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Post-translocation movements and ranging behaviour of roroa (great spotted kiwi, *Apteryx maxima*)

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Abstract: Translocations are increasingly used in kiwi (*Apteryx* spp.) conservation management, and their outcome is largely influenced by post-release dispersal and survival. A translocation of roroa (great spotted kiwi, *A. maxima*) to the Nina Valley, near Lake Summer Forest Park, is the first reintroduction of the Arthur's Pass roroa population. In 2015, eight wild-caught adults were translocated from Arthur's Pass National Park, following the release of ten captive-hatched subadults during 2011–13. We monitored the translocated kiwi by radio telemetry during 2015–17. Dispersal was highly variable among the released wild birds. The straight-line distance from the release site to the last recorded location ranged 0.5–10.3 km. Seven of the wild birds remained in the Nina Valley and covered an area up to 1,700 ha (95% utilisation distribution). Releasing the wild birds had no measurable impact on the ranging behaviour of previously released subadults. The current population founder group comprises a maximum of 13 unrelated individuals, and therefore further releases are necessary for a genetically viable population. Additionally, expansion of the pest-controlled area is crucial for the long-term persistence of the reintroduced population in the Nina Valley.

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INTRODUCTION

Kiwi (*Apteryx* spp.) are flightless ground-dwelling birds endemic to the three main islands of New Zealand, and most of them are threatened with extinction (Robertson *et al.* 2021). Roroa (great spotted kiwi, *A. maxima*, previously known as *A. haastii*, Shepherd *et al*. 2021) is native to the north-western part of the South Island, New Zealand, with a range currently separated into four known subpopulations: i) Arthur's Pass, ii) Paparoa Range, iii) Westport, and iv) the north-west Nelson region. Roroa population size is estimated to have decreased from approximately 16,000 to 14,000

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individuals during 2008–2018, and is likely still declining (Holzapfel *et al.* 2008; Germano *et al.* 2018). Until recently, much of the extant roroa population received little or no regular management for invasive predators, which are considered the primary driver of population decline (Innes *et al.* 2015). Consequently, roroa conservation status is 'Nationally Vulnerable' (Robertson *et al.* 2021).

Several management actions have been adopted to address the ongoing kiwi population decline and reduce the threat of extinction. Kiwi conservation management focuses mostly on either suppression or elimination of invasive predators, i.e. mustelids (Mustelidae), common brushtail possum (*Trichosurus vulpecula*), and feral cats (*Felis catus*), mainly through trapping and poisoning using aerial 1080 (sodium fluoroacetate); and advocacy and avoidance training to mitigate predation by dogs (*Canis familiaris*) (Robertson *et al.* 2011). Another management regime involves head-starting chicks under the Operation Nest Egg (ONE) programme. This approach consists of removing eggs from the wild, hatching them in captive facilities, and keeping the young kiwi in a predator-free environment until they reach a size at which they can fend off stoats (*Mustela erminea*), their main predator, before they are released back to the wild (Colbourne *et al.* 2005; Gillies & McClellan 2013). Subadults from the ONE programme are either returned to their source population or released elsewhere to establish or reinforce an existing kiwi population.

Kiwi translocations have become an increasingly popular tool in the conservation management of all kiwi species (Miskelly & Powlesland 2013; Jahn *et al.* 2022a). To date, translocations have played a relatively minor role in roroa management compared to the other kiwi species. Roroa transfers involve mainly wild-caught birds, whereas releases of ONE subadults dominate in North Island brown kiwi (*A. mantelli*), rowi (*A. rowi*), and tokoeka (*A. australis*) management (Jahn *et al.* 2022a). The first documented translocation of roroa was a 1915 release of 19 birds onto Te Hauturu-o-Toi/Little Barrier Island, but despite initial population establishment, this introduction failed, likely within 15 years post-release (Oliver 1955; Colbourne 2005). There were no other attempts to establish new populations until the 21st century. Wild-caught roroa from the north-west Nelson and Westport populations were reintroduced in 2004 to Lake Rotoiti, Nelson Lakes National Park, and in 2010 to the Flora Valley, Kahurangi National Park (Gasson 2005; Toy & Toy 2020). Following these initial efforts, ONE subadults from the Arthur's Pass population were reintroduced in 2011 to the Nina Valley. The Nina Valley is part in Lake Sumner Forest Park, Conservation Area Nina Doubtful Rivers, and Lewis Pass Scenic Reserve.

The Nina Valley reintroduction project was similar to the Rotoiti and Flora translocations focusing on ecosystem restoration and being driven by attempts to restore the former species distribution (Holzapfel *et al.* 2008; Hulsman *et al.* 2010; Morrison & Yong 2014). The project was initiated by the Hurunui College Nina Valley Restoration Group in co-operation with the Department of Conservation (DOC). During 2011–13, ten ONE subadults initially sourced as eggs taken from the Hawdon Valley, Arthur's Pass National Park, were released to the Nina Valley to re-establish a roroa population. Subsequently, eight wild-caught adults from the Hawdon Valley were translocated to the Nina Valley in April 2015 to expand the initial founder group. The birds were released at several sites in the central part of the Nina Valley, within the 1,600 ha trapped area that stretches alongside the Nina River.

