A Plan for Monitoring Potential Effects of the Proposed Wharekirauponga Underground Mine Project on Native Frogs

From: Dr. Brian Lloyd, Lloyds Ecological Consulting

To: Cassie McArthur, OceanaGold

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EXECUTIVE SUMMARY

Two species of native frogs occur in Coromandel Forest Park above the proposed Wharekirauponga Underground Mine: Archey's frog (*Leiopelma archeyi*) and Hochstetter's frog (*L. hochstetteri*). Archey's frog is a terrestrial species living in forest, while Hochstetter's frog is semi-aquatic living close to forest streams. The conservation status of both species is "At Risk – Declining".

The proposed mine could affect populations of native frogs living above the underground mine. Surface vibration from underground blasting could affect local populations of Archey's frogs, while dewatering of streams and groundwater caused by mine dewatering could affect local populations of Hochstetter's frogs. In addition, small areas of Archey's frog habitat will be cleared for construction of drill sites. Archey's frog in these areas will be translocated to nearby release sites, where their survival prospects are unknown. A proposed pest animal management mitigation package is likely to improve survival of both frog species in the pest control areas.

This monitoring plan provides details of a programme designed to monitor potential effects of the proposed mine project and a proposed pest animal management mitigation package on local population of the two native frog species throughout the mine project's life.

To ensure that conclusions from monitoring the effects of vibration, dewatering and pest control are robust, the monitoring programmes will be undertaken using Before-After-Control Impact (BACI) designs. To separate effects from mining activities and pest control, monitoring will be undertaken in three area: two treatment areas and a non-treatment area. Characteristics of the treatment and non-treatment areas for each species will be as similar as possible. Monitoring will begin before the effects of mining and pest control begin and continue throughout the mine's life.

There will be ongoing monitoring of the survival of translocated frogs at release sites to measure the success of Archey's frog translocation as a mitigation method and inform adaptive management to improve translocation outcomes.

The standard capture-recapture method for monitoring Archey's frog populations will be used to monitor Archey's frog populations but with larger plots than the standard 10 x 10 m plots to improve the quality of population estimates. Spatially explicit analyses will be used to obtain demographic estimates where possible.

Hochstetter's frog populations will be monitored using replicate searches for frogs in their daytime refuges along 20 m long stream transects. General Linear Mixed Effect Models will be used to compare frog counts on transects in different areas and different surveys. N-mixture modelling will be used to estimate frog abundance on transects. To achieve acceptable statistical power and robust abundance estimates for Hochstetter's frogs, there will be 45 transects in each of the three treatment and non-treatment areas and 6 replicate searches of each transect during annual surveys. Fewer transects or replicates reduce the likelihood of correctly identifying 100% increases (or 50% decreases) in frog abundance between surveys to unacceptably low likelihood levels (< 80%).

INTRODUCTION

Two species of Leiopelmatid native frogs occur in Coromandel Forest Park above the proposed Wharekirauponga Underground Mine: Archey's frog (*Leiopelma archeyi*) and Hochstetter's frog (*L. hochstetteri*). The conservation status of both species is "At Risk – Declining" (Burns et al., 2024). Archey's frog is a terrestrial species living in forest, while Hochstetter's frog is semi-aquatic living close to forest streams. A detailed assessment of potential ecological impacts of the proposed Wharekirauponga Underground Mine on local populations of the two frog species (van Winkel, 2024) identified two potential impacts from the proposed mine (Figure 1):

- surface vibration due to underground blasting, and
- dewatering of streams and groundwater as a result of mine dewatering.

