Estimating the Proportion of Coromandel's Archey's Frog Population in the Area Affected by Vibrations from the Proposed Wharekirauponga Underground Mine

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EXECUTIVE SUMMARY

OceanaGold are proposing establishing a gold mine under Coromandel Forest Park, in an area where Archey's frogs are present. Although there will be minimal above-ground disturbance, 3.15 km^2 of forest above the underground mine will be subject to transient and intermittent vibrations from underground blasting for approximately eleven years. There is uncertainty around whether vibrations from underground blasting will have a negative impact on Archey's frogs inhabiting the area above the mine. Very little is known about the effects of substrate vibrations on frogs, but it has been suggested that vibrations from underground blasting could disrupt frog behaviour and contribute to egg clutch abandonment. To assess the potential impact of underground blasting, OceanaGold is attempting to estimate how many Archey's frogs and what proportion of the species' Coromandel population is resident in the vibration footprint.

Initially, Archey's frog's likely distribution range in Coromandel was inferred from location records in the Amphibian & Reptile Distribution Scheme (ARDS) for the period 2000 to 2017 and results of Archey's frog surveys undertaken for Ocean Gold during the period 2017 to 2022. The inferred distribution range covers an area of 520 km^2 extending 105 km along the length of Coromandel's axial mountain range from Waihi in the south to Moehau in the north. The distribution range comprises three discrete areas of contiguous of woody native vegetation above 200 m a.s.l. separated by areas of highly modified vegetation.

To obtain better information on Archey's frogs distribution and abundance in Coromandel and verify the species' inferred distribution range, in 2022 OceanaGold initiated a programme of surveys for Archey's frogs throughout its likely distribution range. The survey programme combined nocturnal searches along transects, to define the species' distribution range and relative abundance, with replicate nocturnal searches of 10x10 m plots, to obtain local population density estimates from N-mixture modelling.

Progress on the survey programme has been disappointing with only a small fraction of the proposed work completed because of delays in obtaining permits to undertake fieldwork from the Department of Conservation (DOC). Conclusions drawn from the survey results to date are tentative because of small sample sizes and uneven sampling resulting from constrained access. Archey's frogs were found throughout the length of their likely distribution range, with frogs found along 24 of 40 (60%) transects in the likely distribution range. To obtain better information on the proportion of the likely distribution range frogs inhabit, more surveys are required both in areas not yet surveyed and in areas where frogs were not found on transects to confirm their absence.

Information from the surveys is consistent with previous observations that Archey's frogs are most abundant in mid to high altitude unmodified native forest. Encounter rates along transects in the three main vegetation types at three elevation classes 0–400, 400–600 m and 600–800 m a.s.l. were respectively: 2.0, 15.74 & 10.8 frogs/km for podocarp-hardwood forest; 0.68, 5.3, & 14.3 frogs/km for kauri forest and 1.1, 4.3 & 0.0 frogs/km for forest regenerating from mānuka, kanuka scrub.

Because of inadequate sampling, results from replicate plot searches were limited, but both plot counts, and population estimates from replicate plots show a similar pattern to encounter rates along transects with higher values in unmodified forest and at higher altitudes. Population estimate for plots at all elevation were 12.8 frogs plot^{-1} (i.e., 1,280 frogs ha^{-1}) for plots in podocarp forest compared to 0.53 frogs plot^{-1} (i.e., 53 frogs ha^{-1}) for plots in forest regenerating from mānuka, kanuka scrub. Population estimates for plots in podocarp-hardwood forest in the 0–400, 400–600 m elevation classes were 4.1 (i.e., 410 frogs ha^{-1}) and 28 frogs plot^{-1} (i.e., 2,800 frogs ha^{-1}) respectively.

Two sources of information were used to estimate the number of Archey's frogs in the vibration footprint of the proposed mine: nocturnal surveys of 20x20 m plots undertaken by OceanaGold to fulfil the Access Arrangement Conditions to enter and carry out exploration works in the Wharekirauponga prospect, and the results of a capture-recapture study investigating the effect of past vegetation disturbance on abundance of Archey's frog. Neither of these studies were designed to estimate the number of Archey's frogs, consequently estimates derived from them are tentative and cover a wide range depending on assumptions underlying the estimates. Density estimates ranged from 195 to 937 frogs ha^{-1} for all-age frogs and estimates of the total number of adult Archey's frogs in the footprint ranged from 48,888 to 152,774.

The higher estimates are all derived from the results of the capture-recapture study. The closed population analyses used in the capture-recapture study will have overestimated plot populations because of the movements of frogs across plot boundaries, i.e., the edge effect. The high boundary-to-area ratio of twenty-four 10x10 m plots and the small size of plots relative to frogs' nightly movements indicate that overestimates of plot populations could be large.

The range of population density estimates for Archey's frogs in the vibration footprint is much higher than the density estimates from replicate plot counts in similar vegetation types: ranging from 195 to 937 frogs ha^{-1} in the vibration footprint compared to 53 frogs ha^{-1} in forest regenerating from mānuka, kanuka scrub. Frog counts from searches of plots in the vibration footprint were also considerably higher than counts from replicate plots in the same low elevation (0–400 m) and vegetation types (forest regenerating from mānuka, kanuka scrub and kauri forest) during these surveys. After correcting for truncation and size, the mean plot count for 10x10 m plots in the vibration footprint plots surveyed to fulfil OceanaGold's Access Arrangement was 1.95 frogs/ plot and the mean count for first searches of twenty-four 10x10 m capture recapture plots was 2.8 frogs/plot. This compares with 0.06 frogs/plot search for 18 plots in low altitude forest regenerating from mānuka, kanuka scrub and 0.25 frogs/plot search for 20 plots in low elevation kauri forest during surveys with replicate plot searches.

It is difficult to reconcile the difference between estimates from the vibration footprint and results from the Coromandel-wide surveys. It is possible that the higher counts from plots in the vibration footprint compared to counts from replicate plot searches in similar habitats could be a consequence of differences in the methods. During plot search undertaken in the vibration footprint to fulfil the Access Arrangement Conditions, potential frog micro-habitats in the plot were searched, including beneath and among logs, roots, leaf litter, vegetation and crevices. By contrast during plot searches in the Coromandel-wide survey, plot habitat was not disturbed.

Support for this explanation is that the mean frog count from replicate plot searches of six 10x10 m plots in, and close to the vibration footprint during the Coromandel wide survey was 0.17 frogs/plot search, well below the 1.95 & 2.8 frogs plot^{-1} previously observed in the vibration footprint. The discrepancy between results from the surveys in the vibration footprint and elsewhere in Coromandel should be investigated by surveying more plots for Archey's frogs in and around the vibration footprint using the same methods and personnel in all areas to provide direct comparisons between frog abundance inside and outside the vibration footprint.

More survey work is required to confirm the total area of Archey's frog's distribution range in Coromandel but results of surveys to-date indicate that the 520 km^2 estimate is credible. If the 520 km^2 estimate is correct the vibration footprint area comprises 0.61% of for Archey's frog's Coromandel distribution range. However, if failure to find frogs along 40% of transects in the likely distribution range during the Coromandel-wide survey is interpreted as evidence that frogs are not present in the areas surrounding transects where no frogs were found, the distribution range could be reduced to 312 km^2 (i.e., 60% of 520 km^2), in which case the vibration footprint area is 1.01% of Archey's frog's Coromandel distribution range.

Assuming Archey's frog densities in the vibration footprint and the rest of its Coromandel distribution range are similar, it is likely that between 0.61% and 1.01% of the species' Coromandel population is resident in the vibration footprint. However, results from the transect searches and replicate plot searches show that frog densities are highest in undisturbed podocarp hardwood forest at mid to high elevations (> 400 m a.s.l.). The vibration footprint is <400 m a.s.l., with half of its area in forest regenerating from mānuka, kanuka scrub, 48% kauri forest and only 2% in undisturbed podocarp hardwood forest. By comparison, 35% of the likely Coromandel distribution range is >400 m a.s.l., 18% is undisturbed podocarp hardwood forest and only 9.3% is forest regenerating from mānuka, kanuka scrub. Thus, it seems likely that the frog density in the vibration footprint is considerably lower than the average frog density in the rest of the distribution range and the proportion of frogs resident in the vibration footprint will be considerably less than the vibration footprint's area as a proportion of the distribution range's area (i.e. 0.61% or 1.1%).

INTRODUCTION

OceanaGold is proposing to develop a new gold mine approximately 10 km north of Waihi township (McNeill, 2021). The orebody to be mined lies beneath Wharekirauponga catchment (Figure 1) in Coromandel Forest Park, an area administered by the Department of Conservation. Surface infrastructure for the mine will be located on farmland outside of the forest park, with access to the orebody via tunnels extending under the forest park. Above ground infrastructure in the forest will be minor, with fenced vents placed on unformed roads owned by the Hauraki District Council.

Figure 1. Coromandel with locations of places mentioned in the text.

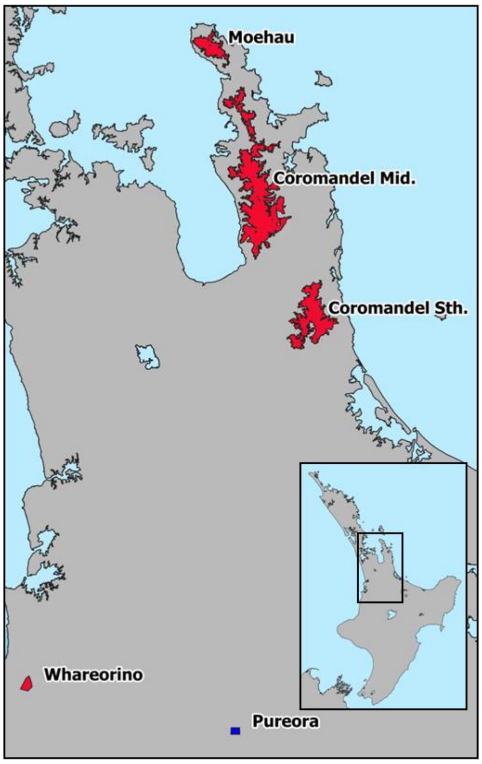


Figure 2. Locations of Archey's frog populations in North Island, New Zealand, showing both naturally occurring populations (red) and a translocated population (blue).

During surveys to select sites for exploration drilling, Archey's frog (*Leiopelma archeyi*) were found in forest above the proposed underground mine (Boffa Miskell Limited, 2018; Wildland Consultants, 2011). Archey's frog is a small (≤ 40 mm), terrestrial and nocturnal frog: one of only three extant endemic frog species in New Zealand. All three endemic species belong to the endemic family Leiopelmatidae, a unique evolutionary lineage, thought to be the world's most archaic frog lineage (Roelants et al., 2007). Leieopelmatid frogs have suffered major declines since human arrival in New Zealand as a consequence of habitat destruction and predation by introduced mammals (Bell, 2010; Bishop et al., 2013; Easton, 2018). At least three species have suffered extinction since human arrival, while two of the extant species are now restricted to fragmented or relict distributions on North Island mainland, and a third is restricted to predator-free offshore islands near the north of South Island.

Archey's frog's conservation threat status was previously Threatened–Nationally Vulnerable (Newman et al., 2013; Newman et al., 2010) in New Zealand's species threat ranking system (Townsend et al., 2008), but in the most recent conservation status review (Burns et al., 2018), undertaken in 2018, the species' threat status was improved to At Risk–Declining. The criteria for this ranking are:

> *The total population comprises 5,000–20,000 mature individuals, and there is an ongoing or predicted decline of 10–30% in the total population or area of occupancy due to existing threats, taken over the next 10 years or three generations, whichever is longer.*

In the most recent version of the IUCN Red List of Threatened Species (2017) (International Union for Conservation of Nature, 2017), Archey's frog is listed as critically endangered, with a stable population of 5,000 to 20,000 mature individuals.

Avoiding and minimising the impact on Archey's frogs from the minor areas of vegetation clearance above the Wharekirauponga underground mine is relatively straightforward. Previously to minimise the impact of mine-related vegetation clearance on Archey's frogs, an Access Arrangement (August 2016: R92455) with the Department of Conservation for OceanaGold to enter and carry out exploration work in the forest park required frog surveys, to be carried out before vegetation clearance was undertaken (Boffa Miskell Limited, 2018, 2019, 2021) and vegetation clearance was not undertaken in areas where five or more Archey's frogs are recorded during searches of a 20x20 m plot over at least three nights with suitable conditions for frog activity. It is proposed that conditions for vegetation clearance will be relaxed in future, with clearance allowed in areas with no trees greater than 50 cm diameter at breast height but that any frogs found during vegetation clearance will be relocated to a pre-prepared release area where pest control has been undertaken for a period of at least one month.

However, there is concern that vibrations from underground blasting will have a negative impact on Archey's frogs inhabiting the area above the mine. Very little is known about the effects of substrate vibrations on frogs, but it has been suggested that vibrations from underground blasting could disrupt frog behaviour and contribute to egg clutch abandonment (van Winkel, 2022). It was thought that vibrations may have contributed to egg clutch abandonment by captive Archey's frogs at Auckland Zoo. However, Archey's frogs persist in areas subject to vibrations with amplitudes of 2 mm s^{-1} at Golden Cross mine, north-west of Waihi. In the absence of evidence about the adverse effects of vibration on Archey's frogs, a precautionary approach has been adopted by OceanaGold, with the presumption that vibrations from underground blasting with amplitudes ≥ 2 mm s^{-1} might have detrimental effects on Archey's frogs (van Winkel, 2022).

Underground blasting is an essential component of underground mine construction and operation. Consequently, if vibrations from underground blasting have detrimental effects on Archey's frogs, there are no realistic options for avoiding or mitigating the effects. Assessing the proportion of the Archey's frog population exposed to vibrations from underground blasting is an important component of an environmental impact assessment for the mine and will be required for developing a residual effects management programme. In this report, I use all currently available information to obtain preliminary estimates of the number of Archey's frogs present in the area above the Wharekirauponga underground mine where the predicted amplitude of vibrations from underground blasting is ≥ 2 mm s^{-1} (i.e., the predicted vibration footprint) and estimate the proportion of Coromandel's Archey's frog population likely to be in the vibration footprint.

POPULATIONS OF ARCHEY'S FROGS

Archey's frogs are only found in North Island, New Zealand (Bishop et al., 2013), with naturally occurring populations of Archey's frogs restricted to Coromandel (Bell, 1994) and Whareorino (Bell, Daugherty, & Hitchmough, 1998; Thurley & Bell, 1994) in west Waikato (Figure 2). Translocations from Whareorino in 2006 and 2016 established a small population 70 km to the east, at Pureora Forest (Bishop et al., 2013; Cisternas, 2018). Geo-referenced records of Archey's frog sightings held in the Amphibian & Reptile Distribution Scheme (ARDS), held in DOC's BioWeb Herpetofauna database, provide some information on the species' distribution. However, the ARDS does not provide reliable information on species' distribution because frogs' geographic distribution and search effort are confounded. The scheme is not based on formal surveys with spatially representative sampling strategies and does not include information on search effort, or where frogs were not found.

Coromandel

The 2019 version of the ARDS database includes 437 records of Archey's frog sightings in Coromandel. On examination 8 records in the database were of sightings from before 1970, 59 records were duplicates or had coordinates that did not fit their location descriptions, and 46 records were duplicates of records from OceanaGold's surveys during the period 2018–19. All 113 of these records were removed from the database, leaving 324 valid recorded sightings in the ARDS database for the 48-year period 1970 to 2017.

Valid ARDS records of Archey's frogs in Coromandel were augmented by 608 geo-referenced records from environmental surveys undertaken for the Wharekirauponga Underground Mine project (Boffa Miskell Limited, 2018, 2019, 2021, 2022) and another 26 from a study on the effect of habitat disturbance on Archey's frogs (Hotham, 2019; Hotham, Muchna, & Armstrong, 2023). These additional 634 records from the period 2018–2022 include information on where frogs were not found but are not the product of spatially representative sampling strategies as most sampling was targeted around the mine project.

All 958 geo-referenced records of Archey's frog sightings in the Coromandel since 1970 are in, or on the fringes of, the main block of almost contiguous indigenous woody vegetation above 200 m a.s.l. along Coromandel Peninsula's axial mountain range (Figure 3a). This block of indigenous vegetation encompasses an area of about 900 km^2, extending 123 km, in a north-south direction. There is a 4 km wide gap at its northern extent, and an 18 km wide, 267 km^2, gap without Archey's frog records in the southern half of the block, leaving a total area of about 632 km^2. Mapping the geo-referenced sightings indicates that Archey's frogs have a disjunct distribution in the Coromandel peninsula with three discrete populations (Figure 3a), referred to in this report as South, Middle and Moehau. Presumably, population fragmentation in Coromandel is a consequence of habitat destruction since human arrival (Easton, 2018).