The Nina translocation was the first – and to-date only – roroa reintroduction within the Arthur's Pass population. Therefore, it was vital to monitor the birds' post-release behaviour, to inform the planning of future releases, and provide information for potential management interventions. Lessons on post-release dispersal and territory establishment were available from Lake Rotoiti (Gasson 2005) and intensive monitoring was underway in the Flora Valley (Toy & Toy 2020), but it was not clear if the same behaviours would occur in the genetically distinct Arthur's Pass population (Taylor *et al.* 2021). We intensively monitored the translocated population in the Nina Valley to understand the released birds' dispersal pattern and identify where and when they established home ranges. Based on these data, and monitoring data from the source population in the Hawdon Valley prior to this translocation, we were able to address the following research questions: i) What were the dispersal paths and distances moved of wild-caught adult roroa following the translocation? ii) What were the changes in the home range size of adults before-and-after the translocation? iii) Were there any changes to the ranging behaviour of the previously translocated ONE subadults following the release of wild-caught adults into the same general area?

METHODS

Study areas

The translocation of roroa was carried out from the Hawdon Valley (42°57'S, 171°45'E), Arthur's Pass National Park, to the Nina Valley (42°28'S, 172°19'E) near Lake Sumner Forest Park. Both valleys are within the historical range of roroa (Taylor *et al.* 2021). They are 70 km apart, east of the main divide near Arthur's Pass and Lewis Pass, respectively, indicating similar climate characteristics. The floor of the Hawdon Valley lies at 570–780 m a.s.l. and is surrounded by mountain peaks 1,400–1,930 m a.s.l. The floor of the Nina Valley lies at 610–860 m a.s.l. and is surrounded by mountains 1,500–1,780 m a.s.l. River terraces and steep slopes in both valleys are covered by native montane beech forest until the bush line at about 1,300 m. The dominant tree species are mountain beech (*Fuscospora cliffortioides*), silver beech (*Lophozonia menziesii*), with red beech (*F. fusca*) at lower altitudes (Read & O'Donnell 1987; Blakely *et al.* 2008).

Translocation and monitoring

Eight wild-caught birds, four male and four female, were translocated to the Nina Valley in April 2015. These birds were part of a roroa monitoring programme in the Hawdon Valley for up to five years before the translocation. All were of unknown age but were confirmed to be breeding pairs by radio telemetry monitoring. The birds were tracked, captured, and transported to the Nina Valley according to best practice guidance (Morrison & Yong 2014). The pairs were placed in pre-determined release burrows 800–900 m apart (closer only if separated by the Nina River), outside of known roroa territories, to mimic natural territorial structure. One pair was placed together in one large burrow while three other pairs had males and females placed in separate nearby burrows to allow paired individuals to stay in close contact. Burrow entrances were blocked for the rest of the day to encourage birds to remain sheltered and calm. The entrances were unblocked one hour after sunset, and the birds were allowed to move freely. A similar approach had been previously adopted for the release of ten unpaired subadult ONE birds during 2011–13. The average age of these roroa at release was 1.1 years (range 0.9–1.3 years). They were released in January 2011 (2), February 2011 (3), February 2012 (3), and January 2013 (2). In these instances, the 2–3 subadults were placed together in one large release burrow.

After the 2015 translocation, we monitored all eight translocated wild-caught birds and four kiwi previously released as ONE subadults using ground-based radio telemetry. The remaining ONE birds were not monitored because they had either dropped their transmitters before 2015 (4), died soon after the release – likely drowned (1), or occupied remote areas of the Nina Valley (1), which prevented regular monitoring. However, we included location data for one unmonitored ONE bird that was incidentally captured and paired with a monitored ONE bird. All the monitored birds were fitted with leg-mount diagnostic transmitters designed for roroa (Sirtrack V2.0 GSK, <2% of the body weight, 142–174 MHz) before the 2015 translocation transfer, and then for up to two years following the release. The transmitters allowed us to locate each bird for health checks and transmitter changes, or to remotely triangulate bird locations (Neill & Jansen 2014). To triangulate the birds, we recorded the bearing of the signal multiple times from several (>3) points to achieve at least a 90° overall angle between the bearings (Kenward 2001). Subsequently, we estimated the locations of monitored kiwi from a series of intercepting bearings using triangulation software Locate 3.34 (Pacer Computing).

Monitoring intensity differed throughout the monitoring period. In the first week after the release of the wild-caught adults, we aimed to triangulate all the birds every day. In the following month, we attempted to triangulate the birds at least once a week, and subsequently, the frequency of checks decreased to once every two weeks. After five months post-release, we attempted to triangulate the birds at least once every 2–3 weeks and after 18 months every 4–6 weeks. Locations of the roroa in the Hawdon Valley were triangulated fortnightly during the three months before the translocation. Locations of the four ONE birds in the Nina Valley were also triangulated for three months before the introduction of additional birds. As site visits were generally multi-day trips, we attempted to triangulate the birds on each day, when practicable. Both triangulation and close approach (homing) took place during the day to locate nocturnal kiwi at their daytime shelters. Daytime triangulation provided ample time for a single surveyor to obtain multiple bearings while a kiwi is stationary at its daytime shelter. This approach generally reduced large location error when attempting to triangulate a moving animal, compared to more accurate GPS tracking (Guthrie *et al.* 2011). To measure triangulation accuracy, we estimated the location error from a beacon test carried out by placing a transmitter underground at a known location in the birds habitat and then triangulating it multiple times (Millspaugh & Marzluff 2001). We estimated the location error of triangulated location fixes at 42.0 m (±7.1 *SE*, n = 8) with the mean distance between the observer's location and the beacon 201 m (26.4 *SD*).

