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RESEARCH

Habitat use of the northern striped gecko *Toropuku inexpectatus* and biases in detection

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Abstract: The northern striped gecko (*Toropuku inexpectatus*) is an arboreal gecko endemic to Aotearoa | New Zealand, formally described in 2020 and primarily known from one monitored population on the Coromandel Peninsula. Little is known about the northern striped geckos' use of habitat, which impedes monitoring, and thus limits effective conservation management. We evaluated the geckos' habitat use via Very High Frequency radio telemetry of 32 individual geckos for three months in the summer of 2024 and compared data to the available habitat. We also investigated potential observer biases during systematic searching (visual searching at night), currently the preferred monitoring method. The geckos used a wide variety of forest habitat, preferring edge habitats and shrub-like vegetation. While inactive during the day, and in close proximity to the forest edge, geckos sheltered under the leaf litter on the forest floor. While away from the forest edge, geckos moved into the forest canopy and did not utilise the forest floor. We uncovered observer biases in systematic search techniques, favouring observation of geckos near forest edges and often on or near the fern kiokio (*Parablechnum novae-zelandiae*). Systematic searches only captured a portion of gecko habitat use and largely failed to locate geckos in the complex vegetation that was preferred by them. The limitation of systematic searching indicates the potential for undiscovered populations in the remote forests of the Coromandel Peninsula. Overall, our results contribute to a better understanding of the ecology of the northern striped gecko and where to find them, potentially enabling improvements in surveys and monitoring and, ultimately, conservation of one of the most elusive geckos of Aotearoa.

Keywords: arboreal, cryptic species, forest, lizard, observer bias, radio telemetry

Introduction

Successful monitoring of any species requires an effective method by which to detect animals (Fitzgerald 2012). Understanding how a species may use available habitat can allow existing detection methods to be adapted to increase efficiency or new methods to be developed (Pop et al. 2018). For example, Bell (2009) developed a tree mounted artificial retreat to improve detection efficiency of arboreal geckos (*Hoplodactylus duvaucelii*; *Dactylocnemis pacificus*; *Mokopirirakau granulatus*), for which terrestrial trapping and visual surveying were less efficient and, at times, ineffective. Many lizards in Aotearoa | New Zealand are similarly cryptic (Bell & Patterson 2008) and the monitoring tools available are not universally effective (Lettink & Hare 2016; Lettink & Monks 2016). Resultingly, many endemic lizards are poorly known (Hitchmough et al. 2016, 2021, 2026; Towns et al. 2016) and can be difficult to adequately monitor. Current techniques for surveying terrestrial or semi-terrestrial lizards in Aotearoa include systematic searches of natural habitat or trapping using many different device types e.g. artificial cover objects, tracking tunnels, pitfall or Gee's minnow traps (Lettink & Hare 2016; Lettink & Monks 2016). Our understanding of species ecology may also be biased by the chosen survey method e.g. terrestrial traps will rarely detect canopy species, potentially leading to important habitat or interactions being overlooked (Lettink & Monks 2016).

Arboreal geckos are notoriously difficult to survey compared to ground-dwelling lizards. Systematic searching for arboreal species is ineffective in tall canopy and may be heavily reliant on observer skill. Many of the commonly used terrestrial traps are ineffective, as animals rarely encounter them. In Aotearoa, all arboreal gecko species bar Pacific gecko (*Dactylocnemis pacificus*) are considered At-Risk or Threatened with extinction (Hitchmough et al. 2026), albeit with low confidence. The distributions of most species are unlikely to be fully understood and population trends are difficult to generate, hampered by a lack of suitable survey and monitoring techniques. Adapting current methodologies or developing more targeted approaches requires a deeper

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understanding of how the target species uses habitat. Radio telemetry can provide more detailed, and less biased, insights into microhabitat selection and a more detailed idea of distribution for otherwise cryptic species (Boback et al. 2020). Such work has been carried out previously for Aotearoa's arboreal geckos in the genera *Naultinus* and *Mokopirirakau* (e.g. Hare et al. 2007; Romijn et al. 2014). Hare et al. (2007) used radio telemetry to locate *Naultinus manukanus* that were up to 0.85 m beneath the surface of foliage on cloudy days, making them very difficult to detect using systematic surveying alone. Romijn et al. (2014) reports that radio-telemetry of *Mokopirirakau* 'Southern North Island' revealed that the species, previously thought to be nocturnal, emerged a similar amount during both day and night. Such insights provide high value to species monitoring where particularly cryptic species or challenging habitat to survey leads to few detections.

Forests on the Coromandel Peninsula are dense, with some areas undisturbed by human development, particularly in difficult and remote terrain where kauri (*Agathis australis*) logging was not feasible. In such areas, species can go largely unnoticed by humans (Bell 2009; Hoare et al. 2013) and this was the case with the northern striped gecko (*Toropuku inexpectatus*), first found in 1999 (Whitaker et al. 1999). The northern striped gecko was described as a distinct species in 2020, when it was separated from its congener, the southern striped gecko (*Toropuku stephensi*; Hitchmough et al. 2021). Based on systematic searching, southern striped geckos are thought to preferentially use vines (*Muehlenbeckia australis*) and have been found during the day beneath large piles of nīkau palm (*Rhopalostylis sapida*) leaves; they have not been found emerged during the day (Hare & Cree 2005). More recently, surveys and translocation projects have frequently detected the species utilising extensive tracts of bracken fern (*Pteridium esculentum*) and flax (*Phormium tenax*; authors' pers. obs.). The northern striped gecko is a highly cryptic species thought to be primarily arboreal, though little is known about its ecology or about trends in the known populations. This paucity of information was represented in its recent description and conservation status assessment: Threatened - Nationally Vulnerable, with qualifiers: Data Poor (lack of data on its population size), Range Restricted (naturally occurs in an area less than 1000 km^2), and Sparse (naturally small or scattered populations; Hitchmough et al. 2021; Rolfe et al. 2022). The best-known population of northern striped geckos occurs at Mahakirau Forest Sanctuary, where monitoring has occurred since 2016 at an accessible site within a vast tract of regenerating native forest. This population provides the opportunity to learn more about the species' ecology and potentially adapt current methods to enhance our ability to monitor known populations and potentially discover new ones.