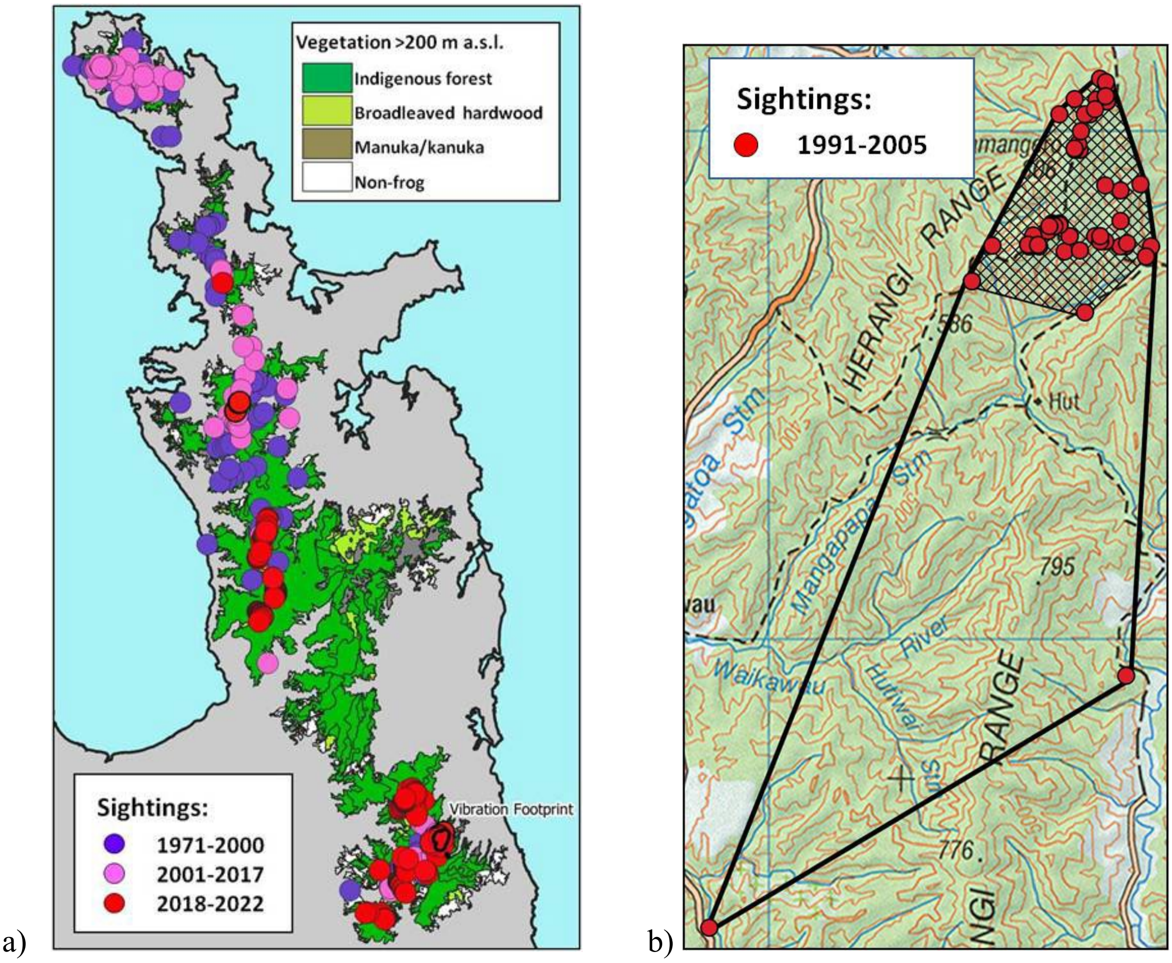


Figure 3. Locations of all recorded sightings of Archey's frogs in (a) Coromandel, 1970–2022, and (b) Whareorino, 1991–2005. LCDB vegetation types above 200 m a.s.l. are shown in the Coromandel map.

Whareorino

Almost all recent research and conservation effort on Archey's frogs have been undertaken at Whareorino or translocating frogs from Whareorino (Bridgman, 2015; Egeter et al., 2019; Eggers, 1998; Germano, Bridgman, Thygesen, & Haigh, 2023; Ramírez, 2017; Thurley & Bell, 1994). However, there is little available information on the distribution range of the Archey's frog population at Whareorino other than a brief mention that early surveys in the area only found Archey's frogs over 6 km^2 (Eggers, 1998). This is contradicted by information in the 2019 version of the ARDS, which includes 92 geo-referenced sightings of live Archey's frogs at Whareorino between 1991 and 2005. There is little obvious difference between habitats (i.e., terrain and vegetation types) in the area of a 77 km^2 minimum convex polygon (MCP) around the 92 sightings (Figure 3b). Removing two outlying sightings reduces the area of the MCP around the main cluster of 90 sightings to 10 km^2. Reported survey effort outside of the core 6 km^2 is limited, consequently Archey's frog could be present over a far wider area.

Mapping Frog Sightings in Coromandel to Vegetation Types

Recorded sightings of Archey's frogs were mapped to vegetation types in the Land Cover Database version 5.0 (LCDB v5.0) (Thompson, Grüner, & Gapare, 2003). The database is the most recent spatial database for vegetation types in Coromandel, last corrected during summer 2018–19. All 92 recorded sightings of Archey's frogs at Whareorino and 89.8% of the 958 recorded sighting in Coromandel were in areas classified as "*Indigenous forest*" (Table 1). Another 7.8% of the Coromandel sightings were in areas of "*Broadleaved indigenous hardwood*". The rest of the Coromandel sightings were in "*Manuka and, or kanuka*" (1.5%) or in areas where the vegetation is now unsuitable for frogs (0.9%) such as pasture, forestry or mine sites. Descriptions of the three main LCDB vegetation types where Archey's frogs were found are:

- "*Indigenous forest*": vegetation dominated by indigenous tall forest canopy species;
- "*Broadleaved indigenous hardwood*": an advanced successional stage back to indigenous forest with canopy height ranging from 3–10 m; and
- "*Manuka and, or kanuka*": early successional scrub dominated by mānuka (*Leptospermum scoparium*) or kānuka (*Kunzea ericoides*) with broadleaved forest species increasingly evident as succession advances.

Table 1. Distribution of all geo-referenced records of Archey's frog sightings (1970–2022) among LCDB vegetation types in Coromandel.

LCDB v5 Vegetation Type	Frog Records	
	N.	%
Indigenous forest	860	*89.8%*
Broadleaved indigenous hardwood	75	*7.8%*
Manuka and, or kanuka	14	*1.5%*
Other	9	*0.9%*
Total Records:	958	

Published Information on Archey's Frog's Habitat Preferences

The occurrence of most Archey's frog sightings in LCDB vegetation type *Indigenous forest* is consistent with published information on Archey's frogs preferred habitat in Coromandel (Archey, 1922; Cree, 1989; Hotham, 2019; Hotham et al., 2023; Stephenson & Stephenson, 1957). Cree (1989) described optimal Archey's frog habitat as forest with a canopy dominated by rimu, rewarewa, towai, with some emergent kauri and tree rata (a mixed podocarp-hardwood forest) at mid to high altitudes (> 400 m a.s.l.). Forests with old-growth tree species and complex interior structures including epiphytes, ground cover and tree ferns are especially favoured by Archey's frogs. An investigation on the effects of past vegetation disturbance on Archey's frog abundance at low to moderate altitudes (Hotham, 2019; Hotham et al., 2023) concluded that mature forest species, such as tree ferns (*Cyathea dealbata*) and rewarewa (*Knightia excelsa*), are associated with higher frog abundance, presumably because they contribute to the leaf litter and increase moisture retention. Frog abundance was also associated with low-growing forest species and ground cover of ferns, sedges and rushes found in mature forest, all of which contribute to forest-floor complexity. Several authors have noted that Archey's frogs are most abundant at mid to high altitudes, presumably as a consequence of higher rainfall and humidity (Cree, 1989; Stephenson & Stephenson, 1957), but possibly a consequence of lower rodent abundance at higher altitudes. Generally, Archey's frogs are thought to occur at lower densities in areas of kauri re-growth, tawa forest, and mānuka-kānuka scrub and avoid exposed windy sites, solid rocky outcrops and well-drained steep ridges or hillsides areas with sparse groundcover.

LIKELY POPULATION DISTRIBUTION RANGE

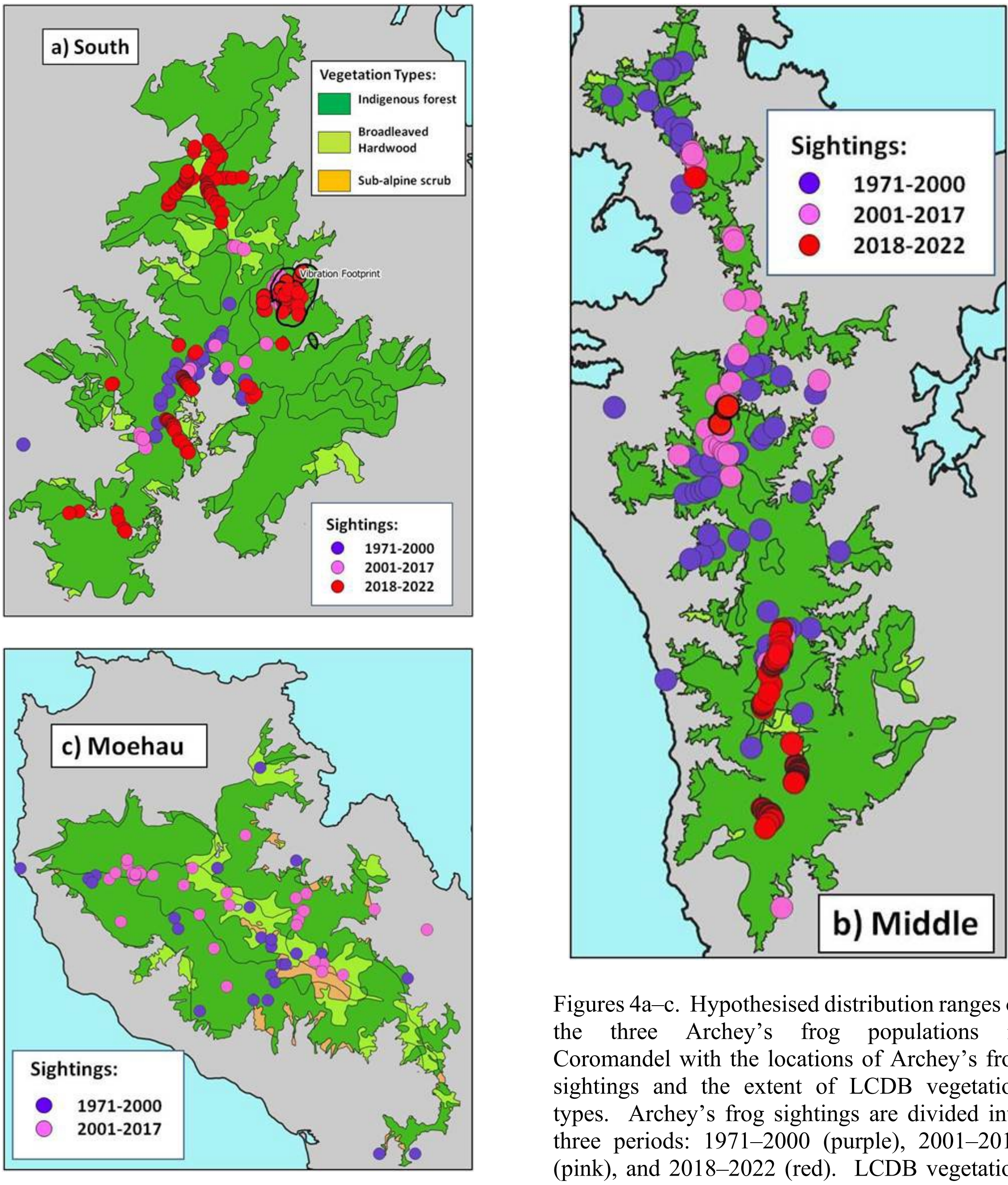
I used information on Archey's frog's habitat preferences and geo-referenced Archey's frog sightings to hypothesise likely distribution ranges for the three Coromandel populations of Archey's frog. The two LCDB vegetation types: *Indigenous forest* and *Broadleaved indigenous hardwood* are both suitable for Archey's frogs, I therefore hypothesised that in each of the three regions with clusters of sightings, frog distribution extends throughout adjacent contiguous areas of these two suitable LCDB vegetation types at elevations higher than 200 m a.s.l. along Coromandel's axial mountain range (Figures 4a–c). The hypothesised distribution ranges include areas without records of Archey's frog sightings, but extrapolation of the distribution ranges to these areas was considered warranted by the presence of nearby sightings in continuous extents of suitable LCDB vegetation types. Fragmented forest patches separated from the main block of forest by areas of unsuitable vegetation were not included in the distribution ranges. High altitude scrub in the Moehau range is wrongly classified as *Manuka and, or kanuka* in the LCDB. Because there are several records of Archey's frogs in this vegetation type, areas of high-altitude scrub wrongly classified as *Manuka and, or kanuka* were included in the distribution range for the Moehau population.

Table 2. Areas of LCDB vegetation types in the ranges of the natural occurring Archey's frog populations.

Archey's Frog Ranges:	Area (km^2)							
	South		Middle		Moehau		Whareorino	
LCDB vegetation type:								
Indigenous forest	126.6	*92%*	328.0	*97.5%*	35.7	*77.1%*	§6.00	*100%*
Broadleaved indigenous hardwood	11.0	*8%*	8.5	*2.5%*	8.1	*17.5%*	0	
Moehau Scrub	0		0		2.5	*5.4%*	0	
All vegetation types	137.6		336.5		46.3		§6.00	

§ The published estimated distribution range (Eggers, 1998) is used instead of the larger MCP ranges from sighting records.

The areas of the hypothesised distribution ranges for the three Coromandel Archey's frog populations are 137.6, 336.5 and 44.7 km^2 for the Southern, Middle and Moehau populations respectively (Table 2) giving a total of 520 km^2. The LCDB vegetation type *Indigenous forest* comprises between 80% and 97% of these distribution ranges, with *Broadleaved indigenous hardwood* covering most of the rest of the distribution ranges. Only 18 (1.9%) of the 958 geo-referenced Archey's frog sightings since 1970 were outside of the three hypothesised distribution ranges, but all 18 were close to distribution range boundaries. Eight of the outlying sightings were in indigenous forest just below the 200 m a.s.l. contour. Two were historical sightings in indigenous forest areas now converted to pasture or exotic forest. The other eight outlying sightings were in unsuitable vegetation types such as mānuka-kānuka scrub, pasture or exotic forest.



Figures 4a–c. Hypothesised distribution ranges of the three Archey's frog populations in Coromandel with the locations of Archey's frog sightings and the extent of LCDB vegetation types. Archey's frog sightings are divided into three periods: 1971–2000 (purple), 2001–2017 (pink), and 2018–2022 (red). LCDB vegetation types are indigenous forest (dark green); broadleaved indigenous hardwoods (pale green); and sub-alpine scrub (orange).

Variation in Habitat Quality

Indigenous forest, the dominant LCDB vegetation type throughout most of Archey's frog's Coromandel distribution, is a diverse vegetation type with a wide range of forest including mature undisturbed kauri forest and podocarp-hardwood forest, as well as forests at various successional stages after disturbances, including forests that have developed over the last fifty years from mānuka-kānuka scrubland. Altitude, substrate, slope and aspect will all introduce more variation in the composition and structure vegetation and its suitability for Archey's frogs. Variation in habitat quality in the *Indigenous forest* vegetation type may well give rise to significant variation in the densities of Archey's frogs within it.

Changes in the Distribution Range

Because many records in the ARDS are from the period 1970–2010, the hypothesised distribution range might not reflect the current distribution of Archey's frogs. During the fifty years since 1970 there will have been changes in the frog populations and their habitats. Changes in predation pressure may have affected frog abundance locally or throughout Coromandel. Frog distribution may have changed in response to changes in habitat quality caused by a variety of factors including successional changes, loss of habitat due to human disturbance, degradation by browsing animals, or the effects of climate change.

During the period 1994–97, there was a major population decline in a capture-recapture plot (Bell, 2010; Bell, Carver, Mitchell, & Pledger, 2004) on Tapu Ridge (Figure 1). There were also contemporary reports of declines in Archey's frog abundance at Tokatea Ridge (Bell et al., 2004) and Moehau (Thorsen, 1999) in north Coromandel, and reports of their absence from forest near Thames and Waihi (Thorsen, 1999) in south Coromandel. The reported declines in the Coromandel population were presumed to be a consequence of the fungal infection chytridiomycosis, first detected in Archey's frogs during 2001 in a dead frog found on Moehau (Bell, 2010; Bell et al., 2004). However, subsequent research (Bishop et al., 2009; Melzer & Bishop, 2010; Ohmer, Herbert, Speare, & Bishop, 2013) has shown that the species has some resistance to chytridiomycosis and that the infection is widespread in apparently healthy populations of Archey's frogs at both Whareorino and Coromandel. Monitoring of the Tapu Ridge capture-recapture plot during the period 1997–2007 documented a partial recovery in the plot population (Bell, 2010).

THE DISTRIBUTION OF SIGHTINGS

Temporal Distribution

A histogram of the numbers of Archey's frog sighting records in the ARDS in five-year bands between 1980 and 2020 (Figure 5a) shows the number of records dipped during the period 1990–1999. This dip in the number of records corresponds to the reported decline in frog numbers during the period 1994–97, attributed to the fungal disease chytridiomycosis (Bell et al., 2004), and a reported subsequent partial recovery in frog abundance (Bell, 2010; Burns et al., 2018). Adding 608 sighting records from mine-related surveys and 26 from Hotham's (2019) study (Hotham, 2019) to a histogram of frog sighting records for the period 1980–2020 (Figure 5b) produces a large increase in the numbers of sighting records from 2015 onwards reflecting the recent increase in survey effort.

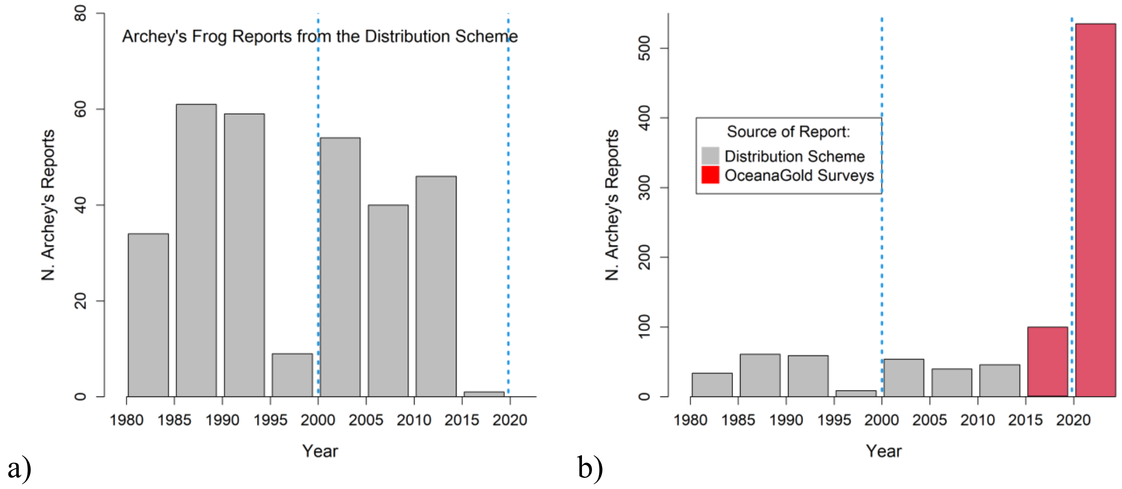


Figure 5. Histograms of the number of recorded sightings in five-year bands showing (a) records from the ARDS and (b) records from the ARDS (grey) and mine surveys (red) combined.

Temporal and Geographic Distribution

A plot of the geographic distribution of sighting over time (Figure 6) shows that the increase in the numbers of sighting records from 2015 onwards is limited to the southern half of Coromandel. This southward shift in the distribution of sightings is driven by mine-related survey effort, with 634 Archey's sightings in the Coromandel since 2018 from either mine-related surveys or Hotham's (2019) study. Only seven of the 634 sightings since 2018 were north of Tapu Ridge (Figure 4c): two from a short transect undertaken for OceanaGold during 2022 and five from Hotham's (2019) capture-recapture study at Mahakirau.

