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RESEARCH

Spatial patterns and habitat use of penned and hard-released arboreal geckos translocated to an offshore island free of introduced mammals

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Abstract: Temporary penning prior to release is a strategy increasingly being used in lizard translocations to improve site fidelity and increase chances of translocation success. However, it is yet to be tested on a range of lizard taxa. Between 2015 and 2018, 49 individuals of a New Zealand endemic arboreal gecko species (ngahere gecko, *Mokopirirakau* "southern North Island") were translocated to mammal-free Mana Island near Wellington as mitigation for a development project. Twenty-five of these geckos were tracked for this study with geckos being either hard-released (n = 9) or released into a 0.52 ha pen for 10–31 months (n = 16). Using radio-telemetry, we compared the behaviour, habitat use, dispersal, and home ranges of geckos from both groups in the weeks immediately following removal of the pen. Hard-released geckos travelled further from their initial release point and between location fixes than penned geckos. Hard-released geckos also had a larger home range size than penned geckos using both minimum convex polygons and fixed kernel methods, albeit with significant variation among individuals within each group. Habitat use was similar in both groups, but only hard-released geckos used grass, which was unexpected due to the arboreal nature of the species. In conclusion, our results support the use of penned-releases for translocations of arboreal geckos to restrict initial post-translocation dispersal and aid population establishment.

Keywords: lizard, mitigation, *Mokopirirakau*, penning, radio-tracking, soft-release, translocation

Introduction

Many of New Zealand's extant indigenous lizards have experienced major reductions in range and abundance, as a result of the introduction of a suite of predatory mammals and large-scale habitat destruction (Whitaker 1973, 1978; Towns & Daugherty 1994). Currently, 85.9% of lizard species in New Zealand are classified as threatened or at risk under the New Zealand threat classification system (Hitchmough et al. 2021). Conservation efforts include predator control and eradication, habitat protection and enhancement, and translocations to predator-free islands or mainland sanctuaries. Mitigation-driven translocations are also becoming more frequent in New Zealand lizards, typically in response to land-use development (Germano et al. 2015; Romijn & Hartley 2016). Additionally, translocation as a climate change adaptation tool might be increasingly necessary due to rising temperatures and unstable climates (Thomas 2011; Butt et al. 2020). Hence, translocations are a particularly important conservation tool for New Zealand lizards. However, long-term success rates of reptile and amphibian translocations in New Zealand and internationally are relatively low (8–42% with a successful outcome) with many outcomes being uncertain (29–58%; Germano & Bishop 2009; Miller et al. 2014, Romijn & Hartley 2016). In New Zealand, it is difficult to confirm translocation outcomes in many endemic lizard species due to their highly cryptic lifestyles, delayed maturation, extreme longevity, and low reproductive outputs (Knox & Monks 2014; Bell & Herbert 2017). Additionally, due to the slow life-histories of most New Zealand geckos, post-release monitoring may need to span multiple decades to determine translocation success. Thus, it is vital to understand the effects of translocations on lizards, particularly on individual post-release behaviour in different scenarios, so that translocation strategies can be implemented in such a way that maximises the likelihood of a successful outcome and allow for the ability to measure and report on that outcome through post-release monitoring.

Translocation success tends to be higher if the potential negative impacts on translocated individuals are reduced and if site fidelity at the release site can be achieved, allowing populations to establish with individuals having overlapping ranges (Griffith et al. 1989; Ebrahimi & Bull 2012; Knox et al. 2017). Factors negatively affecting translocated individuals include dispersal from the release site outwards into a large landscape, potentially reducing individual interactions and leading to movement into less optimal habitat, competition for

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food and shelter resources, and increased activity levels (due to insufficient food resources, a lack of shelter, or unsettled behaviour) leading to higher predation risks (Dodd & Seigel 1991; Armstrong & McLean 1995; van Heezik et al. 2009). These factors may lead to reduced population density, increased vulnerability to predation, reduced mating opportunities and reproductive rates, and consequently increased extinction risk by lowering overall fitness or exposing the population to Allee effects (Dennis 1989; Nunney & Campbell 1993; Sullivan et al. 2004). Recent research into translocation strategies for green geckos *Naultinus* spp. has indicated that releasing geckos into a temporary enclosure (also known as a pen) improves site fidelity in released animals, and ultimately translocation success in the form of population establishment (Knox & Monks 2014). The work has ultimately resulted in a recommendation that penned release be adopted as a translocation strategy for the diurnal *Naultinus* geckos endemic to New Zealand (Flynn-Plummer & Monks 2021) and be tested for other lizards (Monks et al. 2017).

In this study we compare the effects of hard-release and penned-release strategies during translocation of the ngahere gecko *Mokopirirakau* "southern North Island", a cathemeral (neither prescriptively diurnal nor nocturnal), arboreal gecko endemic to New Zealand. This involved radio-tracking ngahere geckos translocated into an existing pen on a predator-free offshore island that were penned for 10–31 months (penned geckos), along with newly arrived geckos hard-released (hard-released geckos) into the wild without the same pen in place at release. We radio-tracked 25 geckos for six weeks across the period January 2018 to March 2018 to enable comparison of movements, behaviour, habitat use, and tendency to disperse within regenerating forest at the release location. Our hypotheses were based on similar studies and previous findings for diurnal jewelled geckos, *Naultinus gemmeus* (Knox & Monks 2014; Knox et al. 2017), and are as follows: during the entire duration of the radio-tracking programme (1) hard-released ngahere geckos will have larger, less stable, and less established home ranges compared to penned geckos; (2) hard-released geckos will show more extensive dispersal (represented as larger directional or random distances) from the release site; (3) hard-released geckos will also exhibit larger daily movements than penned geckos; and, (4) movement behaviour (i.e. microhabitat use, height above ground, and activity) will be relatively similar for individuals in the same release group regardless of sex, but differ between release groups.

Methods

Study Species

The ngahere gecko is a medium-sized (adults are c. 10–20 g and c. 75–98 mm snout-vent-length) gecko species of the lower North Island, New Zealand (Romijn et al. 2014; van Winkel et al. 2018; TB, unpubl. data). Ngahere geckos are highly cryptic and occur in forest and shrubland habitats. They have typically been found on tree trunks and branches or foliage, and occasionally on the ground or in rock crevices (Romijn et al. 2014). In an urban reserve in Wellington, radio-tracked geckos exhibited short-term site fidelity to particular trees (which are usually 7–13 m tall), with an average movement of 9.5 m per day and peak activity during the day (Romijn et al. 2014). When they are in forest/scrub edges or on rock, they are more terrestrial (Romijn et al. 2014). Threats include introduced predatory mammals (Towns & Daugherty 1994; Towns et al. 2002; Barr 2009), both indigenous and introduced avian species (Whitaker 1968; Ramsay & Watt 1971; Fitzgerald et al. 1986), habitat fragmentation and destruction due to human activities (Brockerhoff et al. 2008; Barr 2009), and potentially poaching for the black market pet trade (Jewell & McQueen 2007; Knox et al. 2012). The ngahere gecko is classified as an at risk–declining species under the New Zealand threat classification system due to their predicted decline, although there is a lack of data to support this assessment fully due to knowledge gaps (Hitchmough et al. 2021).