Data analysis

The home range and dispersal path estimations were based on the analysis of daytime location fixes, similarly to other roroa studies (Jahn *et al.* 2013; Toy & Toy 2020). Most of the location fixes used in the analysis (76%) were obtained through triangulation. Additionally, we supplemented the triangulation data with locations from kiwi recaptures and transmitter retrievals, done by DOC staff or contractors.

To estimate the dispersal path of the

translocated birds, we constructed a smoothed line between the release site and the last known location for each bird by calculating a rolling average of up to nine consecutive location fixes. We chose to use nine fixes because this was the overall number of location fixes for the bird with the shortest duration of post-release monitoring. Additionally, we calculated the straight-line distance between the release site and the last known location for each bird to supplement the information on the dispersal path length. To identify the area most likely crossed by each bird during post-release dispersal, we analysed their utilisation distribution (UD) based on the movement path using R 4.0.3 (R Core Team 2020) and the package 'move' 4.0.6 (Kranstauber *et al.* 2020). To construct the UD, we used the dynamic Brownian bridge movement model suited for irregular sampling because it incorporates the Brownian motion variance, location fixes timestamps, and the location error (Kranstauber *et al.* 2012). We used the data collected after the 2015 translocation to estimate the dispersal path and the UD for all the translocated wild-caught adults and four ONE birds that were released during 2011–12 (none of the birds released in 2013 were actively monitored). Lastly, we tested whether the UD size of the translocated adults was larger than that of the resident ONE birds. We used a Mann–Whitney *U* test, and we repeated this method in the following tests.

To identify possible changes in the home range size resulting from the translocation, we compared the home ranges of the adults in the Hawdon Valley before the translocation and after the translocation in the Nina Valley. Given that several birds moved substantially in the first six months post-release, we excluded this period from the home range estimation. We used location (homing) data obtained from DOC from up to five years before the translocation (3.1 years on average) to supplement the triangulation data collected during the three months immediately before the transfer. The longer monitoring period before the translocation compensated for infrequent location fixes and was not expected to substantially increase home range estimates due to a high population density and stable territorial structure of roroa in the Hawdon Valley. Because the data had substantial time gaps, we did not use the dynamic Brownian bridge movement model due to a large uncertainty of the movement paths between the consecutive location fixes. Therefore, we constructed minimum convex polygons (MCP) to estimate home range sizes, similar to other roroa studies (Keye *et al.* 2011; Jahn *et al.* 2013; Toy & Toy 2020). We used the R package 'splancs' 2.1.42 (Rowlingson & Diggle 2021) to calculate the size of MCP based on all location fixes and 'ggmap' 3.0.0 (Kahle & Wickham 2013) to map both MCP and UD. To inspect if the home range of translocated birds had become stable or kept shifting, we carried out an incremental area analysis with the R package 'adehabitatHR' 0.4.19 (Calenge 2006). Subsequently, we tested whether the MCP home range size of the wild adults increased due to the translocation.

To assess possible impacts of the wild birds' translocation on the ranging behaviour of the previously released ONE birds, we examined their home ranges in the two years before-and-after the release of the wild adults. Three of the four ONE birds were released to the Nina Valley in 2011, the fourth individual in 2012, so the two year pre-release period started after the birds had been in the Nina for 26 and 14 months respectively. We assumed that this was sufficient time for the ONE birds to settle and establish stable home ranges, despite their transitioning from subadult to adult life stages during the monitoring period (Colbourne *et al.* 2020). To investigate if the home ranges of the ONE birds shifted following the release of the wild adults, we carried out an overlap analysis of their MCPs using the R package 'splancs' 2.1.42 (Rowlingson & Diggle 2021). We included ONE bird location fixes from two years pre- and 0.5–2 years post-translocation of the wild adults, including location data (homing) obtained from DOC. We excluded the six months period after the wild bird's translocation from the MCP comparison to focus on the long-term effects of the wild bird's introduction as the immediate effects were captured in the previous UD analysis. Additionally, we tested whether there was a difference in the MCP home range sizes between the two periods.

RESULTS

Dispersal path and utilisation distribution

All but one of the eight released wild adults stayed in the Nina Valley during the post-translocation monitoring (Fig. 1). The only bird known to have left the valley (male 'wild 3') was still within approximately one kilometre of the release site two weeks post-release but could not be detected afterwards. Eight weeks later, it was found dead, hit by a car, more than 10 km from the previous last known location in the Nina Valley. Another bird (male 'wild 2') was not detected from 11 months post-release after being reliably found in a defined area for eight months. We could not detect the transmitter's signal despite repeated searches over several months within and outside the Nina Valley, including an aircraft telemetry search of the nearby valleys. However, we assumed that the bird likely survived and stayed, but its transmitter failed. This was based on repeated male calls recorded in its presumed territory 17–20 months post-release and nightly activity pattern indicating possible incubation by its mate, female 'wild 2' (PJ & LM *unpubl. data*). Attempts were made to recapture male 'wild 2' during transmitter checks of female 'wild 2', but no male roroa was found.

