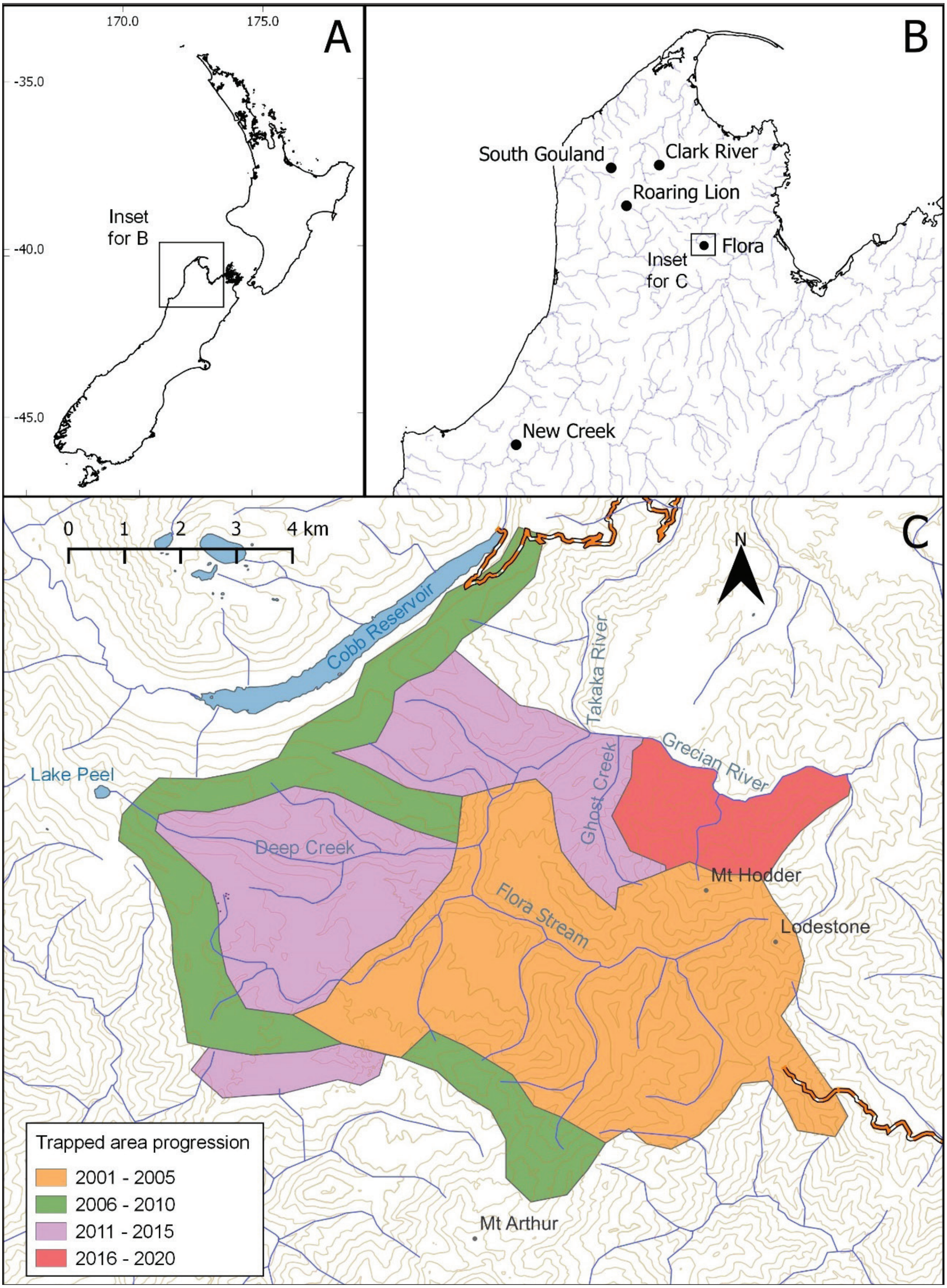

Figure 1. Location of the Flora Stream project area in relation to the translocation source sites, and the expansion of stoat trapping in the Flora between 2001 and 2020.

River (41°03′S, 172°26′E); South Gouland (40°56′S, 172°20′E) (Table 1; Fig. 1). Multiple translocations were performed for logistical reasons, to reduce the impact on source site kiwi populations, and to maximise genetic diversity of the new population. We attempted to translocate established pairs of roroa. Each translocated kiwi was named by local iwi and fitted with a unique alpha-numeric metal band and a leg-mounted GSK diagnostic v2.0 VHF transmitter (Wildtech and Sirtrack). In each translocation all kiwi were released in the same general area. In the first two translocations, known partners were released into burrows within a few metres of each other. On four occasions in subsequent translocations, partners of known pairs were released in the same burrow.

Four kiwi that dispersed outside the trapped area were retrieved and released a second time within the area.