Translocation

Between 2015 and 2018 in the Hutt Valley, Wellington, a rock aggregate quarry underwent a six-staged expansion of 6.8 ha over an area containing a ngahere gecko population. As part of the mitigation for this construction ngahere geckos found in the construction footprint were salvaged and translocated to Mana Island and a telemetry study was undertaken to determine the effects of penning versus hard-releasing geckos. Geckos were translocated to Mana Island Scientific Reserve (−41.088466° S, 174.780744° E), a location within the historical range of the species. It is believed that 150 years of vegetation clearance for farming destroyed the original land cover and habitat for this species (Timmins et al. 1987; Miskelly 1999), and heightened populations of mice (*Mus musculus*) may also have contributed to the local extinction of the geckos on the island (Newman 1994). Since 1987, a planting programme has established more than 500 000 shrubs and trees, which has considerably increased the habitat availability on the island for these geckos. Today, c. 200 hectares of new forest and shrubland habitat is available for these geckos on the island.

During June 2015, a 0.52 hectare soft-release pen (height of 686 mm with a 100 mm lip) was constructed on Mana Island to contain the first cohort of translocated animals. The placement of the pen was decided on the basis of suitable habitat available that needed minimal vegetation cut back (i.e. dense secondary forest that included mānuka *Leptospermum scoparium*, kānuka *Kunzea ericoides*, and *Pittosporum* spp.). The pen installed was used in an attempt to "anchor" the population at the release location with the aim of encouraging the establishment of a stable and self-sustaining (i.e. functionally breeding) population. Animex® exclusion fencing (Animex®, Chicago, USA), purpose-built for containing or excluding reptiles and amphibians, was used and is sufficiently robust for the strong and gusty winds of the Wellington region.

A total of 49 ngahere geckos salvaged from the quarry through three successive salvage stages between 2015 and 2017 were released on Mana Island: quarry stages 1 and 2 geckos were released into the soft-release pen (2015–2017) and quarry stage 3 geckos were hard-released (February 2018) between 10 and 39 m from the pen site. The release sites consisted mainly of kānuka, mānuka, ngaio *Myoporum laetum*, *Olearia paniculata, Pittosporum* spp., flax *Phormium tenax*, and rank exotic grassland. Fifty-two closed-cell foam covers (Bell 2009) were installed on trees 20–25 m apart at the pen site in June 2015 and then another 52 foam covers were installed in the pen site, totalling to 104 foam covers in the pen site. A further 33 foam covers were installed in the hard-release site (10 m apart) in September 2017 to provide refugia for geckos during the establishment phase, ensure a similar microhabitat is available to geckos released at both sites, and assist with a post-release gecko monitoring programme, the results of which are to be reported separately from this study. Foam covers were installed on ngaio, kānuka, *Olearia paniculata*, and kōhūhū *Pittosporum tenuifolium* (≥ 20 cm diameter at breast height where possible). All translocated geckos were released under a foam cover.

Radio-Tracking

Twenty-five geckos were fitted with 0.78 g, 160 MHz BD-2 radio-transmitters (Holohil, Ontario, CA) in a backpack harness design, modified from van Winkel and Ji (2014). The harnesses were coloured black using a xylene-free, non-toxic, waterproof permanent marker to reduce the visibility of tracked geckos to avian predators. Transmitters were only attached to adult individuals that weighed more than 8.5 g, ensuring that the combined weight of the transmitter and harness did not exceed 7.5% of the gecko body mass (Knapp & Owens 2005).

The pen was removed on 16 January 2018. Between 13 and 28 January 2018, 16 of the geckos that were living in the penned area for 10–31 months were captured, fitted with transmitters, and then released in the same spot that they were caught. Nine geckos, fitted with transmitters, were hard-released into a pre-selected area with similar habitat near the penned area on 4 February 2018. The geckos were radio-tracked between 13 January and 10 March 2018 using a TR-4 receiver (Telonics, Inc., Arizona, USA) and a hand-held three-element Yagi antenna (Sirtrack, Hawkes Bay, NZ). The Yagi antenna and receiver was used to home in on the approximate location of the gecko, and then the receiver without the antenna was used to home in on the precise location of the gecko. We randomly selected a different animal to be tracked first during each tracking session and the remaining individuals were tracked in a logical order to minimise disturbance. Tracking was carried out twice a day (around 1000 and 2200 hours) for 12 days on and 3 days off, weather permitting. Weather variables were recorded before the beginning of each tracking session. These included the time at recording, air temperature (°C) at a minimum of 1.3 m above the ground in the shade, cloud cover (estimated as eighths of the sky covered), wind speed (km s^{-1}, anemometer), and observed rainfall (mm, National Institute of Water and Atmospheric Research's CliFlo database; www.cliflo.niwa.co.nz). During the initial release of each gecko, morphometric measurements were recorded: sex, reproductive status, snout-to-vent length (SVL), vent-to-tail length (VTL), and weight. Global positioning system (GPS) coordinates were recorded at the initial release site and dorsal photographs were taken of each individual for identification purposes. At each subsequent location fix, microhabitat, vegetation species, height of vegetation, height of the gecko above ground, distance and bearing from the previous fix, and activity were recorded when possible.

Statistical Analysis

All statistical analyses were performed in the statistical programme R (v1.0.153; R Core Team 2021), where $p < 0.05$ was considered to be statistically significant and missing values were omitted from analysis. Effect sizes (eta squared) were estimated by dividing the sum of squares by the total sum of squares, which were calculated using a linear regression model. Effect sizes were considered small > 0.02, medium > 0.13, and large > 0.26 (Cohen 1988). Mean values are shown with the standard error (SE). If assumptions of the homogeneity of variances and normality were not satisfied, data were log transformed. Collinearity between factors were tested using variance inflation factor (VIF) scores using the car package (Fox & Weisberg 2011), with VIF scores > 10 used to indicate a strong correlation between variables. As all factors had a VIF score < 10, they were all included in subsequent analyses.

For dispersal and microhabitat selection, we performed linear mixed models (LMMs) using the lme4 package (Bates et al. 2015) and Type II Wald chi-square tests in the car package (Fox & Weisberg 2011) were used to estimate *p*-values. The fixed factors included release type, sex, temperature, rainfall, SVL, and the interaction between release type and sex. The dependent variables were analysed separately and included (1) straight-line distances between fixes and (2) the height of the gecko above ground. Individual gecko was included as a random effect to account for sampling individuals multiple times and the location fix number, date, and time were also included as random effects. The hours between each fix were added as an offset. A linear model (LM) was performed to determine which factors influenced the straight-line distance between the release point and location of each gecko at the end of the study (dependent variable). The fixed factors included were release type, sex, SVL, and the interaction between release type and sex. The hours between the initial and final fix were added as an offset. The proportional similarity index (Psi) was used to measure the overlap between two populations, penned and hard-released geckos, using the formula:

$$\text{'Schoener's D'} = 1 - 0.5(\sum |p_{xi} - p_{yi}|) \quad (1)$$

where p_{xi} is the proportion of item i used by release group x and p_{yi} is the proportion of item i used by release group y. The pairwise overlap was then calculated using the Psi between each group using the 'RInSp' package (Zaccarelli et al. 2013). This was used to compare activity, and the usage of tree species and microhabitat type between the two release types. The null hypothesis was tested to determine whether the observed variation in behaviour and microhabitat use arose by chance by randomising the release group for each individual's proportion of use for each variable and replicating this 10 000 times. A two-tailed *p*-value was calculated using the formula:

$$p = 2x_n x_o y \quad (2)$$

where x_n is the null overlap value, x_o is the observed overlap value, and y is the number of replications performed in the null hypothesis.