Here, we quantify habitat use by northern striped geckos within the Mahakirau Forest Sanctuary by using radio telemetry. Specifically, we: (1) evaluate the habitat use of geckos by comparing habitat at points geckos were found using telemetry with habitat at points generated pseudo-randomly within the same area, (2) compare habitat use revealed by telemetry with that indicated by systematic visual surveys, and (3) provide estimates of gecko home range and information on movements based on telemetry. Our results contribute a greater understanding of habitat use by northern striped geckos and how existing survey methods may be biased, which we hope will inform future surveys to improve detection of the studied and unknown populations.

Methods

Gecko tracking

Geckos were captured and tracked in Mahakirau Forest Sanctuary, Te Tara-o-te-Ika-a-Māui | Coromandel Peninsula, Aotearoa | New Zealand. The sanctuary spans an elevation of 280 –580 m and consists of mostly regenerating podocarp/conifer forest. It was originally dominated by kauri (*Agathis australis*), rimu (*Dacrydium cupressinum*), miro (*Pectinopitys ferruginea*), kahikatea (*Dacrycarpus dacrydioides*), Hall's tōtara (*Podocarpus laetus*), taraire (*Beilschmiedia tarairi*), and northern rātā (*Metrosideros robusta*). Although the study site includes a diverse flora, it is currently dominated by tree ferns, rewarewa (*Knightia excelsa*), and mānuka (*Leptospermum scoparium*) in the canopy, and by kiekie (*Freycinetia banksii*) and kiokio (*Parablechnum novae-zelandiae*) in the understorey. Specific location details, including GPS locations of the surveyed gecko population, have been withheld due to poaching concerns.

Geckos were first found using systematic searches at night, between the hours of 2200 and 0200. Systematic searches were conducted along a 4 km track with hard forest edges bordering each side and involved carefully looking for body shape and eye shine of emerged geckos, but did not involve disturbing habitat. Forty-four northern striped geckos were located via systematic searching and 32 of them were subsequently radio-tracked over three months (early January–early April 2024). Each gecko was identifiable through unique dorsal patterning on the head (Knox et al. 2013; SS unpubl. data), enabling us to avoid repeated sampling of individuals during the three-month field study. After capture, geckos were measured (snout-vent length; SVL) using a ruler and weighed using a Pesola spring balance. Sex was recorded for adults based on visual inspection; males have an obvious hemipenial sac. Pregnancy was recorded for adult females based on visual inspection if moderately advanced, or gentle palpation of the abdomen if at an earlier stage.

The Very High Frequency (VHF) transmitters used in this study were Lotek PicoPip Ag376. Transmitters weighed 0.7 g, never exceeding 7.5% of any gecko's body weight (including harness material), consistent with other studies (Mellor et al. 2004; Hoare et al. 2013; Romijn et al. 2014; Knox et al. 2017; Altobelli et al. 2022; Yee et al. 2022). Transmitters were applied using the backpack method (Fig. 1), a commonly used technique for Aotearoa's geckos (Hare et al. 2007; Hoare et al. 2007; Knox & Monks 2014; van Winkel & Ji 2014). Transmitters were secured between the shoulder blades with non-toxic adhesive Fixomull Stretch medical tape, cut into c. 5 mm wide and c. 400 mm long strips. The white tape was dulled using a graphite pencil to reduce visibility to potential predators. Starting at the upper belly, the tape was wrapped around the body below the front legs, over the transmitter, crossing over each shoulder, and finishing on the belly, forming a secure backpack (Fig. 1a; van Winkel & Ji 2014). Transmitters were aligned along the spine to ensure even weight distribution, and with tape covering most of the transmitter to prevent snagging (van Winkel & Ji 2014). A small piece of red reflective tape was added to enhance detection during night-time spotlighting (Fig. 1b). Before release, each gecko was observed walking to ensure it could move freely with the backpack attached and, particularly, move its front legs up and above its head without hindrance. If movement was restricted, the backpack was removed and reattached.