Table 1. Source site, translocation date and number of roroa translocated to the Flora.

Source site	Date	Number of adults (sub-adults)		
		Paired	**Single males**	**Single females**
Clark River	May 2010	10	1 (1)	0
New Creek	March 2013	8	1	3
Roaring Lion	May 2013	4	3	1
South Gouland	April 2016	8	1 (1)	1 (1)

Post-release monitoring

We aimed to locate all translocated kiwi the day after release, then twice a week for two months and thereafter at about fortnightly intervals. Monitoring continued until May 2018 when achievement of operational targets relating to dispersal, pair formation, and location of home ranges within the project area had been demonstrated. Transmitters were then removed. Monitoring finished earlier for kiwi that died, disappeared or whose transmitter failed or fell off (monitoring truncated). Dispersal monitoring was truncated for the four kiwi that were retrieved.

TR4 receivers (Telonics™) and 3-element folding Yagi aerials (Sirtrack Ltd) were used to locate kiwi. Teams of volunteers trained in radio-telemetry took bearings (Silva mod 15 mirror compass) of the strongest signal direction from multiple locations whose co-ordinates were recorded. Usually, bearings were taken from three or more locations; hill tops and ridge lines were preferred to maximise coverage. As the project area covers 10,000 ha of deep valleys, individual bearings were frequently taken more than 2 km from the kiwi. The location of each kiwi was estimated by manual triangulation of bearings plotted using MapToaster Topo NZ™. This enabled signal strength, topography and locations from which a signal could not be detected, to be taken into account. Each triangulation was subjectively attributed an indication of accuracy taking account of the number of bearings taken, the strength of the VHF signal, the degree to which the bearings converged and the topography. Short-range and ridge-top bearings were considered better quality than long-distance bearings and those taken in gullies where signals may 'bounce'.

Aerial surveillance was undertaken when a kiwi could not be located by monitoring teams on the ground.

Telemetry accuracy was tested by comparison of triangulated positions with exact locations determined by tracking-to-burrow (n = 87). To minimise disturbance to the kiwi, we limited tracking-to-burrow to an annual transmitter change and installation of cameras outside nest burrows. The accuracy test covered the range of topography encountered in the project area as well as a range of volunteers undertaking telemetry. The mean difference between triangulated locations and known kiwi burrows was 186 m (n = 87, 95% *CL* ± 31 m).

Monitoring of night movements

Most telemetry estimated the position of daytime roosts. At night, kiwi may move to areas in which they do not roost. We monitored kiwi night movements on 13 occasions spread over five years, with teams taking bearings of any kiwi within range every 20 minutes throughout the night. Bearings were taken from two to four fixed locations; observers did not move location during the night. Bearings taken at night are approximate as the signal volume fluctuates as the kiwi moves. The accuracy of night-time triangulations could not be quantified.

Analysis

A dispersal range was calculated for each kiwi for the period from release until it settled into a home range or until monitoring ended if earlier. A kiwi was identified as settling in a home range if it paired and remained in an area for more than six months or, for a single kiwi, if it remained in an area for more than a year. Single kiwi were identified *post-hoc* as taking longer to settle than kiwi in pairs, hence the difference in definition. Dispersal ranges were calculated as minimum convex polygons (MCP) using Ranges 9 v2.02 (www.anatrack.com).

MCP were used rather than kernel density estimates to enable comparison with previous studies and to avoid emphasis on nest sites. Tracking resolution was set to 186 m, as determined in the triangulation accuracy test giving a buffer of 93 m around the outermost locations.

Before home range analyses, poor quality triangulations (11% of the total) were discarded leaving 3,751 locations which were mapped. Forty-two high-quality triangulations located a kiwi in areas remote from all other locations for that kiwi; these were considered outliers, *sensu* Burt (1943) and were excluded from home range analyses. Incremental area analyses (IAA) were performed on the remaining locations for each kiwi using Ranges 9 v2.02. Home ranges were only calculated if IAA curves reached an asymptote. Home ranges were calculated for individuals and for pairs.

To investigate movements over time, annual IAA and home range analyses were performed for each kiwi. These analyses used 1 July as the start of the annual period to align with the start of the roroa breeding season (Heather & Robertson 2015). A multi-year home range covering the period of monitoring was also calculated for each kiwi.

RESULTS

Dispersal phase

Monitoring of 28 roroa continued until they established a home range; the monitoring of the other 16 was truncated. The dispersal phase was very variable; kiwi that established a home range dispersed for between 9 and 878 days before settling and covered between 33 and 1,745 ha (Fig. 2; Appendix 1). Kiwi whose monitoring was truncated (Appendix 2) dispersed over a greater area ($t = 4.568$, $df = 40$, $P = 4.6E\text{-}05$) and for longer ($t = 2.203$, $df = 29$, $P = 0.036$), than those that established home ranges (Table 2). The maximum straight-line distance an individual kiwi moved from its release site was 9.8 km (Appendices 1 and 2) but its dispersal route will have been longer. Dispersal of some kiwi appeared unidirectional but others moved back and forth. Six kiwi paused in an area for up to 11 months before moving.