Home Ranges

Home range sizes were estimated, firstly, by converting the distance travelled and bearing from the previous fix data into coordinates in order to be used in the RANGES9 software v1.5 (Kenward et al. 2014). This was done using basic trigonometry and the first GPS coordinate in Microsoft Excel:

$$\text{x-coordinate}_f = \text{x-coordinate}_i + (D * \cos\theta) \quad (3)$$
$$\text{y-coordinate}_f = \text{y-coordinate}_i + (D * \sin\theta) \quad (4)$$

where coordinate_f = coordinate for current fix, coordinate_i = coordinate from previous fix, D = distance travelled from the coordinate_i to coordinate_f coordinate (m), and θ = angle from coordinate_i to coordinate_f (radians). We used 95% minimum convex polygons (MCPs; Mohr 1947) using a harmonic mean peel centre (Hc) to estimate the home range area and the 50% and 95% fixed kernel estimate (Worton 1987), using the default parameters for the smoothing function, to determine core areas of activity (utilisation distribution; Seaman & Powell 1996). A maximum of 95% was used to mitigate the effects of outliers for both methods and to avoid overestimation in home range sizes using kernel methods, since a 100% kernel includes areas that individuals are not observed in (Powell 2000; Grueter et al. 2009; Powell & Mitchell 2012).

LMMs were performed and *p*-values were estimated using Type II Wald chi-square tests to determine which predictor variables (release type, sex, SVL, and the interaction between the release type and sex) were important in explaining variation in home range size among individuals. The location fix number was used as a random effect to account for differences in the number of fixes between individuals.

Results

From 13 January to 10 March 2018, each animal was located telemetrically between 4 and 43 times to form a total of 507 fixes from 25 geckos with an average of 21 fixes (SE ± 2.4) per gecko. The length of tracking of a particular individual ranged from 4 to 52 days (mean = 26 days) as some transmitters came off earlier with sloughed skin. Additionally, there was no significant difference in weight between geckos pre and post transmitter attachment (Welch two sample *t*-test, $t = 0.27$, df = 20, $p > 0.5$).

For the distance between fixes, height above ground, and distance between initial and final fixes, respectively, penned geckos had a mean ± SE of 3.0 ± 0.2 m, 2.2 ± 0.1 m, and 12.7 ± 2.9 m while hard-released geckos had a mean ± SE of 6.0 ± 0.7 m, 1.7 ± 0.1 m, and 38.1 ± 13.8 m. Release type was found to be significant ($p \leq 0.01$) with a large effect size (> 0.26) that influenced the distance travelled between fixes and distance between initial and final fixes (Tables 1, 2). Hard-released geckos travelled further between fixes and from the release point (Tables 1, 2). Sex and the interaction between release type and sex were also found to significantly ($p < 0.02$) influence the height of a gecko above ground (Table 1). However, only the effect size of the interaction between the release type and sex was large (> 0.26; Table 1). Notably, the use of grass was only observed in the hard-release group and they were also observed on tree trunks more than penned geckos were (Fig. 1). In contrast, penned geckos were observed to use foliage and foam covers nearly double that of the hard-release group (Fig. 1). However, the overall observed microhabitat use and behaviour of penned and hard-released geckos had high overlap, where none of these variables were significantly different between release types (mean pairwise overlap: 0.78 for vegetation species, $p = 0.85$; 0.77 for microhabitat type, $p = 0.13$; and 0.96 for activity, $p = 0.19$).

Home range sizes of geckos were estimated using 10–43 location fixes for each of the 12 penned and 7 hard-released geckos (with four penned and two hard-released individuals excluded in this study due to having < 10 fixes; Table 3). The mean 95% MCP estimate was 121.1 m^2 (SE ± 19.3) for penned geckos and 423.4 m^2 (SE ± 146.0) for hard-released geckos (Table 3, Fig. 2a). The mean 95% fixed kernel estimate was 148.3 m^2 (SE ± 42.5) for penned geckos and 465.0 m^2 (SE ± 127.7) for hard-released geckos (Table 3; Fig. 2b). The core areas (50% fixed kernel) for penned geckos ranged from 6.97

Table 1. Results for the linear mixed models with individual as a random effect and distance between fixes ($n = 507$) and height off the ground ($n = 251$) as dependent variables. Hours between fixes was added as an offset. The intercepts that were chosen to calculate the estimate are in brackets next to each of the predictor variables. Significant *p*-values (< 0.05) and large effect sizes (> 0.26) are indicated in **bold**.

Predictor variables	Dependent variables: Distance between fixes (m) *t*-value	Estimate ± SE	*p*-value	Effect size	Height above ground (m) *t*-value	Estimate ± SE	*p*-value	Effect size
Release type (Penned)	−–0.51	−1.92 ± 3.74	**0.02**	**0.64**	3.54	1.45 ± 0.41	0.50	0.02
Sex (Male)	1.22	4.45 ± 3.66	0.47	0.07	4.71	1.86 ± 0.39	**0.005**	**0.32**
SVL	1.15	0.26 ± 0.23	0.25	0.12	1.73	0.04 ± 0.02	0.08	0.03
Temperature	0.64	0.06 ± 0.10	0.52	0.05	0.28	0.01 ± 0.03	0.78	< 0.001
Rainfall	0.23	0.01 ± 0.05	0.82	0.006	−1.57	−0.03 ± 0.02	0.12	0.07
Release type (Penned): Sex (Male)	−0.98	−4.31 ± 4.40	0.33	0.12	−3.80	−1.81 ± 0.48	**< 0.001**	**0.57**

Table 2. Results for the linear model with distance between initial and final fixes ($n = 25$) as the dependent variable and total hours between the initial and final fix as an offset. The intercepts that were chosen to calculate the estimate are in brackets next to each of the predictor variables. Significant *p*-values (< 0.05) and large effect sizes (> 0.26) are indicated in **bold**.

