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SHORT COMMUNICATION

Penned release reduces area use by translocated barking geckos (*Naultinus punctatus*)

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Abstract: Globally, translocations of herpetofauna have been notoriously unsuccessful. Most previous translocations of green geckos (*Naultinus* spp.) have failed to result in population establishment. However, recent penned releases of jewelled geckos (moko kākāriki; *Naultinus gemmeus*) have led to increased site fidelity, reduced dispersal, reduced home range sizes, and reduced minimum daily movements, facilitating population establishment. The success of these penned releases prompted use of the method in a translocation of 19 barking geckos (*Naultinus punctatus*) to Mana Island, New Zealand, the first application of the technique to this species. We evaluated the effect of penning on area use by geckos over a three-month penned period followed by a two-week un-penned period. We aimed to determine whether barking gecko area use decreased over time, which can be an early indication of territory establishment. Mean barking gecko area use decreased significantly throughout the study, supporting previous work on jewelled geckos that suggests penning is an effective tool for translocations of green geckos and may also be beneficial to other lizard taxa.

Keywords: conservation; green geckos; monitoring; translocation

Introduction

The reintroduction of species within their historical range is a technique regularly used by conservation managers for ecosystem restoration (Seddon et al. 2007); however, translocations of herpetofauna have received less scientific attention than those of mammals and birds (Germano & Bishop 2008). Translocation success for animals can be measured in four stages, from initial survival and growth of individuals through evidence of reproduction and of population growth, to ultimate evidence of a viable population (Miller et al. 2014). Despite success rates of translocations for herpetofauna increasing from 19% to 41% over the past two decades (Dodd & Seigel 1991; Germano & Bishop 2008) research on release strategies and improving site fidelity of translocated individuals is still required to further improve success (Germano & Bishop 2008). The penned release strategy (restricting dispersal for a pre-determined period of time to enable animals to habituate to the release area and form stable territories within the release site; Bright & Morris 1994) shows promise as a tool for increasing the success rate of herpetofaunal translocations (Germano & Bishop 2008), but has received little scientific attention. Studies on gopher tortoises (*Gopherus polyphemus*; Tuberville et al. 2005) and jewelled geckos (*Naultinus gemmeus*; Knox & Monks 2014; Knox et al. 2017) demonstrate that penned releases reduce initial dispersal and increase site fidelity, which may ultimately increase the probability of population establishment and growth.

Translocation is a valuable conservation management tool used in ongoing efforts to restore lizard populations in New Zealand, including green geckos (*Naultinus* spp.), that have been subject to human-induced declines (Knox & Monks 2014). Initially, geckos were hard-released into new sites; that is, they were placed in suitable habitat without a barrier to dispersal. Despite multiple attempts and follow-up surveys, few previous green gecko translocations could be considered successful (Knox & Monks 2014). Nine hard releases over 1994–2010 of > 150 individual *Naultinus* geckos resulted in only three individuals being re-sighted, albeit with a variable amount of search effort; all of these hard-release translocations are considered failures according to the success criteria proposed by Miller et al. (2014). The only green gecko translocation between 1994 and 2010 that can be considered successful, through to evidence of population growth stage, i.e. stage 3 in Miller et al. (2014), involved a penned release (Knox & Monks 2014; E. Richardson, University of Otago, pers. comm.). More recent green gecko translocations have not yet had sufficient monitoring duration to evaluate success, though initial monitoring of the penned release translocations described by Knox et al. (2017) has documented both survival and reproduction, i.e. success at stages 1 and 2 of Miller et al. (2014) (C. Knox, Wildlands Consultants, pers. comm.).

