



Suitability of radio telemetry for Aotearoa | New Zealand's only extant semi-aquatic frog, *Leiopelma hochstetteri*

Tobia C. Dale^{1*} , Sara M. Smerdon², Jennifer M. Germano³ , Nicolas J. Rawlence^{1,4} , Joanne M. Monks¹⁺  and Stephanie S. Godfrey¹⁺ 

¹Department of Zoology, University of Otago – Ōtākou Whakaihu Waka, PO Box 56, Ōtepoti Dunedin 9054, Aotearoa New Zealand

²Mahakirau Forest Sanctuary, Coromandel, New Zealand

³Biodiversity, Heritage and Visitors Group, Department of Conservation, Nelson 7042, New Zealand

⁴Coastal Peoples Southern Skies Centre of Research Excellence, PO Box 56, University of Otago, Dunedin 9054, New Zealand

*Authors for correspondence (Email: tobia.dale@hotmail.com, stephanie.godfrey@otago.ac.nz)

⁺These authors contributed equally and should be considered joint last authors

Published online: 9 April 2026

Abstract: Radio telemetry is a valuable technique to gain insights into the ecology of a species by enabling repeated observations of an individual, regardless of its activity or detectability. The miniaturisation of transmitters has allowed a wide variety of taxa to be studied using radio telemetry, including amphibians. In Aotearoa | New Zealand, all three extant endemic Leiopelmatid frogs are threatened and require ecologically informed conservation management. Radio telemetry has previously been used to explore the movement ecology of the two terrestrial *Leiopelma* species. However, the movement ecology of the semi-aquatic Hochstetter's frog (*Leiopelma hochstetteri*) remains poorly understood. To determine whether a simple waistband harness design was suitable for *L. hochstetteri*, we conducted a field study at Mahakirau Forest Sanctuary, Coromandel Peninsula, New Zealand. While assessing harness suitability, we made repeat observations of individuals with fully functional transmitters ($n = 9$) for up to 16 days, providing insight into the species' movement ecology. The longest distance moved between observations was 16.9 m. Minor abrasion occurred in the hip joints of ten frogs. Following refinements to the waistband length to reduce abrasion, radio telemetry will potentially be a beneficial tool to gain information needed for conservation planning.

Keywords: abrasion, conservation, Mahakirau Forest Sanctuary, movement ecology, threatened species, tracking

Introduction

For ongoing *in situ* conservation or translocation efforts, understanding the movement patterns and habitat preferences of amphibian species is necessary (Baldwin et al. 2006). The miniaturisation of radio telemetry provides the opportunity to gather detailed information on the movement and habitat use of ever smaller amphibians (Slater 1965; Altobelli et al. 2022; Pašukonis et al. 2022). A harness attachment is the most frequently used attachment style for amphibians due to their sensitive skin, and adjustments, such as additional leg holes, can be made to improve the fit if necessary (Altobelli et al. 2022; Pašukonis et al. 2022). Confirming the applicability of radio telemetry transmitters and identifying the most appropriate harness design for different species is necessary to ensure an animal's well-being is maintained and that the harness accommodates species-specific behaviour and morphological differences.

Leiopelmatid frogs, endemic to Aotearoa | New Zealand, were widely distributed across the North Island and South Island

prior to human arrival c. 1250 AD (Worthy 1987a; Bunbury et al. 2022). Habitat loss and the introduction of mammalian predators caused *Leiopelma* populations to decline and become fragmented, which in some cases resulted in species extinction (Bell 1985; Worthy 1987b). Considering historic and ongoing threats faced by Leiopelmatid frogs, targeted research exploring species' movement ecology is needed to inform adaptive conservation strategies and safeguard remnant populations. Previous work demonstrated that a simple waistband harness was effective for radio tracking the terrestrial frogs *Leiopelma archeyi* and *Leiopelma hamiltoni* (Germano 2006; Altobelli et al. 2023). The technique has not yet been applied to the semi-aquatic Hochstetter's frog (*Leiopelma hochstetteri*).

Based on geographic isolation and high genetic structuring between the regional populations, *L. hochstetteri* is managed as eleven evolutionarily significant units (Burns et al. 2025). Previous monitoring has relied on finding *L. hochstetteri* under rocks or when emerged (Tessier et al. 1991; Slaven 1992; Whitaker & Alspach 1999; Johnson et al. 2024). During monitoring, individuals are often found utilising the same

retreat or an alternative retreat within 0.5 m of a previous observation, leading to the suggestion that *L. hochstetteri* are a sedentary species (Tessier et al. 1991; Slaven, 1992). The extent of such sedentary behaviour is contradictory as *L. hochstetteri* are also known to have the capacity to move long distances of between 100 and 1000 m between recaptures (Tessier et al. 1991; Slaven, 1992). Improved population monitoring for *L. hochstetteri* is required as a lack of repeat observations prevents valuable information regarding retreat sites, dispersal distances, or movement patterns being captured (Tessier et al. 1991; Slaven 1992; Johnson et al. 2024).