However, van Winkel (2024) concluded that there was no evidence to suggest that mining activity would have adverse effects on native frogs above the Wharekirauponga Underground Mine. Vibrations are unlikely to result in measurable effects on Archey's frog populations above the proposed Wharekirauponga Underground Mine because they are intermittent and at amplitude levels unlikely to result in biological responses that have negative impacts frogs or their reproduction. Additionally, populations of both native frog species have persisted in the vicinity of the nearby Golden Cross mine, despite experiencing similar vibrations from underground blasts for many years. Potential hydrological changes resulting from mine dewatering are also unlikely to have measurable effects on frog populations as hydrological modelling showed that reductions in stream flow and wetted width caused by mine dewatering would be minor in comparison to natural fluctuations and unlikely to affect Hochstetter's frog habitat quantity or quality (i.e., food resources, refuges, breeding habitat) in lower stream catchments above the mine. Hydrological modelling also showed that mine dewatering would not affect higher order catchments where Hochstetter's frog are more abundant. Dewatering will have no effect on Archey's frogs as moisture in their forest habitat is maintained by surface groundwater, which will not be affected by the mining activities.

Despite concluding that there was no evidence that mining activity would have adverse effects on native frogs, van Winkel (2024) recommended monitoring populations of the two frog species above Wharekirauponga Underground Mine throughout the mine's life to identify any adverse effects associated with the mine and anticipated positive effects resulting from a proposed pest animal management mitigation package (Boffa Miskell Limited, 2023). The proposed pest control, described in the Wharekirauponga Pest Animal Management Plan (WAPMP) (Boffa Miskell Limited, 2023), is a comprehensive programme of pest control in the upper Wharekiraiponga Stream catchment (Figure 1) targeting a range of animal pests including: rats, mice, possums, mustelids, cats, hedgehogs, pigs, goats and vespulid wasps in the area above the underground mine.

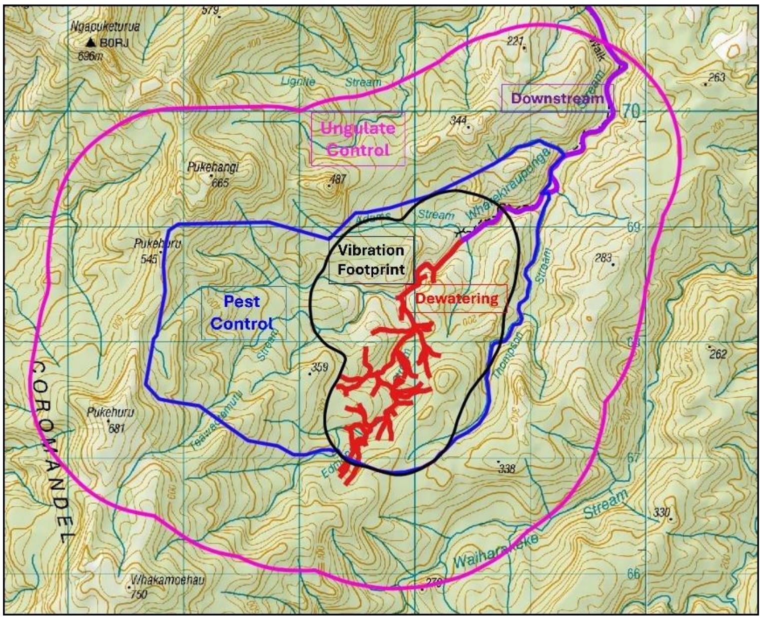

Figure 1. Map of the upper Wharekirauponga Stream catchment showing the boundary of the predicted 2 mm/sec vibration footprint for the mine (black), boundaries of the proposed pest and ungulate control areas (blue & magenta respectively); drainage channels and streams likely to be directly affected by dewatering (red) and sections of the Wharekirauponga Stream downstream from dewatered sections (purple).