Many green gecko populations have undergone decline in numbers and locations due to predation by introduced mammals and wasps, habitat modification, introduced avian predators and poaching for illegal trade (Hare et al. 2007; Knox & Monks 2014; Scott 2016), yet little research on their ecology exists and this is needed for effective conservation management (Hare et al. 2016). The barking gecko (*Naultinus punctatus*, Gray 1843; Wellington green gecko; Bell 2014)

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is considered ‘Vulnerable’ under IUCN threat listing criteria (Hitchmough et al. 2019) and ‘At risk, Declining’ under the New Zealand Threat Classification System (Hitchmough et al. 2016). The population we studied is on Mana Island, a 217 ha Scientific Reserve within the natural range of barking geckos (Brown et al. 2016), from which introduced mammalian predators have been eradicated (Newman 1994; Miskelly 2010). Previous hard-release translocations of barking geckos to Mana Island appear to have failed. Forty-eight barking geckos (29 wild-sourced and 19 ex-captive) were translocated to the same area of habitat on Mana Island between 1998 and 2005. These geckos comprised 16 females, of which five were gravid, 27 males and five sub-adults and were hard-released in eight batches comprising 1–20 individuals. None of these 48 barking geckos have been re-sighted despite significant search effort, including a 10-day targeted search by experienced herpetologists in 2008 (Knox & Monks 2014; Lynn Adams, Department of Conservation, pers. comm.).

In November 2018, a further 19 barking geckos were translocated to Mana Island. This release involved temporarily holding geckos in a pen containing suitable habitat for a period of three months before removing the pen, following the success of this technique for congeneric jewelled geckos (Knox & Monks 2014; Knox et al. 2017). The release of barking geckos on Mana Island presented an opportunity to monitor use of space and habitat by *N. punctatus* for the first time. Due to constraints on the number of geckos available for translocation, and the history of lack of successful hard-release translocations for this species and site, it was not possible to include a hard-released group as an experimental control. We aimed to: (1) determine whether barking geckos translocated into a pen decrease area used over a three-month period following release, as has been observed for *N. gemmeus*; (2) evaluate whether barking geckos remain in the release area immediately following removal of the pen; and (3) collect incidental data on habitat use by barking geckos, for which little ecological information is known as evidenced by the ‘data poor’ qualifier applied to their national threat ranking of ‘At Risk: Declining’ (Hitchmough et al. 2016). Reductions in area use over time could indicate the establishment of site fidelity within the release area and provide an early indication of whether this release method has utility for the species.

Methods

The barking gecko is one of nine species of *Naultinus* green geckos endemic to New Zealand (Nielsen et al. 2011), reaches 95 mm snout-vent length and is distributed over the southern half of Te Ika-a-Māui (North Island; van Winkel et al. 2018). Our focus was a population translocated to Mana Island (41.0901°S, 174.7812°E). Mana Island (Te Mana o Kupe) has a history of Māori settlement, followed by European occupation involving farming of sheep and cattle. It is now an ecological restoration site dominated by planted native forest, shrubland and grassland from which sheep, cattle and mice have been eradicated (Miskelly 1999; Miskelly 2010). Restoring the natural ecological community on Mana Island, including barking geckos and other lizard species, is a key conservation goal for the island (Miskelly 1999). Following the previous failed hard-release translocation of barking geckos to Mana Island (Knox & Monks 2014) and research demonstrating the potential of penned release for green gecko translocations (Knox & Monks 2014; Knox et al. 2017) the decision was made to attempt a penned release for barking geckos on Mana Island in 2018. A release pen was constructed by members of the Friends of Mana Island Trust based on best practice techniques for the translocation of green geckos, see Monks et al. (2017) for details. Briefly, the pen was 0.80 m high and constructed of Animex Fencing material (animexfencing.com), with an inward-facing overhang of 0.10 m and had 1 m grass buffers either side to prevent dispersal via overhanging vegetation. The pen surrounded an irregular-shaped c. 100 m^2 area of suitable habitat, consisting of dense bush and shrubs (Table 1). Pōhuehue (*Muehlenbeckia complexa*), mingimingi (*Coprosma propinqua*), and mānuka (*Leptospermum scoparium*) dominated the vegetation community surrounding the penned area.