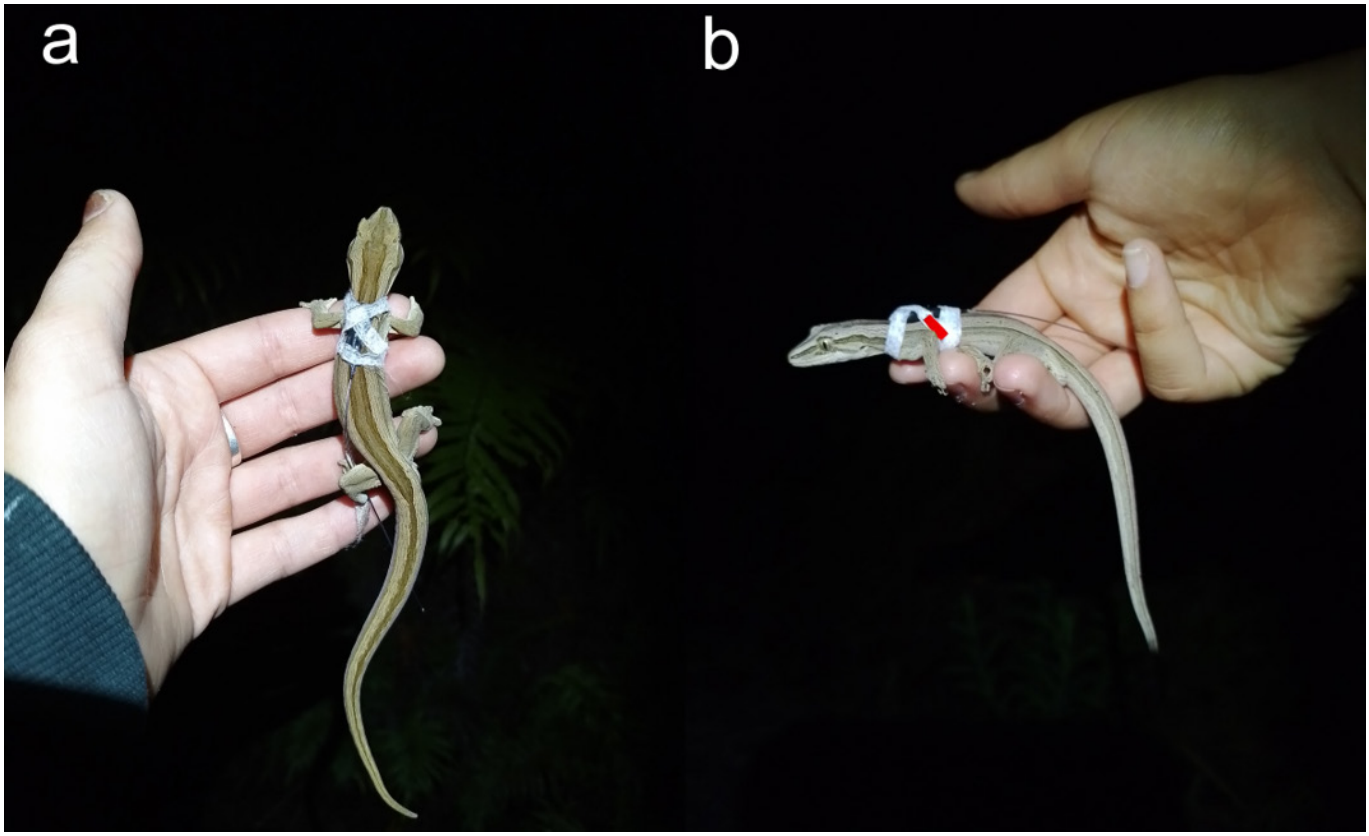

Figure 1. (a) northern striped geckos (*Toropuku inexpectatus*) with Lotek PicoPip Ag376 transmitters attached with backpack style harness. (b) shows red reflective tape which aided in subsequent detection by spotlighting.

Geckos were tracked at night (c. 2200 – 0200) and during the day (c. 1100 – 1700). Geckos were located with a Biotracker VHF Receiver (Lotek, Canada) using the close approach technique (Neill & Jansen 2014). Geckos were either visually sighted or their position triangulated using a high volume of radio signals in the area, particularly when signal could be heard without the Yagi antenna.

Whether geckos were sighted or not, each time a gecko was located using radio telemetry we measured whether the gecko was emerged (e.g. was exposed on a branch) or not (e.g. under leaf litter). Additionally, at locations where geckos were either sighted using systematic searching or found via radio telemetry, we measured the distance each gecko was from the forest edge (metres) and their height from the ground (metres). Habitat data collected at each gecko location included the plant species or structure on which the gecko was observed, the most abundant species within 1 m of the gecko, the most abundant canopy species (canopy referring to horizontal edge habitat) above the gecko location, canopy height (estimated in metres), and canopy cover (%). Canopy cover was recorded using Canopeo (version 1.1.7; Patrignani & Ochsner 2015). One attempt to get a telemetry fix (i.e. gecko location discovered via telemetry) was made per gecko, per period (day and night); consequently, fixes were on average 22.53 hours apart.

Transmitters occasionally fell off the geckos, most commonly due to skin shedding. Occasionally the medical tape would lose its adhesive properties in extremely wet weather, particularly if the transmitter had been attached in the rain. However, transmitters that detached were located using VHF radio telemetry, as described above, and reassigned to other geckos to increase sample size. Transmitters signalling from under leaf litter or grass on the ground and which had not moved for three days were carefully searched for by slowly sifting through the substrate to find the transmitter, while also looking for the presence of a gecko. Near the end of the fieldwork and the transmitters' battery life (c. 75 days), geckos with transmitters still attached were tracked, caught, and the medical tape and transmitter carefully removed. Geckos that had their transmitters manually removed were re-weighed to assess any weight loss during the study.

Resource selection

We collected representative habitat data at the study site to compare to habitat used by the tracked geckos. Data were collected along the same forest edges where geckos were caught and tracked. The c. 4 km stretch was split into 70 transects, each 30 m in length. Habitat points were selected by generating a random value of distance along each transect (0 to 30 m), side of the track (left or right), and a perpendicular distance from the transect (0 to 20 m). The range of perpendicular distance was based upon gecko movements during telemetry. In total we generated 700 random habitat points, and at each point the same variables were recorded as at gecko locations.

To explore how geckos were using available habitat, we modelled whether points were random habitat surveys (0) or telemetry fixes (1) as a function of the habitat characteristics at either, using a binomial generalised additive model with a logit link function. The fixed covariates which described

habitat were distance from forest edge, canopy height, canopy coverage, and the presence or absence of the five most common plants within one metre of telemetry fixes, i.e. kiokio, kiekie, gorse (*Ulex europaeus*), punga (*Cyathea* spp., *Dicksonia* spp.), and hookgrass (*Gahnia* spp.). We chose to use only five of the 36 different species present at gecko locations to avoid over-parameterising the model and prioritise species used by geckos rather than those which were most common in the environment.

The continuous predictor variables were checked for concurvity, a function that describes non-linear dependencies among covariates (Amodio et al. 2014). Variables with estimated pairwise concurvity greater than 0.3 (Johnston et al. 2019) were ranked using univariate deviance explained, and the worst performing variable was removed from the model. For the models described here, distance from forest edge and canopy height were concurved, and the latter was excluded as a result. Full models were created using all independent predictor variables with no interaction terms. Once created, backward stepwise model selection was used to remove predictor variables. The Akaike's Information Criterion (AIC; Akaike 1998) value derived using the "MuMin" package (Barton 2025) was used to rank models. Variables with the highest p-value were removed and models retested until the model with the lowest AIC was reached. No other models had AIC values within two of the top model, so only the results from the top model are presented. Model validation was performed using diagnostic plots, where residuals were normally distributed, and the *gam.check* function from the "mgcv" package (Wood 2017). P-values for each continuous variable in the final model were low (< 0.01) and did not improve upon altering basis dimension (set to $k=8$). The output from *gam.check* is heuristic, and low p-values may indicate problems with data such as low deviance explained, lack of explanatory covariates, and unmodelled spatial or temporal structure of the data (Wood 2017).