Several small (150 m^2) areas of Archey's frog habitat above the underground mine will be cleared to allow construction of drill sites. To minimise Archey's frog mortality during habitat clearance in these areas, frogs will be translocated from them to nearby release sites. Briefly, before habitat areas are cleared, intensive and repeated nocturnal searches for Archey's frogs will be undertaken in the clearance areas and any frogs found will be translocated to prepared release sites. There will be 6 prepared release sites, all in areas of Archey's frog habitat with ongoing local ungulate and predator control programmes. Each of the release sites will be a 400 m^2 enclosure surrounded by fences designed to prevent frogs from leaving the release site and exclude predators, such as rats and mice. The fences will be built using plastic sheeting embedded in the ground. Fences will be removed from the releases site when the translocated frogs have established home range in the enclosures, probably one or two years after translocation. Ongoing monitoring of the success of the translocation will be an important component of the translocation process to measure the success of Archey's frog translocation as a mitigation method and inform adaptive management to improve translocation outcomes.

MONITORING PLAN OBJECTIVES

This monitoring plan provides details of a programme designed to monitor potential effects of the proposed Wharekirauponga Underground Mine project and the proposed pest animal management mitigation package on local population of the two native frog species throughout the mine project's life.

Potential effects on frog populations to be monitored are the effects of:

- surface vibrations from underground blasting undertaken for the mine project on Archey's frogs,
- reductions in stream flow and wetted width as a result of mine dewatering on Hochstetter's frogs,
- pest control on both species of frogs within and outside areas likely to be affected by vibration or dewatering caused by the proposed mine project, and
- translocating Archey's frog from areas of habitat cleared for mine infrastructure.

Results from the monitoring programme will be used to determine:

- whether positive effects of pest control on native frog populations provide effective offsets for any negative effects of either vibrations from the underground blasting or dewatering; and
- the success of Archey's frog translocations used to mitigate habitat clearance.

The monitoring programme is being undertaken to fulfil Land Use Consent Conditions for OceanaGold's Waihi North Project specified by Hauraki District Council. The programme is designed to verify whether pest control achieves a net gain in native frogs within the WAPMA (Consent Condition 155). Results from the monitoring programme will provide the basis for Annual Frog Monitoring Reports to the Hauraki District Council (Consent Condition 165) and to determine how long pest control continues after completion of underground mine blasting activities (Consent Condition 163).

MONITORING ARCHEY'S FROGS

Monitoring of Archey's frogs will be undertaken using capture-recapture methods based on the standard method recommended for monitoring Archey's frog populations (Haigh, Pledger, & Holzapfel, 2007; Lettink, 2012b). Details of the capture-recapture method proposed for monitoring Archey's frogs are provided in Appendix A. Briefly, the method entails repeated nocturnal searches of a permanently marked plot for emergent Archey's frogs. Captured frogs will be photographed to allow identification of individuals from their unique distinctive patterns of skin markings (Bradfield, 2004). Buccal swabs will also be taken from captured frogs to trial identification by DNA profiling (Ambu & Dufresnes, 2023). After processing, captured frogs will be released at their capture sites, with accurate location recorded for each capture site to allow spatially explicit capture-recapture analyses (Royle, Chandler, Sollmann, & Gardner, 2013; Tourani, 2022). Capture-recapture sessions will be undertaken annually with up to 5 plot searches during each primary session. Successive searches within a primary session will be spaced at least three nights apart, to ensure sampling independence, but less than two weeks apart to minimise frog dispersal and mortality between searches. Estimates of the numbers of frogs in a plot during individual primary sessions will be obtained from the capture histories of individual frogs using closed population capture-recapture analyses (Lukacs, 2018; Williams, Nichols, & Conroy, 2001) and spatially explicit methods (Efford, 2017; Royle et al., 2013). Estimates of a range of other demographic parameters will be obtained from capture histories from three or more successive primary sessions using robust capture-recapture methods (Kendall, 2018; Kendall & Bjorkland, 2002; Williams et al., 2001).

Although the same capture-recapture methods will be used for monitoring the effects of vibrations and pest control on Archey's frog populations and for monitoring the success of Archey's frog translocations from habitat clearance areas, different designs will be required for the two monitoring programmes.