Predictor variables	*f*-value	Estimate ± SE	*p*-value	Effect size
Release type (Penned)	10.27	−5.69 ± 19.99	**0.005**	**0.29**
Sex (Male)	0.92	46.25 ± 19.70	0.42	0.06
SVL	2.74	2.13 ± 1.29	0.11	0.05
Release type (Penned): Sex (Male)	3.74	−46.14 ± 23.87	0.07	0.10

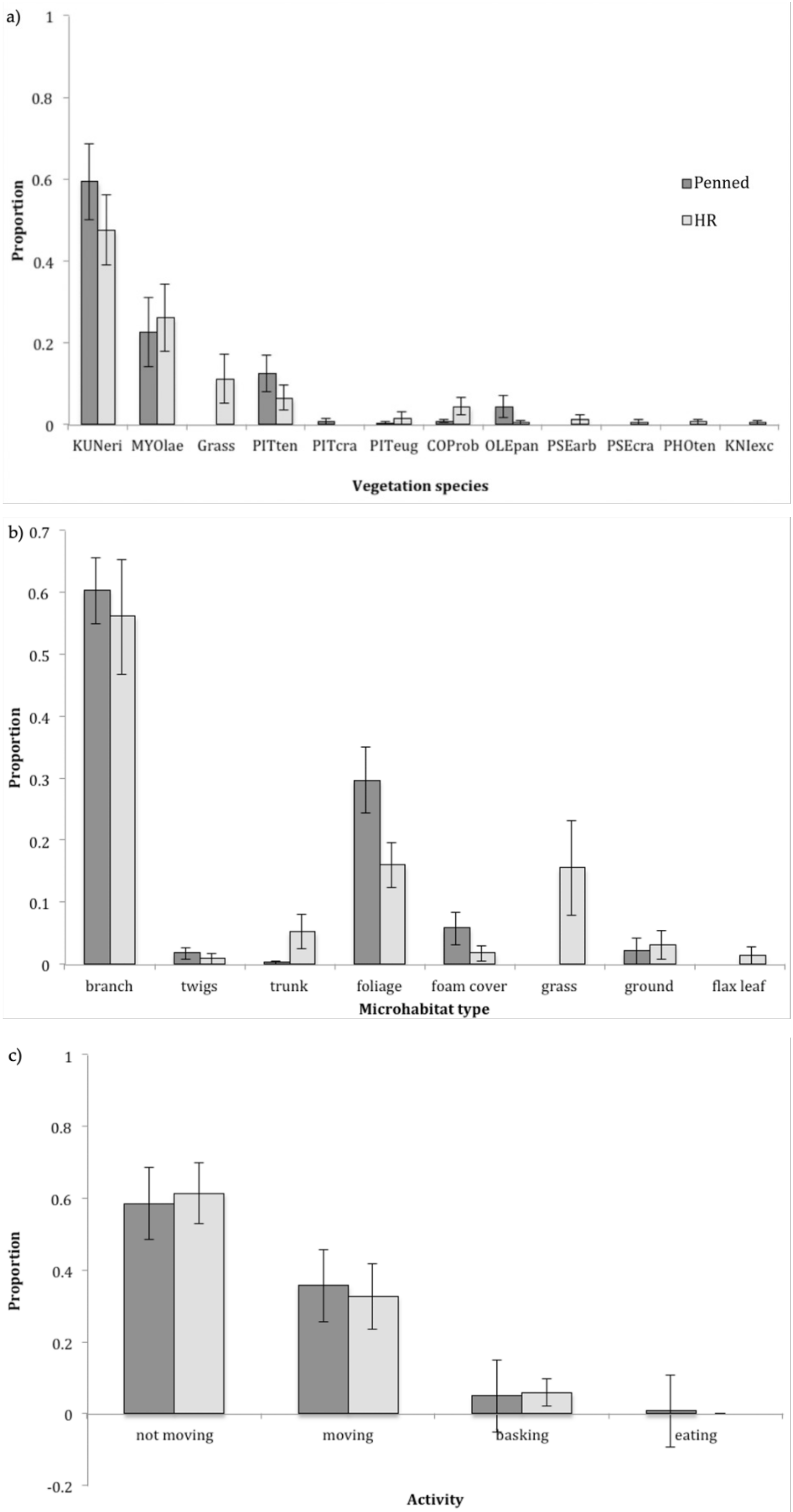

Figure 1. Mean proportion of usage of each (a) vegetation species, (b) microhabitat type, and (c) activity in penned (dark grey; *n* = 16) and hard-release (HR; light grey; *n* = 10) ngahere geckos on Mana Island. Error bars represent the standard error. Plant abbreviations: KUNeri = *Kunzea ericoides*, MYOlae = *Myoporum laetum*, Grass = unknown grass species, PITten = *Pittosporum tenuifolium*, PITeug = *Pittosporum eugenioides*, PITcra = *Pittosporum crassifolium*, COProb = *Coprosma robusta*, OLEpan = *Olearia paniculata*, PSEarb = *Pseudopanax arboreus*, PSEcra = *Pseudopanax crassifolius*, PHOten = *Phormium tenax*, and KNIexc = *Knightia excelsa*.

Table 3. Home range area of hard-release and penned ngahere geckos on Mana Island, estimated by the MCP and fixed kernel methods (n = 19).

ID	Sex	SVL (mm)	Weight (g)	No. of fixes	95% MCP (m^2)	95% fixed kernel (m^2)	50% fixed kernel (m^2)
Penned							
1	M	75	9.80	35	198.79	89.25	25.14
2	F	76	11.48	32	169.03	178.56	52.23
3	M	78	10.28	33	240.65	263.6	91.34
4	F	83	14.11	12	54.31	59.04	18.59
5	M	90	14.76	43	119.26	188.52	47.55
6	M	86	15.02	39	106.97	93.76	31.72
7	M	88	12.66	10	117.79	88.25	38.27
8	M	85	12.53	12	187.12	554.68	127.59
9	M	80	12.22	14	39.72	16.52	6.97
10	M	85	13.53	24	31.08	27.01	12.61
11	F	83	14.82	30	119.58	159.51	42.43
12	F	84	12.57	28	68.57	60.73	16.44
Mean ± SE		82.75 ± 1.24	12.82 ± 0.46	26 ± 3.04	121.07 ± 19.30	148.29 ± 42.54	42.57 ± 9.339
Hard-release							
13	M	73	10.64	19	47.68	96.88	25.73
14	F	81	11.98	32	43.81	44.36	13.57
15	M	77	13.13	31	116.84	314.1	70.32
16	M	83	14.55	23	1058.87	747.78	291.68
17	M	83	11.76	23	419.01	492.01	165.96
18	M	72	8.88	29	538.99	592.22	146.59
19	M	78	11.70	30	738.28	967.74	243.32
Mean ± SE		78.14 ± 1.70	11.81 ± 0.68	26.71 ± 1.89	423.35 ± 146.03	465.01 ± 127.69	136.74 ± 40.30