Dispersal of kiwi in established pairs that stayed together through the translocation was of significantly shorter duration ($t = 2.459$, $df = 25$, $P = 0.021$) and covered a significantly smaller area ($t = 3.317$, $df = 26$, $P = 0.0027$) than the dispersal of kiwi that formed new pairs in the project area. However, only three of 11 translocated pairs that were monitored until they established a home range stayed together. Of the four pairs in which the partners were released in the same burrow only one pair stayed together. The dispersal phase of kiwi in translocated pairs that separated was not significantly different in duration ($t = 0.193$, $df = 20$, $P = 0.85$) or area ($t = 0.725$, $df = 20$, $P = 0.48$) from kiwi translocated without a partner.

Pairing

Pairs were assumed to have formed when male and female kiwi overlapped their home range or bred. Nine kiwi formed transitory associations during the dispersal phase, including two comprised of same sex birds. By the end of radio-telemetry monitoring, 34 of the translocated kiwi had paired, four had not and monitoring of six was truncated too soon to tell. Four kiwi are known to have paired with non-translocated kiwi, one with an immigrant, most likely from the Cobb Valley, and three with offspring of translocated birds. Seven of the pairs comprised partners from different source sites. Five kiwi changed partners during the project, three of them after they had bred. The members of one of the pairs that separated after release occupied adjacent home ranges with new partners.

Home Ranges

Thirty-nine kiwi established home ranges, the areas of 30 of these were quantified (Appendix 3). The IAA of the home ranges of the seven kiwi monitored for eight years show an asymptote after 3.5–5.8 years. Eighty-five percent of annual home

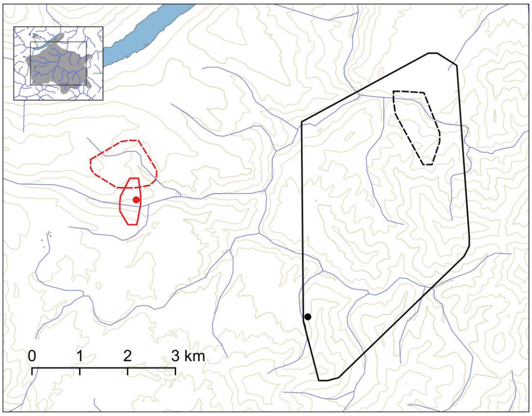

Figure 2. Illustration of variability in roroa post-translocation dispersal in the Flora Stream project area. Te Manu-huna had the smallest dispersal range (solid red) and he settled in a home range after nine days (dashed red). Tahi had the largest dispersal range (solid black) and he took 878 days to settle in a home range (dashed black). Release locations shown as spots. Inset shows location of these ranges in relation to the trapped area in 2020 (shaded grey).

Table 2. Duration and extent of post-translocation dispersal of roroa in the Flora Stream project area in relation to: whether dispersal monitoring was completed or truncated; translocation status (single or as a pair) and persistence of pairs post-translocation.

Dispersal monitoring	Translocation as a pair or single kiwi and persistence of the pair post-translocation	Mean duration of dispersal (days)	Mean dispersal area (ha)	Maximum dispersal (km)	Number kiwi
Completed	Translocated with partner, pair persisted post-translocation	84	117	2.5	6
	Translocated with partner, pair separated post-translocation	216	445	6.0	16
	Translocated without partner	197	316	4.4	6
Truncated		311	973	9.8	16

range IAA plots reached an asymptote, on average after 15 locations (n = 114; 95% *CL* ± 0.98; range 4–27). Home ranges were not calculated if IAA did not reach an asymptote.

Multi-year home ranges for individual kiwi varied from 29 to 475 ha ($\bar{x}$ = 142, n = 29, 95% *CL* ± 38 ha). Mean annual home ranges varied from 26 to 126 ha (Appendix 3). The ratio between the size of the multi-year home range and the mean annual home range, an indicator of inter-annual home range movement, ranged from 1.2 to 3.8 ($\bar{x}$ = 2.1; n = 23; 95% *CL* ± 0.31).

The size of both multi-year and annual home ranges varied between different regions of the project area (Fig. 3). Independent one-way ANOVA analyses with *post-hoc* testing using Tukey's correction showed the Flora annual home ranges were significantly larger than those in Ghost Creek (P = 0.019) and Deep Creek (P < 0.001) but Ghost Creek and Deep Creek home ranges were not significantly different in size (P = 0.21). Multi-year home ranges were significantly larger in the Flora than in Ghost Creek (P = 0.013), but not Deep Creek (P = 0.057) and there was no significant difference between Ghost Creek and Deep Creek (P = 0.81).