We aimed to monitor all the wild-caught adults for at least two years post-release but we achieved this with only three birds translocated in 2015 (Table 1). Two birds dropped their transmitters at approximately one year post-release and could not be found for transmitter re-attachment. The DOC staff and contractors could not recapture another bird for a transmitter change despite several attempts one year after the translocation, so we monitored it until the transmitter battery died 1.5 years post-release. The remaining two birds either dispersed and died or were not able to be detected

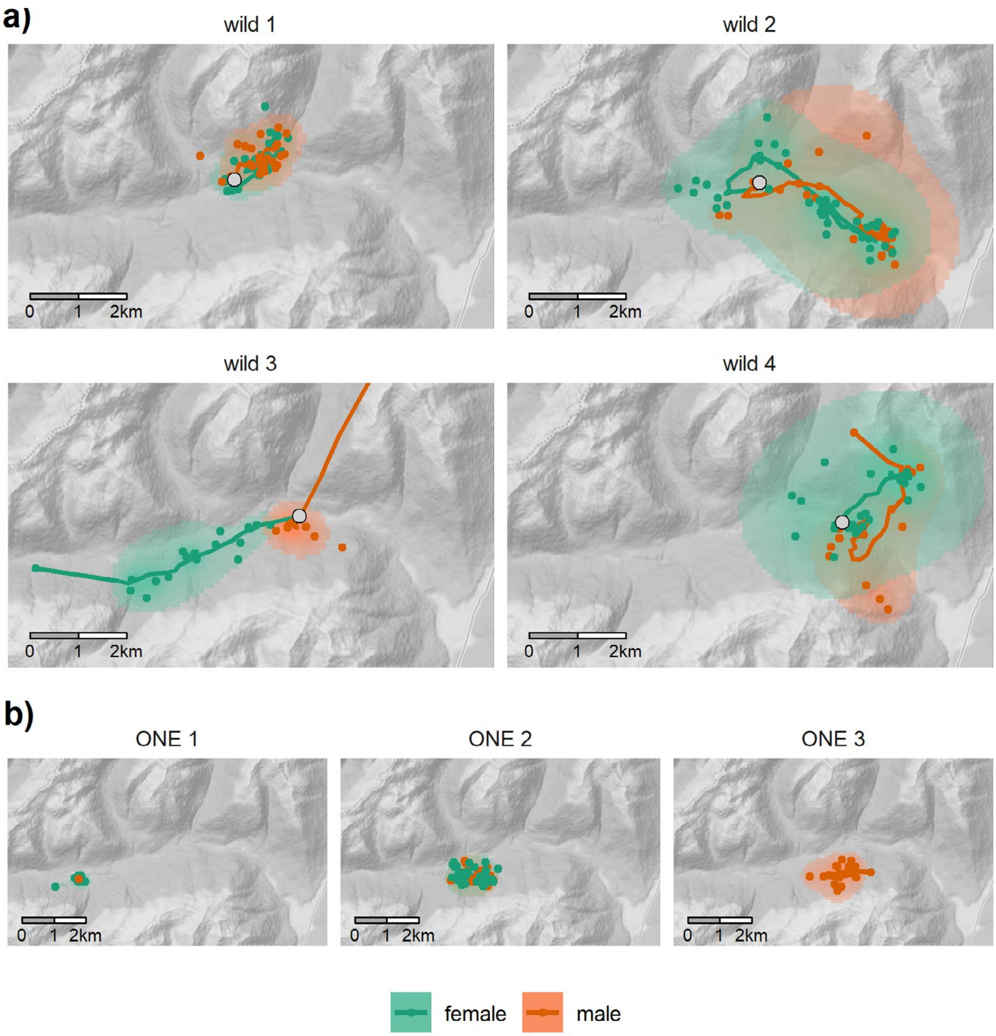

Figure 1. Utilisation distributions (UD) and dispersal paths of (a) wild-caught roroa (great spotted kiwi, *A. maxima*) translocated in 2015 and (b) roroa from the Operation Nest Egg (ONE) released during 2011–13 in the Nina Valley. The maps display release sites (grey circles) of the birds translocated on 16 April 2015 (pairs 'wild 2–4') and 23 April 2015 (pair 'wild 1'). The coloured dots show the location fixes of the birds following the 2015 translocation until May 2017. Solid lines connect each bird's first and last point during this monitoring period and represent the rolling average of up to nine consecutive location fixes. The coloured polygons display 95% UD for each bird except for male 'ONE 1', which was not actively monitored, so we did not have a sufficient number of location fixes for the UD calculation. The last location of male 'wild 3' is not shown as it left the Nina Valley after at least two weeks and dispersed within ten weeks post-release 10.3 km north-west from the release site.