To determine the suitability of radio telemetry for *L. hochstetteri*, we conducted a field study in September 2024 at Mahakirau Forest Sanctuary, Coromandel, New Zealand. Firstly, we evaluated whether a simple waistband harness can be safely used on *L. hochstetteri*, allowing repeat observations. Secondly, we used data collected to describe the movement patterns of the small cohort of frogs.

Methods

Study site

Mahakirau Forest Sanctuary is an unfenced mainland sanctuary protected by a QEII Trust covenant located on the Coromandel Peninsula, North Island. Although *L. hochstetteri* occurs across various streams within the sanctuary, the study focused on a single two-kilometre stretch. The forest surrounding the stream was dominated by kareao (*Ripogonum scandens*), kiekie (*Freycinetia banksii*), hangehange (*Geniostoma ligustrifolium*), kanono (*Coprosma autumnalis*), and rewarewa (*Knightia excelsa*). Many small water seepages branched from the stream, which can become fast flowing during heavy rain.

Harness construction and attachment

To visually search retreat sites for *L. hochstetteri*, rocks in the main stretch of the stream and the adjacent seepages were turned for four days and nights (Whitaker & Alspach 1999). When a frog was found, global positioning system coordinates were taken using a Garmin GPSMAP[®]. For every frog found, snout-to-vent length (SVL) in mm was measured without handling. Only frogs with a SVL > 30 mm were then captured and weighed to ensure the harness weighed no more than ten percent of the frogs' body weight (Richards et al. 1994). Frogs exceeding five grams were fitted with a NTF-1-1 radio transmitter (Lotek, Canada) and silicone tubing harness weighing a combined 0.5 g. The decision to use a Lotek transmitter was influenced by the battery failure rate of an alternative transmitter brand used by Altobelli et al. (2023). An initial health check was performed to check for abrasion, scarring, and to ensure that the frog was alert and responsive. An attempt to sex frogs was made by considering body size, sexually dimorphic forelimb size, and presence of ova (Bell 1978). However, Leiopelmatid frogs are very difficult to sex as they have no secondary sex characteristics, limited sexual size dimorphism, and no acoustic sex-based behavioural differences as seen in most other anurans (Germano et al. 2011), so identification of sex was not possible for all individuals.

Frogs were individually placed in a container with a wet paper towel while the harness was constructed following the methodology outlined in Altobelli et al. (2023). A strip of red reflective tape that sat flush on the transmitter was an additional modification to aid in the location of individuals

at night without causing unnecessary disturbance. To attach the harness, the frog was held in one hand with its front arms naturally extending outwards (Fig. 1). The harness was looped around the extended forearms before being repositioned and tightened around the narrowest part of the frog's waist, ensuring that no pinching or folding of the skin had occurred. If the harness was considered too tight once attached, it was removed and replaced with a silicone tube 1–2 mm longer. The frog was then released at its point of initial capture, which had been marked with a peg.

Movement tracking

Transmitters were attached to eleven frogs, that were located at c. 12 hour intervals, once in the morning and once in the evening. The direction (bearing) and distance from the individual's last observation was recorded. Health checks were attempted at seven-day intervals, following the initial health check procedure. Harnesses were removed upon first observing abrasion, six to sixteen days after initial harness attachment. Photos of abrasions were taken and scored against a six-point abrasion scale (Table 1): (1) minor abrasions where initial abrasion had begun, (2) shallow abrasion accompanied with light grey skin discolouration, (3) a small abrasion no greater than 1 mm in depth (Fig. 2). Additional scores were not observed during the study: (4) abrasion greater than 1 mm in depth, (5) moderate abrasion greater the 1.5 mm in depth, and (6) severe abrasion that is visibly deep and impairing movement.

Statistical analysis

Statistical analyses were completed in R Studio version 4.3.2 (R Core Team 2023). Body condition was calculated using scaled mass index (SMI; \hat{M}_i), to provide a representative measure of the frogs' health and energy reserves while accounting for proportional variations (Peig & Green 2009; MacCracken & Stebbins 2012; Equation 1).

$$\hat{M}_i = M_i \left[\frac{L_0}{L_i} \right]^b \quad (1)$$

Where \hat{M}_i is the scaled mass index, and body mass is M_i . The linear body measurement taken from SVL in mm is L_i , with L_0 representing mean L value for the study population (Peig & Green 2009). The calculation used swapped ^bSMA from the Peig and Green (2009) equation to ^bmodelled directly through a non-linear regression as it is more applicable for calculating the scaled mass index of frogs (Brodeur et al. 2020).

A paired t -test was used when assumptions of the test were met to determine if there was a significant change in the SMI of tracked frogs pre- vs. post-tracking. A Pearson's correlation was used to explore the relationship between the abrasion scores averaged across both hip joints against the duration of wear. Two frogs were excluded from movement analysis due to faulty trackers.