The sizes of annual home ranges of single and paired kiwi were not significantly different ($\bar{x}$ ± 95% *CL* single kiwi 91 ± 13 ha, n = 10; paired kiwi 78 ± 7.5 ha, n = 104; t = 2.000, df = 18, P = 0.061).

Members of a pair had almost the same multi-year home range (Fig. 4). The multi-year home ranges of kiwi in adjacent pairs sometimes slightly overlapped (Fig. 4), but there was no concurrent overlap. Half the kiwi that settled into a home range were occasionally located roosting up to 2.4 km outside it.

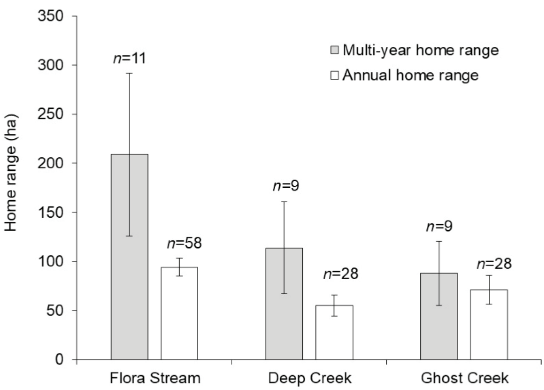

Figure 3. Mean area with 95% *CL* of multi-year (2-7 years) and annual home ranges in three regions of the project area: Flora Stream; Deep Creek; and Ghost Creek.

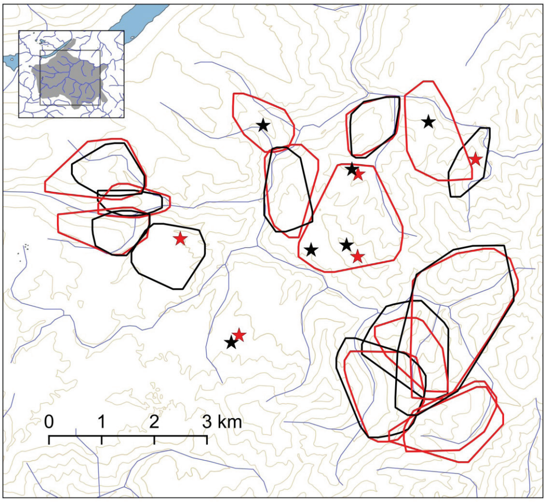

Figure 4. Distribution of multi-year home ranges of roroa present in the project area (trapped area shaded grey on inset) at the end of radio-telemetry monitoring. Red = females, black = males, stars = kiwi known to be present but without a transmitter.

Commonly, annual home ranges moved incrementally (e.g. Fig. 5a), but on six occasions movement was to an adjacent area (e.g. Fig. 5b), and once a pair separated and established new home ranges with new partners 6.2 km from their original partners. Intra-annual movement sometimes coincided with breeding activity (particularly following predation of egg or chick), occasionally followed handling, but often was unexplained.

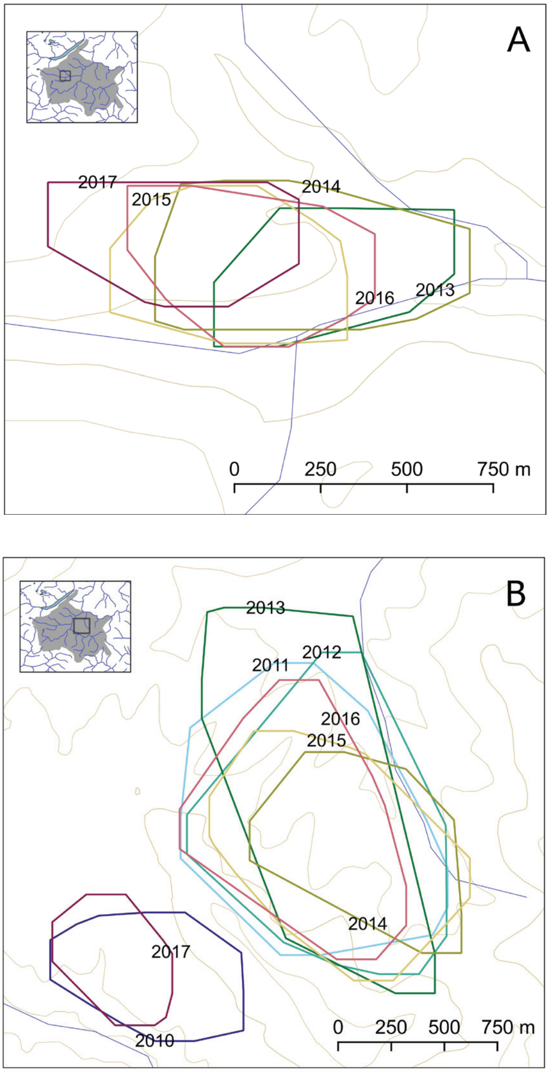

Figure 5. Examples of how home ranges of individual roroa move from year to year in the Flora Stream project area (trapped area shaded grey on inset). (A) shows incremental shifts by 'Hoire'; (B) shows movement to an adjacent area by 'Aorere'.