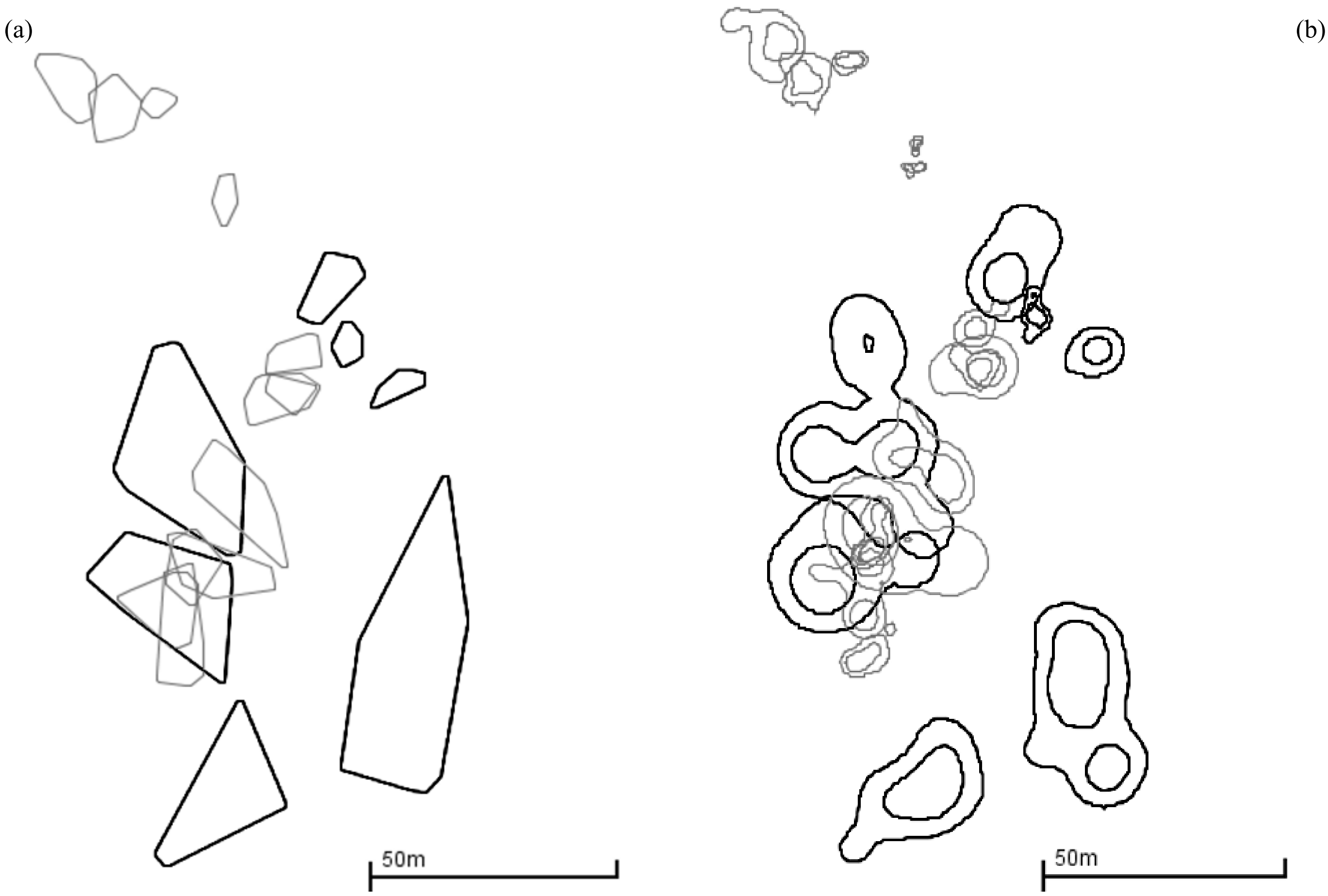

Figure 2. (a) The 95% MCP estimate of home range size for the hard-release (black, n = 7) and penned (grey, n = 12) ngahere geckos on Mana Island. Each polygon represents a single individual's home range area. (b) The 50% (inner) and 95% fixed kernel (outer) contours for the hard-release (black, n = 7) and penned (grey, n = 12) ngahere geckos on Mana Island.

to 127.6 m^2 (42.6 ± 9.3), representing 23%–46.7% of each animal's total home range area (here the 95% fixed kernel was considered to be the total home range area). Core areas for the hard-released geckos ranged from 13.6 to 291.7 m^2 (136.7 ± 40.3), representing 22.4–39% of each animal's total home range area. Only the release type was found to significantly ($p < 0.04$) influence home range size for both home range estimates, whereas no significant correlation was found between home range size and sex or SVL using either home range estimate ($p > 0.1$; Table 4). Penned geckos were found to have smaller home range sizes than hard-released geckos using both home range estimates (Fig. 2a,b; Tables 4, 5; LMM $p < 0.05$). Both penned and hard-released geckos exhibited substantial variation in home range size among individuals within each group (one sample *t*-test, 95% MCPpen: $t = 6.3$, df = 11, $p < 0.001$; 95% kernelpen: $t = 3.5$, df = 11, $p = 0.005$; 95% MCPHR: $t = 2.9$, df = 6, $p = 0.03$; 95% kernelHR: $t = 3.6$, df = 6, $p = 0.01$).

Discussion

Home Ranges and Dispersal

This study suggests that penned individuals had a reduction in post-release dispersal, as shown by their smaller home range sizes, smaller daily distances travelled, and smaller distances between the initial and final locations than the hard-released geckos. All penned geckos remained within the penned area during the entire tracking programme, despite the pen being removed, whereas many of the hard-released geckos immediately moved out of the hard-release area. This increased dispersal and home range size in hard-released geckos increases the likelihood that these individuals may disperse far from the release site potentially making it difficult for them to find mates, thus, reducing the probability that they will contribute to a breeding population. Therefore, the rate of population growth and likelihood of population establishment may be reduced. The hard-released geckos' greater dispersal might be a result of their exploratory behaviour involving searching for better resources and retreat sites, as they were not accustomed to this new environment. Alternatively, it may be that the hard-released geckos were searching for familiar features that were present in their previous home range prior to being translocated.

These findings support our hypotheses that hard-released ngahere geckos will have larger, less stable, and less established home ranges compared to penned geckos (hypothesis 1), show extensive dispersal from the release site (hypothesis 2), and have larger daily movements than penned geckos (hypothesis 3). Our results are consistent with past studies using penning and other soft-release methods in other lizard species (Ebrahimi & Bull 2012; Knox & Monks 2014; Knox et al. 2017).

The 50% fixed kernel home range estimates represent the core areas of each of the geckos, from which individuals in our study generally had one to two main core areas of activity within their home range. These areas of highest activity in an individual's home range area are often associated with their home or refuge sites and basking sites (Osterwalder et al. 2004, Kerr & Bull 2006, Stevens et al. 2010). In our study these areas likely concentrate around a specific tree or group of trees, particularly for penned geckos, while hard-release individuals tended to have larger core areas making it unlikely that site fidelity to a particular tree or group of trees was occurring, a behaviour observed previously in this species (Romijn et al. 2014). Thus, penning is likely to improve translocation success in *Mokopirirakau* spp. translocations by improving site fidelity to release sites. However, exhibition of site fidelity may be species-specific or somewhat habitat-specific, so more studies investigating site fidelity in other arboreal lizard species and other habitat types would further support this idea that penning improves translocation success for arboreal lizards. In addition, whether penning is necessary for terrestrial lizard species requires more study, as some species have displayed a lack of homing and significant post-release movements post translocation, such as hard-releases of *Woodworthia* cf. *brunnea* (Lettink 2007) and *Oligosoma grande* (Whitmore et al. 2011).