Monitoring the Effects of Vibrations and Pest Control on Archey's Frogs

Sampling Design

To ensure conclusions from monitoring are robust, monitoring the effects of vibrations and pest control will be undertaken using a Before-After-Control Impact (BACI) design (Christie et al., 2019; Green, 1979; Smith, 2002; Stewart-Oaten, Bence, & Osenberg, 1992). BACI designs require that monitoring using the capture-recapture method is undertaken in matching treatment and non-treatment areas and that monitoring begins before treatment begins and continues throughout the duration of treatment. To separate effects from the mining activities and pest control, monitoring will be undertaken in three areas, two treatment areas and a non-treatment area (Figure 2).

- One treatment area will be in the area potentially affected by mining activities and within the WAPMP pest and ungulate control area (V+PC).
- A second treatment area will be outside of the area potentially affected by mining activities but within the WAPMP pest and ungulate control area (PC).
- Non-treatment areas will be outside of both areas potentially affected by mining activities and the pest and ungulate control areas (NT).

Monitoring will be undertaken annually in both treatment areas and the non-treatment area, beginning two years before the treatment areas are likely to be affected by mining activities and, or pest control operations, and continuing until two years after mine closure.

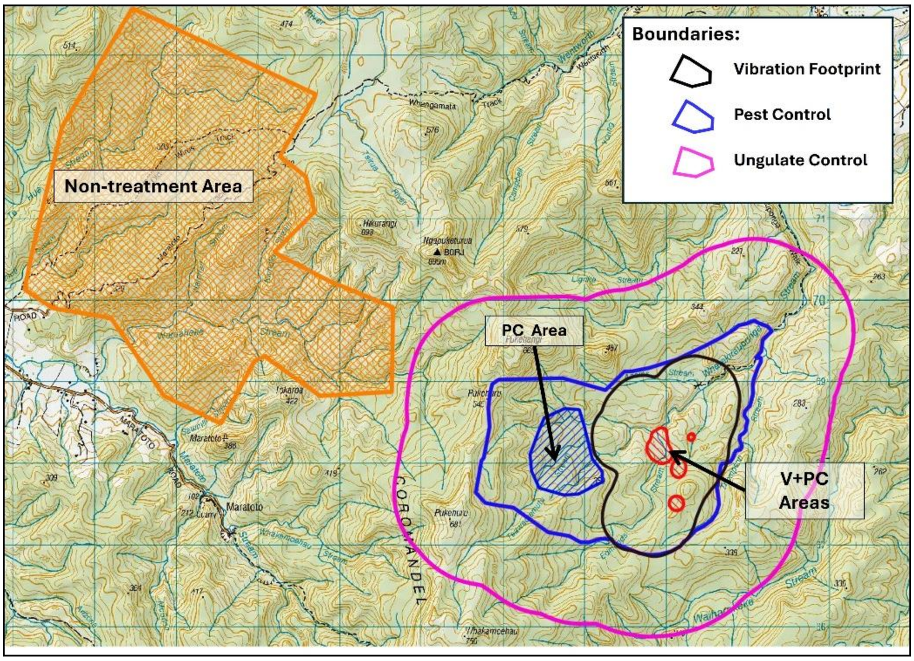

Figure 2. A map showing boundaries of the predicted 2 mm sec^{-1} vibration footprint for the mine (black), the WAMPB pest control area (blue) and ungulate control area (magenta), with areas proposed for locating the pest control treatment (PC) monitoring plot (blue hatching), the vibration and pest control (V+PC) monitoring plot (red hatching) and an area for locating a non-treatment plot (orange hatching).