Results

Of the eleven frogs that had transmitters attached, harnesses were only recovered from ten individuals and repeat observations were only recorded for nine individuals (Table 2). The variation in the number of individuals during analysis was caused by faults in two transmitters. The length of the silicone waistband used to attach transmitters to the eleven *L. hochstetteri* individuals varied between 24–26 mm depending

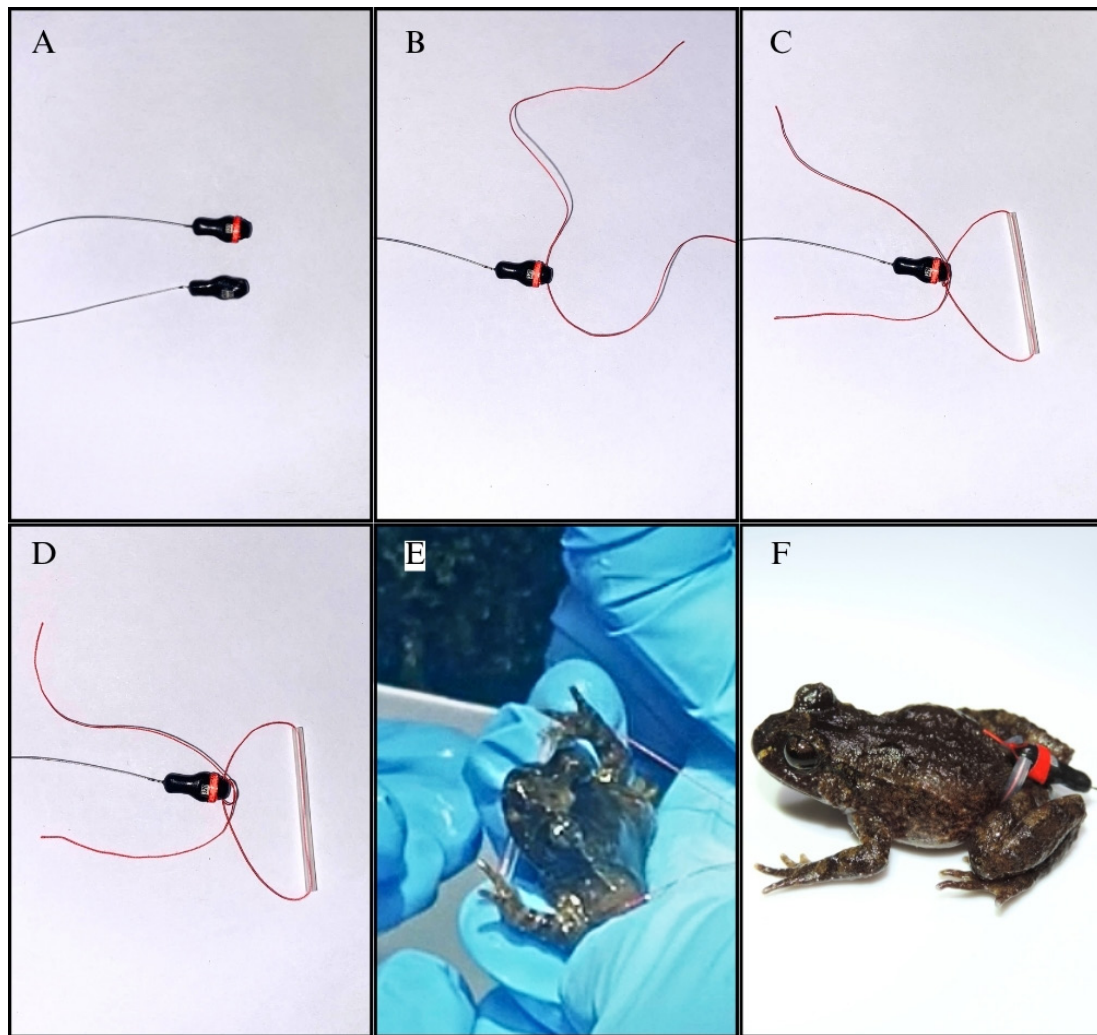


Figure 1. Harness construction and attachment to *L. hochstetteri*, methodology outlined in Altobelli et al. (2023). (a) Transmitter with and without reflective tape. (b) Cotton thread through the manufacturer-included hole. (c) Silicone tube added with one side of cotton threaded back through the hole in the opposite direction. (d) Addition of slip knot. (e) Position of frog during harness attachment. (f) Frog with a harness attached.

Table 1. Six-point abrasion scale developed with Department of Conservation veterinarian used to assess the severity of harness-induced abrasion experienced by *L. hochstetteri* after wearing a harness for six to sixteen days. Scores 4, 5, and 6 were not observed during the field study.