Table 1. Estimated dispersal path, distance, and size of utilisation distribution (UD) of the translocated wild-caught roroa (great spotted kiwi, *A. maxima*) and previously released Operation Nest Egg (ONE) roroa in the Nina Valley. The number of location fixes and monitoring length include only the period following the 2015 translocation of the wild-caught birds. Mean dispersal speed is based on the estimated dispersal path. The 75% and 95% UD represent an area where the individual would be located with the specified probability during the monitoring period.

pair	sex	dispersal path (m)	straight distance (m)	# location fixes	monitoring length (days)	dispersal speed (m/day)	75% UD (ha)	95% UD (ha)
wild 1	M	2,844	463	35	728	4	71	213
	F	2,985	1,079	39	746	4	91	204
wild 2	M	4,999	2,968	31	325	15	519	1,692
	F	7,046	1,660	44	736	10	433	1,459
wild 3	M	10,929	10,304	9	71	154	55	125
	F	5,824	5,552	20	346	17	141	420
wild 4	M	4,857	1,888	28	362	13	279	645
	F	3,614	1,514	33	554	7	555	1,653
ONE 1	F	629	62	15	718	1	9	36
ONE 2	M	2,951	475	40	749	4	56	172
	F	2,550	274	35	749	3	62	183
ONE 3	M	2,533	514	21	749	3	101	240

due to likely transmitter failure, as mentioned above. In contrast, we managed to monitor all four ONE birds for the two years following the 2015 translocation.

Although the seven surviving wild birds appeared to settle within the project area, only two (pair 'wild 1') settled in the proximity of their release site and stayed during the monitoring period. The length of their dispersal path was similar to the path length of three previously released ONE birds, that had been in the valley for more than four years at the time of the wild adults' release (Table 1). The remaining five birds moved widely around the valley without any clear pattern. In most cases, the dispersal path changed direction several times before home ranges started to stabilise after approximately six months. Three of the four translocated pairs separated during the first four months. However, two reunited within the six months post-release in new areas, after being in different parts of the valley (>2 km apart) between approximately 1–3.5 months and crossing the Nina River repeatedly. The last pair ('wild 3') parted within two weeks post-release, headed in nearly opposite directions (Fig. 1), and the male later died outside the Nina Valley.

During the post-translocation monitoring period, the mean dispersal speed and the size of the utilisation distribution (UD) were highly variable among the released wild-caught birds (Table 1; Fig. 1). Both the core 75% UD and broader 95% UD were significantly larger among the newly released wild-caught birds compared to the resident ONE birds ($P = 0.036$, Mann-Whitney U test). The larger UD of the wild birds was consistent with their longer dispersal paths and straight-line distance between the first and last known locations, despite a 35% shorter average monitoring period compared to the ONE birds.

Home range size before and after translocation

After six months post-release, the translocated wild birds appeared to be restricted to more defined areas, indicating stabilisation of their home ranges. The home range area (100% MCP, Fig. 2) kept incrementally increasing and appeared to reach an asymptote only in the three translocated wild birds that were monitored for the entire two years post-release. They had >22 location fixes per bird in the period 0.5–2 years post-release. The home range of the four surviving wild birds was still increasing at the end of their monitoring periods, which lasted 0.9–1.5 years, resulting in a lower number of location fixes (<15). Similar to the three wild birds, home ranges of three of four resident ONE birds reached an asymptote within the two year monitoring period. In contrast, the home range of the last bird (male 'ONE 3') continued to gradually increase even after two years.

The MCP home range size varied substantially among the monitored individuals (Fig. 3). The mean home range size of the translocated wild adults was 76.34 ha (±11.16 *SE*), significantly larger

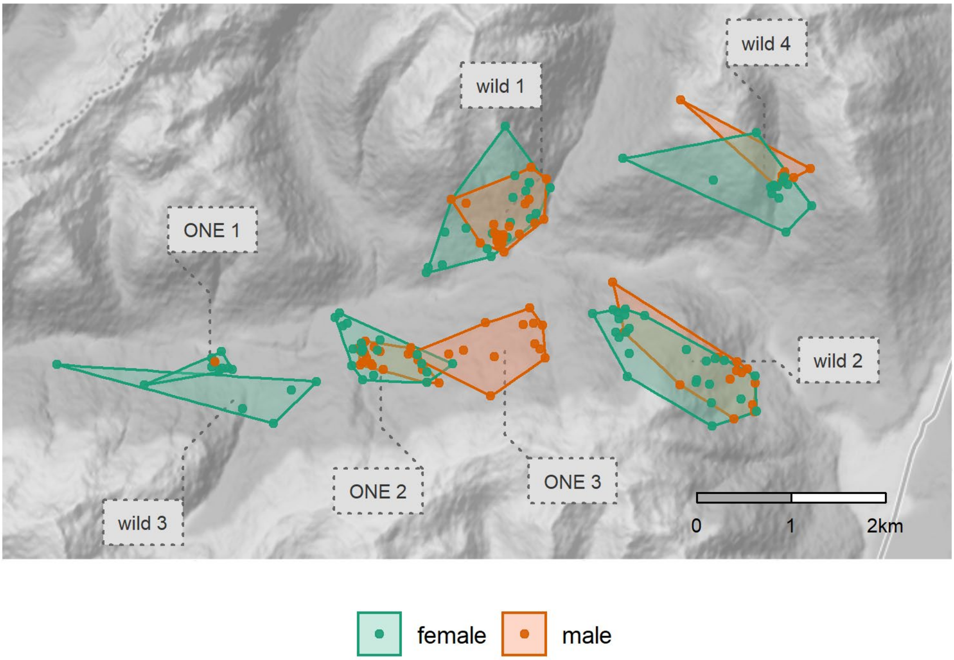

Figure 2. Minimum convex polygons (100% MCP) and location fixes of the monitored ONE and wild-caught roroa (great spotted kiwi, *A. maxima*) in the Nina Valley after six months from the 2015 translocation (mid-October 2015 – May 2017). This monitoring period ranged among individual birds between 5–19 months. An MCP was not possible to construct for an unmonitored ONE male with a single recorded location.