Nineteen barking geckos (10 male and 9 female) were translocated to Mana Island from the Wellington region, sourced from captivity ($n = 16$) and salvaged from development ($n = 3$); also termed a mitigation-driven translocation *sensu* Germano et al. (2015). Of the captive geckos, four males were born in 2014; three males and seven females were born in 2015; and one of each sex was born in 2016. Dorsal images of each gecko were used for individual identification, which proved accurate for barking geckos (TPFP & JMM, pers. obs.; Fig. 1), as has previously been demonstrated for congeneric jewelled geckos (Knox et al. 2013). The captive bred group was released onto mānuka 1.10 m above the ground. The rescued group was released onto 0.58 m high mingimingi on the other side of the pen. Groups were released 7.8 m apart to reduce the chance of immediate aggressive interaction between the two. All geckos were released within the pen on 2 November 2018. We marked the release location of all geckos with identity (ID) numbered flagging tape as the first reference. We monitored the area use and habitat use of the 19 barking geckos over a three-and-a-half-month period from their release in November 2018, including a 2-week period following the removal of the pen on 2 February 2019. One observer (TPFP) familiarised himself with the study species and site prior to observations; he was the consistent observer throughout the monitoring period and trained and supervised occasional observers to ensure consistency. We used four distinct monitoring periods that ranged between 6 and 15 days long. The monitoring periods were: (1) 6 days from 2 November 2018, (2) 10 days from 28 November 2018, (3) 15 days comprising 6 days from 4 January 2019 and another 9 days from 23 January 2019 (data from two trips combined for analyses to achieve sample size), and (4) 15 days from 2 February 2019.

Each monitoring session involved walking around the penned-area systematically for four 25-minute stints over a 3 h period, carefully searching the vegetation for geckos. The remaining time during this 3 h period was used to search the 30-m wide strip of habitat immediately surrounding the pen to look for any geckos that had escaped the pen, using the same technique. All searching was done in weather conditions considered favourable for gecko emergence based on observations of conspecifics (not raining; wind-speed < 35 km h^{-1}; TPFP & JMM, pers. obs.) with the aim of minimising variability associated with weather. We used sawhorses to gain sufficient height to survey canopy tops (up to 2.4 m tall). During favourable weather, monitoring sessions were undertaken twice daily (morning and afternoon); however, on eight occasions surveys could only be undertaken once during the day due to unfavourable conditions.

When an individual was found and identified visually using

Table 1. Plant species present within the c. 100 m^2 pen on Mana Island into which barking geckos, *Naultinus punctatus*, were released in November 2018. Availability: percentage availability estimate for each plant species within the pen. Used: percentage of plant species that geckos were sighted on during the study. Probability of use relative to availability: use of habitat by geckos relative to (divided by) its availability in the pen (values > 1: plant species was used more than expected based on availability; values < 1: plant species used less than expected).

Plant species	Availability (%)	Used (%)	Probability of use relative to availability
Grass matrix	50	9.1	0.2
Māhoe (*Melicytus ramiflorus*)	32.3	27.6	0.9
Mānuka (*Leptospermum scoparium*)	10	22.3	2.2
Tauhinu (*Ozothamnus leptophyllus*)	2.6	8.4	3.2
Pōhuehue (*Muehlenbeckia complexa*)	1.9	26.4	13.9
Taupata (*Coprosma repens*)	1.2	2.3	1.9
Beach spinach (*Tetragonia implexicoma*)	1	2.1	2.1
Five-finger (*Pseudopanax arboreus*)	0.8	1.4	1.8
Mingimingi (*Coprosma propinqua*)	0.2	0.5	2.5