Score	Description
0	No signs of abrasion
1	Initial stages of abrasion are visible
2	Shallow abrasion accompanied with light grey skin discolouration
3	A small abrasion no greater than 1 mm in depth.
4	Abrasion greater than 1 mm in depth. Vet care is not required at this stage unless the frog is presenting with: emaciation, loss of body condition, dehydration, dull or infected eyes, nasal discharge, restriction of movement, limp posture.
5	Abrasion is greater than 1.5 mm in depth. If the frog appears in good condition otherwise and movement is not impeded by the injury, it can be released <i>in situ</i> . If the frog is presenting any of the signs listed in score 4, it should be confined to a sterile container on a wet paper towel. Upon reaching phone reception, photos and videos should be sent to the appropriate vet for a final outcome decision.
6	Abrasion has significantly impaired the frog's movement, is visibly deep, and loss of limb is of concern. Vet assistance is required. The frog should be confined to a sterile container on a wet paper towel. The frog must then be transported to the appropriate facility on a wet paper towel at a stable temperature of between nine and thirteen degrees Celsius.

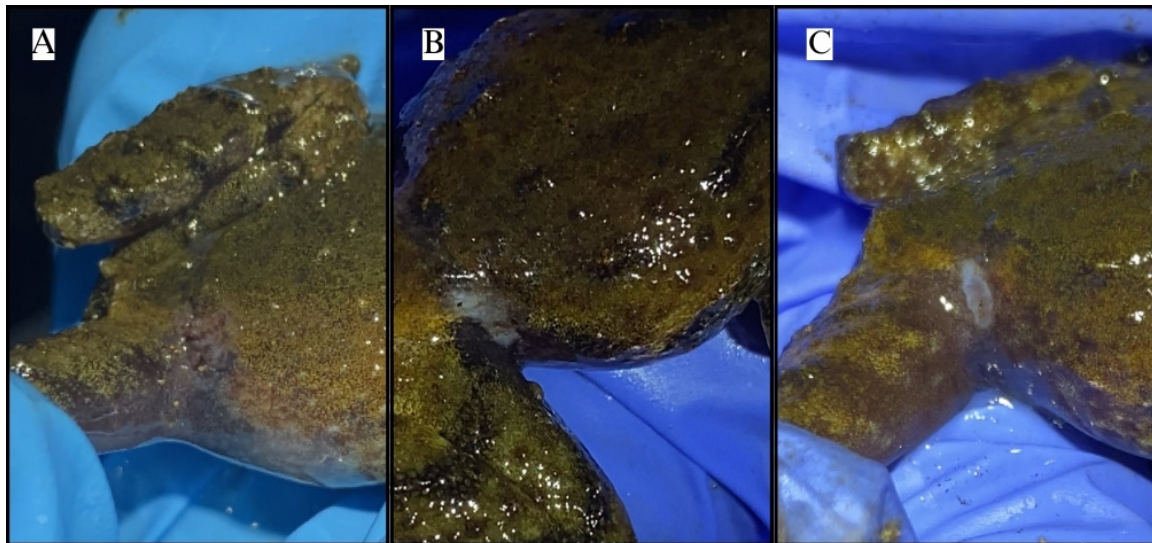


Figure 2. Examples of abrasion on the right hip joint of different *L. hochstetteri* individuals: (a) score = 1 after six days of wear, (b) score = 2 after nine days of wear, and (c) score = 3 after fifteen days of wear.

Table 2. Summary of *L. hochstetteri* measurements, transmitter outcomes, and abrasion scores.

Frog ID	Start weight (g)	End weight (g)	SVL (mm)	Sex	Waistband length (mm)	Days worn	Transmitter fate	Right hip abrasion	Left hip abrasion
F3	5	5.25	34.3	M	24	10	Recovered	3	3
F4	6.9	7	39.4	F	25	11	Recovered	2	3
F5	5.25	5	36	F	24	9	Recovered	2	2
F9	5.5	6.5	38.3	F	24	11	Recovered	2	3
F17	6.05	6.25	39	F	25	13	Recovered	2	2
F21	6.5	7	30.5	F	25	13	Recovered	3	3
F25	7.5	7.5	39.4	F	25	9	Recovered	2	1
F33	5.75	6.75	38	Unknown	25	15	Recovered	3	3
F46	8	7.25	40	Unknown	25	16	Recovered	2	3
F50	6.55	7.5	40	F	26	6	Recovered, faulty	1	1
F88	6.5	-	37	F	25	-	Not recovered, faulty		

on the size of the frog's waist. The SVL of the eleven frogs varied between 30.5–40.0 mm (mean 37.5 mm; SD 2.91 mm). Ten of the eleven frogs were initially found in the main stretch of stream: nine under rocks, and one emerged at night on top of a rock. The eleventh was found amongst rocky debris in a side seepage. Harness attachment took an average of two attempts (range = 1–4), as a frog often jumped out of the harness when placed in the container before the harness could be secured. During harness attachment, five frogs displayed tonic immobility, a passive defence mechanism where a frog becomes limp and unable to right themselves in an effort to remain still (Ferreira et al. 2019), which individuals recovered from in an average of 7.5 mins (SD 9.3 mins).