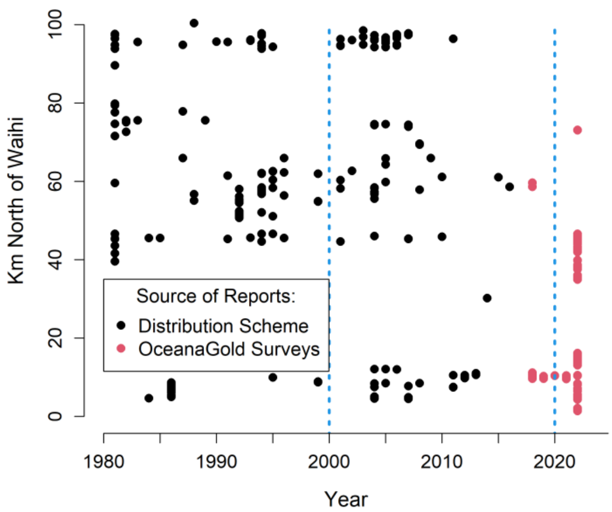


Figure 6. Changes in the geographical distribution of recorded sightings during the period 1980 to 2022, with location indicated by distances north of Waihi. Records from the ARDS (black) and mine-related surveys (red).

Temporal Distributions Among Frog Regions

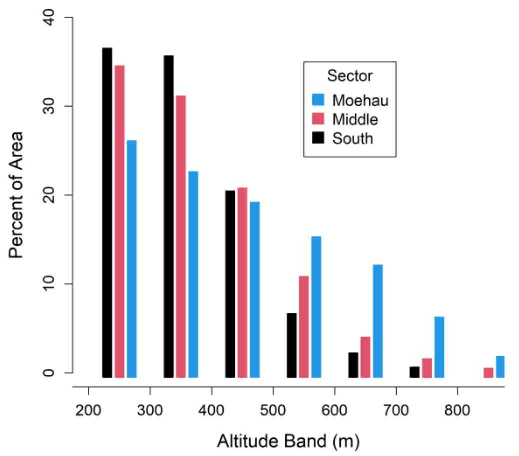
During the 47-year period 1971–2017, when all recorded frog sightings were from the ARDS, sightings were relatively evenly distributed among the three Coromandel frog regions (Table 3, Figures 3a & 4a–c), with 111, 128 and 67 sightings in southern, middle and Moehau regions respectively. Comparisons of the recorded sighting densities in the three regions during this period show the highest sighting densities were in the Moehau region (0.47 and 0.97 records/km^2), with lower densities in the southern and middle regions (0.10–0.42 records/km^2). During the five-year period 2018–2022, when all sightings were from either mine-related surveys or Hotham's (2019) study, there were high numbers of sightings in both the southern and middle regions (316 and 318), but none in the Moehau region (Table 3). Although the sighting density in the southern region was higher than the middle region (2.30 *v.* 0.94 records/km^2), most surveys in the middle region were restricted to the region's southern half, south of Tapu Ridge (Figure 1).

Table 3. Distribution of recorded Archey's frog sighting among Coromandel frog regions during three periods.

Period	Coromandel Frog Regions			All
	South	Middle	Moehau	
a) N. Records:				
1971–2000	53	94	22	169
2001–2017	58	34	45	137
2018–2022	316	318	0	634
Area (km^2):	137.6	336.5	46.3	520.4
b) Records/km^2:				
1971–2000	0.39	0.28	0.47	0.32
2001–2017	0.42	0.10	0.97	0.26
2018–2022	2.30	0.94	0.00	1.22

Altitudinal Distribution

To investigate the effect of altitude on frog distribution, I examined how altitude affected the distribution of Archey's frog sightings in the three Coromandel distribution ranges. I divided each of the three distribution ranges into 100 m wide altitudinal bands and estimated the areas of frog habitat and the number of frog sightings per km^2 in each altitudinal band. All three of the distribution ranges had similar proportions of their area in the mid altitudinal band (≥ 400 < 500 m a.s.l.), but the middle Coromandel and Moehau distribution ranges had higher proportions above 500 m a.s.l. than the southern Coromandel distribution range (Figure 7a). The southern range only extended into the 600–700 m band, while the middle range extended into the 700–800 m band and the Moehau range extended up to > 800 m. Moehau had a much higher proportion of its area above 600 m a.s.l. than the other two areas.



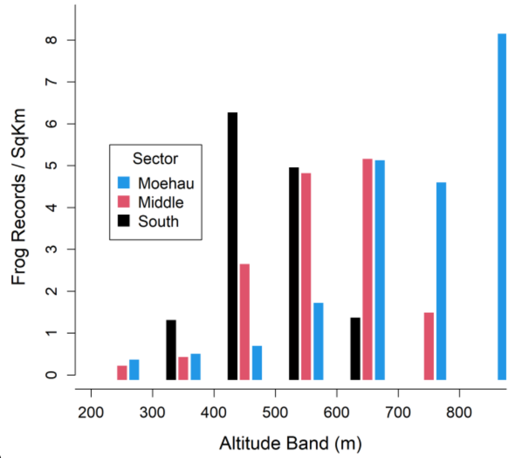


Figure 7. Areas of habitat (a) and numbers of Archey's frog records per square kilometres (b) in 100 m wide altitudinal bands in the three Coromandel distribution ranges.

The density of frog sightings in the middle distribution range increased with altitude rapidly from 400 m a.s.l. upwards before declining in the 700–800 m band (Figure 7b), while density of sightings in the Moehau range was greatest above 600 m. The altitudinal distribution pattern in these two areas is consistent with observations that Archey's frogs are most abundant in mid and high-altitude forests.

In the southern range, there is an extremely high density of sightings below 500 m as a consequence of intense survey effort for the Access Agreement in the Wharekirauponga catchment. For comparison with the middle and Moehau ranges, I removed sightings in the Wharekirauponga catchment around the mine project from the southern range. Even with the low altitude frog sightings around the mine project removed, the altitudinal distribution pattern of frog sightings in the southern range is different from the other two ranges with highest densities in the 400–500 m band and densities declining at higher elevations.

Combining Vegetation Types from Two Spatial Databases

To improve information on the structure and extent of vegetation along Coromandel's axial mountain ranges and assess whether there have been changes in areas of vegetation that could have affected Archey's frog distribution since 1980, I used information on vegetation types in two spatial databases collected 35 years apart (1983 and 2018). The two databases are: the NZ Land Resource Inventory Version 3 (NZLRI)[1] and the more recent Land Cover Database Version 5.0 (LCDB)[2]. Information on vegetation types in the NZLRI database was derived from stereo aerial photograph interpretation, with field verification and measurement, undertaken between 1973 and 1983 (Blaschke, Hunter, Eyles, & Van Berkel, 1981; Hunter & Blaschke, 1986). LCDB v5.0 is the most recent spatial database for vegetation types in the

[1] https://lris.scinfo.org.nz/layer/48055-nzlri-vegetation/
[2] https://lris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand

Coromandel, last corrected during summer 2018–19. Satellite imagery is the primary data source for classifying vegetation types in LCDB (Thompson et al., 2003).

In NZLRI the area above 200 m a.s.l. along the Coromandel and Moehau Ranges includes seven indigenous woody vegetation types (Table 4), whereas in the LCDB there are only three vegetation types:

- *Indigenous forest* – Tall forest, dominated by indigenous conifer and broadleaved species.
- *Broadleaved indigenous hardwoods* – Scrub communities dominated by indigenous mixed broadleaved species, usually in an advanced stage of succession toward indigenous forest.
- *Manuka and, or kanuka* – Scrub dominated by mānuka and, or kānuka; typically an early successional stage in reversion toward forest.

Vegetation types in the two spatial data bases do not correspond exactly but are complementary. NZLRI provides information on vegetation composition in 1983, whereas although LCDB provides relatively little information on vegetation composition, it provides information on the extent of vegetation types in 2018.

Table 4. Aligning indigenous woody vegetation types in NZLRI v3 (1983) and LCDB v5 (2018).

Frog Habitat Quality		NZLRI (1983)	LCDB (2018)
	(N 2)	Kauri forest	
Suitable	(N3a)	Lowland podocarp-hardwood forest	Indigenous forest
	(N3b)	Mid-altitude podocarp-hardwood forest	
Suitable	(N5)	Hardwood forest	Broadleaved indigenous hardwoods
	(M 6)	Mixed native scrub	
Suitable	(M 5)	Sub-alpine scrub§	
Unsuitable	(M 1)	Mānuka, kānuka	Mānuka and, or kānuka

§ Sub-alpine scrub on Moehau Range is wrongly classified as mānuka and, or kānuka scrub in LCDB

Combined NZLRI and LCDB Vegetation Types in the Three Frog Regions

All three frog regions are dominated by vegetation classified as either *Kauri forest* or *Podocarp-hardwood forest* in NZLRI (Table 5). Most (97%) of areas with these NZLRI vegetation types were reclassified as *Indigenous Forests* in LCDB with the remainder reclassified as *Broadleaf indigenous hardwoods* (i.e., *Broadleaf Forest*). The southern frog region is dominated by a mixture of *Lowland podocarp-hardwood forest* (42%) and *Kauri forest* (31%), whereas the middle and Moehau regions are dominated by *Kauri forest* (75% and 48% respectively), with relatively small proportions of *Lowland podocarp-hardwood forest* (6.2% and 12.6% respectively).

Table 5. Areas of NZLRI (1983) and LCDB (2018) vegetation types in the three Archey's frog regions. Abbreviation for NZLRI vegetation types are: *Mk-Kk* = Manuka, kanuka scrub; *Podocarp* = Lowland podocarp-hardwood forest; *Hardwood* = Hardwood forest; *Grassland* = Low producing pasture.

Vegetation Types: LCDB		Frog Regions							
	NZLRI	South		Middle		Moehau		All	
Broadleaf Forest:									
	Mk-Kk	4.7	*(3.4%)*	3.9	*(1.2%)*	0.8	*(1.8%)*	9.4	*(1.8%)*
	Sub-alpine Scrub					2.2	*(4.7%)*	2.2	*(0.4%)*
	Kauri	1.2	*(0.8%)*	1.3	*(0.4%)*	4.1	*(8.9%)*	6.6	*(1.3%)*
	Podocarp	3.9	*(2.8%)*	2.4	*(0.7%)*	0.2	*(0.4%)*	6.5	*(1.3%)*
	Other	1.2	*(0.9%)*	0.9	*(0.3%)*	0.8	*(1.6%)*	2.9	*(0.6%)*
Indigenous Forests:									
	Mk-Kk	11.1	*(8.1%)*	26.4	*(7.8%)*	1.7	*(3.6%)*	39.2	*(7.5%)*
	Sub-alpine Scrub					4.0	*(8.5%)*	4.0	*(0.8%)*
	Kauri	**43.0**	***(31.2%)***	**252.2**	***(74.9%)***	**22.3**	***(48.1%)***	**317.4**	***(61.0%)***
	Podocarp	**58.1**	***(42.2%)***	**20.8**	***(6.2%)***	**5.9**	***(12.6%)***	**84.7**	***(16.3%)***
	Hardwood	9.5	*(6.9%)*	13.7	*(4.1%)*	0.0	*(0.1%)*	23.3	*(4.5%)*
	Grassland	2.8	*(2.1%)*	6.3	*(1.9%)*	1.9	*(4.1%)*	11.0	*(2.1%)*
	Other	2.1	*(1.5%)*	8.6	*(2.6%)*	0.0	*(0.0%)*	10.7	*(2.1%)*
Sub-alpine Scrub									
	Other	0.0	*(0.0%)*	0.0	*(0.0%)*	2.5	*(5.4%)*	2.5	*(0.5%)*
Total		137.6		336.5		46.3		520.4	

Vegetation Changes Between 1983 and 2018

I classified the vegetation types in the two databases for areas above 200 m a.s.l. along the Coromandel and Moehau Ranges as either suitable or unsuitable for Archey's frogs and then aligned vegetation types in the two databases (Table 4). *Manuka and, or kanuka scrub* in LCDB was considered unsuitable for Archey's frogs, whereas the other indigenous woody vegetation types were all considered suitable. The only vegetation types in NZLRI considered unsuitable for Archey's frogs are high and low producing pasture. LCDB includes a variety of vegetation types unsuitable for frogs: pasture, plantation forestry, exotic shrubland, surface mine or dump and orchards. There were minor anomalies in the comparisons of vegetation types. Areas on Moehau Range classified as *Subalpine scrub* in NZLRI are wrongly classified as *Manuka and, or kanuka* scrub in LCDB. A small area classified as *Fern* in NZLRI, which included many frogs, was classified as forest in LCDB, whereas a different area classified as *Fernland* in LCDB is unsuitable for Archey's frogs. The regions used in this analysis are not the same as the three frog distribution regions as they include areas of vegetation unsuitable for frogs, including the gap between southern and middle frog regions.

Table 6. Changes in the areas of vegetation types suitable for Archey's frogs between 1983 and 2018 above 200 m a.s.l. in four regions along Coromandel's axial mountain range.

a)

Areas (km^2)	Southern	Gap	Middle	Moehau	All
Total Area:	177.8	267.7	395.1	58.7	899.3
Areas of Frog Habitat:					
NZLRI 1983	128.3	116.8	312.2	41.8	599.0
LCDB 2018	140.5	210.4	345.3	45.8	742.1
Net Change (km^2)	+12.3	+93.7	+33.1	+4.0	+143.1

b)

Areas (km^2)	Southern	Gap	Middle	Moehau	All
Suitable:					
Unchanged	112.9	105.7	295.3	35.2	549.1
Improved	0.00	0.00	2.62	0.00	2.62
Degraded	5.93	2.86	4.15	4.35	17.29
Succession to Suitable	21.7	101.9	43.3	6.3	173.1
Changed to Unsuitable	9.39	8.24	10.13	2.27	30.0
Unsuitable, Unchanged	27.9	49.0	39.6	10.6	127.1

c)

% Changes 1983→2018	Southern	Gap	Middle	Moehau	All
Gained	17%	87%	14%	15%	29%
Lost	7%	7%	3%	5%	5%
Percentage Net gain	10%	80%	11%	10%	24%
Improved	0%	0%	1%	0%	0%
Degraded	5%	2%	1%	10%	3%

Conclusion on Changes to Vegetation Types Over Time

Between 1983 and 2018, there were net gains in areas of vegetation types suitable for Archey's frogs in all four regions (Table 6). In the regions where frogs have been found (southern, middle and Moehau), net gains were modest (10%–11%), with gains in frog habitat of between 14% and 17% resulting from successional changes to indigenous forest being partially offset by the conversion of between 3% and 7% of frog habitat in 1983 to unsuitable vegetation types, primarily pasture and plantation forestry, by 2018. In the gap, the region where Archey's frogs have not been found, there were the largest gains in areas of vegetation types suitable for Archey's frogs, with an 80% net gain resulting from successional changes from mānuka and, or kānuka scrub[3] to indigenous forest or broadleaved hardwoods (87%), offset by minor losses (7%) caused by indigenous forest being converted to pasture or plantation forest. It should be noted that it is fifty years since areas were classified using NZLRI (1983). Since then, natural regeneration of *Manuka, kanuka scrub* will have converted most of these scrub areas to regenerating forest dominated by early successional species, with the successional process

[3] The different nomenclatures for mānuka and, or kānuka scrub in the two spatial databases are used according to which spatial database is being referred to.

faster at lower altitudes. In the absence of disturbance, vegetation types in areas classified as *Kauri forest* or *Lowland podocarp-hardwood forest* in NZLRI during 1983 are unlikely to have changed significantly since then.

SURVEYS FOR ARCHEY'S FROGS IN COROMANDEL

In 2022, to verify the hypothesised likely distribution range of Archey's frogs in Coromandel (Figure 4 a–c), OceanaGold initiated a programme of surveys for Archey's frogs throughout the species' likely Coromandel distribution range. To ensure comprehensive coverage, the likely distribution range was divided into twenty-three survey sectors (Figure 8). In the proposed programme of surveys, nocturnal searches along transects are undertaken in all sectors to define the species' likely distribution range and estimate its relative abundance in different geographic regions and habitats. In sectors where Archey's frogs were found along transects, replicate nocturnal searches of up to eight randomly located 10x10 m plots were to be undertaken to obtain local population density estimates using N-mixture modelling (Royle, 2004).

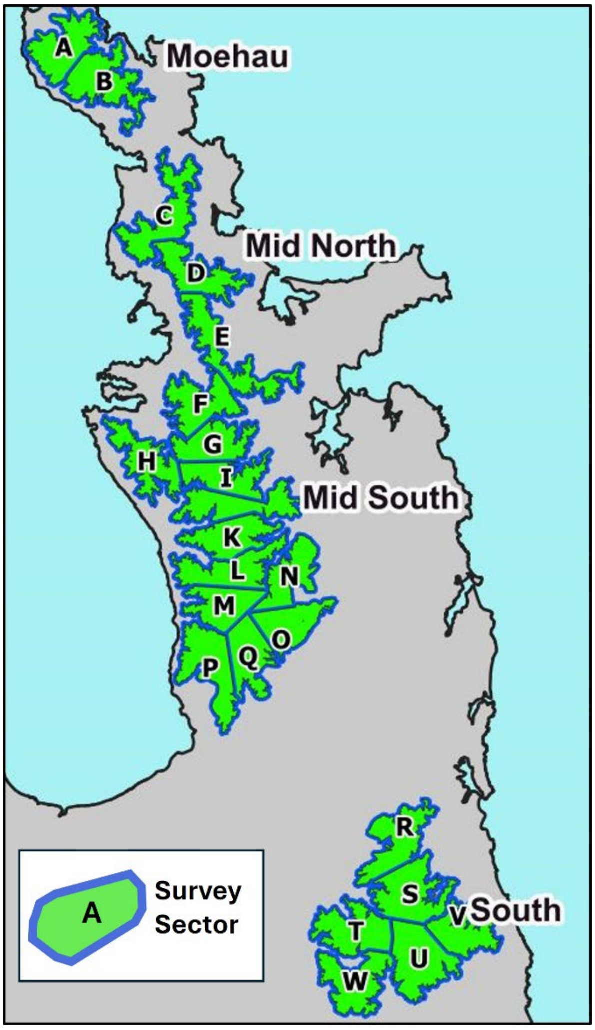


Figure 8. Proposed survey sectors for surveys of Archey's frogs' distribution in Coromandel.