Three female kiwi from a later translocation appropriated all or part of the home range of kiwi from earlier translocations. By the end of the radio-telemetry monitoring, mapped home ranges were spread over approximately 5,000 ha. Last known locations of kiwi whose monitoring was truncated were dispersed over 10,000 ha. All but one of the home ranges were within 1 km of another pair (Fig. 6). There was one instance of two single females sharing a home range, although they were never found in a burrow together.

All night monitoring was carried out over five years on 13 occasions during December to May. Periods of non-breeding, incubation and up to two months after chick hatch were covered. Sixteen kiwi were monitored, up to six on any one night, giving a total of 69 nights of kiwi activity. On 24 occasions a kiwi moved outside the annual home range estimated from daytime roosts, usually into space between adjoining pairs' annual home ranges. The maximum distance outside the home range was about 600 m, the average foray length was 200 m. Seven incursions into another pair's home range were observed, all less than 100 m. Kiwi remained within detection range all night on 31 occasions. The percentage of the annual home range covered by these kiwi varied from less than 5% to about 60%,

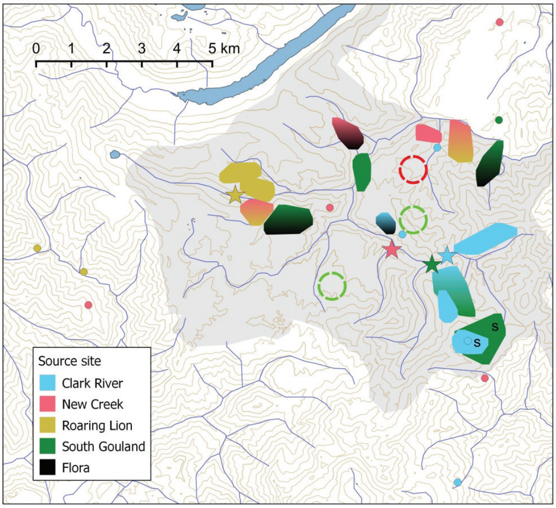

Figure 6. Home range locations of roroa monitored to the end of the project, and the last known positions of other translocated kiwi, in relation to the trapped area shown shaded grey. Stars = release locations; solid polygons = quantified annual home ranges of pairs unless annotated with 's' for single; dashed circles = approximate home ranges identified by calling of roroa pairs without transmitters; spots = last known locations of other roroa, excluding kiwi who died. Colours indicate origin of roroa pre-translocation as per legend; graded colour = pairs of mixed origin.

but was less than 25% on 24 occasions. Eleven kiwi monitored through the night more than once in a year, covered different parts of their home range on different nights.

DISCUSSION

Translocation targets and goals

Monitoring should enable managers to assess whether translocation objectives are being met, and adjust management of the population (IUCN/SSC 2013). Forty-four roroa were translocated into the Flora Stream area without death or injury. One year after translocation, 26 kiwi (59%) were known to have established home ranges within the project area exceeding the short-term translocation target of 50%. A further 11 kiwi (25%) were within the project area but had yet to establish a home range.

Eight years after the first translocation, the trapped area had been increased to accommodate dispersal of the kiwi. Thirty kiwi (68%) were known still to be in the project area, six had dispersed outside it, five had disappeared with their last tracked location being within the project area, and three had died. One of the kiwi that died did so three years after translocation due to emaciation consistent with starvation and/or old age; the other two died during dispersal, one in a tomo (sinkhole) and one stuck in a burrow. Twenty-eight (93%) of the kiwi remaining in the project area were known to have a partner, at least two of the pairs involved kiwi hatched in the Flora.

Dispersal was variable which may reflect individual responses to a novel, stressful situation (Parker *et al*. 2012). Many variables in translocation methods could have contributed to the dispersal response: source site altitude and habitat; method of capture; length of holding period; method of transfer; time of year; release location. Of the roroa that dispersed outside the project area, one did so after it appeared to have settled and paired, but the rest were single birds dispersing soon after translocation.