Harnesses were only able to be recovered from ten frogs. One frog's transmitter (F88) had a fault and failed to emit a signal 36 hours after attachment, so it could not be recovered. A second faulty transmitter (F50) was recovered, allowing comparative SMI pre- and post-tracking to be calculated. The movement data collected for frog F50 was excluded from statistical analysis. Of the ten frogs where harnesses were recovered, none slipped their harnesses, wearing them for

between six to sixteen days (mean 11.3 days; SD 3.0 days; Table 2). There was no significant difference between initial SMI (mean 6.30; SD 0.90) and SMI at the point of transmitter removal (mean 6.61; SD 0.84) ($p = 0.12$, $df = 9$, $t = -1.74$).

Harnesses rotated freely during frog movement, with the transmitter observed against the ventral pelvic patch on three occasions. On the first two occasions, the transmitter's position was corrected by gently moving the transmitter's antenna. The third instance of a rotated harness was left to self-correct to the dorsal position, which occurred by the next fix c.12 hours later. One frog (F4) was found with an antenna looped around a fern stem and was untangled without touching the frog.

Abrasions occurred on all ten frogs whose harnesses were removed. Abrasions were present only in the hip joints between the thigh and trunk of the frog and were scored between one to three (Table 2; Fig. 3). When abrasion scores were averaged for each frog, there was a positive correlation and significant relationship between the length of time a harness was worn and an increase in abrasion score ($r = 0.69$, $p = 0.03$, $df = 8$, $t = 2.67$).

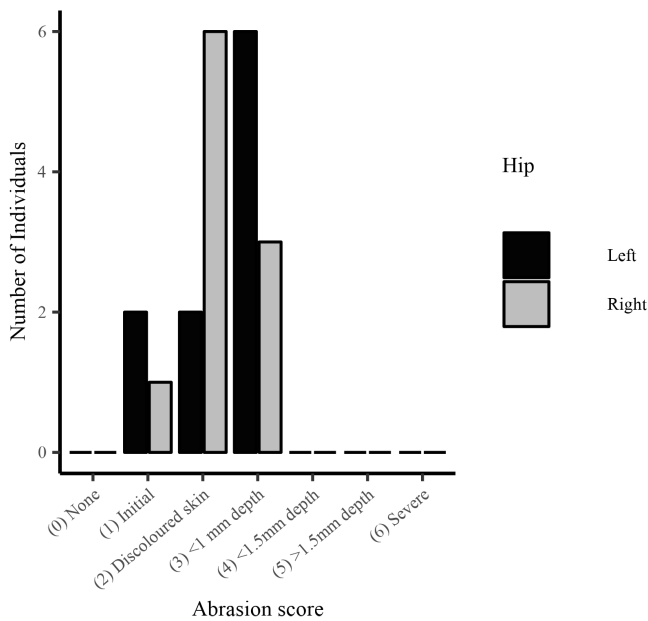


Figure 3. Degree of abrasion on each hip following harness removal of ten frogs ($n = 20$). Further detail of each score is provided in Table 1.

Movement ecology

A total of 182 repeat observations were recorded from the nine frogs that had functioning trackers for the duration of the study. Frogs were found emerged on ten occasions, with half of their body partially emerged on five occasions. Frogs were observed in a retreat site the remaining 167 times. Retreat sites varied and frequently included bank crevices (34.1%), under rocks (20.3%) or under and amongst rocky debris (11.0%). Frogs were found in a variety of locations within the catchment, with 42.3% of observations occurring in the main stream, 36.3% within the stream bank, 11.5% up a side seepage, 4.9% within the side seepage bank, 4.4% at the side of the stream, or 0.5% at the water's edge.

The number of movements and time spent at a single retreat site varied among individuals. The average distance of the first movement following harness attachment was 0.95 m (SD 0.66 m; range = 0.16–2.37 m), while the average distance moved between all other fixes was 0.71 m (SD 1.96 m). The largest distance measured in a straight line between fixes was 16.9 m (time between fixes was 11 hours and 56 minutes) (Fig. 4); this was the only recorded movement between seepages over the duration of the study. The longest period of fidelity to a single retreat site was 128 hours (mean 66 hours; SD 35 hours).

Discussion

Ensuring animal welfare standards are maintained while conducting radio telemetry research is essential to gaining informative insights into a species' movement ecology. This is the first study to assess the suitability of a simple single loop, silicone waistband harness to attach radio telemetry equipment to the semi-aquatic *L. hochstetteri*. Wearing a harness over a period of six to sixteen days did not significantly affect the body condition (SMI) of radio tracked *L. hochstetteri*, and average movements of 0.7 m across all fixes and the record