Coromandel Survey Methods

Field Methods

Details of the field methods proposed for the distribution and abundance surveys are provided elsewhere (Lloyd, 2022b, 2022c). Briefly, the proposed surveys use nocturnal searches along transects to establish Archey's frogs' distribution and relative abundance, combined with replicate nocturnal searches of plots to estimate abundance. Both types of searches are conducted on warm moist nights (>10°C and relative humidity >90%). Frogs are not handled during searches and disturbance to frogs and their habitat is kept to a minimum. Nocturnal searches along transects entail field teams searching for Archey's frogs at night along transects through native vegetation, on Coromandel's main axial mountain range. The proposed replicate plot search method entailed repeated nocturnal searches of each of a geographically representative sample of plots distributed throughout areas where Archey's frogs were found during transect searches. Each plot was searched at least five times with all replicate searches of a plot undertaken within a 4-week period. To reduce disturbance to frogs and the development of avoidance behaviour by frogs, replicate searches of individual plots were not undertaken on consecutive nights. The plots are all square permanently marked plots. The first 9 plots were 20x20 m, but subsequent plots were 10x10 m plots. Transect routes and the locations of plots and frogs found along transects are recorded on handheld GPS units. Ambient climatic conditions (e.g., temperature, relative humidity, rain and wind) during transect and plot searches are recorded.

Survey Locations

Transect can be either along existing tracks or, where the terrain is safe, off-track. Transect routes depend on the locations of usable tracks and forest access points with access permission and the nature of the terrain. During the period October 2022 to June 2023, transects were restricted to unformed legal roads in Hauraki District or private land because the DOC access permit had lapsed.

In the initial proposed survey design (Lloyd, 2022c), there were two 10x10 m plots 20 m apart at eight sites in each of the 23 survey sectors (Figure 8), giving a total of 368 plots. For logistical ease, plot locations were to be within 200 m of viable access routes, but actual plot locations were selected randomly. When the DOC access permit lapsed, the original procedure for selecting plot locations randomly was revised because surveys were restricted to unformed legal roads. Instead, plot locations were selected within shapefiles of the unformed legal roads using a generalized random tessellation stratified (GRTS) algorithm (Stevens & Olsen, 2004) implemented with the R-function *grts* in the R-library *spsurvey*.

Site Information

Information on elevation and vegetation types along the transects and at the plot locations was obtained from publicly available spatial databases. The geoprocessing tool in QGIS (QGIS Development Team, 2022) was used to assign locations of plots, frogs found on transects and sections of transect to vegetation types and elevation classes in the spatial data bases. The QGIS geometry tool was used to calculate the lengths of sections of transects.

Elevation classes were obtained from the NZ Contours (Topo, 1:50 k) database downloaded from Land Information NZ. Contour lines were converted to 100 m wide polygons in QGIS. The resulting elevation variable was used as an unordered factor with eight 100 m-wide elevation classes: 0 – 100, 100 – 200, … and 700 – 800 m a.s.l.. Information on vegetation types was obtained from the NZ Land Resource Inventory Version 3 (NZLRI) spatial database (Newsome, Wilde, & Willoughby, 2008). The NZLRI vegetation types were used instead of vegetation types from the more recent (2018–19) Land Cover Database Version 5.0 (Thompson et al., 2003), because the latter provides much less information on vegetation composition and there have only been minor changes in the vegetation cover in Coromandel between compilation of the 1983 and 2018 databases.

Data Analyses

General Linear Models

General Linear Models (GLMs) were used to investigate factors affecting the Archey's frog encounter rate along transects and numbers of frogs found during plot searches. Separate GLMs were undertaken using Poisson and negative binomial distributions implemented using respectively the R-functions *glm* with a logarithmic link function and *glm.nb* (R-library *MASS*). For analyses of data from transect searches the dependent variable was the number of frogs encountered on sections of transect, with the logarithms of lengths of sections used as an offset. For analyses of data from plot searches the dependent variable was the number of frogs found during each plot search, with the logarithms of plot sizes used as an offset. Explanatory variables in GLMs were month, region, temperature and relative humidity (RH) at the start of nocturnal searches, elevation class and NZLRI vegetation types. Because the relationship between the numbers of frogs encountered and both temperature and RH was non-linear, temperature and RH were converted to unordered factors, with four categories for temperature (< 12, 12–14, 14–17 and 17–20ºC) and five categories for RH (75–90, 90–92, 92–94, 94–98 and 98–100%). All explanatory variables in the GLMs were unordered factors. GLMs were undertaken for each of the explanatory variables separately and then in multiway models combining explanatory variables. Starting from the full multiway GLM stepwise regression with backward elimination (Cameron & Trivedi, 1998) was used to select the best GLM to fit the observed data.

Generalised Linear Mixed Effect Models

Generalised linear mixed-effects models (GLMMs) with Poisson error distributions were used to investigate the effects of likely search-level explanatory variables on frog counts during plot searches, with the total number of frogs found during each search as the dependent variable and plot identity as the random effect or grouping variable. Potential search-level explanatory variables were month, temperature and RH. Initially, separate GLMMs were undertaken for each of the likely survey-level explanatory variables. Survey-level explanatory variables with significant effects on frog counts in GLMMs with only one explanatory variable were than included in a single multi-way model together with significant plot-level explanatory variables from the GLMs. GLMMs with Poisson error distributions were implemented using the R-function *glmer* (R-library *lme4*).

N-mixture Modelling

To facilitate N-mixture modelling (Kery & Royle, 2016; Madsen & Royle, 2023; Royle, 2004) and the calculation of confidence intervals, counts from 20x20 m plots were converted to counts from four 10x10 m sub-plots. To retain valid random distributions, this was achieved by allocating each frog found in a 20x20 m plot randomly to one of 4 virtual 10x10 m sub-plots. N-mixture modelling was used to obtain estimates of the numbers of frogs present in the actual and virtual 10x10 m plots from counts of frogs found during replicate surveys of the plots. N-mixture modelling was undertaken with the R-package *unmarked* (Fiske & Chandler, 2011, 2020), which uses maximum likelihood estimation of marginal likelihoods in hierarchical models. To investigate the effects of elevation class and vegetation type on the numbers of frogs present in plots, N-mixture modelling was undertaken both using models with elevation class and vegetation type as covariates and using models with subsamples of the data defined by elevation class and vegetation type.

Miscellaneous Analytic Methods

Exact confidence intervals around Poisson means for frog encounter rates and numbers of frogs per 10x10 m plot search were calculated using the R-function *PoissonCI* in R-package *DescTools*. To compare the patterns of encounter rates along transects and plot counts among different combinations of elevation classes and vegetation types, values of mean encounter rate and plot counts were scaled by dividing by their mean values. The length of transects required to have 80% and 95% probabilities of detecting frogs on transects with different encounter rates were calculated using the quantile function for exponential distribution (*qexp*) in R to generate plots of cumulative density function for 80% and 95% probability of finding frogs along a transect for a range of encounter rates.

Coromandel Survey Results

Progress has been extremely disappointing, with only a small fraction of the proposed work completed because of restricted access to Department of Conservation (DOC) administered land. Initially surveys were undertaken with authorisation of DOC Permit 73879-RES, which allowed frog surveys on public conservation land in Coromandel Forest Park, south of Tapu-Coroglen Road. This permit lapsed during mid-October 2022 and a new permit for the proposed surveys (102031-RES) was issued in May 2023. When the new permit was finally issued, most DOC tracks in Archey's frogs' distribution range in Coromandel were closed as a result of extensive damage caused by extra-tropical cyclones Hale and Gabrielle during January and February 2023. The tracks remain closed for an extended period. Surveys undertaken after mid-October 2022 were restricted to either unformed legal roads in Hauraki District, or areas of privately owned land. This report provides an update of the results from Archey's frog surveys undertaken between December 2021 and June 2024 and discusses the implications of the results.

Transects

Nocturnal searches for Archey's frogs were undertaken along 56 transects during the 2¼-year period 19 March 2022 to 19 June 2024. Forty of the 56 transects with a combined length of 123 km were within Archey's frog's likely Coromandel distribution range, while the other 16 with a combined length of 50 km were outside of the frog's likely distribution range (Figure 9). No Archey's frogs were found along transects outside of their likely distribution range, whereas Archey's frogs were encountered along 24 of the 40 (i.e. 60%) transects in their likely distribution range (Table 7 and Figures 10a–d). A total of 594 Archey's frogs were found along 123 km of transects, giving a mean encounter rate of 4.84 frogs/km (Range: 0 – 67.2 frogs/km). Archey's frogs were found on transects in 4 regions of Archey's frogs' likely Coromandel distribution range (Table 8 and Figures 10a–d). Results from transects outside of the likely distribution range were not analysed.

Table 7. Summary of results from transects in Archey's frog's likely distribution range.

	N. Transects (%)		Transect Length (km)				N. Frogs	Encounter Rate (Frogs/km)	
			Total	Mean	Med.	Range		Mean	Range
Without Frogs	16	(40%)	46.9	2.93	2.7	(1.7, 6.3)	0		
With Frogs	24	(60%)	75.9	3.16	3.2	(2.0, 6.5)	594	7.82	(0.23, 67.2)
All transects	40		122.8	3.07	3.0	(1.9, 6.5)	594	4.84	(0, 67.2)

Table 8. Archey's frog encounter rates along nocturnal transects by region.

Region	N. Transects	Total Length (km)	N. Frogs	Frogs/km	CI95%
Moehau	2	1.7	24	13.80	(8.8 – 20.5)
Mid-north	5	12.0	6	0.50	(0.2 –1.1)
Mid-south	12	45.9	357	7.77	(7.0 – 8.6)
South	21	63.2	207	3.28	(2.8 – 3.8)
Total	40	122.8	594	4.84	(4.5 – 5.2)

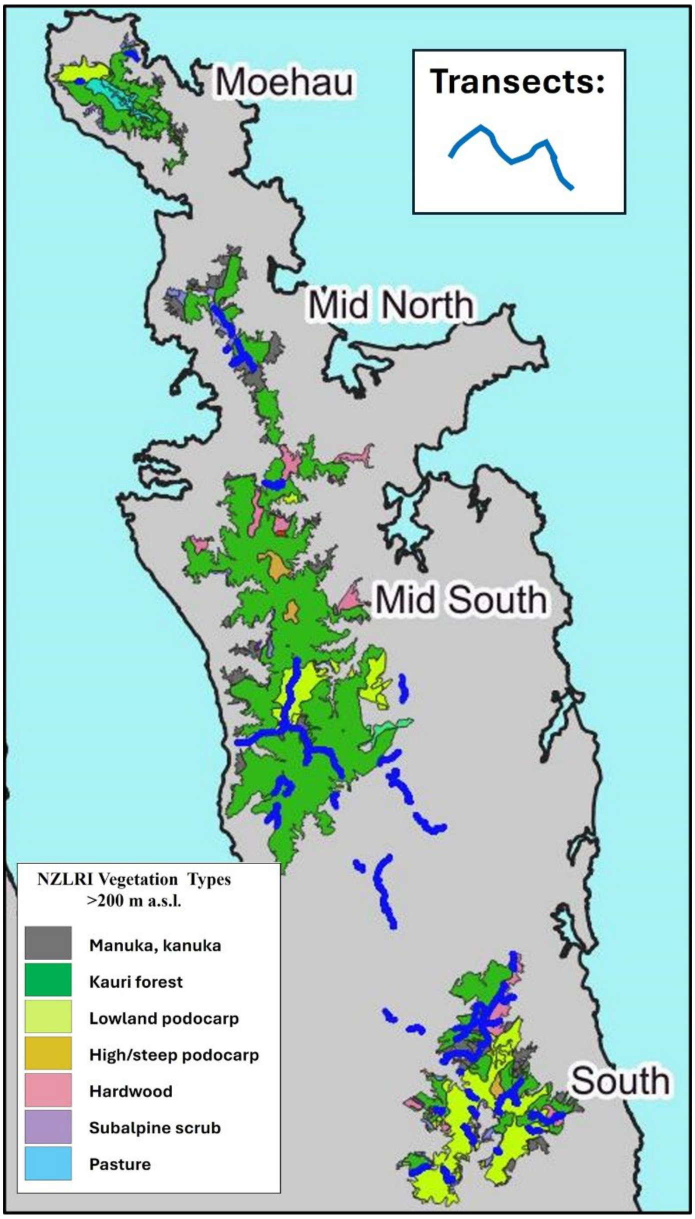


Figure 9. Locations of transects searched for Archey's frogs between March 2022 and June 2024.

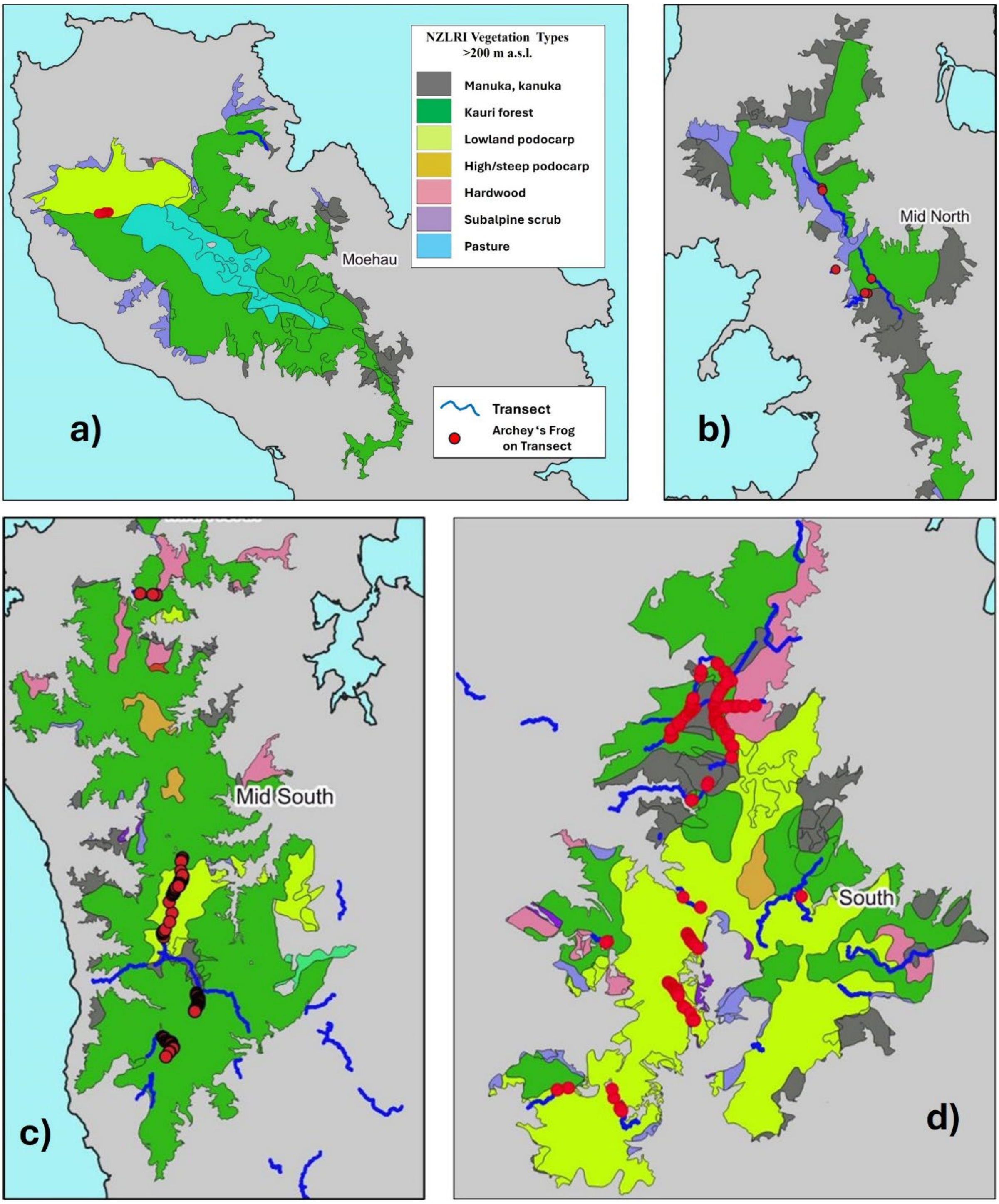


Figure 10. The locations of Archey's frogs found along transects in the Moehau (a), mid-north (b), mid-south (c) and south (d) frog regions in Coromandel.

General Linear Models

GLMs were undertaken using the number of frogs encountered on sections of transect as the dependent variable, logarithms of the lengths of transect sections as an offset and 6 explanatory variables: month, region, temperature, relative humidity, elevation class and vegetation types. In GLMs with single explanatory variables, all 6 explanatory variables were significant ($p < 0.0001$) in both Poisson and negative binomial models. Multiway GLMs with all 6 explanatory variables failed due to absence of samples for many combinations of the explanatory variables' values. The number of explanatory variables in multiway models was sequentially reduced until models ran successfully. Four different multiway models ran successfully: two models with temperature-RH interaction and either vegetation or elevation and two models with vegetation-elevation interaction and either RH or temperature. All 4 models were significant ($p < 0.0001$) in both Poisson and negative binomial models. Because the models are not nested it was not possible to select a best model from the 4 models. Unbalanced sampling and lack of replication means that it is not possible to untangle the effects of these 4 explanatory variables. In the sample of transects, associations between values of different explanatory variables could be structural (e.g., elevation affecting vegetation types, or temperature affecting RH) or just sampling artefacts caused by unbalanced sampling.

Effects of the Explanatory Variables on Encounter Rates

Archey's frog encounter rates were significantly different ($p < 0.0001$) in the four regions, ranging from 0.5 frogs/km in the mid-north region to 13.8 frogs/km in the Moehau region (Table 8), with mid-range values of 7.8 and 3.3 frogs/km for transect in the mid-south and southern regions. Extreme values of encounter rates in the northern and Moehau regions are probably a result of the small sample sizes in the two regions compared to the other two regions (Table 8).

Table 9. Archey's frog encounter rates along nocturnal transects by month.

Month	N. Transects	Total Length (km)	N. Frogs	Frogs/km	CI95%
January	0				
February	0				
March	10	38.0	53	1.40	(1.0 – 1.8)
April	4	7.1	36	5.08	(3.6 – 7.0)
May	5	18.4	301	16.39	(14.6 – 18.3)
June	6	15.61	111	7.11	(5.8 – 8.6)
July	0				
August	1	3.6	0	0.00	(0.0 – 1.0)
September	0				
October	2	2.4	7	2.95	(1.2 – 6.1)
November	11	35.8	84	2.35	(1.9 – 2.9)
December	1	2.0	2	0.99	(0.1 – 3.6)
All	40	122.8	594	4.84	

Most transect searches were undertaken during autumn, early winter, and spring (Table 9). Average encounter rates for transects searched during each of the 8 months when transects were searched were significantly different ($p < 0.0001$), ranging from 0 frogs/km, for a single transect searched during August, to the highest monthly encounter rate of 16.4 frogs/km, for 5 transects searched during March.