Moreover, the efficacy of penning may be dependent on the length of confinement (Tetzlaff et al. 2019). A previous study confining *Tiliqua adelaidensis* showed that lizards confined for longer were more likely to disperse, although only a short confinement period (one vs five days) was tested (Ebrahimi & Bull 2013). Thus, for penning to be beneficial to lizards, they may need to be confined for a longer time period (i.e. several months to greater than a year) as seen in our study (> 12 months) and others (9 months, Knox & Monks 2014; 4 months, Knox et al. 2017;).

Additionally, there was substantial variation in home range size among individuals within each of the two release

Table 4. Results for the linear mixed models with the number of fixes as a random effect and home range size ($n = 19$) as dependent variables. The intercepts that were chosen to calculate the estimate are in brackets next to each of the predictor variables. Significant *p*-values (< 0.05) and large effect sizes (> 0.26) are indicated in **bold**.

Predictor variables		*t*-value	Estimate ± SE	*p*-value	Effect size
95% MCP	Release type (Penned)	0.21	0.005	**0.005**	**0.67**
	Sex (Male)	1.87	0.05	0.24	0.10
	SVL	0.74	0.0009	0.39	0.01
	Release type (Penned): Sex (Male)	−1.58	−0.05	0.07	0.21
95% fixed kernel estimate	Release type (Penned)	0.02	0.007	**0.003**	**0.65**
	Sex (Male)	0.02	0.05	0.13	0.13
	SVL	0.001	0.0009	0.38	0.01
	Release type (Penned): Sex (Male)	0.02	−0.05	**0.04**	0.21

types with home range sizes ranging between 43.8 and 1058.9 m^2 and 31.1 and 240.7 m^2 (95% MCP) for hard-release and penned geckos, respectively. This variation suggests ngahere geckos might exhibit behavioural flexibility among individuals.

Microhabitat Use and Behaviour

In both release groups, the most selected for plant species appeared to be kānuka, ngaio, and kōhūhū. Typical microhabitat use in both release groups included tree branches, foliage, trunks, and foam covers, with geckos less frequently recorded on twigs or on the ground. Geckos were predominately found on branches more than any other microhabitat, regardless of release type. The use of the grassland microhabitat in hard-released geckos was unexpected as this is highly atypical behaviour for an arboreal gecko species and likely reflects the stressed state of the geckos upon release into a new environment. The importance of the role of grass, and other ground cover, as refugia for stressed lizards in translocation projects may be underappreciated. Penned geckos used foliage and foam covers more frequently, suggesting that these geckos might have some familiarity with where the foam covers were located and chose to occupy these when not in the canopy. In contrast, the hard-released geckos were likely to be less familiar with their new environment and hence were not as frequently recorded in foam covers, but more on tree trunks. Despite there being slight differences in microhabitat use as discussed above, overall microhabitat use was not significantly different between release types. Additionally, the geckos showed no significant difference in whether they were moving or not moving, resting, or basking behaviour.

Sex and the interaction between release type and sex influenced the height a gecko was found at. The significant differences observed in the interaction of the release type and sex for the gecko height above ground are likely due to the differing sex ratios in the release types rather than a true interaction effect. Males were found at greater heights than females, which might be due to males searching for females by travelling between trees from the canopy. However, it is unknown whether our study was undertaken during the breeding season with only one individual (penned) being pregnant, however, most other New Zealand geckos tend to mate in autumn (Cree & Hare 2016). Males at greater heights than females are also observed in another arboreal lizard species, such as the brown anole *Anolis sagrei* (Herrmann et al. 2018). However, the opposite has been observed in a closely related *Mokopirirakau* species (*M. granulatus*; Schlesselmann 2014; T Bell, J Monks, S Herbert, unpubl. data).

Weather variables often have an impact on lizard behaviour and home range size (Hoare et al. 2013; Parlin et al. 2020; Fisher et al. 2020), however, in our study temperature and rainfall did not show an impact on lizard behaviour and movements.

From these findings on microhabitat use and behaviour our hypothesis that movement behaviour would differ between release types regardless of sex (hypothesis 4) was not supported, as height above ground and microhabitat use did not significantly differ between release groups and sex affected height both within and between release groups.

Limitations

In our study, the MCP estimator using 100% MCP data required at least 30 location fixes to reach an asymptote in the incremental area analysis (Appendices S1 and S2 in Supplementary Materials), indicating a fully revealed home range (Harris et al. 1990), however, we included individuals that had less than 30 location fixes (six penned and four hard-release individuals) so the home range estimates here are likely to be underestimates. Since we were comparing spatial use between two release types, both release types should represent underestimates of their home ranges so our concluding results should not be impacted.

Since tracking of the hard-release geckos started later than that of penned geckos, our results may be affected by warmer weather permitting greater activity in one group. However, this is unlikely as temperature did not influence distances between fixes and even though penned geckos were tracked in the warmer month of January, they did not show larger home range sizes or dispersal.

Future Studies and Implications

Our study was undertaken over a relatively short time period (radio-tracking for 4–52 days) so further studies investigating the dispersal of translocated lizards over longer time periods would provide insights on whether our findings are consistent over time. This is important to investigate as hard-release lizards may initially disperse further before settling in an area soon after, a scenario that may have not been captured within the time period of our study. Moreover, penned geckos might have remained in a relatively small home range area due to not realising that the pen was removed, while in a prolonged study penned geckos may disperse further away from the release site. Additionally, penned geckos may exhibit home site shifts (e.g. during different seasons) leading to greater dispersal that was not captured in our short-term study.

This study builds on previous work on jewelled geckos (Knox & Monks 2014; Knox et al. 2017) by using a different arboreal gecko species to determine whether findings that penning decreases post-translocation dispersal are consistent for other arboreal species. Penning likely has contributed to early stage population establishment of ngahere geckos on Mana Island in this translocation (this study; TB, unpubl. data). The ways in which penning contributed to establishment likely includes (1) restriction of large-ranging movements seen in released geckos, as noticed in the hard-release group, thus preventing dispersal of geckos over the wider landscape; (2) the pen acting as a safety mechanism for disoriented geckos showing atypical behaviour in released geckos, until they have settled into their new environment; and, (3) once the geckos were settled and familiar with their new environment, this enabled the geckos to establish home ranges of various sizes in proximity to others, thus facilitating interactions and breeding, and in the medium to longer term, population recruitment. In addition to this, the pen has facilitated successful post-translocation population monitoring, which has confirmed the population as having tentatively arrived at Translocation Success Stage 2 (evidence of reproduction; Miller et al. 2014; TB, unpubl. data).