The long-term conservation goals for this project relate to the establishment of a self-sustaining population. This requires that recruitment exceeds mortality, and that the effective population size is sufficient to avoid inbreeding depression and ensure genetic variation is sufficient to enable survival and adaptation in the face of environmental change (IUCN/SSC 2013; Taylor *et al*. 2017). To reduce the likelihood of inbreeding depression, we sourced roroa from four sites in NW Nelson. Subsequent pairing of roroa from different source sites occurred. Translocations from different source sites could lead to outbreeding depression, a risk that is difficult to quantify for a long-lived species (IUCN/SSG 2013) such as roroa (Robertson *et al.* 2005). In general, the risk of inbreeding depression is seen as greater than the risk of outbreeding depression (Ralls *et al*. 2018) and, in addition, it appears likely that the conditions needed for outbreeding depression (Frankham *et al*. 2011; Frankham 2015) are not present in roroa. Translocation from multiple source sites was therefore deemed appropriate. There is new evidence of genetic variation across the range of roroa that may be explained by isolation by distance (H. Taylor *pers. comm*.), suggesting that roroa caught closer together will be more genetically similar to one another than those caught at extremes of the species' range, but that this is part of a genetic continuum rather than specific adaptation to differing environments (H. Taylor & K. Ramstad, In, Germano *et al*. 2018). Breeding success and effective population size in the Flora stream area are discussed separately (Toy & Toy *in prep*.).

The study area lies on the eastern edge of the range of roroa in NW Nelson (Germano *et al*. 2018). The translocations were performed assuming that the habitat would be suitable given the recent occupation of the area by roroa, and the ongoing intensive predator control. Establishment of home ranges and breeding by the translocated kiwi support this assumption. However, past occupancy may not indicate current or future suitability (IUCN/SSC 2013) and it is rarely possible to understand what makes habitat suitable (Osborne & Seddon 2012). Certainly, habitat suitability involves more than predator control. To demonstrate that the Flora population is sustainable under changing environmental conditions (e.g. summer drought) requires continued monitoring. Acoustic recorders are being used to monitor call rates and to indicate changes in population distribution. This will show if the long-term translocation outcome of dispersal into adjacent areas has been met and whether additional predator control is necessary. Other methods will be necessary to show if carrying capacity has been reached and genetic diversity is adequate.

Informing management decisions

Monitoring showed kiwi were establishing home ranges outside the trapped area. Trapping was extended to cover an additional 4,000 ha in the Deep Creek, Ghost Creek and Grecian River areas to encompass this dispersal. Frequent monitoring also enabled retrieval of four roroa that dispersed further away where they were vulnerable to predation. All paired within the project area after their second release. Six kiwi that dispersed outside the project area and could not be retrieved likely remain part of the functional translocated population as they moved to adjacent areas.

Translocation lessons learned

Learning from monitoring will benefit the design of future translocations. Long-term post-translocation monitoring is recognised as good practice (Parker *et al.* 2013; IUCN/SSC 2013), but what constitutes long-term cannot be specified *a priori* and must be reviewed in response to monitoring results. This study showed that roroa can settle in a stable home range after nine days, but they can also take nearly 2.5 years. Annual home ranges shifted and, as a result, multi-year home range expansion for some kiwi continued for six years which may result from translocation, but could be normal for a relatively low-density population. The longer an animal is followed, the more space it will likely use, which can translate into larger home-range estimates (Fieberg & Börger 2012). Retrieval of kiwi or expansion of a predator control area may be of great benefit during the dispersal phase, but are unlikely to be justified by subsequent home range expansion. Therefore, we conclude that, in relation to dispersal, radio-telemetry monitoring should continue until stable home ranges are demonstrated to have established, which in the Flora Stream area took more than 2.5 years. However, since our translocation objectives also related to breeding outcomes, longer monitoring was necessary (Toy & Toy *in prep.*). To maximize the effectiveness of the translocation, all kiwi should be monitored since dispersal is very variable between individuals.

Le Gouar *et al.* (2012) recommend that release strategies should be designed to minimise adverse effects associated with post-release dispersal. We tried three approaches: releasing known pairs in the same burrow to minimise dispersal; releasing kiwi from successive translocations in areas without resident kiwi to reduce the likelihood of territorial clashes with previously released kiwi; and releasing kiwi in clusters to limit dispersal by acoustic anchoring. Our sample size was too small to test these ideas but we observed that one of four pairs released in the same burrow persisted, compared with two of seven released in separate nearby burrows. We conclude that there is no advantage to releasing in the same burrow. We did not determine what keeps pairs together, but if they did stay together they established home ranges more quickly and nearer to the release site than if they formed new pairs. Gasson (2005) reported similar findings in roroa translocated as part of the Rotoiti Nature Recovery Project.

In each translocation, we released kiwi in clusters in areas without resident kiwi. We found dispersal was variable, but later translocations caused little disruption to home ranges of previously released kiwi. Some kiwi dispersed several kilometres before establishing a home range, but of 17 pairs that established home ranges, all except one settled within 1 km of at least one other pair. Roroa calls of both sexes are audible from more than 1 km away in good conditions (McLennan & McCann 1991; RT & ST *pers. obs.*). This suggests there was acoustic anchoring. Roroa translocated to Rotoiti also established home ranges within calling range of each other (Gasson 2005) although they dispersed shorter distances than we observed in the Flora, which might be due to the presence of physical barriers at Rotoiti. Acoustic anchoring has been investigated as part of translocation protocols for other New Zealand birds: North Island kokako (*Callaeas wilsoni*) (Molles *et al.* 2008), and North Island Robin (*Petroica longipes*) (Bradley *et al.* 2011).