Table 10. The joint effects of ambient temperature and RH on Archey's frog encounter rates along nocturnal transects.

RH (%)	Temperature (°C)				All Temperatures Frogs/km (CI95%)		RH (%)
	6 – 12	12 – 14	14 – 17	17 – 20			
75 – 90	0	4.49		0.81	1.64	(0.8 – 3.0)	75 – 90
90 – 92		5.13	**14.40**		11.18	(9.7–12.8)	90 – 92
92 – 94		1.62	6.27		4.34	(3.1 – 5.9)	92 – 94
94 – 98	0.99	**10.36**	5.55	0	4.90	(4.3 – 5.6)	94 – 98
98 – 100	3.44	5.85	0.51	0	2.79	(2.3 – 3.3)	98 – 100
All RH	2.65 (1.7 – 3.9)	5.79 (5.0 – 6.7)	5.69 (5.1 – 6.3)	0.21 (0.04 – 0.6)	Frogs/km (CI95%)		
Temperatures:	6 – 12	12 – 14	14 – 17	17 – 20			

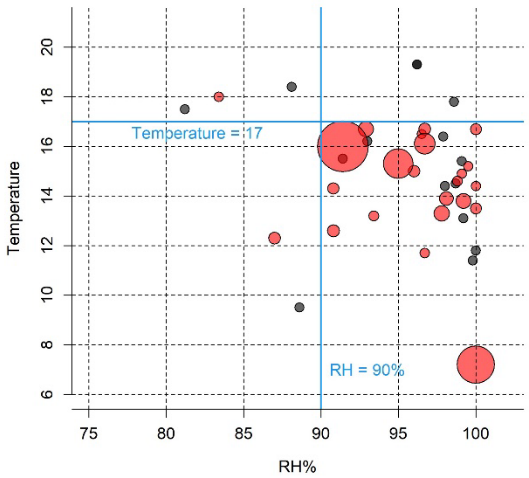


Figure 11. The joint effects of ambient temperature and RH on Archey's frog encounter rates during transect searches. Symbol size is proportional to the mean encounter rate for each combination of temperature and RH classes.

Ambient temperature and RH during transect searches and an interaction between the two factors all had significant ($p < 0.0001$) effects on Archey's frog encounter rates (Figure 11 and Table 10). On warm nights (14 – 17°C) more frogs were encountered at lower RH values (90 – 92%), whereas on cooler nights (12 – 14°C) more frogs were encountered at higher RH values (94 – 98%). Generally, fewer frogs were encountered when RH was below 90% or when temperatures were above 17°C.

In comparisons of encounter rates along transects in the six NZLRI vegetation types (Table 11), highest encounter rates were on transects through *Lowland podocarp-hardwood forest* (N3a) and *Kauri forest* (N 2) with 7.91 and 4.44 frogs/km respectively. Encounter rates were lower in *Mānuka, kanuka scrub* (M 1) and *Hardwood forest* (N 5), with 2.21 and 1.56 frogs/km respectively.

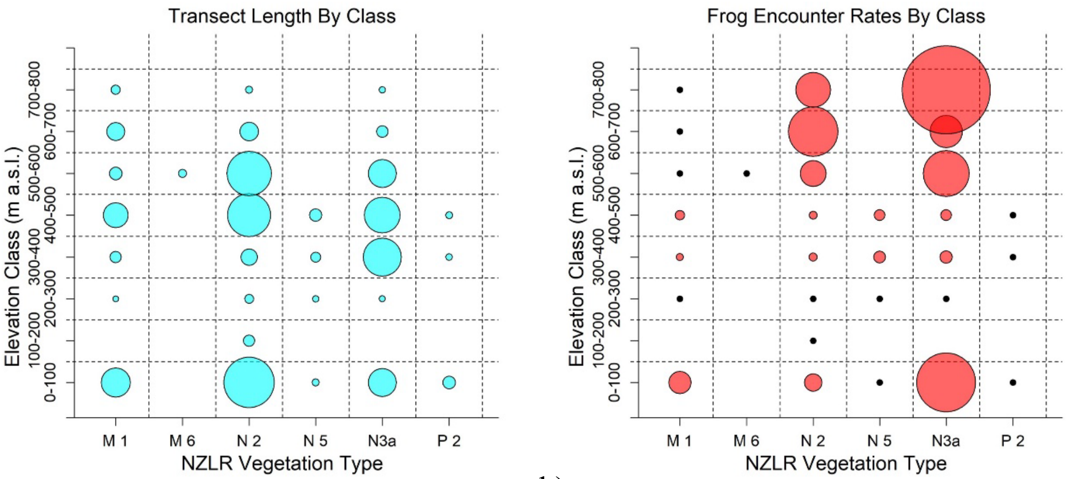
Table 11. Archey's frog encounter rates along nocturnal transects by NZLRI vegetation types.

NZLRI Vegetation Type	N. Frogs	N. km	Encounter Rate	
			Frogs/km	*(CI95%)*
Mānuka, kanuka scrub (M 1)	53	23.97	2.21	*(1.66 – 2.89)*
Kauri forest (N 2)	231	52.08	4.44	*(3.88 – 5.05)*
Lowland Podocarp hardwood (N3a)	303	38.31	7.91	*(7.04 – 8.85)*
Hardwood forest (N 5)	7	4.48	1.56	*(0.63 – 3.22)*
Mixed native scrub (M 6)	0	0.85	0.00	*(0.00 – 4.34)*
Grassland (P 2)	0	3.16	0.00	*(0.00 – 1.17)*

NZLRI vegetation types and elevation classes and an interaction between the two all had significant ($p < 0.0001$) effects on Archey's frog encounter rates during transect searches (Tables 12 & Figures 12b). Encounter rates on transects through *Lowland podocarp-hardwood forest*, *Kauri forest* and *Mānuka, kanuka scrub* were all higher at elevations above 400 m a.sl.. After examining the pattern of frog encounters on transects in combinations of the 6 NZLRI vegetation types and eight 100 m wide elevation classes, the 100 m wide elevation classes were folded into 3 elevation classes (0–400 m, 400–600 m and 600–800 m) for further analyses (Table 13). Interaction between NZLRI vegetation types and elevation classes with only three elevation classes had significant ($p < 0.0001$) effects on Archey's frog encounter rates. With the three elevation classes the combined influence of vegetation type and elevation were more apparent (Table 13). Highest encounter rates were along transects through *Lowland podocarp-hardwood forest* in the 400–600 m and 600–800 m elevation classes (15.7 & 10.8 frogs/km) and *Kauri forest* (N 2) above 600 m (14.3 frogs/km). Encounter rates on transects though mid-altitude (400–600 m) *Kauri forest* and *Mānuka, kanuka scrub* were considerably lower (5.3 & 4.3 frogs/km). Encounter rates on transects though low altitude (0–400 m) areas of *Lowland podocarp-hardwood forest*, *Kauri forest*, *hardwood forest* and *Mānuka, kanuka scrub* were ≤ 2 frogs/km.

Table 12. Archey's frog encounter rates (Frogs/km) along nocturnal transects by NZLRI vegetation types and 100 m wide elevation classes. Cells with no encounter values are for combinations of elevation class and vegetation type without transects. Vegetation types are: *Mānuka, kanuka* (M 1), *Mixed native scrub* (M 6), *Kauri forest* (N 2), *Hardwood forest* (N 5), *Lowland podocarp–hardwood forest* (N3a), and *Low producing pasture* (P 2).

Elevation (m a.s.l.)	NZLRI Vegetation Type							Elevation (m a.s.l.)
	M 1	M 6	N 2	N 5	N3a	P 2	All	
700 – 800	0		9.8		27.7		5.6	≥ 700
600 – 700	0		14.8		9.0		7.9	600 – 700
500 – 600	0	0	6.8		13.5		8.0	500 – 600
400 – 500	5.6		4.0	0	17.9	0	7.1	400 – 500
300 – 400	1.3		0.8	1.77	1.7	0	1.2	300 – 400
200 – 300	0.5		0.8	2.07	2.3	0	1.8	200 – 300
100 – 200	0		0	0	0		0	100 – 200
0 – 100			0				0	0 – 100
All	2.21	0	4.44	1.56	7.91	0	4.84	
Veg. Type	M 1	M 6	N 2	N 5	N3a	P 2		



a) b)

Figure 12. The total lengths of sections of transects (a) and mean frog encounter rates along sections of transects in different NZLRI vegetation types and elevation classes (b). Symbol size for each combination of elevation class and vegetation type is proportional to length of transects in (a) and the mean frog encounter rate in (b).

Table 13. Archey's frog encounter rates along nocturnal transects by NZLRI vegetation types and three elevation classes.

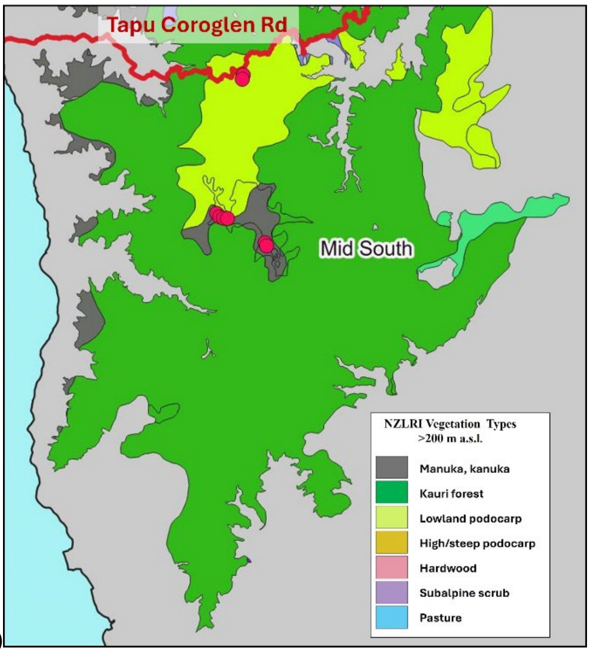
NZLRI Vegetation	Elevation (m a.s.l.)	N. Frogs	N. km	Encounter Rate Frogs/km	*(CI95%)*
Mānuka, kanuka (M 1)	0–400	9	8.36	1.08	*(0.49 – 2.04)*
	400–600	44	10.28	4.28	*(3.11 – 5.74)*
	600–800	0	5.33	0.00	*(0.00 – 0.69)*
Kauri forest (N 2)	0–400	13	19.17	0.68	*(0.36 – 1.16)*
	400–600	149	28.08	5.31	*(4.49 – 6.23)*
	600–800	69	4.84	14.27	*(11.1 – 18.1)*
Lowland podocarp hardwood (N3a)	0–400	42	21.03	2.00	*(1.44 – 2.70)*
	400–600	237	15.05	15.74	*(13.8 – 17.9)*
	600–800	24	2.22	10.80	*(6.92 – 16.1)*
Hardwood forest (N 5)	0–400	7	3.96	1.77	*(0.71 – 3.64)*
	400–600	0	0.51	0.00	*(0.00 – 7.16)*
Mixed native scrub (M 6)	400–600	0	0.85	0.00	*(0.00 – 4.34)*
Pasture (P 2)	0–400	0	0.77	0.00	*(0.00 – 4.81)*
	400–600	0	2.39	0.00	*(0.00 – 1.54)*

Replicate Plot Searches

Summary

There were 41 plots, comprising thirty-two 10x10 m plots and nine 20x20 m plots. All thirty-two 10x10 m plots were in the southern frog region (Figures 13b). Eight of the 20x20 m plots were in the south of the mid-south frog region (Figure 13a) and one in the southern frog region. The numbers of replicate searches of the plots varied between 2 and 5, with 2 plots searched twice, 15 plots searched three times, 1 plot searched 4 times and 23 plots searched five times. This gave 168 plot searches with a mean of 4.10 searches per plot. All plot searches were undertaken during summer (1 December–1 April), with 80 searches during 2021–22 and 88 during summer 2022–23. For GLMM and GLM modelling plot size was used as an offset, whereas for N-mixture analyses and to produce summary statistics the nine 20x20 m plots were each converted to four 10x10 m virtual subplots giving a total of 68 10x10 m plots and 291 plot searches with a mean of 4.28 searches per plot.

a)



b)

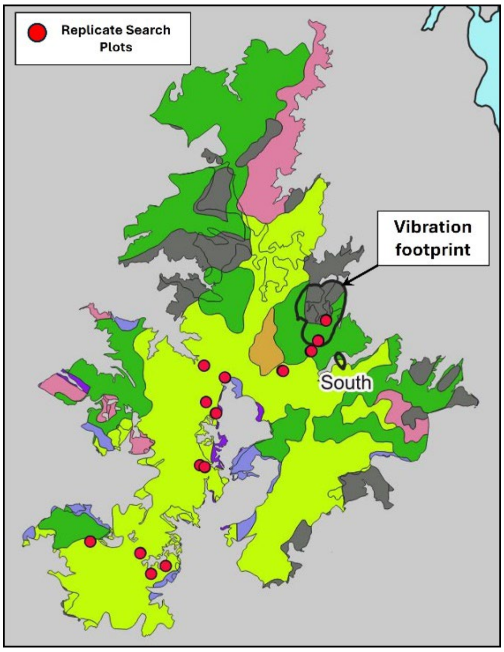


Figure 13. The locations of plots in the mid-south (a) and southern (b) frog regions.

GLMM & GLMs to Investigate Factors Affecting Frog Counts During Plot Searches

The final classes used for modelling the effects of elevation, temperature and RH were selected following iterative modelling in GLMs to achieve the best separation between classes. The original five 100 m wide elevation classes were collapsed into the same three classes used for analysing transect data: 0–400 m, 400–600 m and 600–800 m a.s.l.. Three classes were used for temperature (8–13ºC, 13–18ºC and 18–24ºC) and two for RH (70–90% and 90–100%).

In one-way GLMMs, month and temperature classes did not have a significant ($p > 0.1$) effects on the frog counts during plot searches, whereas RH class had a significant ($p < 0.01$) effect. All multiway GLMMs failed because there were insufficient searches. The starting model for multiway GLMs had two interaction terms: elevation x vegetation and temperature x RH. The best multiway GLM model retained elevation class and vegetation type ($p < 0.0001$) and RH class ($p < 0.001$) but dropped interaction terms and temperature.

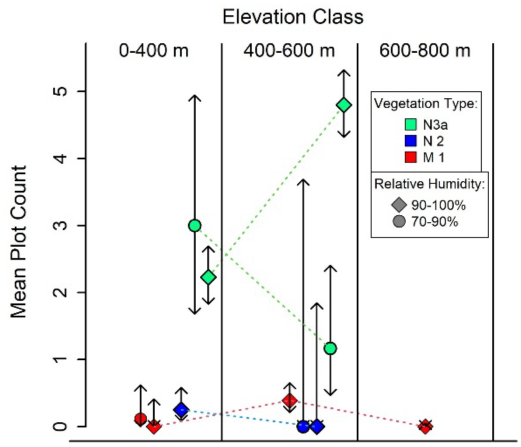


Figure 14. Mean frog counts for searches of 10x10 m plots plot in different NZLRI vegetation types and elevation classes, with high and low RH during searches.

Table 14. Comparisons of results from replicate searches of 10x10 m plots in the three different NZLRI vegetation types *Mānuka, kanuka scrub* (M 1), *Kauri forest* (N 2) and *Lowland podocarp hardwood (N3a)*. Frog counts per plot search is the mean numbers of frogs found per search of 10x10 m plots. The estimated number of frogs per plot and detection probabilities are estimates obtained from N–mixture models of the numbers of frogs present in 10x10 m plots and the probability that a frog will be detected during a plot search.

Vegetation Type	N. Plot Searches	Total Frogs Found	Count per Plot Search		Estimated Frogs/Plot		Detection Probability	
			N.	*(CI95%)*	N.	*(CI95%)*	*P.*	*(CI95%)*
M 1	134	15	0.112	*(0.06 – 0.18)*	0.534	*(0.22 – 1.27)*	0.228	*(0.09 – 0.48)*
N 2	23	5	0.217	*(0.07 – 0.51)*				
N3a	134	489	3.65	*(3.33 – 3.99)*	12.8	*(9.7 – 16.8)*	0.270	*(0.21 – 0.34)*
All	291	509	1.75	*(1.60 – 1.91)*	4.12	*(3.5 – 4.8)*	0.415	*(0.37 – 0.46)*

There was an interplay between effects of the three factors vegetation type, elevation class and RH on frog counts during plot searches (Figure 14). Vegetation type had the biggest effect

(Table 14), with mean frog counts for plots in *Lowland podocarp hardwood forest* (3.65 frogs/search; CI95% 3.3–4.0) 17 times higher than for plots in *Kauri fores*t (0.22 frogs/search; CI95% 0.07–0.51) and 33 times higher than for plots in *Mānuka, kanuka* (0.11 frogs/search; CI95% 0.06–0.18). Mean frog counts for plots in *Lowland podocarp hardwood forest* and *Mānuka, kanuka* were both higher for plots in the 400–600 m elevation class than in the 0–400 m elevation class (Table 15). There were no plots in *Lowland podocarp hardwood forest* in the 600–800 m elevation class and no frogs were found during 80 searches of 16 plots in *Mānuka, kanuka* in the 600–800 m elevation class. Only one of the 5 plots in *Kauri forest* were outside of the 0–400 m elevation class and no frogs were found in that plot despite 3 searches. RH during searches only had a significant effect ($p < 0.001$) on frog counts in plots within *Lowland podocarp hardwood forest* in the 400–600 m elevation class (Figure 14).

Table 15. Comparisons of results from replicate searches of 10x10 m plots in three different elevation classes and three different NZLRI vegetation types *Mānuka, kanuka scrub* (M 1), *Kauri forest* (N 2) and *Lowland podocarp hardwood (N3a)*. Frog counts per plot search is the mean numbers of frogs found per search of the 10x10 m plots. The estimated number of frogs per plot and detection probabilities are estimates obtained from N–mixture models of the numbers of frogs present in 10x10 m plots and the probability that a frog will be detected during a plot search.