Summary

Currently, little is known of ngahere geckos so our study is vital in understanding their spatial use and the efficacy of penned vs hard-release techniques in translocations of arboreal geckos. To summarise, we found that geckos that were hard-released had larger home range sizes and dispersed further. Microhabitat use and behaviour did not significantly differ between release types. However, there was considerable individual variation in home range sizes within each release type, suggesting that ngahere geckos exhibit plasticity in their spatial use. Thus, our results suggest that penning improves translocation success of this species. Moreover, our study provides insight on the microhabitat selection and home ranges of translocated ngahere geckos, although long-term studies would allow for a more complete understanding of these aspects of life history in this species.

This research is useful for improving lizard translocation protocols in New Zealand as it has been shown that penning may enhance translocation success by reducing dispersal and increasing site fidelity to release sites (Knox & Monks 2014; Knox et al. 2017; this study). Thus, it is recommended that a release strategy utilising pens be used for future relocations and translocations of any arboreal gecko species where founder populations are to be released into new locations where the species is not already present. Pens are also recommended where a population monitoring programme is to be implemented post-release.

Author contributions

GY, TB, and JM contributed to the conceptualisation and methodology of the study. GY and TB collected the field data. GY conducted the statistical analysis and original draft preparation. All authors contributed to writing, reviewing, and editing.

Data and Code Availability

The data and code from this article are openly available at https://github.com/graceyee/ngahere-gecko-radiotracking.

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References

Armstrong DP, McLean IG 1995. New Zealand translocations: theory and practice. Pacific Conservation Biology 2: 39–54.

Bates D, Mächler M, Bolker B, Walker S 2015. Fitting linear mixed-effects models using lme4. Journal of Statistical Software 67(1): 1–48.

Barr BP 2009. Spatial ecology, habitat use, and the impacts of rats on chevron skinks (*Oligosoma homalonotum*) on Great Barrier Island. Unpublished MSc thesis. Massey University, Auckland, New Zealand.

Bell TP 2009. A novel technique for monitoring highly cryptic lizard species in forests. Herpetological Conservation and Biology 4: 415–425.

Bell TP, Herbert, SM 2017. Establishment of a self-sustaining population of a long-lived, slow-breeding gecko species (Diplodactylidae: *Hoplodactylus duvaucelii*) evident 15 years after translocation. Journal of Herpetology 51(1): 37–46.

Brockerhoff EG, Shaw WB, Hock B, Kimberley M, Paul T, Quinn J, Pawson S 2008. Re-examination of recent loss of indigenous cover in New Zealand and the relative contributions of different land uses. New Zealand Journal of Ecology 32: 115–126.

Butt N, Chauvenet ALM, Adams VM, Beger M, Gallagher RV, Shanahan DF, Ward M, Watson JEM, Possingham HP 2020. Importance of species translocations under rapid climate change. Conservation Biology 35(3): 775–783.

Cohen J 1988. Statistical power analysis for the behavioral sciences. 2nd edn. USA: Laurence Erlbaum Associates. 567 p.

Cree A, Hare K 2016. Reproduction and life history of New Zealand lizards. In: Chapple D ed. New Zealand lizards. Switzerland, Springer. Pp. 169–206.

Dennis B 1989. Allee effects: population growth, critical density, and the chance of extinction. Natural Resource Modeling 3: 481–538.

Dodd CK, Seigel RA 1991. Relocation, repatriation, and translocation of amphibians and reptiles: are they conservation strategies that work? Herpetologica 47: 336–350.

Ebrahimi M, Bull CM 2012. Food supplementation reduces post-release dispersal during simulated translocation of the endangered pygmy bluetongue lizard *Tiliqua adelaidensis*. Endangered Species Research 18: 169–178.

Ebrahimi M, Bull CM 2013. Determining the success of varying short-term confinement time during simulated translocations of the endangered pygmy bluetongue lizard (*Tiliqua adelaidensis*). Amphibia-Reptilia 34: 31–39.

Fisher M, Muth A, Johnson RF 2020. A long-term study of home range of Coachella fringe-toed lizards, *Uma inornata*. Journal of Herpetology 54(2): 174–182.

Fitzgerald BM, Meads MJ, Whitaker AH 1986. Food of the kingfisher (*Halcyon sancta*) during nesting. Notornis 33: 23–32.

Flynn-Plummer T, Monks JM 2021. Penned release reduces area use by translocated barking geckos (*Naultinus punctatus*). New Zealand Journal of Ecology 45: 3432.

Fox J, Weisberg S 2011. An R Companion to Applied Regression. 2nd edn. Thousand Oaks, SAGE. 449 p.

Germano JM, Bishop PJ 2009. Suitability of amphibians and reptiles for translocation. Conservation Biology 23: 7–15.

Germano JM, Field KJ, Griffiths RA, Clulow S, Foster J, Harding G, Swaisgood RR 2015. Mitigation-driven translocations: are we moving wildlife in the right direction? Frontiers in Ecology and the Environment 13: 100–105.

Griffith B, Scott JM, Carpenter JW, Reed C 1989. Translocation as a species conservation tool: status and strategy. Science 245: 477–480.

Grueter CC, Li D, Ren B, Wei F 2009. Choice of analytical method can have dramatic effects on primate home range estimates. Primates 50: 81–84.

Harris S, Cresswell WJ, Forde PG, Trewhella WJ, Woollard T, Wray S 1990. Home-range analysis using radio-tracking data–a review of problems and techniques particularly as applied to the study of mammals. Mammal Review 20: 97–123.

Herrmann N, Yates SS, Fredette JR, Leavens MK, Moretti R, Reynolds RG 2018. Lizards on islands within islands: microhabitat use, movement, and cannibalism in *Anolis sagrei* (brown anole) and *Anolis smaragdinus* (Bahamas green anole). Caribbean Naturalist 1–17.

Hitchmough R, Barr BP, Knox C, Lettink M, Monks JM, Patterson GB, Reardon JT, van Winkel D, Rolfe J, Michel P 2021. Conservation status of New Zealand reptiles, 2021. Wellington, Department of Conversation. 15 p.

Hoare J, Melgren P, Chavel E 2013. Habitat use by southern forest geckos (*Mokopirirakau* "southern forest") in the Catlins, Southland. New Zealand Journal of Zoology 40: 129–136.

Jewell T, McQueen S 2007. Habitat characteristics of jewelled gecko (*Naultinus gemmeus*) sites in dry parts of Otago. DOC Research and Development Series 286. Science and Technical Publishing. Wellington, Department of Conservation. 19 p.

Kenward R, Casey N, Walls S, South AB 2014. Ranges 9: For the analysis of tracking and location data. Online manual. Wareham, UK, Anatrack Ltd.

Kerr GD, Bull CM 2006. Exclusive core areas in overlapping ranges of the sleepy lizard, *Tiliqua rugosa*. Behavioral Ecology 17: 380–391.

Knapp C, Owens AK 2005. An effective new radio transmitter attachment technique for lizards. Herpetological Review 36: 264–266.

Knox CD, Cree A, Seddon PJ 2012. Direct and indirect effects of grazing by introduced mammals on a native, arboreal gecko (*Naultinus gemmeus*). Journal of Herpetology 46: 145–152.