Home ranges established over a larger area than was predicted prior to the translocations. Currently, the trapped area is about 9,000 ha, similar to the 10,000 ha minimum area required for long-term kiwi persistence (Brown *et al.* 2015), but much of the trapped area is unoccupied. Understanding habitat and range requirements is a complex issue (Powell & Mitchell 2012; Osborne & Seddon 2012) but is clearly fundamental to translocation success. In the project area, several kiwi from later translocations established home ranges in areas through which kiwi in earlier translocations had dispersed, suggesting the habitat was suitable for roroa, but unknown factors discouraged the previously released kiwi from settling there. Home ranges in the Flora region of the project area are larger than those in Deep Creek or Ghost Creek. The reason for this might relate to resource availability. More detailed monitoring of night-time habitat use might be informative but suitable technology, such as GPS tags (Kie *et al.* 2010), is not yet available for kiwi.

Almost everything we currently know about home range for any kiwi species is based on daytime roosts, but this information may under-estimate the actual home range size since kiwi's knowledge of habitat quality may extend beyond the home range estimated from their daytime roosts. Burt (1943) describes a home range as the area traversed by an individual in its normal activities of feeding, sheltering and breeding. He states that occasional movements outside the area should not be considered as part of the home range. Powell & Mitchell (2012) suggest regular but infrequent movements to a place should be assessed in the context of all that is known about the species. They suggest that an animal keeps an up-to-date cognitive map of the status of resources and where to meet its requirements. Such a map may enable kiwi to respond to events such as incursions by other kiwi into their home range or unusual weather conditions that affect their fitness. Our night-time monitoring and two dropped transmitters showed that kiwi regularly moved outside the home range estimated from daytime roosts. McLennan & McCann (1991) and Gasson (2005) also identified nocturnal use of habitat in which roroa did not roost. Ultimately, home ranges will be dynamic as animals respond to changes in environment and neighbours (Fieberg & Börger 2012). The fact that multi-year home ranges in the project area are substantially larger than annual home ranges reflects this. Changes to home range also occur within a year. Our annual home range estimations were made using locations made throughout the year. Other roroa studies, (Keye *et al.* 2011; Jahn *et al.* 2013) were restricted to a few months duration. This may contribute to our annual home range estimates being larger than those found in these other studies.

The extent and nature of the terrain in the project area necessitated long-distance bearings and included areas prone to 'bouncing' signals and non-detection, all factors that increase the size of the error polygon (Harris *et al.* 1990). As a result, we had a large buffer in the MCP analyses compared to Jahn *et al.* (2013) who did close-approach telemetry resulting in an 18 m triangulation error. Running our MCP analyses using the minimum 1 m triangulation error permitted in Ranges 9 v2.02 negates our large triangulation error and gives a mean annual home range of 42 ha. That this is larger than the 20–34 ha mean home range size reported in other studies by Jahn *et al.* (2013), suggests that our large home ranges are not just a consequence of triangulation error but also reflect our all-season, multi-year monitoring.

Large home range size could be a feature of a low-density and/or translocated population. Opportunity for incremental and more major movements of home range, would be more limited in a higher density, established population. However, if large home ranges are a symptom of translocated kiwi's unfamiliarity with a new area, they might be expected to decrease over time, but this did not occur. If larger home range size is a feature of low-density populations, this should be included when modelling population size.

'Post release monitoring is often viewed as difficult and expensive, and even optional' (Parker *et al.* 2013). The ability of community groups to deliver such an effort has been questioned (Galbraith *et al.* 2016). The intensity and duration of post-translocation monitoring in this study is unusual following kiwi translocations (P. Jahn *pers. comm.*). It was needed to trigger management required to achieve the translocation targets and goals. Transmitters were then removed and intensive monitoring ceased. The project has shown that with training, support and leadership, volunteers can provide the long-term commitment and carry out the tasks necessary for long-term post-translocation monitoring at manageable cost. Annual acoustic monitoring is underway in the Flora, but to understand whether long-term goals are met, other more intensive methods such as territory mapping and genetic analysis will be required.

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Home Ranges were calculated using Anatrak Ranges 9 ©. Maps were drawn using QGIS 2.18.17 Open Source Geospatial Foundation Project, using data sourced from the LINZ Data Service licensed for reuse under CC BY 4.0. This paper was greatly improved following comments received from Peter Jahn, Helen Taylor, Jen Germano, Craig Symes and an anonymous reviewer – thank you.

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Appendix 1. Duration and extent of post-translocation dispersal for roroa in the Flora Stream project area monitored throughout the dispersal period. Kiwi are grouped based on whether pre-translocation pairs persisted or separated.