Veg. Type	Elevation Class (m a.s.l.)	N. Plot Searches	N. Frogs Found	Frog Count per Plot Search N.	*(CI95%)*	Estimated Frogs/Plot N.	*(CI95)*	Detection Probability *P.*	*(CI95)*
M 1	0–400	18	1	0.056	*(0 – 0.31)*				
	400–600	36	14	0.389	*(0.21 – 0.65)*				
	600–800	80	0	0	*(0 – 0.05)*				
M 1	400–800	116	14	0.121	*(0.07 – 0.20)*	0.416	*(0.14 – 1.23)*	0.213	*(0.06 – 0.52)*
N 2	0–400	20	5	0.250	*(0.08 – 0.58)*				
	400–600	3	0	0	*(0 – 1.23)*				
	600–800	0							
N3a	0–400	53	122	2.30	*(1.91 – 2.75)*	4.10	*(2.9 – 5.7)*	0.514	*(0.40 – 0.63)*
	400–600	81	367	4.53	*(4.1 – 5.0)*	27.9	*(16.4 – 47.6)*	0.158	*(0.09 – 0.26)*
	600–800	0							

Abundance Estimates from N-Mixture Modelling

Abundance estimates for 10x10 m plots in *Lowland podocarp hardwood forest* and *Mānuka, kanuka* obtained from N-mixture models (Table 14) were very different, with 12.8 (CI95%: 9.7–16.8) frogs/plot in *Lowland podocarp hardwood forest* and 0.534 (CI95%: 0.22–1.27) frogs/plot in *Mānuka, kanuka.* There were not enough data from *Kauri forest* plots to obtain reliable abundance estimates from N-mixture modelling. In N-mixture models with elevation class and vegetation type (Table 15), the only groups with enough data for reliable abundance estimates were plots in *Lowland podocarp hardwood forest* in the two lower elevation classes and plots in *Mānuka, kanuka* with 400–600 m and 600–800 m elevation classes collapsed into a single 400–800 m elevation class. There were not enough data to obtain reliable abundance estimates for plots in *Mānuka, kanuka* in the 0–400 m elevation class. N-mixture models with vegetation type and elevation class as covariates all failed because of insufficient data.

Comparing Results from Transect Searches and Replicate Plot Searches

Transect searches and replicate plot searches provide very different metrics. To compare patterns in the two data sets, estimated values for different vegetation types and elevation classes in the two data sets were scaled by dividing by their mean values (Table 16). Although the transect data set is only preliminary, transects have been undertaken throughout most of the frog's likely distribution, sampling most available combinations of the three elevation classes and six NZLRI vegetation types. By contrast, data from replicate plot searches is patchy, with plots only undertaken in the southern part of the likely distribution range (Figures 13a&b) and in a limited sample of elevation classes and vegetation types (Table 15). Despite differences between the two data sets, the strongest signal in both is high values for samples from mid-elevation (> 400 m a.s.l.) *Lowland podocarp hardwood forest* compared to values in other vegetation types and at lower elevations.

Table 16. A comparison of results from transect and replicate plot searches using scaled values of frog encounter rates and plot counts in different vegetation types and elevation classes. Scaled values are mean estimates for vegetation types and elevation classes divided by the overall mean values for all searches.

NZLRI Vegetation Type	Elevation (m a.s.l.)	Frogs per km on Transects		Frogs per Plot Search		Scaled to Mean	
		Mean	*(CI95%)*	Mean	*(CI95%)*	Transect	Plots
Mānuka, kanuka scrub (M 1)	0–400	1.077	*(0.49 – 2.04)*	0.056	*(0 – 0.31)*	0.22	0.03
	400–600	4.279	*(3.11 – 5.74)*	0.389	*(0.21 – 0.65)*	0.88	0.22
	600–800	0.000	*(0 – 0.69)*	0	*(0 – 0.05)*		
Kauri forest (N 2)	0–400	0.678	*(0.36 – 1.16)*	0.250	*(0.08 – 0.58)*	0.14	0.14
	400–600	5.306	*(4.49 – 6.23)*	0	*(0 – 1.23)*	1.10	0.00
	600–800	14.27	*(11.1 – 18.1)*			2.95	
Lowland podocarp hardwood (N3a)	0–400	1.997	*(1.44 – 2.70)*	2.30	*(1.91 – 2.75)*	0.41	1.32
	400–600	15.74	*(13.8 – 17.9)*	4.53	*(4.1 – 5.0)*	**3.26**	**2.59**
	600–800	10.80	*(6.92 – 16.1)*			2.23	
Hardwood forest (N5)	0–400	1.767	*(0.71 – 3.64)*			0.37	
	400–600	0	*(0 – 7.16)*			0.00	
	600–800						
All vegetation types and elevation classes		4.84	*(4.45 –5.24)*	1.75	*(1.60 –1.91)*	1.0	1.0

Discussion of Coromandel Survey Results

Evaluating the Likely Distribution Range

Conclusion drawn from the survey results to date can only be tentative because of the small sample sizes and uneven sampling. However, Archey's frogs were found throughout the length of the proposed likely distribution range (Figures 10a–d). As yet, there is insufficient information to assess what proportion of the likely distribution range Archey's frogs are present in, but Archey's frogs were found along 24 of 40 transects (60%) in their likely distribution range indicating that they are widespread (Table 8). Additional surveys are required in areas around transects where frogs were not found to confirm their absence.

Finding frogs on transects north of the Tapu-Coroglen Road (Figures 10a&b) confirms that frog populations persist in north Coromandel despite the lack of frog sightings in the ARDS from the area since 2010. Information from two transects in the Moehau region are particularly encouraging. Although no frogs were found on a transect through low elevation *Kauri forest* in the Moehau region, 24 frogs were found along a short 0.53 km transect (i.e. 45.4 frogs/km) through *Lowland podocarp forest* in the 600–800 m elevation class, indicating that a healthy population of Archey's frogs remains in the Moehau region.

Effects of Vegetation Type and Elevation

Results from transect searches (Table 13) and replicate plot searches (Table 15) both confirm observations by several authors (Archey, 1922; Cree, 1989; Hotham, 2019; Hotham et al., 2023; Stephenson & Stephenson, 1957) that Archey's frogs are most abundant in undisturbed native forest at mid to high elevations (> 400 m a.s.l.). Encounter rates on transects in *Lowland podocarp-hardwood forest* above 400 m a.s.l. and *Kauri forest* above 600 m a.s.l. were up to 14 times higher than encounter rates along transects in low elevation (< 400 m a.s.l.) forest (Table 13). Erratic and inadequate sampling means interpreting results from replicate plot searches is problematic, nevertheless mean plot counts showed a similar pattern to encounter rates along transects, with mean counts from plots in *Lowland podocarp-hardwood forest* above 400 m a.s.l. ten times higher than plots in *Kauri forest* below 400 m a.s.l. and eighty times higher than plots in *Mānuka, kanuka* below 400 m (Table 15).

Assessment of the Transect Search Method

Nocturnal searches for Archey's frogs along transects proved to be a rapid, effective and efficient method for obtaining information on the species' distribution and relative abundance in different areas. However, given the extent of the likely frog distribution range (520 km^2), results from the transect searches undertaken to-date can only be considered preliminary, despite comprising 40 transects with a combined length of 123 km. Results from many more transects will be required to obtain a good understanding of Archey's frog's distribution and relative abundance in Coromandel. Although most transects to-date have been along established tracks, ideally transects should be off-track to allow wider geographic coverage and sample more representative undisturbed habitats.

While finding frogs along a transect is proof that frogs are present in an area, not finding frogs is not proof that frogs are not present in an area. Not finding frogs along a transect could be a result of several factors including unsuitable ambient conditions during the transect search, the transect being along a highly modified track not representative of surrounding habitat, or searchers being ineffective. Alternatively, finding frogs along a transect is a random process, and not finding frogs in an area where frogs are present could be a stochastic phenomenon. The distances between frogs found randomly along a transect can be modelled using the exponential distribution. Figure 15 shows the minimum transect lengths required to have 80% and 95% probability of detecting frogs randomly spaced along a transect over a range of encounter rates from 1 to 20 frogs/km. In areas with low mean encounter rates (i.e., low frog densities), minimum transect lengths to achieve 80% and 95% probabilities of detecting frogs are relatively long. For instance, when the expected encounter rate is 1.2 frog/km, transects need to be 1.34 km and 2.5 km long to achieve 80% and 95% probabilities of finding a frog respectively. Comparison of the lengths of the 16 transects where frogs were not found and the 24 transects where frogs were found shows transects where frogs were not found tended to be shorter than transects where frogs were found (Table 7 and Figure 16), with most transects where frogs were not found being < 3 km and several < 2 km. Thus, failure to find frogs on a transect could be because the transect is too short to have a high probability of finding frogs.

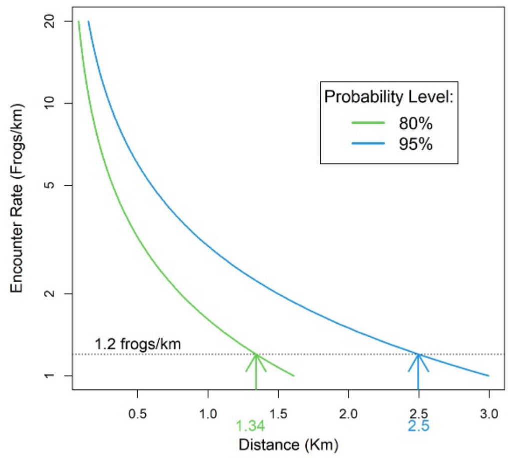


Figure 15. Minimum transect lengths required to have 80% and 95% probability of detecting frogs randomly spaced along a transect over a range of encounter rates from 1 to 20 frogs/km. Note that the x-axis in the figure is logarithmic.

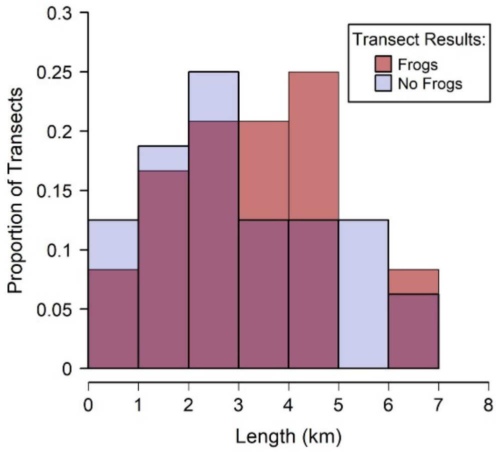


Figure 16. Histograms comparing the distribution of transect lengths for transects where frogs were found and transects where frogs were not found.

When no frogs are found on a transect, before concluding that there are no frogs in the surrounding area, additional transects should be undertaken nearby, preferably off-track to ensure that the habitat being surveyed is representative of the area.

Improving Information from Replicate Plot Searches

The original survey design (Lloyd, 2022c) with 5 or more replicate searches of 368 10x10 m plots spread throughout Archey's frogs' likely Coromandel distribution range proved to be unrealistically ambitious and because of the effectiveness of transect searches, unnecessarily large. Difficulties in using results from the initial plot searches in N-mixture analyses also indicate that a different sampling strategy is required to obtain reliable population estimates from replicate plot search data. To get the best results from N-mixture modelling, plots should be arranged in groups, with plots in each group located in similar habitat. Population estimates can then be obtained for each group of plots. The grouping strategy for N-mixture modelling fits well with the previously proposed modified survey design combining transect and plot searches (Lloyd, 2022a).

In the modified proposal frog encounter rates along transects provide estimates of relative densities used to extrapolate density estimates from areas with both transects and replicate plot searches to areas with only transects searches.

Few population estimates were obtained using N-mixture modelling because successful modelling requires large sample sizes from relatively homogenous areas. However, the population estimates for 10x10 m plots obtained from N-mixture modelling (Tables 14 & 15) exhibit the same pattern as observed in encounter rates along transects (Table 13). Frog abundance in *Mānuka, kanuka* and *Low altitude podocarp hardwood forest* at all elevations were very different, with 0.53 frogs /plot in *Mānuka, kanuka* and 12.8 frogs/plot in *Low altitude podocarp hardwood forest*, a 24-fold difference. The difference was even greater for comparison between the two vegetation types above 400 m, with 0.42 frogs/plot in *Mānuka, kanuka* and 27.9 frogs/plot in *Low altitude podocarp hardwood forest*, a 67-fold difference.

All previous estimates of Archey's frog densities have relied on closed population capture-recapture analyses of frogs in 10x10 m plots (Bell et al., 2004; Germano et al., 2023; Hotham et al., 2023). None of the population estimates from capture-recapture analyses are directly comparable with the population estimates obtained from N-mixture modelling, because they are from plots in different areas and different years. Closest comparisons are for a single 10x10 m capture-recapture plot in *Lowland podocarp hardwood forest* in the 400–600 m elevation class in Coromandel surveyed during 2007 with an estimated population of c. 90 frogs in (Bell, 2010) and for 24 plots in the proposed mine's vibration footprint with an estimated 9.4 frogs per plot (Hotham, 2019).

Capture-recapture is established as the standard method for estimating and monitoring Archey's frog populations, whereas N-mixture modelling has not been used previously for monitoring Archey's frogs. However, N-mixture modelling provides several advantages: frogs do not have to be handled; field work is less technically challenging, wider geographic sampling can be achieved for similar effort, and underlying assumptions of the analytic method are not contradicted as they are in closed capture-recapture analyses. How useful N-mixture modelling will be for estimating population size and monitoring population trends in Archey's frogs remains to be tested by comparing estimates from the two methods.

Optimising Search Conditions

Results from transect searches indicate that season, ambient temperature and RH during searches all have significant effects on encounter rates. The highest encounter rates are from searches during autumn, April–June (Table 9). There was an interaction between ambient temperature and RH (Figure 11 & Table 10), with more frogs encountered at lower RH values (90 – 92%), on warm nights (14 – 17 ºC), whereas more frogs were encountered at higher RH values (94 – 98%) on cooler nights (12 – 14 ºC). Generally, fewer frogs were encountered when RH was below 90% or when temperatures were above 17 ºC. In results from plot searches, only RH had a significant effect.

The surveys were not designed to investigate the effects of ambient conditions on frog detection rates during searches, however understanding the effects of ambient conditions on detection rates is important as it will allow scheduling searches on nights when detection rates are likely to be high and provide the basis for modelling the confounding influence of the effects in GLM and N-mixture analyses. Undertaking a study designed to investigate how ambient conditions during searches affect frog detection rates would be worthwhile. The study would entail repeated searches along a small set of transects throughout the year, with searches undertaken over the likely range of ambient conditions. Study transects should be easily accessible and have known populations of Archey's frog. Suitable locations with high encounter rates along previous transects include Grace Darling Stream, a ridge 500 m north of Golden Cross and the Whangamata, Maratoto and Old Wires Tracks.

Vibration Footprint of Wharekirauponga Underground Mine

In the current mine design, vibrations from underground blasting with velocities ≥ 2 mm s^{-1} will be apparent in three catchments: Wharekirauponga, Waiharakeke, and Mataura. The area with vibrations ≥ 2 mm s^{-1} includes 314.9 ha in Coromandel Forest Park, with 302.6 ha in the Wharekirauponga catchment (Figure 17) and 12.3 ha in the nearby Waiharakeke catchment (Lane, 2021).

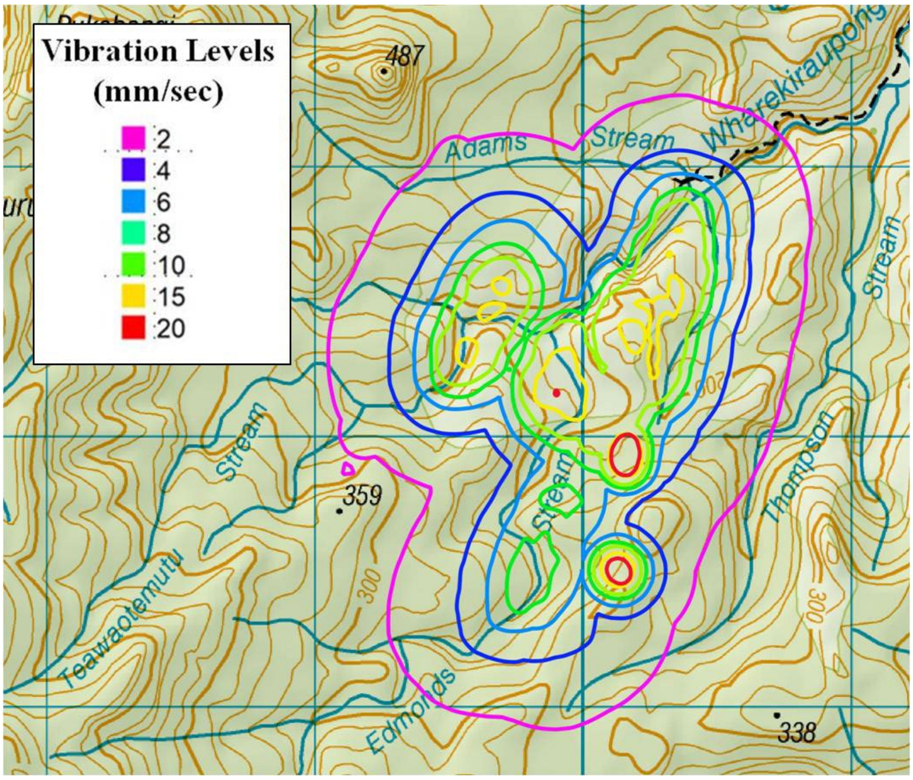


Figure 17. The extent of the predicted vibration footprint of the proposed Wharekirauponga underground mine in the Wharekirauponga catchment for the current mine design. Contours of the vibration levels delineate the maximum extents of seven vibration intensity levels.

In the current mine design, forest areas above the proposed mine and access shaft will be affected by vibrations for approximately eleven years, with the area affected by vibrations ≥ 2 mm s^{-1} expected to peak at 282 ha 10 years after mining commences. Higher vibration levels will extend over smaller areas for fewer years (Figure 18). Only 3.3% of the area will be subject to vibration levels ≥ 15 mm s^{-1}. It should be noted that most vibrations from blasts will be less than the maximum value indicated by the contour, and that vibration events are transient, lasting only seconds, and intermittent, with between 7 and 15 per blasts per week (McNeill, 2021).