Plot Size For Monitoring the Effects of Vibration and Pest Control

In the standard capture-recapture method for monitoring *Leiopelmid* frog populations plots are 10 x 10 m (Bell, Carver, Mitchell, & Pledger, 2004; Bell, 2010b; Cisternas, 2018a; Germano, Bridgman, Thygesen, & Haigh, 2023; Haigh et al., 2007; Lettink, 2012b). In the modified method proposed for the Wharekirauponga Underground Mine project, plots will initially be 30 x 30 m and may be enlarged in response to results from preliminary searches. The 30 x 30 m plot size is proposed for two reasons:

- Existing information indicates frog densities at Wharekirauponga are lower than at other capture recapture sites (Germano et al., 2023; Haigh et al., 2007; Hotham, Muchna, & Armstrong, 2023; Lloyd, 2023). Consequently, larger plot sizes will be required to obtain sufficient captures for reliable demographic estimates (Lloyd, 2024b).
- Increasing plot size reduces the perimeter-to-area ratio and consequently reduces the estimation bias and lack of precision resulting from individual frogs having home ranges straddling plot boundaries (Lloyd, 2024b).

Searching a 30 x 30 m plot will take several hours but should be achievable in a single night. For comparison, during a mark-recapture study (Lloyd, Bollongino, & Overmars, 2021) of two terrestrial snail species (*Powelliphanta hochstetteri* and *Rhytida oconnori*), searches of 70 x 70 m plots were completed in one night. Field work for the snail capture-recapture study was similar to, and possibly more time consuming, than capture-recapture of frogs. The snail plots were in complex forest habitats similar to Archey's frog habitat, with 80 to 120 snails captured and tagged during many searches.

Ideally there would be several capture-recapture plots within each of the three treatment and non-treatment areas with spatial replication to provide information on frog populations throughout each of the areas. However, the effort required to survey a single 30 x 30 m capture-recapture plot means that monitoring more than one or two 30 x 30 m plots in each of the three areas is not realistic. Although surveying several smaller capture-recapture plots in each area would achieve spatial replication, demographic estimates from smaller plots would be much less reliable than those from larger plots (Lloyd, 2024b).

The results of simulations comparing plot population estimates from closed population capture-recapture analyses of a single 30 x 30 m plot and nine 10 x 10 m plots (Lloyd, 2024b) show the quality of estimates from nine 10 x 10 m plots will be extremely low, with high upward bias and very low precision. In addition, when modelled values for the plot population and detection probability were low, estimation failed in a high proportion of the simulations for multiple small plots, but not the single large plot. Thus, although surveying multiple smaller plots in the three areas increases information on spatial variation, it severely compromises the crucial comparisons of demographic parameter estimates between areas and over time required to achieve the monitoring objectives. Despite the advantages of spatial replication, all previous capture-recapture monitoring programmes for *Leiopelmid* frog populations (Bell et al., 2004; Bell, 2010b; Cisternas, Easton, Germano, & Bishop, 2022; Germano et al., 2023) have had only one or two plots in each area.

Plot Locations for Monitoring the Effects of Vibration and Pest Control

Initially there will be one permanently marked 30 x 30 m capture-recapture plot in each of the treatment and non-treatment areas for Archey's frogs (Figure 2). Criteria for selecting plot locations in each of the three areas are:

- The plot in the vibration footprint area (V+PC) will be in an area predicted to be subject to high vibration amplitudes >10 mm sec^{-1} from underground blasting early in the mine's life.
- The plot in the pest control area (PC) will be located as far as practicable from the outer boundary of the pest control area to avoid boundary effects.
- The plot in the non-treatment area (NT) will be as close as practicable to the two treatment plots but located at least 200 m outside the boundary of the proposed ungulate control area, which extends 1 km beyond the outer boundary of the proposed pest control area.

Within suitable parts of the three areas, the actual plot locations will be selected to achieve:

- similarly moderate to high densities of Archey's frogs at all three locations,
- logistical ease, with the plots being accessible and safe for night work, and
- if possible, having similar vegetation types and terrain at all three locations.

Nocturnal surveys will be undertaken throughout suitable parts of the three areas to identify plot locations with moderate to high frog densities before final plot locations are selected.