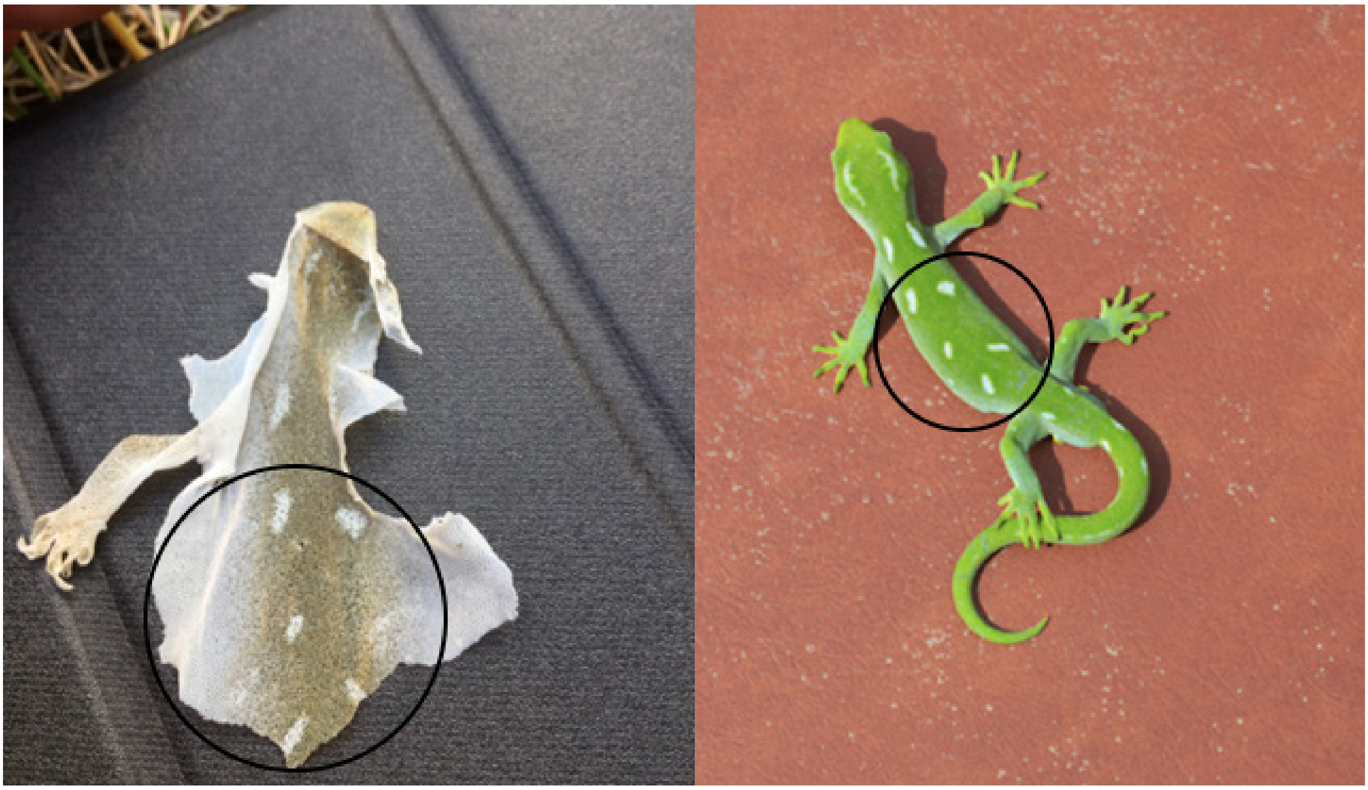

Figure 1. Image of a barking gecko *Naultinus punctatus* male 5 (M5; right) and his slough (left). The same markings are identifiable on both within circles.

photographs, we marked its location with its corresponding ID. Repeat observations became the subsequent reference points, which were marked before we measured the horizontal distance and bearing from previous locations. These spot locations eventually provided a pathway for the movements of all 19 individuals. Geckos were not handled again following release to minimise disturbance that may have influenced movements. We recorded vegetation species (habitat use) for each re-sighting.