Home range estimates

We used minimum convex polygons (MCP) to investigate home range size of northern striped geckos (Perry & Garland Jr. 2002; Laver et al. 2008; Goldingay 2015; Walter et al. 2015). Minimum convex polygons are particularly useful when investigating home ranges of herpetofauna that typically do not move over large areas, and for which obtaining large numbers of fixes is difficult (Rose 1982; Row et al. 2006; Crane et al. 2021). We analysed the home range of the northern striped gecko with MCPs using the package "adehabitatHR" (Calenge 2023). At fine scales, GPS error can preclude accurate measurement of home range. To combat this, we used the GPS location from the capture of tracked geckos as a reference and built polygons using the distance and bearing the gecko had moved compared to the animal's previous location. Discovery curves were made for each gecko to assess whether enough locations were recorded to adequately reveal home range (Calenge 2023). Differences between male and female home ranges were investigated using an analysis of variance (ANOVA).

Results

Forty-four geckos were captured via visual searching, 32 of which were fitted with radio transmitters and tracked during the study (Fig. 2). Four geckos that were of suitable weight were not tracked, as they were in late stages of pregnancy (Fig. 2). The average weight of all geckos measured in this study (both tracked geckos and untracked geckos) was 11.9 ± 0.60 g (SE), and the average weight of tracked geckos was 13.0 ± 0.38 g. Adult male geckos had an average mass of 12.3 ± 0.45 g while adult females had an average mass of 14.3 ± 0.57 g. The mean SVL across all measured northern striped geckos was 75.8 ± 1.45 mm and for tracked geckos was 79.6 ± 0.74 mm. The maximum SVL recorded was 86 mm, and the minimum was 48 mm (Fig. 2).

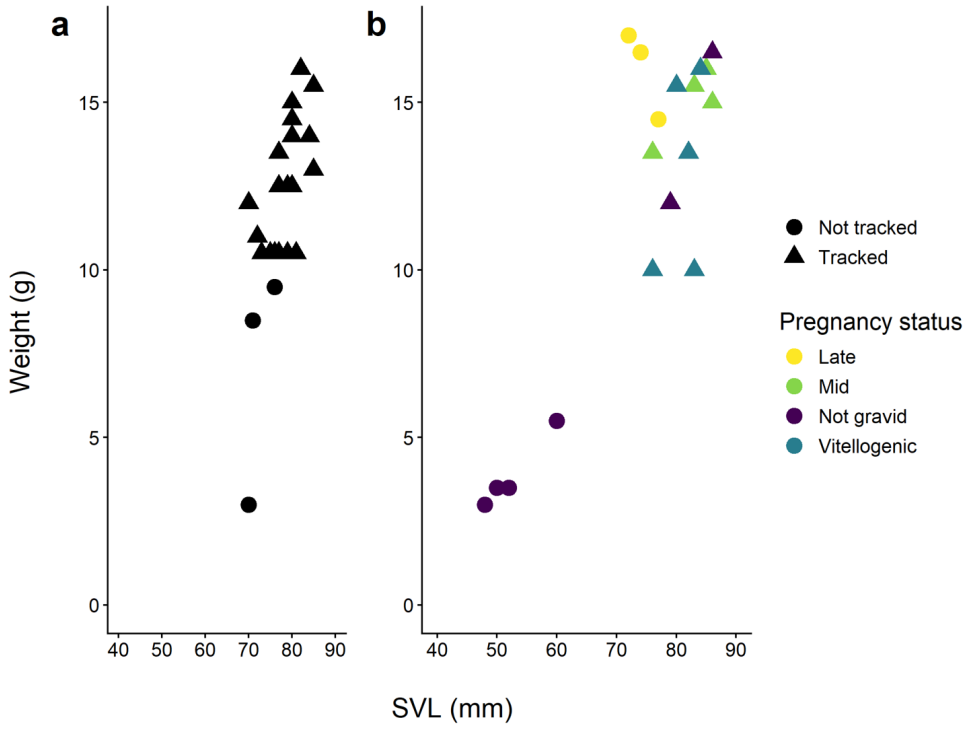

Figure 2. Weight (g) and snout-vent length (SVL; mm) of tracked and untracked northern striped geckos (*Toropuku inexpectus*) split by sex: (a) males and (b) females. Pregnancy status of female individuals is indicated via colour.

Six geckos were re-captured with their transmitters still attached and reweighed; the remainder lost their transmitters and could therefore not be relocated. Three of these geckos had the same weight as when they were first captured, after being tracked for 27 days (female), 16 days (male), and 36 days (female), respectively. One male gecko lost 0.5 g over the course of 33 days (−4.8%), and one male gecko lost 1 g over 28 days (−9.0%). A pregnant female gecko gained 2 g (20%) over the course of 55 days. No skin abrasions were observed on any tracked geckos.

The longest an individual gecko was tracked for was 70 days. The shortest time was three days; the short period was due to poor adhesion of the backpack when applied in wet weather. On average, geckos were tracked for 20.7 ± 2.5 days (SE). In total, 664 fixes were made, 245 fixes during the day and 419 at night. The mean number of fixes per individual was 16.6 (range 3–72 fixes). When located at night, geckos were seen emerged at 122 fixes and not emerged at 257 fixes; emergent status was not recorded at 40 fixes. We did not locate any emerged geckos during the day via telemetry.

Resource selection

Habitat was recorded at 700 randomised points to represent available habitat at the study site. Fifty-seven different plant species were recorded at the height of 1 m (the understorey), a height tier dominated by kiekie and kiokio. Kiekie was present at 230 of 700 (32.8%) random habitat points and kiokio at 213 (30.4%).

Geckos used plant species disproportionately to availability. Geckos preferentially used kiokio (51.7% of observations), gorse (14.0%), hookgrass (9.3%), and mānuka (6.6%) relative to their availability at randomised habitat surveys (30.4%, 2.4%, 1.0%, and 1.6% respectively), while hangehange (*Geniostoma ligustrifolium*) was common at randomised habitat surveys but not at telemetry fixes (Fig. 3a).

Forty-eight canopy species were recorded at randomised habitat points, the most common of which was punga, present at 315 of 700 points (45.0%). Rewarewa was the next most common, with 122 observations (17.4%). Other common canopy species included five finger (*Pseudopanax arboreus*), heketara (*Olearia rani*), lancewood (*Pseudopanax crassifolius*), māhoe (*Melicytus ramiflorus*), and kānuka (*Kunzea ericoides*) (Fig. 3b). Geckos were frequently located where punga was the canopy species (19.4% of fixes) and also favoured mānuka (21.8%), kiokio (17.2%), and gorse (9.5%), all of which were rare at randomised habitat points (< 2%; Fig. 3b).