Monitoring Archey's Frog Translocations

Throughout the translocation process and subsequent monitoring at release sites, whenever a frog is captured, it will be weighed and snout-vent-length measured. It will then be photographed to allow identification from their unique distinctive skin marking patterns and a buccal swab taken to allow identification using DNA profiling. Although DNA profiling of Archey's frogs from buccal swabs is an untested method, if successful it will provide crucial information on the breeding success of translocated frogs, which is not provided by the photographic identification method.

After the release sites are fenced, but before frogs are translocated into them, there will be at least 5 nocturnal searches of each of the enclosed release sites to find any Archey's frogs present before frogs are translocated into the release site enclosures. Standard capture-recapture methods will be used for these pre-translocation searches of the release site enclosures with photographs and buccal buccal swabs obtained for all captured frogs. Pre-release population size estimates for each of the enclosure will be obtained using closed population capture-recapture analyse.

Frogs captured during searches of the habitat clearance areas will be processed as described above with photographs and buccal buccal swabs obtained for all captured frogs. After processing frogs captured in the habitat clearance areas will be released into one of the release site enclosures. Starting approximately 12 months after translocation, capture-recapture surveys using the method detailed in Appendix A will be undertaken annually in each of the 400 m^2 release site enclosures during the period late summer to early autumn (i.e. March to May).

When fences are removed from the release enclosures, larger permanently marked plots (i.e., 40 x 40 m) will be established around the original release sites using Gallagher Poly Wire anchored on 300 mm metal standards. The new 40 x 40 m plots will be centred around the original release sites and be subdivide into 10 x 10 subplots. Capture-recapture surveys of the 40 x 40 m plots centred around release sites will be undertaken annually during the period late summer to early autumn (i.e. March to May) beginning after the fences are removed from the release enclosures.

Throughout capture-recapture surveys at the release site, special attention will be given to recording capture location accurately. This will provide information on the development of translocated frogs home ranges and allow spatially explicit analyses of capture-recapture results after fences around the release enclosure are removed.

MONITORING THE EFFECTS OF DEWATERING ON HOCHSTETTER'S FROGS

Replicate counts of Hochstetter's frogs along stream transects will be used to monitor potential effects of stream flow reductions on Hochstetter's frog populations in the Wharekirauponga catchment (Lloyd, 2024a; van Winkel, 2024).

Field Survey Method

Details of the field survey method are provided in Appendix B. Briefly, surveys entail replicate daytime searches for Hochstetter's frogs in their refuges along 20 m transects in streams. During searches, searchers move slowly upstream along the transects searching for frogs in their refuges beneath rocks, and in debris, rock crevices, leaf litter packs and debris dams. When a frog is found its age-class is estimated from its size and recorded along with its location and characteristics of its refuge. Environmental variables recorded during transect surveys are air and water temperatures, relative humidity (RH) and general weather conditions. Stream characteristics (width, depth and substrate) are recorded every 2 m along each transect. Canopy cover and vegetation type are also recorded for each transect. Each transect is searched several times, with at least one day between replicate searches to ensure independence. The same or similar number of refuges should be searched each time an individual transect is searched, but the number of refuges searched along different transects will vary according to characteristics of the transect.

Sampling Design

Results from simulations (Lloyd, 2024b) indicate that the optimum sample size for the Hochstetter's monitoring programme is 45 transects in each of the three treatment and non-treatment areas with 6 replicate searches of each transect during each annual survey. If fewer transects or replicates are used, the likelihood of correctly identifying 100% increases (or 50% decreases) in frog abundance between surveys will drop to unacceptably low levels (< 80%).