Persistence of pre-translocation pairs	Kiwi name	Duration (days)	Area (ha)	Maximum dispersal distance (km)	Number of contributing locations
Pair persisted	Hoire	77	96	1.3	9
	Ngutu-roa	9	39	0.5	6
	Poai	100	91	1.6	11
	Rameka	184	304	2.5	13
	Te Manu-huna	9	33	0.4	6
	Waiharakeke	122	138	1.9	11
Pair separated	Anatori	122	206	1.8	15
	Aorere	122	116	1.5	11
	Mangarakau	28	317	2.1	8
	Pakawau	170	149	1.4	20
	Parapara	34	169	3.8	3
	Pikopiko	186	494	2.2	16
	Puponga	18	229	2.8	7
	Rata	12	101	2.2	6
	Tahi	878	1,745	6.0	58
	Tai Tapu	47	187	2.7	12
	Te Kau	255	620	2.8	23
	Te Rae	194	515	3.3	25
	Toru	450	685	3.9	43
	Waru	148	500	3.0	20
	Whakahihi	396	494	4.0	30
	Whitu	398	588	3.5	36
Translocated without partner	Patoto	239	319	2.0	23
	Rakopi	170	142	1.5	15
	Te Hapu	483	849	4.4	31
	Toro-Ngangara	69	171	1.9	9
	Turimawiwi	150	286	3.0	20
	Whakangangahu	69	127	1.9	10

Appendix 2. Duration and extent of post-translocation dispersal in the Flora Stream project area for kiwi whose monitoring was truncated during the dispersal period.

Kiwi name	Duration days)	Area (ha)	Maximum dispersal distance (km)	Number of contributing locations	Reason for truncated monitoring
Waikaki	>171	141	1.3	22	Died
Rima	>337	790	3.0	36	Died
Pohara	>535	1,880	5.1	30	Disappeared
Rototai	>82	180	2.0	5	Disappeared
Awaroa	>254	890	2.8	24	Dropped transmitter
Waewae-rakua	>350	867	5.7	18	Dropped transmitter
Anaweka	>537	1,044	6.1	55	Dropped transmitter
Ono	>738	1,314	7.7	52	Dropped transmitter
Opau	>253	196	2.7	28	Dropped transmitter
Whariwharangi	>299	833	2.5	26	Dropped transmitter
Iwa	>83	1,340	8.3	7	Retrieved
Korowhiti	>261	1,645	6.5	19	Retrieved
Rua	>361	1,455	7.8	19	Retrieved
Totaranui	>97	373	4.5	10	Retrieved
Kuikui kuini	>226	2,108	9.8	16	Transmitter died
Wha	>398	520	8.5	17	Transmitter died

Appendix 3. Size of multi-year and annual home ranges of kiwi in the Flora Stream project area (2010-2018). Areas and number of triangulated locations are shown only for home range estimates that reached an asymptote in the IAA. Aorere and Rakopi's multi-year home ranges covered both the Flora and Ghost Creek regions, so were not included. Ratio multi-year home range to annual home range (HR:HRann) was not calculated where there was only one HRann contributing year.

Region of project area	Kiwi name	Multi-year home range (HR)		Annual home range (HRann)		Ratio HR:HRann
		Area (ha)	Number of contributing locations	Mean area (ha)	Number of contributing years	
Flora	Anatori	218	194	86	6	2.5
	Aorere	-	-	43	1	-
	Korowhiti	134	70	102	2	1.3
	Mangarakau	124	52	103	2	1.2
	Pakawau	199	182	75	8	2.7
	Parapara	157	174	88	6	1.8
	Patoto	126	54	90	3	1.4
	Pikopiko	228	182	82	7	2.8
	Puponga	73	15	73	1	-
	Rakopi	-	-	50	1	-
	Rameka	404	177	117	6	3.5
	Totaranui	159	203	89	7	1.8
	Waiharakeke	475	194	126	8	3.8
Deep Creek	Hoire	48	104	26	5	1.9
	Ngutu-roa	157	78	76	4	2.1
	Poai	65	104	33	5	2.0
	Te Kau	244	84	75	4	3.3
	Te Manu-huna	101	90	72	3	1.4
	Toro-Ngangara	65	34	47	2	1.4
	Turimawiwi	127	28	93	2	1.4
	Waru	79	17	79	1	-
	Whakangangahu	137	97	48	4	2.9
Ghost Creek	Aorere	-	-	105	5	-
	Iwa	88	88	51	3	1.7
	Rakopi	-	-	122	3	-
	Rata	132	38	78	2	1.7
	Rua	38	16	38	1	-
	Tai Tapu	113	37	68	2	1.7
	Te Hapu	63	10	63	1	-
	Toro-Ngangara	165	52	79	2	2.1
	Toru	29	15	29	1	-
	Whakahihi	85	77	41	4	2.1
	Whitu	80	57	35	3	2.3