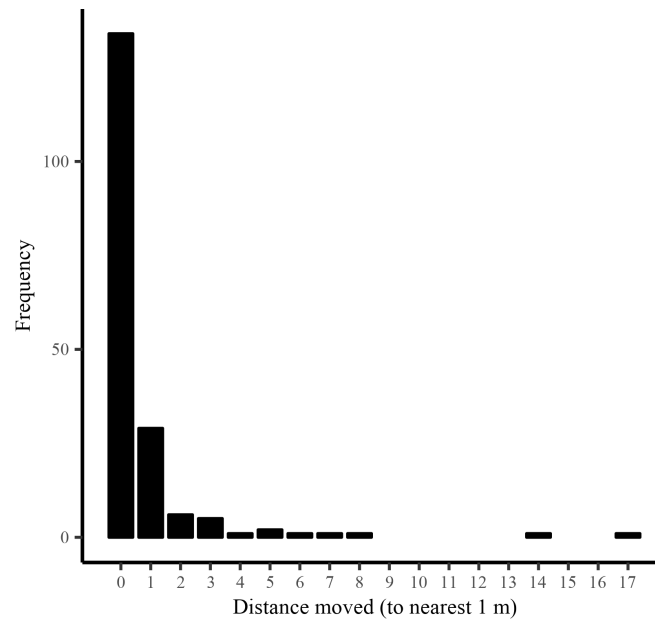


Figure 4. Frequency of distances moved by *L. hochstetteri* individuals ($n = 182$).

of a seepage-seepage movement suggest the harness did not hinder a frog's dispersal ability. All frogs did, however, develop abrasions from this technique that were considered minor but not moderate to severe, as assessed with veterinary assistance from the Department of Conservation (Kate McInnes, pers. comm.). The occurrence of abrasion has implications for the use of this technique over longer time periods, limiting the utility of the method.

While abrasion is not uncommon in the literature (Pašukonis et al. 2022; Muths 2003; McAllister et al. 2004), measures need to be taken to mitigate the occurrence for future studies. A captive trial where daily observations can be made, as done by Altobelli et al. (2023), is recommended to refine the harness fit. This was not possible prior to our field study due to the captive *L. hochstetteri* population at the University of Otago Department of Zoology being moved to Hamilton Zoo. Increasing the length of silicone tubing used for the waistband is the simplest suggestion that is most likely to reduce abrasion while maintaining the transmitter's ability to rotate 360° around the frog's waist. A captive study would allow a larger harness to be trialled with the opportunity for more frequent length refinements, making the harness progressively smaller until the frog no longer slips the harness while ensuring abrasion does not occur (Altobelli et al. 2023). If an increase in the length of the silicone waistband does not reduce abrasion for *L. hochstetteri*, an alternative harness design such as a beaded waistband harness could be trialled under captive conditions, though a bead design is not always appropriate for smaller species due to increased harness weight (Altobelli et al. 2022; Baldwin et al. 2006).

Additional risks to frog wellbeing that occurred within the study include unrecovered harnesses and harness entanglement in foliage. Although the rate of thread degradation is unknown, 100% cotton thread was used to construct harnesses, as it has the ability to degrade, forming a weak link which can eventually release a frog from an unrecovered

harness (Germano 2006; Altobelli et al. 2023). Future work to investigate the degradation rate of 100% cotton thread versus other options would elucidate the length of time required for a weak point to form, freeing a frog from an unrecovered harness. To minimise the risk of entanglement in the future, the length of the transmitter's antenna could be shortened. While entanglement was only observed on one occasion, consideration should be given to whether the full length of the antenna is required, given the antenna had to be manually untangled to free the frog. Increasing waistband length may reduce the risk of entanglement as the likelihood of a frog slipping from the harness would increase. This solution may be favoured over shortening the antenna length, which reduces the signal strength range, depending on the study species' ecology and dispersal ability.

While assessing harness suitability, we gained preliminary insights into the movement ecology of *L. hochstetteri*. If a frog was in the same location, it was assumed that frog had not moved, which is a limitation of the study design, given *L. hochstetteri* are known to show fidelity, returning to previously used retreat sites (Slaven 1992). Site fidelity to retreat sites nearer the main stream may have been higher as the study was conducted during the breeding cycle where females will lay their eggs in the shallow pools of seepages of relatively still side pockets of the main stream (Bell 1978; Beauchamp et al. 2010).

Multiple movements > 3 m were recorded, supporting previous long-distance records (Tessier et al. 1991; Slaven, 1992), and providing some explanation as to why previous mark-recapture studies were unsuccessful in recapturing individuals (Whitaker & Alspach 1999). The ability of *L. hochstetteri* to move many metres away from a stream may be essential for individuals to avoid displacement or washout given they inhabit dynamic stream environments prone to flooding during heavy rainfall (Heaphy 2023). Understanding the movements of *L. hochstetteri* within and between streams and how they use terrestrial habitat would improve population monitoring protocols and mitigation efforts, habitat restoration, and predator control for this species (Crossland et al. 2023; WSP 2024).

As with any study involving direct handling of animals, there is the possibility that natural behaviours are altered in response to the stress of harness attachment and the wearing of a transmitter. Given the primary aim of the study was to assess the harness suitability we did not include a 24-hour stand down period before recording *L. hochstetteri* movements (Rowley & Alford 2007; Liu 2023). Future studies exploring the movements of *L. hochstetteri* could test whether a stand down period to account for any potential changes in behaviour due to handling is necessary. It is unknown how tonic immobility in *Leiopelma* alters subsequent behaviour but this could potentially be analysed secondarily through a compiled radio telemetry dataset if future studies follow a consistent methodology.