(P = 0.036, Mann–Whitney *U* test) than the home range size of the resident ONE birds at 37.31 ha (±13.93 *SE*). The mean home range size of the wild adults increased from that in the Hawdon Valley (54.39 ha ± 5.13 *SE*), but this increase was not significant (P = 0.055, paired Mann–Whitney *U* test).

Home range stability of the previously released ONE birds

The ONE birds that were released 3–4 years before the 2015 translocation did not show any clear signs of changing their ranging behaviour following the release of wild adults. This was despite several translocated individuals moving through the ONE birds' territories (Fig. 1). Particularly, the ONE birds in known pairs ('ONE 1' and 'ONE 2') showed generally lower UD and MCP home ranges (Table 1; Fig. 3), indicating higher site fidelity. There was no major shift in the MCP home ranges of the resident ONE birds following the wild birds' translocation. Between the two monitoring periods, their MCPs had a mean overlap of 39.7% (±6.8 *SE*). Also, there was no significant difference in the MCP home range size of the ONE birds before-and-after the release of the wild adults, excluding the 6-months post-release period (P = 0.625, paired Mann–Whitney *U* test).

DISCUSSION

Post-translocation dispersal

Dispersal of released animals plays a critical role in translocation outcomes (Richardson *et al.* 2015) and is often reported as one of the main issues encountered by various translocation projects (Brichieri-Colombi & Moehrenschlager 2016; Berger-Tal *et al.* 2019). Kiwi translocations to unfenced mainland sites also contend with dispersal outside the project area, particularly from small reserves under 3,000 ha, although this issue occurs in reserves of any area size (Jahn *et al.* 2022a). Indeed, post-release dispersal appeared to be one of the main factors contributing to the failure of several previously reintroduced kiwi populations (MacMillan 1990; Colbourne & Robertson 2000).

In the Nina Valley, only one released bird was observed to disperse outside the project area, and travelled more than 10 km from its release site within ten weeks of translocation. It is unknown if the bird was settling in this remote area or was continuing to disperse because no information was available on its dispersal path between the Nina Valley and the location where it was eventually struck by a car. The remaining seven translocated wild-caught adults stayed within the valley. However, three were monitored for just under one year due to either dropped transmitters or probable transmitter failure, so longer-term movements remain uncertain. Post-translocation monitoring of the ten previously released ONE subadults did not indicate dispersal outside the Nina Valley either (S Yong, DOC, *unpubl. data*). Our monitoring and bird recaptures in the Nina Valley confirmed the survival of two ONE birds for 4.2 years, one for 5.2 years, and three birds for at least 6.2 years post-release.

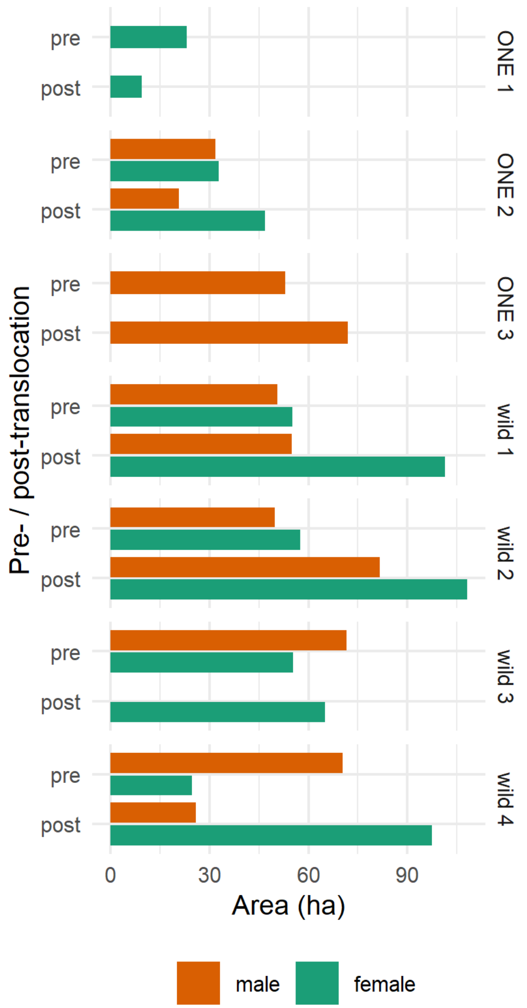

Figure 3. Comparison of 100% minimum convex polygon sizes representing home ranges of the monitored roroa (great spotted kiwi, *A. maxima*) before-and-after the 2015 translocation from the Hawdon Valley to the Nina Valley. The post-translocation period excludes the first six months post-release, in which the birds showed increased movements. The birds are grouped into pairs based on their origin – the Operation Nest Egg (ONE) birds released in the Nina Valley during 2011–13 and wild-caught birds translocated in 2015.