The top-ranked model for resource selection by geckos included the predictor variables distance into forest, canopy cover, canopy height, and the presence or absence of kiokio, gorse, punga, and hookgrass. No other models were within ΔAIC < 2. The top model had a deviance explained of 41.9% and indicated that geckos were more likely to use habitat that was closer to the forest edge, and where gorse and/or hookgrass, but not punga, were present. Geckos were less likely to select habitat with kiokio present (Fig. 4). Notably, in a univariate model with only distance into forest, the deviance explained was 36.6%, likely indicating it is the most important variable driving habitat selection.

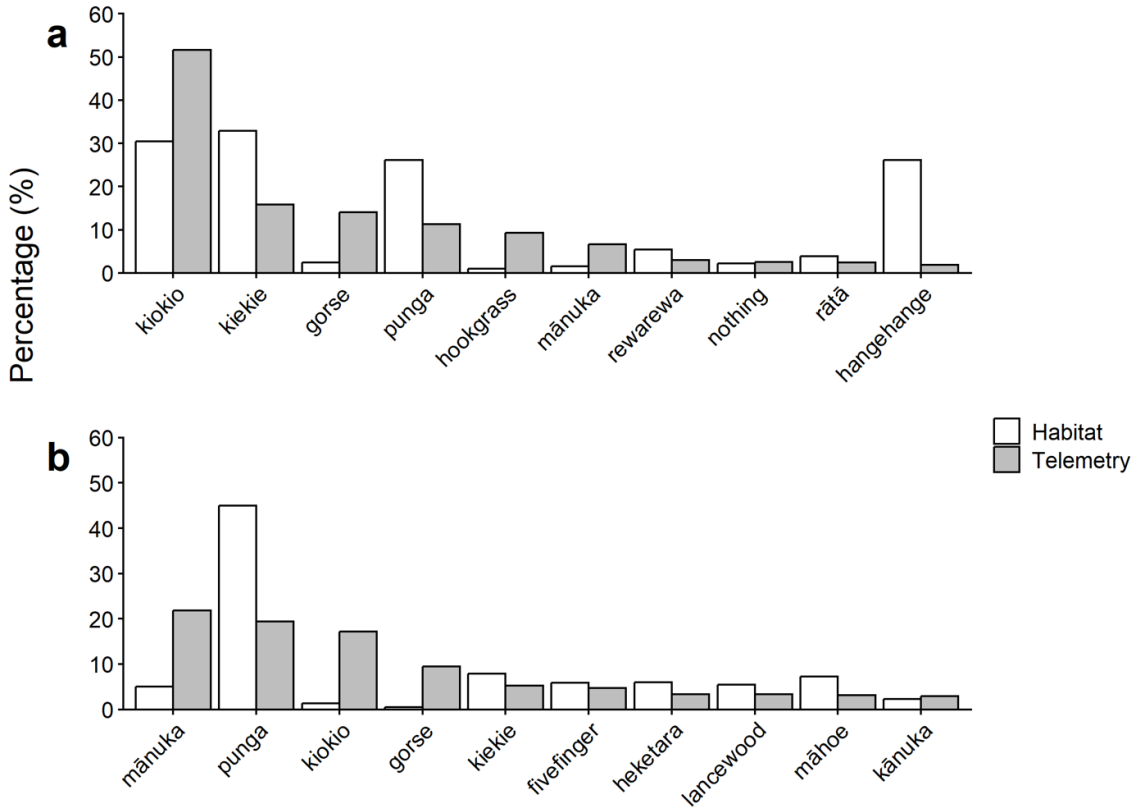

Figure 3. The percentage presence of plant species at telemetry fixes for northern striped geckos (*Toropuku inexpectus*; *n* = 664) and randomised habitat points (*n* = 700). Presented are: (a) vegetation at one metre, and (b) the canopy species. Displayed in both panels are the ten most common species at telemetry fixes.