Current monitoring methods are unable to capture the complex movement ecology of *L. hochstetteri* with surveys conducted during the day, in fine weather, and in streams where frogs are more likely to be easily found (Tessier et al. 1991; Slaven 1992; Whitaker & Alspach 1999; Johnson et al. 2024). The high site fidelity and average movements for *L. hochstetteri* from our study align with previous mark-recapture daily movement studies and the species' sedentary nature (Tessier et al. 1991; Reilly et al. 2015), while the longer movement we detected between seepages highlights the power

of telemetry studies to gain a more accurate understanding of movement than is possible with traditional mark-recapture studies. This study has demonstrated that this method could be used to track *L. hochstetteri* for short periods less than sixteen days, with minor adjustments to the harness design required for future work. Following refinements to harness fit, future studies could be conducted over longer periods of time and during different seasons, however the field site would need to be selected carefully given the impact of repeated habitat disturbance during 12-hour tracking intervals. Future studies exploring the movement ecology of *L. hochstetteri* will continue to improve the understanding of habitat utilisation, microhabitat preferences, and the distances this species is capable of moving to ensure adequate ongoing conservation protection, particularly for populations threatened by habitat disturbance.

Acknowledgements

We would like to thank the iwi and practitioners who contributed to this study, Pare Hauraki, Ngaati Whanaunga, and the Department of Conservation Frog Recovery Group. We are grateful to the Mahakirau Forest Society for providing accommodation. We would like to thank Kate McInnes, Joe Altobelli, and Emily Hotham for their advice. We recognise the contribution of Luke Easton, Katie Ryan, Sarah McGruddy, Emma Naylor, Nicola Carter, Brett Dale, Raine Williams, Cheyenne Walmsley, Mike Kuypers, Aaron Pulford, Rebecca Gribble, Pascale Lubbe, and Liam Ireland for volunteering to assist in data collection, and to Rogier Goessens, our field safety liaison. We acknowledge and thank the peer reviewers for their input to the manuscript.

Additional information and declarations

Conflicts of interest: The authors declare no conflicts of interest.

Funding: Funding for this project was provided by the University of Otago and the Department of Conservation Frog Recovery Group.

Ethics: All frogs included in the field study were handled with authority from the University of Otago Animal Ethics Committee (AUP-24-05) under a Department of Conservation permit (DOC- 7736896).

Data and code availability: Data regarding frog recaptures and the code used in this article in R is openly available from the corresponding author.

Author contributions: TCD and JMG conceptualised this study with support from JMM and SSG. TCD established the methods and undertook the investigation. SMS supported field site logistics and contributed to data collection. TCD drafted the original manuscript which was reviewed and edited by: TCD, SMS, JMM, SSG, JMG, and NJR. All authors contributed to aspects of the project.

References

Altobelli JT, Dickinson KJ, Godfrey SS, Bishop PJ 2022. Methods in amphibian biotelemetry: Two decades in