The absence of a clear dispersal pattern among translocated birds post-release is similar to other roroa reintroduction projects. Translocated roroa both at Lake Rotoiti (Gasson 2005) and in the Flora Valley project areas (Toy & Toy 2020) displayed high variability in overall dispersal distance and dispersal period before settling to stable home ranges. Interestingly, both projects observed shorter dispersal periods and distance in established translocated pairs that stayed together than those individuals who either re-paired or were translocated without a mate. Such behaviour is consistent with the observed dispersal in the Nina Valley, where the only pair that did not separate ('wild 1') showed the shortest dispersal path, distance, and lowest dispersal speed and UD, a pattern of behaviour similar to the resident ONE birds with established territories (Table 1). In contrast, pairs that separated, temporarily or permanently, moved around substantially more before settling down. Pair 'wild 1' was the only pair in the Nina placed in the release burrow together, while individuals from the other pairs were placed approximately 20 m apart, but this factor did not seem to play a role for pair bond survival at Lake Rotoiti or the Flora Valley.

The straight-line dispersal distance was the highest in the pair that separated soon after release ('wild 3') and the individuals headed in near-opposite directions (Fig. 1; Table 1). Only one, the female dispersing over 5.5 km upstream, likely remained in the valley, at least during the monitoring period. Pairs 'wild 2' and 'wild 4' also had long dispersal paths, but repeatedly changed direction resulting in larger UDs, although still within the Nina Valley. Large dispersal distances up to 10 km from the release site were also observed in some roroa translocated to the Flora Valley, resulting in at least 14% of the birds (6 of 44) settling outside the project area (Toy & Toy 2020). Similarly, one individual had a dispersal path >11 km within a year post-release at Lake Rotoiti. However, the project area at Lake Rotoiti is delineated by natural barriers, the lakeshore on one side and a high mountain range on another, which likely limited the dispersal to within the project area boundaries (Gasson 2005).

Home range establishment

The post-translocation monitoring of two years for the released wild-caught adults only produced observable stable home ranges for three birds. Due to the noted transmitter difficulties, the remaining four birds were only monitored for 0.9–1.5 years post-release, resulting in a home range estimation based on 0.4–1 year of data points. During this shorter monitoring period, these birds still had increasing home range areas, so it was likely the home ranges were not fully realised yet. In the Flora Valley project area, roroa have been observed to disperse for up to 2.5 years before establishing stable home ranges, based on monitoring data of up to eight years post-release (Toy & Toy 2020). Therefore, it is possible that the home ranges of the four birds with shorter monitoring duration could have kept expanding or shifting before eventually stabilising.

The estimated home range size (MCP) of the translocated wild-caught birds in the Nina, at 76.34 ha (±11.16 *SE*), was similar to the mean annual home range size (annual period July–June) in the Flora Valley, 73.26 ha (±4.82 *SE*), based on an average 3.8 years post-release monitoring duration for each bird (Toy & Toy 2020). In contrast, the mean home range size of translocated roroa at Lake Rotoiti 6–8 years post-release was 34.42 ha (±9.40 *SE*); however, the monitoring took place during only the winter season (Jahn *et al.* 2013) and therefore is not directly comparable. The mean home range size of translocated birds in the Nina Valley was larger than their pre-translocation mean home range in the Hawdon Valley, which was 54.39 ha (±5.13 *SE*). Although the difference was not statistically significant, given the truncated monitoring of four of the birds post-release, it is likely that the difference would be significant if monitoring for all birds could have been achieved for the full two-year period. The significantly larger home range estimates of translocated wild adults compared to the resident ONE birds in the Nina Valley was likely caused by an ongoing range shift/expansion. In other naturally established populations, the home ranges of adult roroa appear substantially smaller, such as in the North Branch Hurunui, Lake Sumner Forest Park (32.64 ha ±2.15 *SE*, summer–mid-autumn only), or in Gouland Downs, Kahurangi National Park (pair territory size 23 ha, range 9.9–42 ha) (McLennan & McCann 1991; Keye *et al.* 2011).

Translocation impacts on resident birds

The release of the wild-caught adults into the Nina Valley did not appear to substantially impact the ranging behaviour of the previously released ONE birds, likely due to a very low population density and little competition for resources. Apart from a minimal temporary home range shift of unpaired male 'ONE 3' and an insignificant increase in the ONE birds' nightly activity immediately after the release of wild adults, there were no other obvious behavioural changes among the ONE birds (Mander 2016). The ONE birds' home ranges (MCP) before-and-after the 2015 translocation were not identical but had a substantial overlap, which is consistent with a naturally occurring range shift over time (Toy & Toy 2020). Additionally, we found no significant change in the home range size of the resident ONE birds following the release of the wild adults suggesting that the ONE birds were successful in maintaining/defending their territories after the release of the wild-caught birds. The monitoring periods were not the same duration, as we compared home ranges 24 months before and 6–24 months after the release of wild adults. The pre-translocation period was longer due to data points being collected less frequently than after the translocation, but we did not expect it to affect the results.