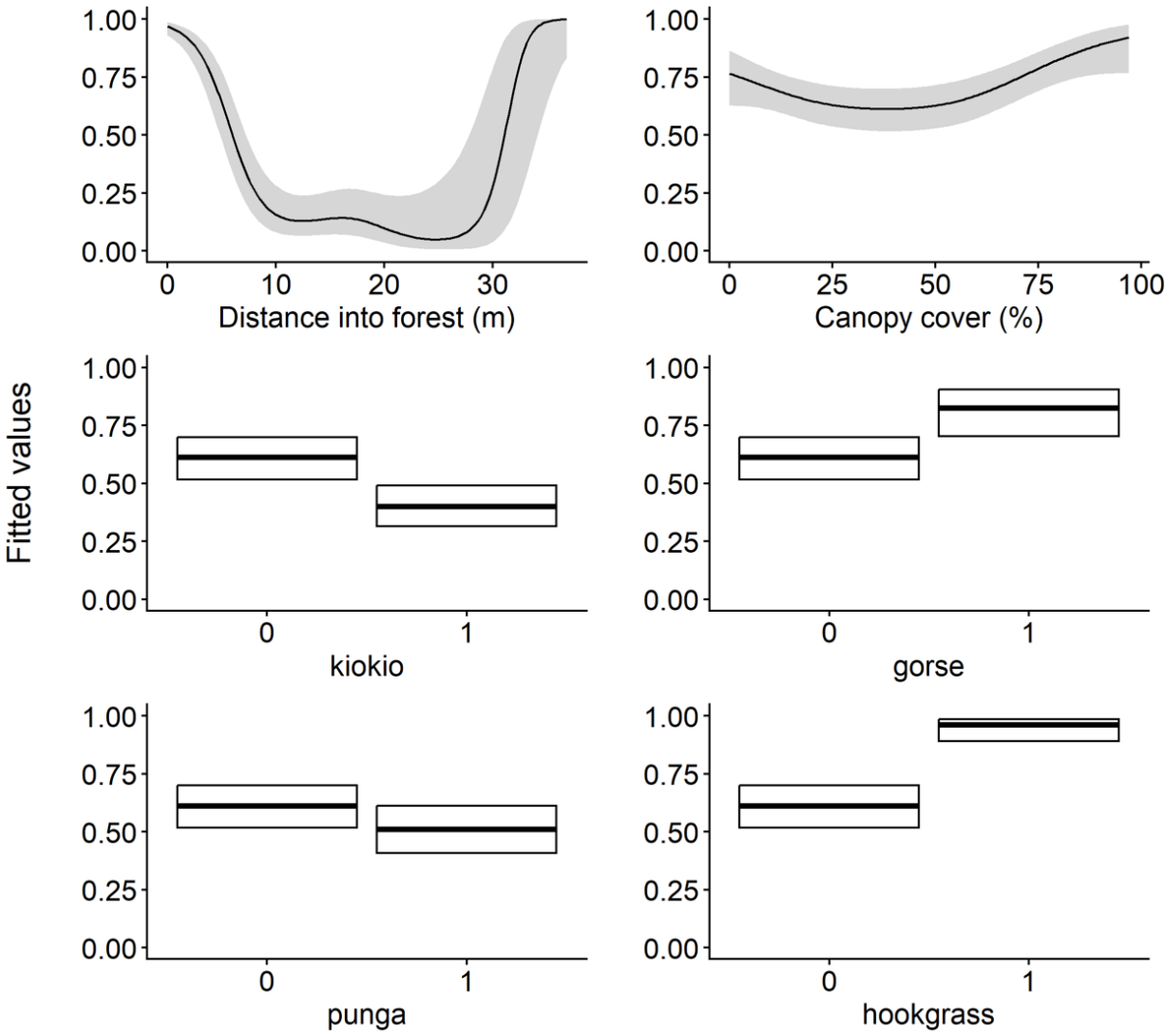

Figure 4. Effect of continuous and parametric explanatory variables from the top generalised additive model (ΔAIC 0) for the habitat use of northern striped geckos (*Toropuku inexpectus*; telemetry locations) versus habitat available (random habitat locations). The 95 % confidence interval of the response is represented by the shaded area (continuous covariates) and the box edges (binomial covariates). The y-axes indicate the response for the value of the predictors, when the continuous variables are set to the median value and the binomial variables are set to zero. Predictor variables include: the distance into the forest (m), canopy cover (%), and the presence or absence of kiokio (*Parablechnum novaezelandiae*), gorse (*Ulex europaeus*), punga (*Cyathea* spp.), and hookgrass (*Gahnia* spp.).

Observer bias

Systematic searches were conducted along forest edges, while geckos used both the forest edge and interior forest. Geckos were recorded up to 36.8 m away from the forest edge, while successful systematic searches did not occur further than 3.6 m away from the forest edge. Systematic searches located geckos primarily on kiokio (87.5%), though tracked geckos used this species less often: 45.4% of locations during the day and 55.6% at night (Fig. 5a). Geckos were not seen on either kiekie or punga during systematic searches, despite tracked geckos using both species moderately during both the day and night (Fig. 5a).

There was a strong difference between the location geckos were found in using systematic searches versus telemetry (Fig. 5b). Geckos were found much more often on leaves of vegetation (68.8%) using systematic searches than they were found using telemetry (night 22.7% and day 3.3%). Telemetry fixes located geckos on the ground far more commonly than systematic searches: 55.6% (night) and 72.3% (day) versus 6.3% during systematic searches (Fig. 5b). When on the ground, geckos were commonly under leaf litter. Average perch heights were highly similar irrespective of method or time of day (telemetry only), 1.2 m for day telemetry, 1.1 m for night telemetry, and 1.0 m for visual observations (Fig. 5c). No visual observations were made of geckos higher than 4 m despite geckos occasionally using higher perches (Fig. 5c).

Minimum convex polygons

Of the 32 geckos, seven individuals did not have more than ten telemetry points and so were excluded from home range analysis (Fig. 6). The remaining 25 had an average home range size of 166 ± 31.9 m^2 (SE). Among the individuals, the minimum home range size was 6.03 m^2 from ten fixes and the maximum was 617 m^2 from 27 fixes. Only six individuals clearly reached an asymptote in home range discovery. The average MCP for this group was similar to that of all other geckos, at 152.7 ± 46.4