Location point data were collectively used to calculate a gecko's home range for each monitoring period if at least five location points were obtained for an individual in that period. We refer to home ranges as "pen area used" because the term "home range" requires more evidence of a gecko's area use being their permanent territory; nevertheless, this metric provides a means of comparing area use over time (Knox et al. 2017). We used the 'adehabitatHR' package (Calenge 2006) to calculate 100% minimum convex polygons (MCPs) for each individual per survey period. This method does not explicitly account for the number of observations per individual. However, by restricting the dataset based on a minimum number of observations, checking observations of geckos were unbiased with respect to distribution of sightings across each monitoring period and using an area estimation technique incorporating both serial autocorrelation of the relocations and duration between observations (Calenge 2006), we are confident that documented changes in area use over time are real and not an artifact of detection probability of geckos over time. We used a linear mixed-effects model with monitoring period as a continuous predictor variable and gecko ID as a random factor to test whether each individual's area use (m^2) changed over time following translocation.

To test whether the five individuals sighted at least five times following the pen's removal displayed a stronger trend in area use over time, potentially skewing overall results, we re-ran the same analysis excluding the eight individuals that were not regularly re-sighted in the final monitoring period. The first and second period were merged because two individuals were re-sighted fewer than five times in November. We applied a square-root transformation to MCPs calculated for each individual per period, to achieve normality.

Availability of plant species (Table 1) was calculated by outlining estimated vegetation cover maps using ImageJ (Schneider et al. 2012). Specifically, Google Earth satellite imagery was used as the basis of a 2D vegetation cover map with detail added based on plant identification in the field. ImageJ was used to trace around the areas occupied by each plant species and summed to give a total area per plant species. Use of plant species by geckos was calculated for each individual over the entire study based on detections of emerged geckos; this plant-use metric for each individual was then averaged across all individuals (Table 1). Average percentage of detected gecko habitat use for a plant species reflects a mean percentage of how many times geckos were found on that vegetation. Habitat-use metrics may be biased towards plant species in which geckos are more detectable by humans (Hare et al. 2007), but still provide some information about habitat use. We used a Pearson's chi-squared test to test whether geckos use habitat in proportion to availability. This test relied on the assumption that all geckos had the same opportunity to occupy habitats by being released at the same time and location.

Results

Search effort involved a total of 75 monitoring sessions totaling 225 hours during 46 days across the 3.5 month period beginning at release in November 2018 and concluding two weeks after removal of the pen in February 2019. We obtained a total of 420 re-sightings of the 19 geckos released (range = 5–62 sightings per gecko). This comprised of 144 sightings of the 10 male geckos and 276 sightings of the nine female geckos. All 19 geckos released were re-sighted at least once in the first and second monitoring periods, 16 were re-sighted in the third monitoring period and 13 were seen in the final monitoring period, after removal of the pen. Re-sighting data from 13 geckos sighted more than five times in one or more monitoring period were included in area use analyses. One female developed poor body condition (malnourished, tail missing and excessive scratch marks) and was removed from the island for treatment; prior to being removed its movement patterns were similar to the other geckos.

Thirteen geckos were re-sighted in the final monitoring period; the fates of the remaining six geckos are uncertain. The slough of one male (Fig. 1) was found on 16 February 2019, toward the end of the final monitoring period and after the pen was removed, 12 m south of the nearest edge of the release area, within mingmingi, in a sheltered area. One female was found 2 m south of the nearest edge of the release area following removal of the pen. These are the only observations of dispersal outside the penned area.