Ideally, in BACI monitoring programmes the values of covariates for treatment and non-treatment areas should be similar (Gelman & Hill, 2007). This was not the case during the pilot study for BACI monitoring of the effect of the mine project on Hochstetter's frogs (Lloyd, 2024a). To achieve a robust BACI design, transects for the pest control treatment sample (PC) should be in sections of streams within the Wharekirauponga catchment not affected by potential dewatering (Figure 3) but at similar elevations (100 – 400 m a.s.l.) and in similar NZLRI vegetation types (manuka/kanuka or kauri forest) to transects in streams likely to be affected by dewatering and pest control. Exploratory surveys will be required to identify suitable non-treatment transects, which should be in sections of streams outside of the mine footprint and the pest and ungulate control area, but as close as possible geographically, at similar altitudes, in similar NZLRI vegetation types and with similar stream characteristics (e.g., substrates, width and gradient) as treatment transects.

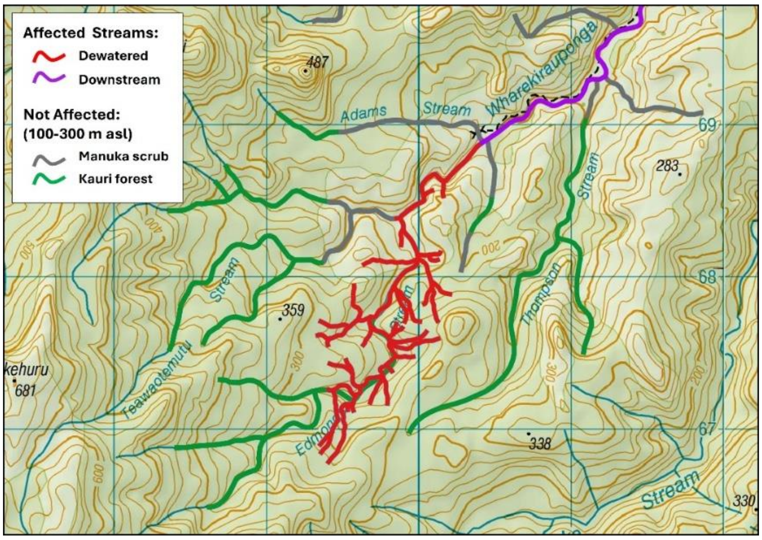

Figure 2. Map of the upper Wharekirauponga Stream catchment showing drainage channels likely to be directly affected by dewatering (red) and stream sections downstream from dewatered sections (purple). Comparable sections of streams within the catchment not affected by dewatering but at similar elevations (100 – 400 m a.s.l.) and with similar vegetation types (green & grey) to sections likely to be affected by dewatering.

Nocturnal Searching as an Alternative to Daytime Searches

Although daytime searches for Hochstetter's frogs in their daytime refuges is the standard method used for monitoring Hochstetter's frog populations nocturnal searches might prove to be a better method and should be trialled. It seems likely that nocturnal searching will increase frog detection probabilities, reduce habitat disturbance and reduce search duration. With increased detection probabilities the number of transects and replicate searches required to achieve reliable results could be reduced.

Numeric Methods

Analyses of results of the surveys using replicate transect searches will be based on the methods described in (Lloyd, 2024a). Three modelling methods will be used: generalised linear models (GLMs), generalised linear mixed-effects models (GLMMs) and N-mixture modelling (Kery & Royle, 2016; Madsen & Royle, 2023; Royle, 2004). GLMs (Gelman & Hill, 2007) will be used to investigate the effects of transect-level explanatory variables on frog counts during searches, with results from surveys in the treatment and non-treatment areas modelled separately. GLMMs (Gelman & Hill, 2007) with Poisson error distributions will be used to investigate the effects of survey-level explanatory variables on frog counts during searches, with the number of frogs found during each transect search as the dependent variable and transect as the random effect or grouping variable. N-mixture modelling will be used to obtain estimates of the numbers of frogs present on transects from counts of frogs found during replicate searches of transects.