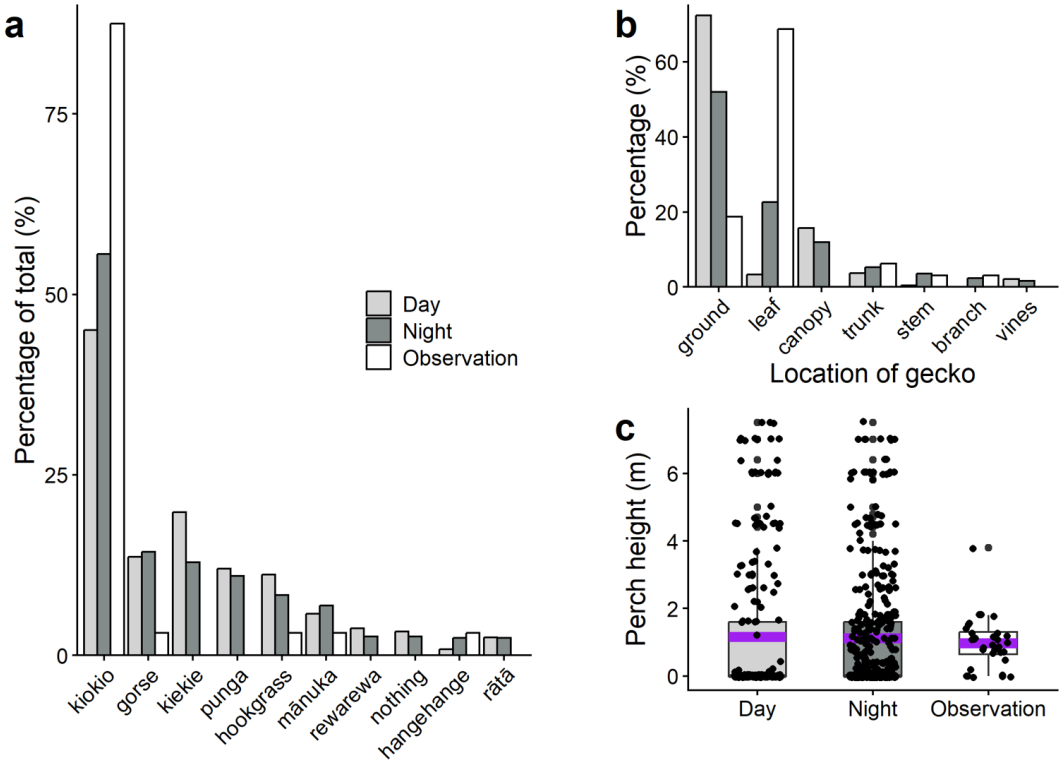

Figure 5. Habitat use and perch heights for northern striped geckos (*Toropuku inexpectus*) from telemetry points at night and during the day compared to locations where geckos were found using systematic searches (Observation). Presented are: (a) the vegetation species at 1 m above the ground, (b) the focal location of the gecko, and (c) the perch heights of the geckos when found; the purple bar represents the average value for each group.

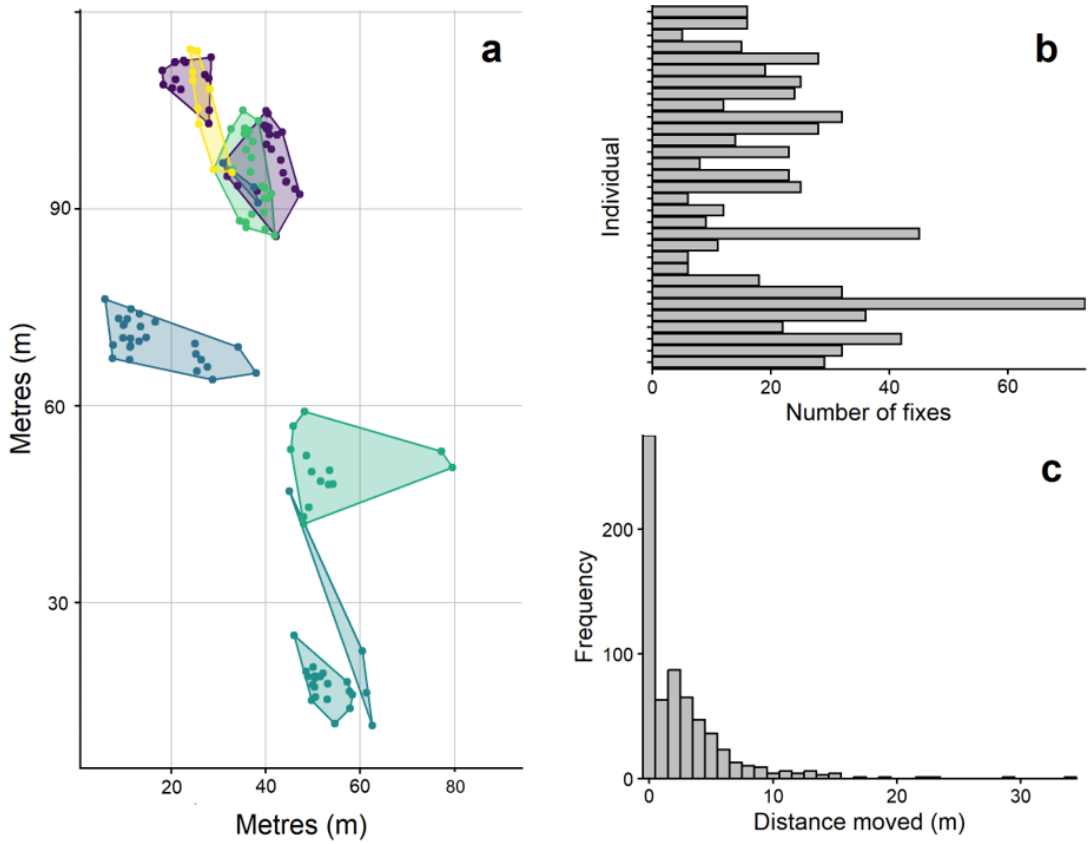

Figure 6. Examples of 100% minimum convex polygons (MCP) and associated tracking and movement data for northern striped geckos (*Toropuku inexpectus*) tracked with radio telemetry. Presented are: (a) locations and MCPs from nine tracked geckos that used nearby habitat to one another; polygons are in their native resolution (metres) and arrangement, though informative coordinate systems have been removed, (b) the number of fixes for all tracked geckos, and (c) the distances that all tracked geckos moved between fixes.

m^2. Male geckos had a larger home-range size on average than females, at 209.7 ± 43.7 m^2 and 89.5 ± 30.9 m^2 respectively ($p = 0.06$, ANOVA). Geckos moved, on average, 2.5 ± 0.1 m between telemetry fixes, with the maximum distance moved between fixes being 28.9 m in 24 hours (Fig. 6).

Discussion

The ability to reliably find and monitor individuals of a wild population is critical when trying to understand distribution, assess trends, and infer effectiveness of management interventions. Many arboreal geckos in Aotearoa | New Zealand are difficult to detect owing to the limited time geckos spend emerged in places that are detectable to ground-based observers. Not only does limited detectability reduce the chance of an observer finding geckos where they are present, but it also biases estimates of distribution and habitat use towards environments that are readily observable. In this study, we tracked 32 northern striped geckos over a maximum of 70 days using radio telemetry to investigate how they were using habitat and address the potential biases arising when using systematic searches (i.e. visual surveys) to detect and monitor the species. Geckos used habitat non-randomly, strongly preferring areas that were closer to the edge of the forest and using habitats with gorse, hookgrass, and mānuka, species that were relatively rare in the study area. Telemetry revealed that geckos commonly used the ground and were under leaf litter frequently, while observers primarily found geckos when emerged on the leaves of vegetation. Tracking gecko movement indicated that individuals rarely moved distances > 10 m between fixes (minimum 12 hours between fixes) and it was common for geckos to not move between fixes. Telemetry indicated that, in general, the geckos had small ranges, and that female geckos' ranges are likely smaller than those of males. With this new information on the habitat use of northern striped geckos, survey and monitoring methods can be adapted to account for the time spent on the ground, likely increasing detection rates for this species.