- review. *Austral Ecology* 47: 1382–1395.
- Altobelli JT, Bishop PJ, Dickinson KJ, Godfrey SS 2023. Suitability of radio telemetry for monitoring two New Zealand frogs (*Leiopelma archeyi* and *L. hamiltoni*). *New Zealand Journal of Ecology* 47: 3532.
- Baldwin RF, Calhoun AJK, deMaynadier PG 2006. Conservation planning for amphibian species with complex habitat requirements: A case study using movements and habitat selection of the wood frog *Rana sylvatica*. *Journal of Herpetology* 40: 442–453.
- Beauchamp AJ, Lei P, Goddard K 2010. Hochstetter's frog (*Leiopelma hochstetteri*) egg, mobile larvae and froglet development. *New Zealand Journal of Zoology* 37: 167–174.
- Bell BD 1978. Observations on the ecology and reproduction of the New Zealand Leiopelmid frogs. *Herpetologica* 34: 340–354.
- Bell BD 1985. Conservation status of the endemic New Zealand frogs. In: Grigg G, Shine R, Ehmann H eds. *Biology of Australasian frogs and reptiles*. The Royal Zoological Society of New South Wales, Surrey Beatty & Sons Pty Limited. Pp 449–458.
- Brodeur JC, Damonte MJ, Vera Candioti J, Poliserpi MB, D'Andrea MF, Bahl MF 2020. Frog body condition: Basic assumptions, comparison of methods and characterization of natural variability with field data from *Leptodactylus latrans*. *Ecological Indicators*. 112: 106098.
- Bunbury MME, Petchey F, Bickler SH 2022. A new chronology for the Māori settlement of Aotearoa (NZ) and the potential role of climate change in demographic developments. *Proceedings of the National Academy of Sciences* 119: e2207609119.
- Burns RJ, Armstrong D, Bell BD, Haigh A, Hitchmough RA, Thurley T, Germano J, Rawlence NJ, Makan T, Michel P 2025. Conservation status of amphibians in Aotearoa New Zealand, 2024. *New Zealand Threat Classification Series* 44. Wellington, Department of Conservation.
- Crossland MR, Kelly H, Speed HJ, Holzapfel S, MacKenzie DI 2023. Predator control to protect a native bird (North Island kōkako) also benefits Hochstetter's frog. *New Zealand Journal of Ecology* 47: 3530.
- Ferreira RB, Lourenço-de-Moraes R, Zocca C, Duca C, Beard KH, Brodie ED 2019. Antipredator mechanisms of post-metamorphic anurans: A global database and classification system. *Behavioral Ecology and Sociobiology* 73(5): 69.
- Germano JM 2006. Responses of the Maud Island frog, *Leiopelma pakeka*, to artificial displacement. Unpublished MSc thesis, University of Otago, Dunedin, New Zealand.
- Germano J, Cree A, Bishop P 2011. Ruling out the boys from the girls: Can subtle morphological differences identify sex of the apparently monomorphic frog, *Leiopelma pakeka*? *New Zealand Journal of Zoology* 38(2): 161–171.
- Heaphy J 2023. Ottawa sanctuary area storms of Jan/Feb 2023 - damage assessment. Wellington, Department of Conservation.
- Johnson CE, Herbert SM, Gilbert J, Armstrong DP 2024. A comparison of methods for estimating abundance of unmarked Hochstetter's frogs. *New Zealand Journal of Ecology* 48: 3572.
- Liu G 2023. The role of interspecific differences in behaviour and life history in determining species persistence in highly modified landscapes. Unpublished PhD thesis, University of New South Wales, Sydney, Australia.
- MacCracken JG, Stebbings JL 2012. Test of a body condition index with amphibians. *Journal of Herpetology* 46: 346–350.
- McAllister K, Watson J, Risenhoover K, McBride T, Adams M 2004. Marking and radiotelemetry of Oregon spotted frogs (*Rana pretiosa*). *Northwestern Naturalist* 85: 20–25.
- Muths E 2003. A radio transmitter belt for small ranid frogs. *Herpetological Review* 34: 345–348.
- Pašukonis A, Serrano-Rojas SJ, Fischer M-T, Loretto M-C, Shaykevich DA, Rojas B, Ringler M, Roland AB, Marcillo-Lara A, Ringler E, Rodríguez C, Coloma LA, O'Connell LA 2022. Contrasting parental roles shape sex differences in poison frog space use but not navigational performance. *eLife* 11: e80483.
- Peig J, Green AJ 2009. New perspectives for estimating body condition from mass/length data: The scaled mass index as an alternative method. *Oikos* 118: 1883–1891.
- R Core Team 2023. R: A language and environment for statistical computing. Version 4.3.2. Vienna, Austria, R Foundation for statistical computing. <http://www.R-project.org/>.
- Reilly S, Essner Jr R, Wren S, Easton L, Bishop PJ 2015. Movement patterns in Leiopelmatid frogs: Insights into the locomotor repertoire of basal anurans. *Behavioural Processes* 121: 43–53.
- Richards SJ, Sinsch U, Alford RA 1994. Radio tracking. In: Heyer WR, Donnelly MA, McDiarmid RW, Hayek L-AC, Foster MS eds. *Measuring and monitoring biological diversity: standard methods for amphibians*. Washington, The Smithsonian Institution. Pp. 155–158.
- Rowley JLL, Alford RA 2007. Techniques for tracking amphibians: The effects of tag attachment, and harmonic direction finding versus radio telemetry. *Amphibia-Reptilia* 28: 367–376.
- Slater LE 1965. Introduction. *BioScience* 15: 81–82.
- Slaven DC 1992. *Leiopelma hochstetteri*: A study of migratory thresholds and conservation status. Unpublished MSc thesis, University of Auckland, Auckland, New Zealand.
- Tessier C, Slaven DH, Green DM 1991. Population density and daily movement patterns of Hochstetter's frogs, *Leiopelma hochstetteri*, in a New Zealand mountain stream. *Journal of Herpetology* 25: 213–214.
- Whitaker AH, Alspach P 1999. Monitoring of Hochstetter's frog (*Leiopelma hochstetteri*) populations near Golden Cross Mine, Waitekauri Valley, Coromandel. *Science for Conservation* 130. Wellington, Department of Conservation.
- Worthy TH 1987a. Osteology of *Leiopelma* (Amphibia: Leiopelmatidae) and descriptions of three new subfossil *Leiopelma* species. *Journal of the Royal Society of New Zealand* 17: 201–251.
- Worthy TH 1987b. Palaeoecological information concerning members of the frog genus *Leiopelma*: Leiopelmatidae in New Zealand. *Journal of the Royal Society of New Zealand* 17: 409–420.
- WSP 2024. Brynderwyns Hills recovery project: Ecology compliance report. New Plymouth, New Zealand Transport Agency - Waka Kotahi.

Received: 25 August 2025; accepted: 11 December 2025

Editorial board member: Margaret Stanley