Time period had a significant effect on overall mean gecko area use (n = 13 individuals), with area use decreasing through time ($t_1 = -2.125$, $P = 0.034$) (Figs 2, 3a). The mean area use for period 1 (51 re-sightings, 8 individuals) was 20.2 ± 3.1 m^2 (SE); period 2 (91 re-sightings, 12 individuals) was 15.8 ± 2.5 m^2; period 3 (151 re-sightings, 15 individuals) was 17.0 ± 2.6 m^2; and period 4 (70 sightings, 5 individuals) was

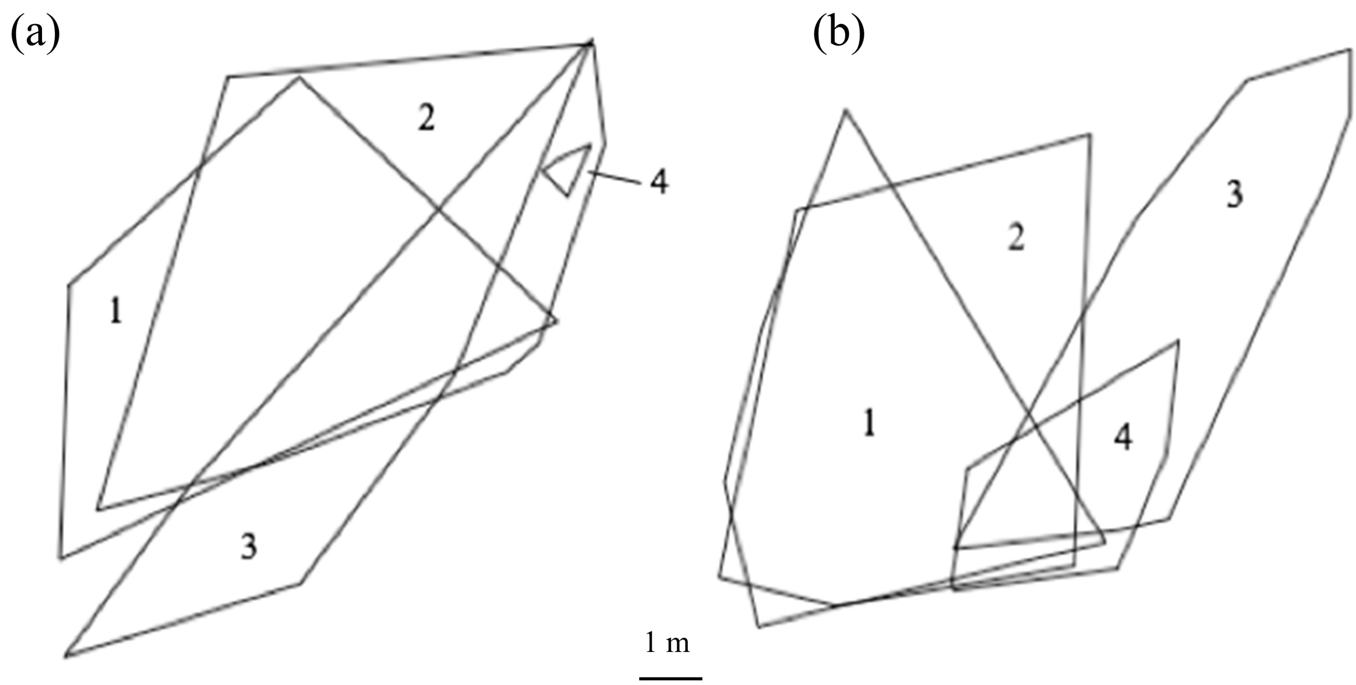

Figure 2. Examples of area use for two individual barking geckos, *Naultinus punctatus*, translocated into a 100 m^2 pen on Mana Island on 2 November 2018. Polygons portrayed are 100% minimum convex polygons Male 3 (a) and Female 3 (b) over time periods 1–4 following translocation between November 2018 and February 2019. Periods 1, 2 and 3 are pre-pen removal and period 4 is post-pen removal.