Several of our findings highlight the difficulties in detection and monitoring of northern striped gecko populations, which currently rely on visual searches at night, and generally along forest edge habitat (Lettink & Monks 2016). There is no established technique that can be used to reliably detect lizards in forest, meaning that we could not formally test differences between data derived from systematic searching and telemetry and were restricted to describing patterns observed. However, the telemetry study revealed that geckos used arboreal habitat during their active phase and took refuge underneath the leaf litter on the forest floor when inactive and close to the forest edge. Tracked geckos spent 62.5% of their time under leaf litter during the day and almost 50% of their time under leaf litter at night. When away from the forest edge, northern striped geckos spent more time in the forest canopy and did not travel to the forest floor to rest, but instead stayed in the canopy.

Our results corroborate previous research on arboreal geckos in Aotearoa, which suggests an observer bias towards detection in certain vegetation where geckos contrast more strongly with their background (Hare et al. 2007). The northern striped geckos in this study were found with kiokio within 1m almost 50% of the time, despite this fern being present in less than 25% of the overall habitat (Fig. 3). Geckos additionally selected smaller, more shrub-like vegetation rather than tall canopy species (Fig. 5). Shrub-dominated habitats like forest edges provide foliage which allows more sunlight and more protection from predators than less dense interior forest understorey habitats (Sartorius et al. 1999; Delgado García et al. 2007). The shrub-dominated forest edges at the study site provide this niche for the northern striped gecko, suggesting the forest edge as preferred habitat for the gecko (Harper et al. 2005; Boback et al. 2020). Preferential use of forest canopies by northern striped geckos when away from forest edges could be due to the canopy providing similar ecological conditions to forest edges, particularly optimal light conditions, resources, and dense foliage to move and hide in (Harper et al. 2005; Delgado García et al. 2007).

Expected observer biases in habitat use were detected when compared with results from radio tracking geckos, a result that would likely have been stronger had we not relied on the forest edge for sourcing geckos for radio tracking. Visual searches are mostly only effective at detecting geckos within c. 2.5 m of a forest edge and at lower heights where geckos can be observed from the ground. Geckos were also more detectable during ground-based searches in some vegetation types, particularly kiokio. Almost 90 % of geckos were found on kiokio during systematic searches, but only 12.5% of gecko locations revealed via telemetry were on kiokio; telemetry revealed they were under leaf litter and other vegetation nearly 62% of the time (Fig. 5), but not visible to searchers. Kiokio, a type of fern, is a dominant plant along the forest edges where systematic surveys took place. Kiokio grows at an accessible height and has layers that can be lifted during searching. Further, northern striped geckos contrast strongly in colour and pattern to the green fronds of kiokio. As such, kiokio is a useful plant for detecting northern striped geckos, like the documented association of southern striped geckos and *Muehlenbeckia australis* vines (Hare & Cree 2005), but its absence in the environment is not necessarily a sign of gecko absence. Telemetry revealed the northern striped gecko used a wider variation of vegetation and micro-habitats than previously known from systematic searches, a finding that is likely to apply to its southern congener and many other arboreal lizards.

Observer biases in sampling elusive reptile species are not uncommon. A multitude of factors, including difficulties in finding cryptic species, particularly those spread across a large area (McDonald 2004; Willson 2016), biases in detecting bolder individuals (Carter et al. 2012), and sampling biases in areas of higher human activity and accessibility (Ficetola et al. 2014) all create biases in detection. Sometimes surveys of cryptic reptiles can only be conducted where or when detections are more likely and in accessible locations (Beane et al. 2014; Willson 2016). Conclusions drawn from encounters in areas with a high-detection probability can lead to misinterpretation of habitat use and species distributions (McDonald 2004; Ficetola et al. 2014), a known issue in conservation planning for the northern striped gecko and other arboreal lizards of Aotearoa.

Understanding a species' home range is another important aspect of movement ecology and conservation planning (Allen & Singh 2016), particularly in considering conservation translocations onto islands or mainland sanctuaries where invasive predators are controlled (Knox & Monks 2014). Like other arboreal geckos (Knox et al. 2017), we found that northern striped geckos have relatively small home ranges of c. 160 m^2, with home ranges of males being larger than those of females. In planning for their conservation, it is important the northern striped gecko can efficiently move and interact with mates

within their home range, without being restricted by habitat fragmentation and destruction (Hundertmark 1998; Bowler & Benton 2005; Schick et al. 2008), such as the development of roads and other infrastructure. Future habitat management in areas where the northern striped gecko is present or may be present should consider these movement patterns and ensure sufficient unfragmented habitat is available for the geckos to function (Bowler & Benton 2005).

Overall, the results of this study have several implications. Understanding habitat use of a species and observer biases in detecting them plays an important role in accurately searching for populations of cryptic species, through better understanding which habitats to search (Hare et al. 2007). Targeted searches can expand known species ranges by making the detection of undiscovered populations more likely, which has implications for conservation assessment and action (Hare et al. 2007). Our habitat analyses suggest northern striped geckos have diverse habitat preferences, demonstrating the importance of maintaining healthy and diverse forest habitat for the effective conservation of the species (Fischer & Lindenmayer 2007), and signalling that other populations of this species may remain undetected across the forests of the Coromandel and possibly beyond.

Furthermore, our telemetry data demonstrate significant use of canopy habitats, suggesting some geckos away from edge habitat might never be detected via current systematic search techniques (McDonald 2004; Carter et al. 2012; Ficetola et al. 2014; Willson 2016). Tracking tunnels have some potential for species that commute between the ground and canopy (Lettink et al. 2022). However, detecting geckos in the canopy might be better facilitated through the use of drones, a technique becoming increasingly common and effective for finding lizards in inaccessible terrain, including the canopy (Aota et al. 2021; Monks et al. 2022; Dubos et al. 2023; Davidge et al. 2024). Although most research to date on drones for finding lizards has been done during the day, modern drones have the capability to fly at night and nocturnal geckos have been detected via this technique (Carey Knox, University of Otago, pers. comm.). We recommend embracing emerging survey techniques and investing in canopy surveys for northern striped geckos to unlock their actual distribution and improve conservation planning for this and other data-poor, canopy-dwelling lizard species.

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Additional information and declarations

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