The comparison of ONE birds' home ranges should, however, consider the transitioning between age class of the monitored birds. While the ONE birds were already adults by the time of the 2015 translocation, they were only recruited to the adult population during the 2-year pre-translocation monitoring period. The ONE birds were 2.4–3.4 years old at the start of the monitoring period, and they would be considered adults at four years or whenever they start breeding (Colbourne *et al.* 2020). Subadult roroa (generally 0.5–4 years old) have been shown to frequently share the territory and even the nesting burrow with their parents (Jahn *et al.* 2013; Toy & Toy 2021b), unlike subadult North Island brown kiwi that usually disperse and establish their own territories (Basse & McLennan 2003). Given that all of the monitored ONE birds appeared settled within 2 km from their original release sites and there was no need to disperse from natal territories, we assumed their ranging behaviour was similar to those of adults throughout the pre- and post-translocation monitoring periods.

Future of the Nina population

Since 2011, 18 roroa have been released in the Nina Valley, ten ONE and eight wild-caught birds. Of these, two birds (one ONE and one wild) are known to have died. The 2015 translocation proposal planned for subsequent releases to establish a self-sustaining and genetically viable population founded by at least 40 unrelated individuals by 2020 (Morrison & Yong 2014), but this target has not yet been met. All of the released birds were sourced from the lower Hawdon Valley. The ten ONE birds were produced by seven different pairs and an offspring of one of these pairs died. Assuming that all birds last recorded alive in the Nina Valley survive and breed, the current founder group is 13 unrelated individuals: seven wild-caught adults and ONE offspring of six different pairs in the Hawdon Valley. However, most of these birds came from adjacent territories in the Hawdon Valley, and despite not knowing their pedigree, a degree of some relatedness is likely (Taylor *et al.* 2021).

The possibility of supplementing the reintroduced Nina population by natural immigration is very low. Prior to the reintroduction project, roroa in the Nina and surrounding valleys had likely been functionally extinct, with only occasional calls reported (Hulsman *et al.* 2010). None of the translocated birds is known to have paired with any original birds that may have survived in the Nina Valley. During a 2012 acoustic survey, only 14 roroa calls from possibly four individuals were recorded, which were likely then recently released ONE birds (Morrison & Yong 2014; Jahn *et al.* 2022b). Based on an acoustic survey in 2017–18 (Jahn *et al.* 2022b), it appears that the roroa population in the Nina Valley is growing due to successful breeding by translocated birds. Therefore, roroa releases to the Nina should resume as soon as possible to avoid genetic overrepresentation among the progeny of the current founder group and potential inbreeding. Failure to establish the population with a sufficiently genetically diverse founder group may lead to inbreeding depression or genetic drift, which may compromise the long-term population sustainability and ultimately lead to local extinction (Groombridge *et al.* 2012; Jamieson & Lacy 2012; Weeks *et al.* 2015).

The current species management plan marks completion of the Nina reintroduction project as high priority and identifies an issue of insufficient pest control in the project area (Roroa Practitioner Group 2021). Only approximately 1,600 ha of the valley is trapped for stoats, mainly alongside the Nina River. Such an area could theoretically cover approximately 25 roroa territories, based on the observed average home range size. However, existing home ranges appear to be spread on the valley slopes, and therefore only a limited portion of each territory is managed for predators along the valley floor. Currently proposed translocation guidelines recommend that translocation project areas should provide habitat for at least 100 pairs to allow sufficient retention of genetic diversity (Department of Conservation 2018). That will require the entire Nina River catchment to be under a sustained pest control regime ideally with a buffer zone covering surrounding valleys to provide safe space for post-release or natal dispersal from the Nina Valley.

Implications for kiwi translocations

The post-translocation behaviour of roroa in the Nina Valley underscores large habitat size requirements for kiwi reintroduction projects in unfenced mainland areas. Large UDs and long dispersal paths show the need for intensive and sufficiently long post-release monitoring. This monitoring has a potential to inform management interventions such as retrieval of dispersed birds, as demonstrated in the Flora Valley (Toy & Toy 2020), or in other large flightless birds, e.g. takahē (*Porphyrio hochstetteri*; Department of Conservation 2020). Radio telemetry is a commonly used method for monitoring translocated kiwi populations, but the monitoring period and effort are highly variable, and usually, a sample of released birds is monitored for only a part of the dispersal period (Jahn *et al.* 2022a). Extended monitoring duration and increased numbers of monitored birds enable better adaptive management, detection of likely population founders based on territory establishment and breeding, and selection of future release sites based on gaps between territories. However, such approach can be more expensive, labour-intensive, and intrusive to radio-tagged birds (Toy & Toy 2021a). Subsequent periodic acoustic surveys, coupled with occupancy analysis (Jahn *et al.* 2022b) and potential identification of individuals by their calls (Digby *et al.* 2014; Dent & Molles 2016), can facilitate non-intrusive and cost-effective population monitoring. Additionally, regular genomic assessments can provide a tool to identify and manage possible inbreeding depression or genetic drift (Ramstad & Dunning 2021), and therefore maximise the probability of a long-term positive translocation outcome.

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