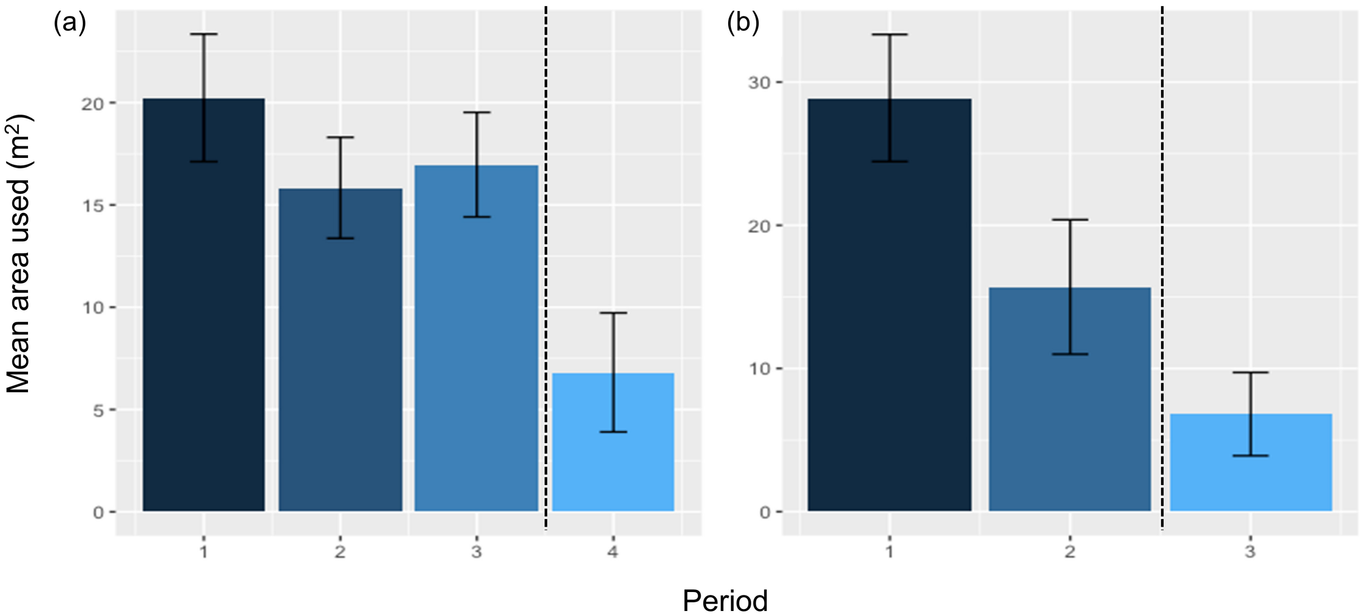

Figure 3. Area use of barking geckos *Naultinus punctatus* translocated to a pen on Mana Island in November 2018 decreased over 3.5 months following release, including the final 2 week monitoring period following removal of the pen. Timing of removal of the pen is indicated by a vertical dashed line in both plots. (a) Overall mean gecko area use (m^2) over three penned periods (1, 2 and 3) and the final un-penned period (4) for 13 geckos re-sighted regularly while the pen was in place. (b) Mean gecko area use (m^2) over two penned periods (1 and 2) and the final un-penned period (3) for individuals regularly re-sighted until the end of the study (n = 5). Error bars are standard errors.

6.8 ± 2.9 m^2. Area use by the five geckos that were regularly resighted until the end of the study similarly decreased across the duration of the study ($t_1 = -4.120$, $P < 0.001$) (Fig. 3b). The mean area use (m^2) for period 1 (65 sightings) was 28.9 ± 4.4 m^2; period 2 (69 sightings) was 15.7 ± 4.7 m^2; and period 3 (70 sightings) was 6.8 ± 2.9 m^2.

Habitat use of detected geckos was not proportional to plant species availability ($n = 420$, X^2_8, $= 58.654$, $P < 0.001$) (Table 1). For example, geckos were detected in the grass matrix 9.1% of the time, which is five-times less than what would be expected based on availability (50% of available habitat was grass). In contrast the mean use of pōhuehue was 26.4%, which is 13.9 times higher than what would be expected based on availability (1.9% of available habitat was pōhuehue). Although a slight change in habitat use was observed across the season, from greater use of mānuka and māhoe (*Melicytus ramiflorus*) in the earlier part of the season to greater use of pōhuehue in the later part of the season, this did not appear to be related to the flowering phenology of these plants, which was very similar to one another and peaked in December.