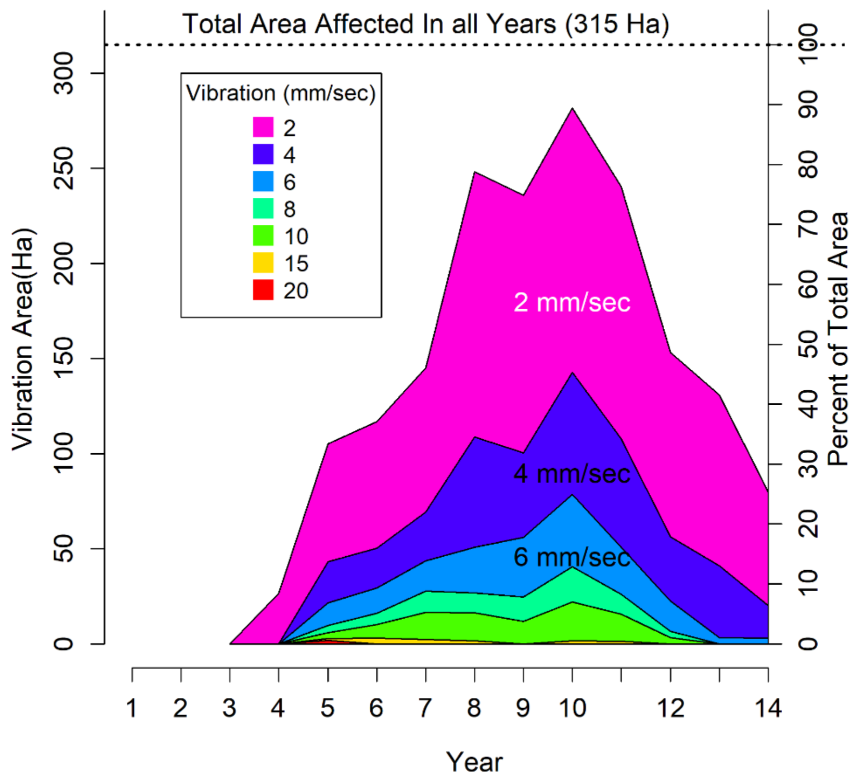


Figure 18. Predicted changes in the extent of areas affected by different vibration intensity levels by year since the start of underground mining, for the current mine design.

Vegetation in the Vibration Footprint

The predicted vibration footprint extends over areas of low altitude forest, with altitudinal ranges of 90–330 and 150–220 m a.s.l. in the Wharekirauponga and Waiharakeke catchments respectively. In the 2018 version of the LCDB, vegetation cover of the entire vibration footprint was classified as *Indigenous forest*. However, in the 1983 NZLRI database 50% of the vibration footprint in the Wharekirauponga catchment (Table 17) was classified as *Manuka, kanuka scrub* (156.3 ha) and 46% as *Kauri forest* (146.3 ha). The small area of vibration footprint in the Waiharakeke catchment was classified as either *Kauri forest* (5.4 ha) or *Low-altitude podocarp-hardwood forest* (6.9 ha). The extensive area of *Manuka, kanuka* scrub (M1) is primarily a consequence of forest disturbance by logging, commercial forestry and mining exploration prior to 1980, but mining exploration during the 1990s, and 2010–2016 has caused localised small areas of disturbance in the vibration footprint (Hotham, 2019). Vegetation in lower altitude areas of the vibration footprint with a history of disturbance is primarily regenerated forest dominated by early successional species such as *Kunzea robusta*, *Cyathea dealbata* and *Knightia excelsa* (Hotham, 2019).

Table 17. Areas of NZLRI vegetation types in the vibration footprint. Abbreviations used in the table are: Mk-Kk = *Manuka, kanuka scrub*; Hwd = *Hardwood forest*; Podocarp or *pod. = Low-altitude podocarp-hardwood forest*; Scrub = *Mixed native scrub*. In mixed vegetation types, lower case italics are used for minor components comprising <50%.

Catchment	Mixed Vegetation Type	ha	*(%)*	Dominant Vegetation Type	ha	*(%)*
WKP	Mk-Kk, *hwd*	122.9	*(39.0%)*	Mk-Kk	156.3	*(49.6%)*
	Mk-Kk, Hwd	33.4	*(10.6%)*	Kauri	146.3	*(46%)*
	Kauri, *pod.*	89.7	*(28.5%)*			
	Kauri, *scrub*	62.0	*(19.7%)*			
	All Veg.	302.6	*(96.1%)*			
Waiharakeke	Kauri, *pod.*	89.7	*(28.5%)*	Kauri	5.4	*(1.71%)*
	Podocarp	6.9	*(2.2%)*	Podocarp	6.9	*(2.2%)*
	All Veg.	12.3	*(3.9%)*			
	All	314.9		All	314.9	

Density Estimates for Archey's Frogs in the Vibration Footprint

There are two sources of information for estimating the density of Archey's frogs in the vibration footprint nocturnal surveys of 20x20 m plots undertaken to fulfil the Access Arrangement Conditions to enter and carry out exploration works in the Wharekirauponga prospect (Boffa Miskell Limited, 2016, 2018, 2019, 2021) and the results of a capture-recapture study investigating the effect of past vegetation disturbance on abundance of Archey's frogs (Hotham, 2019; Hotham et al., 2023).

Nocturnal Plot Surveys to Fulfil the Access Arrangement Conditions

Nocturnal surveys to fulfil the Access Arrangement Conditions (R92455) and its replacement Access Arrangement Variation (48614-AA-V1) were designed to identify areas with high densities of frogs to avoid vegetation clearance in them. Each survey entailed systematic nocturnal searches of a marked 20x20 m plot for Archey's frogs. Many, but not all, plot searches were stopped when 5 frogs were found in a plot, because this was the stipulated threshold for avoiding vegetation clearance under the Access Arrangement at that time. During a plot search, potential frog micro-habitats in the plot were searched, including beneath and among logs, roots, leaf litter, vegetation and crevices (Hare, 2012). Surveys were only undertaken when weather conditions were suitable for surface activity by Archey's frogs: warm (> 10 °C) and humid (> 90% RH), with light, or no wind and some rain either during the survey or earlier in the day.

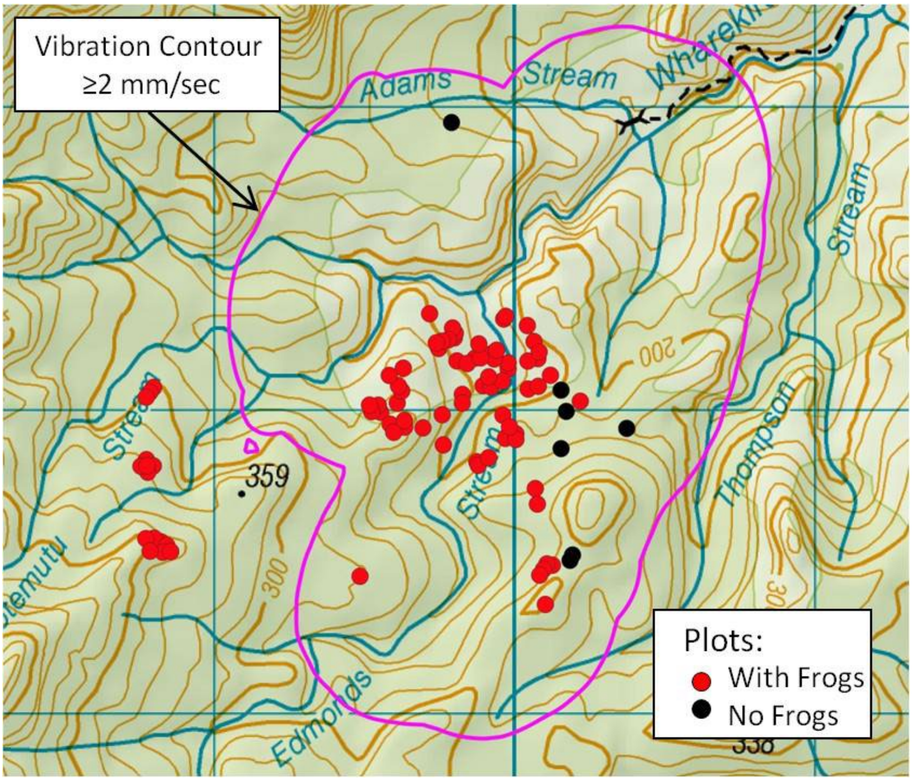


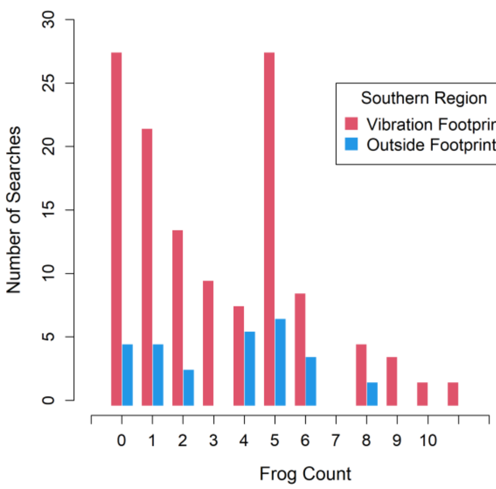
Figure 19. Locations of nocturnal plots in the Wharekirauponga catchment surveyed to fulfil the Access Arrangement Conditions.

Between January 2018 and February 2022, ninety-one plots were surveyed in the Wharekirauponga prospect area (Figure 19). Seventy-six of the plots were in the predicted vibration footprint and 15 outside of the footprint (Table 18). Plot locations were not selected randomly but provide a representative sample across the centre of the vibration footprint. There were 146 plot searches with the number of replicate searches in a plot ranging from one to four. Frogs were found in 69 of the 76 plots in the vibration footprint and all 15 plots outside the footprint. The numbers of frogs per plot found during plot searches (Table 18) were similar inside and outside the vibration footprint (Means: 3.02 v. 3.36). The maximum number of frogs found during replicate searches of a plot (Table 18), i.e. the plot maximum frog count, were also similar inside and outside the vibration footprint (Means: 4.25 v. 4.60). The proportions of searches when 5 or more frogs were found in a plot were not significantly different ($p > 0.1$) inside and outside the vibration footprint (40% of 121 v. 36% of 25).

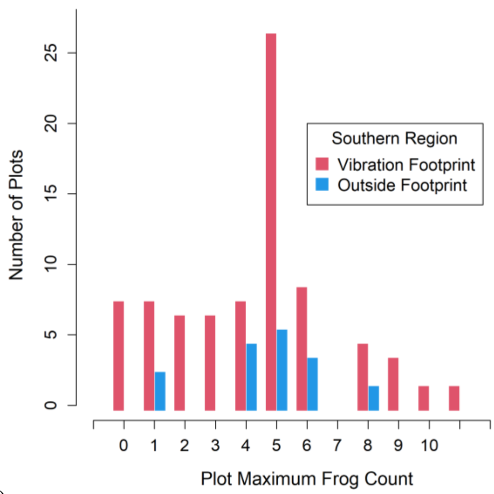
Table 18. Summary of results from 20x20 m plots undertaken in the Wharekirauponga catchment (2018–2022) to fulfil Access Arrangement Conditions. Many plot searches were discontinued when 5 frogs had been found during a search.

20x20 m plots in the WKP	Number			Mean Count/Search	Mean of Plot Maximum Counts
	Plots	Searches	Frogs		
Inside footprint	76	121	365	3.02	4.25
Outside footprint	15	25	84	3.36	4.60
Combined	91	146	449	3.08	4.31

Because many, but not all, plot searches were stopped when five frogs were found in a plot, there is a spike in the numbers of plot counts with five frogs (Figures 20a&b). Thus, the data are right-truncated, but erratically. Although it was more likely for a plot to be searched again when no or few frogs had been found during a plot search, there was no consistent pattern to the number of replicate searches undertaken in plots. These inconsistencies in plot search methods could confound comparisons between results from plots inside and outside the vibration footprint.



a)



b)

Figure 20. Histogram showing the distributions of a) counts from all nocturnal plot searches in the Wharekirauponga catchment and b) the maximum counts from the plots.

Using Simulations to Modify Right-truncated Data

Simulations were used to obtain estimates of the maximum plot counts for the 76 plots in the vibration footprint if none of the 121 searches had been stopped when five frogs were found. Maximum plot counts were right truncated to five (i.e., counts greater than five were reduced to five). The probability distribution of this truncated data was used as the expected distribution for comparisons with distributions of simulated data. Two distribution models were used to simulate the count data: the Poisson distribution and the negative binomial distribution. The negative binomial distribution was used because of overdispersion in the plot counts. (Overdispersion is the presence of greater variability in a data set than expected on the basis of the distribution being used to model the data. For Poisson models, overdispersion is when the variance of counts is greater than the mean.)

Simulated data with the Poisson distribution model were obtained using the R-function (R Core Team, 2021) *rpois(n, lambda = λ)* to generate Poisson distributions of 76 (n) observations for a range of values for the location parameter λ (i.e., mean). Simulated data with the negative binomial distributions were obtained using the R-function *rnbinom(n, size = α, mu= μ)* to generate negative binomial distributions of 76 observations for a range of values for the location parameter μ (i.e., mean) and dispersion parameter α. This parameterisation of the negative binomial distribution is an alternative parameterization often used in ecology, with dispersion, or variability, in the data increasing with α.

a) Poisson location parameter λ

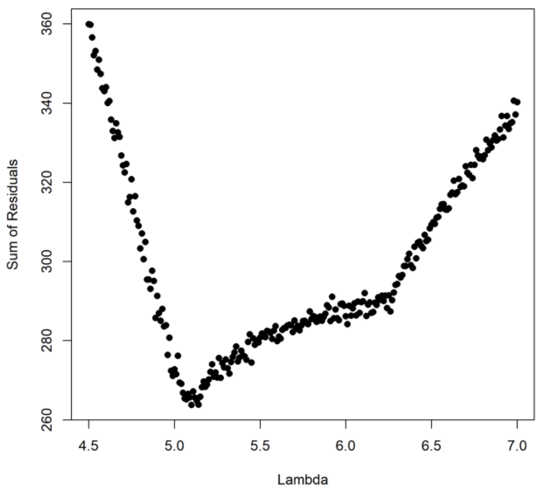
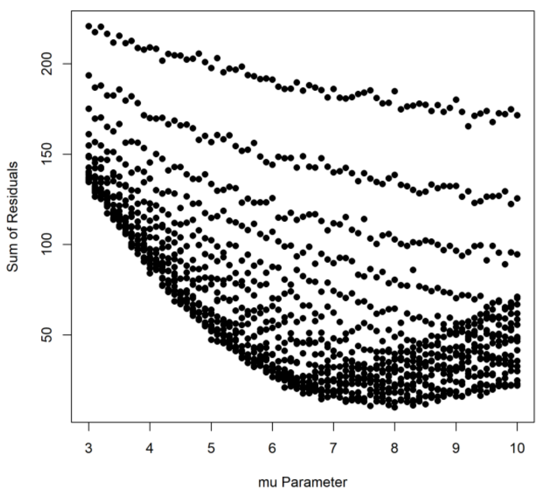
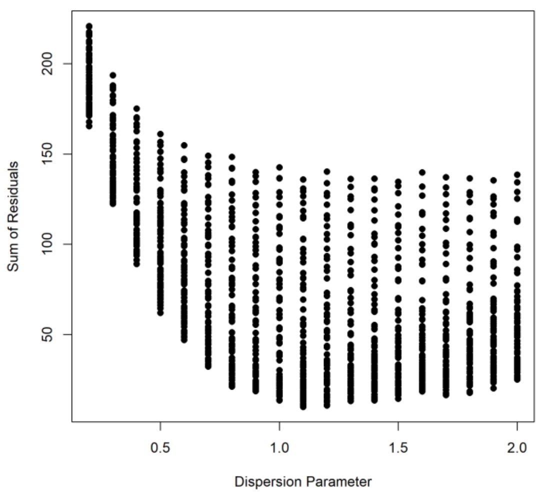


Figure 21. Results of simulations to identify parameters to fit (a) Poisson distribution models and (b) negative binomial distribution models to data from maximum counts for truncated plot counts.



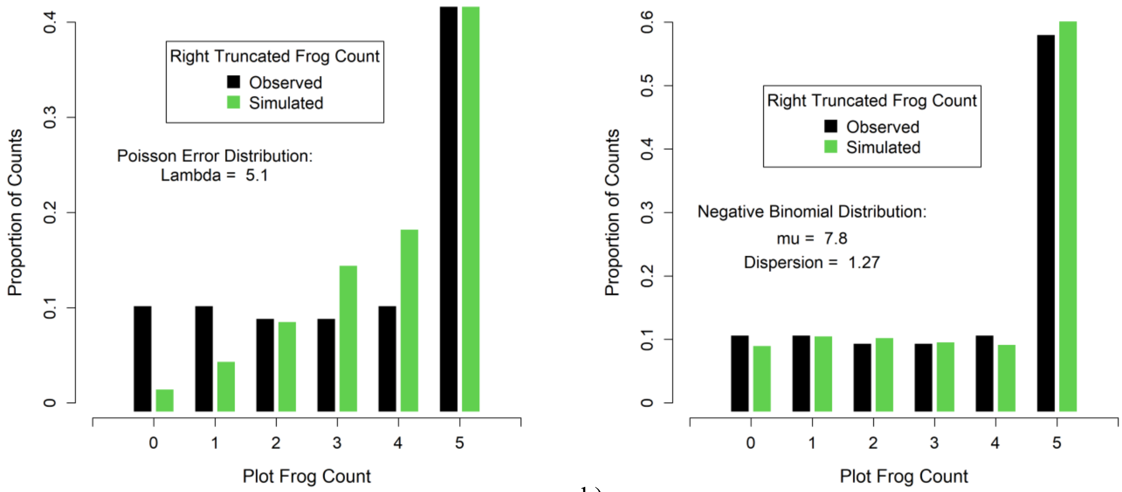
b) Negative binomial location parameter μ



c) Negative binomial dispersion parameter α

Simulated data from the two distribution models were right-truncated to a count of five and a chi-square test used to compare the distribution of the right-truncated simulated data with the distribution of right-truncated plot counts. The best fitting models were identified as the models that minimised residuals in the chi-square test. To simulate data from the Poisson distribution model, one thousand simulations were undertaken for each value of λ. Initially, simulations were undertaken using widely spaced values of λ (Figure 21a): λ = 3–10, by 0.05. When the region of the best model became apparent, to gain finer resolution the ranges and increments of λ values were decreased to 4.5–7.0 by 0.01. To simulate data from the negative binomial distribution, one hundred simulations were undertaken for each combination of μ and α. Initially, simulations were undertaken using widely spaced values of μ and α (Figures 21b&c): μ = 3–10, by 0.1; and α = 0.2–2.0 by 0.1; which gave 1,349 combinations of the two parameter values. When the region of the best model became apparent, to gain finer resolution the ranges and increments of the μ and α values were decreased to: μ = 6.5–9.0 by 0.01; and α = 1.0–1.4 by 0.01; which gave 10,291 combinations of the two parameter values.