Knox CD, Monks JM 2014. Penning prior to release decreases post-translocation dispersal of jewelled geckos. Animal Conservation 17: 18–26.

Knox CD, Jarvie S, Easton LJ, Monks JM 2017. Soft-release, but not cool winter temperatures, reduces post-translocation dispersal of jewelled geckos. Journal of Herpetology 51(4): 490–496.

Lettink M 2007. Detectability, movements and apparent lack of homing in *Hoplodactylus maculatus* (Reptilia: Diplodactylidae) following translocation. New Zealand Journal of Ecology 31(1): 111–116.

Miller KA, Bell TP, Germano JM 2014. Understanding publication bias in reintroduction biology by assessing translocations of New Zealand's herpetofauna. Conservation Biology 28: 1045–1056.

Miskelly C 1999. Mana Island ecological restoration plan. Wellington, Department of Conservation. 136 p.

Mohr CO 1947. Table of equivalent populations of North American small mammals. American Midland Naturalist 37: 223–249.

Monks J, Knox C, Sidaway K 2017. Best practice techniques for the translocation of green geckos (*Naultinus* spp.). Wellington, Department of Conservation. 8 p.

Newman DG 1994. Effects of a mouse, *Mus musculus*, eradication programme and habitat change on lizard populations of Mana Island, New Zealand, with special reference to McGregors skink, *Cyclodina macgregori*. New Zealand Journal of Zoology 21(4): 443–456.

Nunney L, Campbell KA 1993. Assessing minimum viable population size: demography meets population genetics. Trends in Ecology & Evolution 8: 234–239.

Osterwalder K, Klingenböck A, Shine R 2004. Field studies on a social lizard: Home range and social organization in an Australian skink, *Egernia major*. Austral Ecology 29: 241–249.

Parlin AF, Schaeffer PJ, Jezkova T 2020. Modelling the effect of environmental temperatures, microhabitat and behavioural thermoregulation on predicted activity patterns in a desert lizard across its thermally diverse distribution. Journal of Biogeography 47(11): 2315–2327.

Powell R 2000. Animal home ranges and territories and home range estimators. In: Boitani L, Fuller TK eds. Research techniques in animal ecology: Controversies and consequences. New York, Columbia University Press. Pp. 65–110.

Powell RA, Mitchell MS 2012. What is a home range? Journal of Mammalogy 93: 948–958.

Ramsay GW, Watt JC 1971. Notes on the birds of Great Island, Three Kings Islands. Notornis 18: 287–290.

Romijn RL, Hartley S 2016. Trends in lizard translocations in New Zealand between 1988 and 2013. New Zealand Journal of Zoology 43: 191–210.

Romijn RL, Nelson NJ, Monks JM 2014. Forest geckos (*Mokopirirakau* "Southern North Island") display diurno-nocturnal activity and are not reliant on retreats. New Zealand Journal of Zoology 41(2): 103–113.

R Core Team 2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Schlesselmann AK 2014. Habitat use and behaviour by forest geckos (*Mokopirirakau granulatus*) in relation to predator control on Waiheke Island, Hauraki Gulf, New Zealand. Unpublished Post-graduate Diploma dissertation. University of Otago, Dunedin.

Seaman DE, Powell RA 1996. An evaluation of the accuracy of kernel density estimators for home range analysis. Ecology 77: 2075–2085.

Stevens TA, Evans MC, Osborne WS, Sarre SD 2010. Home ranges of, and habitat use by, the grassland earless dragon (*Tympanocryptis pinguicolla*) in remnant native grasslands near Canberra. Australian Journal of Zoology 58: 76–84.

Sullivan BK, Kwiatkowski MA, Schuett GW 2004. Translocation of urban Gila Monsters: a problematic conservation tool. Biological Conservation 117: 235–242.

Tetzlaff SJ, Sperry JH, DeGregorio BA 2019. Effects of antipredator training, environmental enrichment, and soft release on wildlife translocations: A review and meta-analysis. Biological Conservation 236: 324–331.

Thomas CD 2011. Translocation of species, climate change, and the end of trying to recreate past ecological communities. Trends in Ecology & Evolution 26(5): 216–221.

Timmins SM, Atkinson IAE, Ogle CC 1987. Conservation opportunities on a highly modified island: Mana Island, Wellington, New Zealand. New Zealand Journal of Ecology 10: 57-65.

Towns DR, Daugherty CH 1994. Patterns of range contractions and extinctions in the New Zealand herpetofauna following human colonisation. New Zealand Journal of Zoology 21: 325–339.

Towns DR, Neilson KA, Whitaker AH 2002. North Island *Oligosoma* spp. skink recovery plan. Threatened species recovery plan 48. Wellington, Department of Conservation. 60 p.

van Heezik Y, Maloney RF, Seddon PJ 2009. Movements of translocated captive-bred and released Critically

Endangered kaki (black stilts) *Himantopus novaezelandiae* and the value of long-term post-release monitoring. Oryx 43: 639–647.
van Winkel D, Ji W 2014. Attaching radio-transmitters to geckos: Trials and tribulations. Herpetological Review 45: 13–17.
van Winkel D, Baling M, Hitchmough R 2018. Reptiles and amphibians of New Zealand: A field guide. Auckland, Auckland University Press. 376 p.
Whitaker AH 1968. The lizards of the Poor Knights Islands, New Zealand. New Zealand Journal of Science 11: 623–651.
Whitaker AH 1973. Lizard populations on islands with and without Polynesian rats *Rattus exulans* (Peale). Proceedings of the New Zealand Ecological Society 20: 121–130.
Whitaker AH 1978. The effects of rodents on amphibians and reptiles. In: Dingwall PR, Atkinson IAE, Hay C eds. The ecology and control of rodents in New Zealand nature reserves. Wellington, New Zealand Department of Lands and Survey information series No. 4. Pp 75–88.
Whitmore N, Judd LM, Mules RD, Webster TA, Madill SC, Hutcheon AD 2011. A trial wild-wild translocation of the critically endangered grand skink *Oligosoma grande* in Otago, New Zealand. Conservation Evidence 9: 28–35.
Worton BJ 1987. A review of models of home range for animal movement. Ecological Modelling 38: 277–298.
Zaccarelli N, Bolnick DI, Mancinelli G 2013. RInSp: an R package for the analysis of individual specialization in resource use. Methods in Ecology and Evolution 4: 1018–1023.

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Supplementary material

Additional supporting information may be found in the supplementary material file for this article:

Appendix S1. Home range asymptotes for the mean of all geckos (blue line) tracked on Mana Island ($n = 25$) calculated with the incremental area analysis using the 100% MCP home range areas. Each square represents a location fix and black lines link the fixes of one individual. The dashed red line represents the minimum number of fixes required to reach an asymptote.

Appendix S2. Home range asymptotes for all 25 geckos calculated with the incremental area analysis using the 100% MCP home range areas. Each square represents a location fix and black lines link the fixes of one individual. The dashed red line represents the minimum number of fixes required to reach an asymptote.

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