Discussion

Translocated barking geckos contained in a pen for three months following translocation reduced their area use over time, both during the penned phase and after removal of the pen, which is consistent with results of similar studies of other herpetofauna (Tuberville et al. 2005; Knox & Monks 2014; Knox et al. 2017). Congeneric jewelled geckos penned for either nine or four months prior to full release had reduced dispersal, movements and home ranges which were enduring following the removal of the pen (Knox & Monks 2014; Knox et al. 2017). Our study is the first step towards measuring translocation success in barking geckos, and would ideally be followed up by a longer-duration study for this species that involves a simultaneous penned release and hard release.

Only 13 of the 19 (68%) released barking geckos were re-sighted in the final monitoring period of the study, despite thorough searching outside of the penned area (which only resulted in the detection of a single sloughed skin). This most likely reflects decreased detectability of geckos across the summer season following the peak of flowering in most of plant species present at the release site and the decreased need to bask openly to achieve preferred body temperatures as ambient temperatures increased toward the end of summer. Native avian predators may have preyed on some individuals, but this seems unlikely given their strong visual crypsis (Hare et al. 2007) and antipredator behaviour designed to avoid visual predators (Hoare et al. 2007), particularly given results from telemetry studies on translocated jewelled geckos failing to detect predation by birds (Knox & Monks 2014; Knox et al. 2017). Survival after release may be influenced by behavioural changes brought about by captive conditions (Hare et al. 2019), which cannot be discounted in this study given that 84% of the barking geckos involved were captive for 2–4 years prior to translocation. Green geckos can reach high densities in the wild (e.g. jewelled geckos occur at densities of > 500 ha^{-1}) and naturally display small home ranges (Knox 2010; Knox et al. 2017) and movements (Hare et al. 2007). Therefore, it seems unlikely that size of the penned area was restricting territory establishment by barking geckos, though we acknowledge the lack of basic ecological knowledge of this *Naultinus* species restricts inference.

Barking geckos were found disproportionately on mānuka, pōhuehue and tauhinu relative to their availability, which is informative for future monitoring of the species based on visual searching. Barking geckos are well hidden in these thick plants, which offer feeding (flies and nectar) opportunities (TPFP & JMM, pers. obs.) and probably protection against avian predators. For mānuka and tauhinu, there was potential observer bias because the shape and coloration of barking geckos contrasted strongly with these plants. However, we minimised any bias by thoroughly searching all plants in the pen. Our results are supported by a radio telemetry study, which found that wild Marlborough green geckos (*Naultinus manukanus*) used tauhinu and pōhuehue disproportionately to their availability in November, i.e. in the same season as geckos were translocated into the pen in this study (Hare et al. 2007). Mānuka is acknowledged as important barking gecko habitat in the Wellington region (Romijn 2009), is commonly used by jewelled geckos (Whitaker et al. 2002; Jewell & McQueen 2007), and is the plant species on which Auckland green geckos (*Naultinus elegans*) were found 76.2% of the time in a penned release (Scott 2016).

We demonstrate the same decrease in area use by barking geckos following translocation into a penned area as has been demonstrated for jewelled geckos (Knox & Monks 2014; Knox et al. 2017). In contrast to previous, failed attempts to translocate barking geckos to Mana Island (Knox & Monks 2014), most individuals in our study survived in the initial months following translocation and several were regularly re-sighted. Our research further supports penning as a translocation tool to increase initial contact between founders and potentially improve the likelihood of population establishment, which is the basis for the current best practice technique (Monks et al. 2017). The penned release strategy may ultimately lead to improved translocation success for green geckos and other lizards.

Author contributions

TFP undertook the field data collection, analysed the data and wrote the first draft of the manuscript; JM designed the study, supervised the project, edited and revised the manuscript.

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