For simulations with the Poisson distribution model, the best fit model with the minimum value for the sum of residuals in the chi-square test (263.8) had the mean value λ = 5.1 (Figure 21a). Histograms of the distributions of proportions of observations in right-truncated plot data and simulated right-truncated data with the parameter values λ = 5.1 were very different (Figure 22a). For simulations with the negative binomial distribution model, the best fit model with the minimum value for the sum of residuals (6.05) had parameter values μ = 7.8 and α = 1.27 (Figures 21b&c). There was little difference between histograms of the distributions of proportions of observations in right-truncated plot data and simulated right-truncated data with the parameter values μ = 7.8 and α = 1.27 (Figure 22b).



a) b)

Figure 22. Histograms comparing the distributions of right-truncated data from actual plot counts and the fitted model using: (a) a Poisson distribution with location parameter λ = 5.1; (b) a negative binomial distribution with location parameter μ = 7.8 and dispersion parameter α = 1.27.

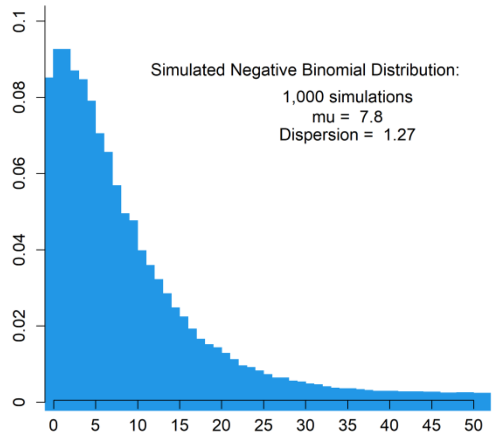


Figure 23. Histogram of the distribution of the simulated negative binomial distribution without truncation.

Without truncation, the simulated data from the negative binomial distribution ($\mu = 7.8$ and $\alpha = 1.27$) has a long tail (Figure 23) with a small proportion (7%) of the simuated counts being ≥ 20. These high values seem unlikely and indicate a limitation in the best-fit model, presumably stemming from deficiencies in the data.

The estimated value for the mean number of frogs found per plot obtained from simulations using the negative binomial distribution (i.e., $\mu = 7.80$) is 134% higher than the mean maximum number of 3.02 frogs found per plot in the original erratically truncated data. Converting the estimate 7.80 frogs found per 400 m^2 plot to frogs/ha gives a density of 195 frogs found per ha or 1.95 frogs per 100 m^2 plot.

Estimates from a Capture-recapture Study (Hotham 2019)

Results from a capture-recapture study investigating the effect of past vegetation disturbance on abundance of Archey's frogs (Hotham, 2019; Hotham et al., 2023) provide three related estimates of Archey's frog density in the vibration footprint. The study used capture-recapture methods with photographic identification of individuals to investigate the effect of past vegetation disturbance on populations of Archey's frogs at two sites in Coromandel: the Wharekirauponga catchment and Mahakirau (Figure 1). There were twelve pairs of 10x10 m plots in the Wharekirauponga catchment, all in the vibration footprint (Figure 24). Paired plots were 20 m apart with one of each pair of plots in previously disturbed habitat and the other in undisturbed habitat. Although plot sites were not selected randomly, the 24 plots provide a representative sample of sites over a large part of the vibration footprint. Each of the plots was searched on three consecutive nights. Closed-population capture-recapture models fitted to the data using Markov Chain Monte Carlo methods provide estimates of the numbers of frogs in each of the plots (Hotham, 2019; Hotham et al., 2023).

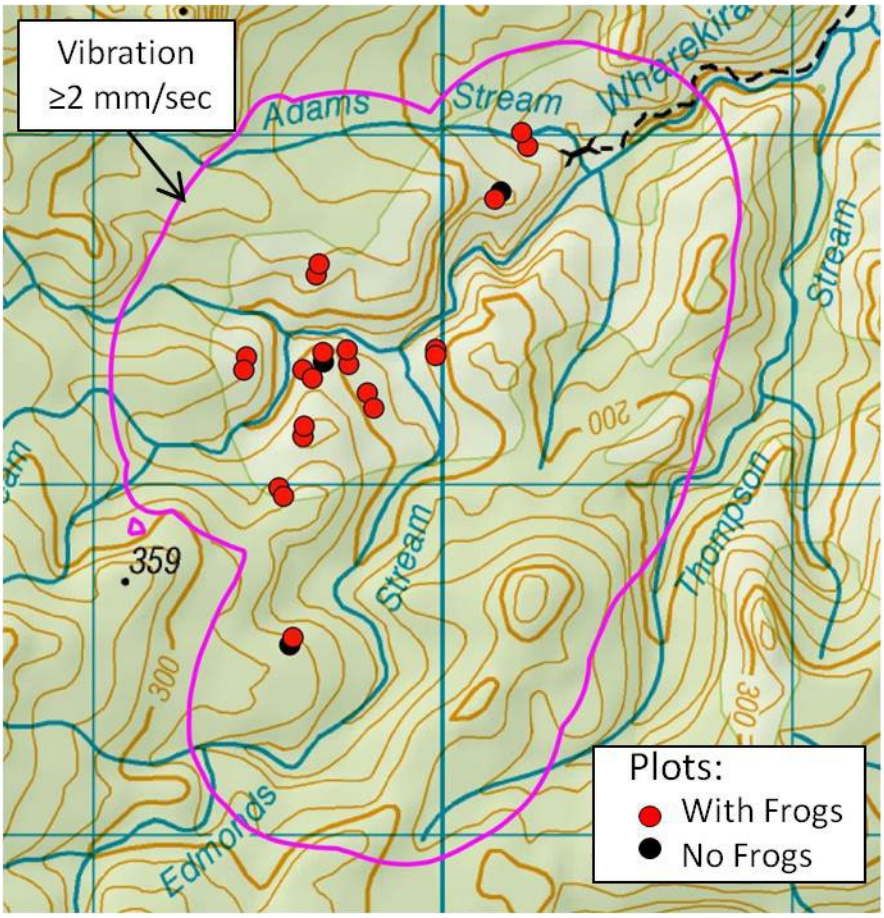


Figure 24. Locations of Hotham's (2019) capture-recapture plots in the vibration footprint of the Wharekirauponga catchment.

The three estimates of Archey's frog density in the vibration footprint obtained from the capture-recapture study are: the total abundance estimate for the twenty-four plots from closed-population analysis: 224.9 (CRI95%: 152–397); the number of uniquely identified individuals found on the twenty-four plots: 150; and the total number of frogs found during first searches of the twenty-four plots: 68. For the last estimate, only counts from the first searches of plots were used because subsequent counts were all lower; presumably as a consequence of capture avoidance in response to the intensive handling experienced by frogs during capture-recapture processing.

Converting these estimates to frogs/ha gives:

- Population estimate from capture-recapture: 937 frogs/ha; CRI95%: 633–1,654.
- Number of uniquely identified individuals: 625 frogs found per ha.
- Total count from first plot searches: 283.3 frogs found per ha.

The study also provides an estimate of the detection probability (p_d), the probability of detecting a frog that is present on a plot during a plot search, i.e., $p_d = C/N$, where C is the number of frogs counted during a nocturnal plot search and N is the number of frogs present on the plot. Estimates of the detection probability can be used to derive the number of frogs in a plot from the count using: $N = C/p_d$. Hotham (2019) provided a detection probability estimate of 0.32 for first capture. The detection probability for previously captured frogs was considerably lower, presumably because of avoidance behaviour in response to previous handling.

Biases in Estimates from Closed Population Capture-recapture Analyses

Two fundamental assumptions for closed population capture-recapture analyses are geographic and demographic closure (no births, deaths, immigration or emigration) and equal capture probability of individuals during a sampling occasion (Lukacs, 2018; Williams, Nichols, & Conroy, 2001). Hotham (2019) justified the use of closed capture-recapture models to obtain abundance estimates for plots on the basis that birth, death, immigration and emigration were all unlikely during three consecutive search nights used for the capture-recapture surveys. Although the assumption that there will be no births, deaths, immigration or emigration during three consecutive nights is reasonable, the plot population is not closed because the plot is unbounded and in continuous habitat. Individuals with home ranges straddling the plot boundaries will spend some of their time outside of the plot, where they are not available for capture. The resulting lower capture probabilities for individuals near plot boundaries inflate population estimates (Ivan, 2018; Royle, Chandler, Sollmann, & Gardner, 2013). The magnitude of this systematic bias, referred to as the "edge effect", will depend on the relative size of plots and the size of the buffer strip containing individuals with home ranges straddling the plot boundaries. In a study of Archey's frogs at Whareorino (Ramírez, 2017), the mean linear, or net, distance moved overnight by individual frogs was 1.34 m (CI95% 0.05–4.44) and the mean overnight path length was 2.88 m (CI95% 0.21–10.56), which means that frogs would frequently leave a 10x10 m plot. Using estimates from Ramírez (2017) for parameters in simulations, median population estimates from closed population estimates for a 10x10 m plot were 33% higher than the simulated population size (Lloyd, 2024). As well as inflating plot population estimates and the numbers of uniquely identified individuals in plots the "edge effect" bias will bias estimates of capture or detection probabilities downwards, thereby inflating density estimates obtained from simple plot counts using the formula $N = C/p_d$.

Estimates of the Number of Archey's Frogs in the Vibration Footprint

The counts from the 20x20 m (i.e., 400 m^2) plots surveyed to fulfil OceanaGold's Access Arrangement Conditions (Boffa Miskell Limited, 2018, 2019, 2021) and estimates from Hotham's (2019) capture-recapture study were used to obtain a range of estimates for the number of Archey's frogs present in 314.9 ha area of the predicted vibration footprint of the proposed mine (Table 19). Estimates of the numbers of adult frogs in the footprint were obtained using the proportions of adult frogs found on plots during surveys, with adults comprising 0.833 of frogs seen during OceanaGold's surveys and 0.548 during Hotham's (2019) capture-recapture study.

Table 19. Estimates of the number of Archey's frogs present in the Wharekirauponga vibration footprint.

Estimate Type / Source	Type Detail	Original Estimate	Frogs/ha		Population	
			All	Adult	All	Adult
C-R Est. for All 24 plots						
Hotham (100 m^2 plots)	Closed Pop. Estimate	224.9	937.1	513.5	295,088	161,708
	N. Unique Individuals	150	625.0	342.5	196,813	107,853
Mean Plot Count						
Hotham (100 m^2 plots)	First search	2.83	283.3	155.2	89,211	48,888
OceanaGold (400 m^2 plots)	From simulations	7.80	195	162.5	61,406	51,171
Mean Plot Count/P_d						
Hotham (100 m^2 plots)	First search	8.9	885.3	485.2	278,785	152,774
OceanaGold (400 m^2 plots)	From simulations	24.4	609.4	507.8	191,892	159,910

Unsurprisingly, given the range of density estimates, the ranges of population estimates are wide: 61,406–295,088 for all age frogs, and 48,888–161,708 for adult frogs. The highest population estimates are all based on estimates from the capture-recapture study either directly (i.e., the plot population estimate from closed population analyses or the number of uniquely identified individuals) or indirectly using the detection probability from the capture-recapture study. As discussed previously, plot population estimates from both closed population capture-recapture analyses and the number of uniquely identified individuals during the capture-recapture study will be inflated by the movement of frogs across plot boundaries, i.e., the edge effect, while the detection probability estimate from the study will be an underestimate, because it is based on the inflated population estimate. The high boundary-to-area ratio of twenty-four 100 m^2 plots and the small plot size relative to frogs' nightly movements indicate that overestimates of plot populations and underestimates of detection probabilities could be large.

Detection probabilities during searches for Archey's frogs can vary widely. During ideal conditions detection probabilities may approach one, while in unsuitable conditions detection probabilities can drop to zero. OceanaGold's surveys and Hotham's surveys (Hotham, 2019; Hotham et al., 2023) were undertaken during similar conditions, on warm moist nights suitable for Archey's frog surface activity, and in similar vegetation types. Consequently, it is reasonable to expect that average detection probabilities would be similar during the two surveys. Population estimates based directly on counts (i.e., without division by the 0.32 detection probability) assume a detection probability of one. A detection probability of one is unlikely, while a 0.32 detection probability is probably an underestimate of the actual detection probability. Presuming that there is no double-counting of frogs during plot surveys, the values 1 and 0.32 bracket the range of possible values for detection probabilities. Hence, the ranges of population estimates obtained from plot counts both with and without division by the 0.32 detection probability provide the most probable range of population estimates for the vibration footprint: 61,406–278,785 for all age frogs and 48,888–152,774 for adult frogs. The ranges of values for the population estimates are extremely wide and although there is no good reason to settle on any particular value, mid-range values seem the most likely, because both of the extreme detection probabilities values (1 and 0.32) are unlikely.

ESTIMATES OF THE PROPORTION OF COROMANDEL ARCHEY'S FROGS IN THE VIBRATION FOOTPRINT

Area of the Vibration Footprint as a Proportion of Archey's Frog's Distribution Range

More survey work is required to confirm the area of Archey's frog's distribution range in Coromandel but results of surveys to-date indicate that the 520 km^2 estimate is credible. Archey's frogs were found throughout the length of the proposed likely distribution range (Figures 10a–d) with frogs found along 60% of 40 transects in the distribution range indicating they are widespread. A small number of frogs were found below 200 m a.s.l. just outside of the likely distribution range indicating the distribution range could be slightly larger than 520 km^2. If the 520 km^2 estimate is correct the vibration footprint area is 0.61% of Archey's frog's Coromandel distribution range.

Not finding frogs along a transect search could be because there were no frogs in the area but could be a result of several factors including unsuitable ambient conditions during the search, the transect not being representative of surrounding habitat, searchers being ineffective or a simple stochastic phenomenon. If failure to find frogs along transects is interpreted as evidence that frogs are not present in the surrounding area the distribution range could be reduced to 312 km^2 (i.e., 60% of 520 km^2), in which case the vibration footprint area is 1.01% of Archey's frog's Coromandel distribution range.

Variations in Frog Density with Vegetation Type and Elevation

Results from transect searches and replicate plot searches show vegetation type and elevation have significant effects on the density of Archey's frog populations (Tables 11–16). Frog densities are highest in undisturbed native forest at mid to high elevations (> 400 m a.s.l.). Differences in frog density estimates for different vegetation types and elevations are large. Encounter rates along transects in forest regenerating from manuka, kanuka scrub below 400 m were 1.1 frog/km compared to 15.7 frog/km in undisturbed podocarp hardwood forest between 400 and 600 m a.s.l. (Table 13). Population estimates from replicate plot searches were 0.5 frogs/plot in forest regenerating from manuka, kanuka scrub compared to 12.8 frogs/plot in undisturbed podocarp hardwood forest.

The vibration footprint is < 400 m a.s.l., with half of its area in forest regenerating from manuka, kanuka scrub, 48% kauri forest and only 2% in undisturbed podocarp hardwood forest (Table 20). By comparison 35% of the likely distribution range is > 400 m a.s.l., 18% is undisturbed podocarp hardwood forest and only 9.3% is forest regenerating from manuka, kanuka scrub (Table 20). Thus, it seems likely that the frog density in the vibration footprint is considerably lower than the average frog density in the rest of the distribution range and the proportion of frogs resident in the vibration footprint will be considerably less than the vibration footprint's area as a proportion of the distribution range's area (i.e. 0.61% or 1.1%).

Table 20. NZLRI vegetation types in Archey's frogs' likely Coromandel distribution range and the vibration footprint.

NZLRI Vegetation Types		% of Area	
		Frog Range	Vibration Footprint
Mānuka, kanuka	(M 1)	9.3%	49.5%
Sub-alpine scrub	(M 5)	1.4%	
Mixed native scrub	(M 6)	0.5%	
Kauri forest	(N 2)	63%	48.3%
Lowland podocarp-hardwood forest	(N3a)	18%	2.2%
Mid–altitude podocarp-hardwood forest	(N3b)	1.3%	
Hardwood forest	(N 5)	4.6%	
Low producing pasture	(P 2)	2.5%	

Discrepancies Between Survey Results and Frog Density Estimates for the Vibration Footprint

Frog counts from previous searches of plots in the vibration footprint were considerably higher than counts from plots in the same low elevation (0–400 m) vegetation types (forest regenerating from mānuka, kanuka scrub and kauri forest) during Coromandel-wide surveys. After correcting for truncation and size, the mean plot count for 20x20 m plots in the vibration footprint plots surveyed to fulfil OceanaGold's Access Arrangement was 1.95 frogs/10x10 m plot and the mean count for first searches of twenty-four 10x10 m capture-recapture plots (Hotham, 2019) was 2.8 frogs/plot. This compares with 0.06 frogs/plot search for 18 plots in low altitude forests regenerating from mānuka, kanuka scrub and 0.25 frogs/plot search for 20 plots in low elevation kauri forest during the surveys (Table 15). The range of population density estimates for Archey's frogs in the vibration footprint is also much higher than the density estimates from replicate plot counts in similar vegetation types: ranging from 195 to 937 frogs/ha in the vibration footprint compared to 53 frogs/ha in forest regenerating from manuka, kanuka scrub during Coromandel-wide surveys (Table14).

It is difficult to reconcile the difference between estimates from the vibration footprint and results from transect searches and replicate plot searches in similar vegetation types and elevations elsewhere in Coromandel. It is likely that higher counts from plots in the vibration footprint compared to counts from replicate plot searches in similar habitats during Coromandel-wide survey could be a consequence of differences in the methods. During plot search undertaken in the vibration footprint to fulfil the Access Arrangement Conditions, potential frog micro-habitats in the plot were searched, including beneath and among logs, roots, leaf litter, vegetation and crevices. By contrast during plot searches in the Coromandel-wide survey, plot habitat was not disturbed. Support for this explanation is the mean frog count from replicate plot searches of six 10x10 m plots in, or close to the vibration footprint during the Coromandel-wide survey was 0.17 frogs/plot search, well below the 1.95 & 2.8 frogs/plot previously observed in the vibration footprint. If higher than expected density of frogs in the vibration footprint is real and not a result of methodological differences between the two surveys, a likely explanation is dispersal from higher density frog populations in podocarp hardwood forest on the mid and high elevation slopes that surround the vibration footprint. The discrepancy between results from the surveys in the vibration footprint and elsewhere in Coromandel should be investigated by surveying more plots for Archey's frogs in and around the vibration footprint and on the slopes above the vibration footprint using the same methods and personnel in all areas to provide direct comparisons between frog abundance inside and outside the vibration footprint.

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