MONITORING TREATMENTS

Monitoring the treatments is an essential component of the monitoring programme. For pest control this will entail monitoring pest animal abundance in the areas around the two pest-control treatment plots and the non-treatment plot for the duration of the monitoring programme. For the vibration treatment monitoring the occurrence, amplitude and duration of vibration from underground blasting will only be required in the area around vibration treatment plot and only for the period when underground blasting takes place. To reduce disturbance in the capture-recapture plots treatment monitoring should be undertaken outside of, but close to, the capture-recapture plots. For monitoring vibrations from underground blasting a suitable vibration monitor (e.g. Omnidots SWARM Vibration Monitor) should be deployed outside, but close to, the vibration treatment plot to record the date and time of occurrence, amplitude and duration of vibrations from underground blasting that might affect frogs in the plot throughout the duration of the monitoring programme. Flow meters should be installed in stream transects in the three areas used for monitoring the effects of stream dewatering.

Details of the programme to monitor pest animal abundance in the areas around the two pest-control treatment plots are provided in the Wharekirauponga Compensation Package Pest Animal Management Plan (WAPMP) (Boffa Miskell Limited, 2023). Proposed monitoring methods include chew cards, camera traps, trap-catch indices, faecal pellets, pig rooting and new monitoring technology. To determine the effects of pest control on the Archey's frog population, it will be important to extend the pest animal abundance monitoring programme to include the area around the Archey's frog non-treatment plot. Using tracking tunnels to monitor rodent abundance is not proposed in the WAPMP, but would allow direct comparison with results from a study of the effects of rat control on Archey's frogs at Whareorino (Germano et al., 2023).

STAFFING REQUIREMENTS

Many tasks in the proposed monitoring programme require high level of technical expertise, including:

- Developing and undertaking individual identification of the frogs, either photographically or by DNA profiling.
- Data curation, which involves quality control as the data are collected, as well as managing and maintaining the project's data base over the life of the project.
- Analyses and interpretation of the capture data to understand the impacts on or benefits to the frog population.
- Development of triggers that would require further compensation if met.
- Preparation of progress reports and effective communication on progress with stakeholders.
- Managing, and leading field survey effort.
- Training search teams.

The proposed monitoring programme will extend over a period of at least 16 years. To ensure success, it will be important to retain personnel with key competencies in the project team throughout the programme's 16-year duration. This is especially true of the programme's leadership. To achieve continuity OceanaGold should consider either appointing a permanent fulltime ecologist to lead and manage the programme or funding a postdoctoral researcher to lead the monitoring programme. Funding a postdoctoral researcher brings the advantages of support provided by their university and independence from OceanaGold conferring added credibility to the results. However, the risk in funding a postdoctoral researcher is that their research interests or career aspirations might not remain aligned with the monitoring programme's objectives.

Retaining other members of the field team for the duration of the project is less critical as field teams will only be required for four to six months each year and team members can be trained or re-trained annually before the field season. The only requirements for searchers in the field are being competent outdoor workers and having good eyesight.

PREPARATORY WORK FOR THE MONITORING PROJECT

General

- Appoint a team leader and assemble and train the field team.
- Obtain necessary authorities from DOC (Authority for Research and Introduction of Material on Public Conservation Land and Authority to Handle Protected Wildlife).
- Design and put in place a programme to monitor pest abundance in areas around the capture recapture plots and stream transects.
- Investigate the effectiveness of DNA methods for identifying individual native frogs:
    - identify suitable DNA methods and providers,
    - in collaboration with DNA experts design and undertake trials of DNA identification methods for the two frog species.

Archey's Frogs

- Consult with workers experienced in photographic matching of Archey's frogs.
- Research pattern-recognition software for photographic identification of Archey's frogs.
- If photographic identification is to be used, the field equipment should be re-designed to be smaller and better suited to field conditions.
- Investigate and trial DNA profiling of Archey's frogs.
- Undertake nocturnal surveys in treatment and non-treatment areas to identify areas with suitable densities of Archey's frogs for the three capture-recapture plots.
- Once suitable locations have been selected for plots, set out the three capture-recapture plots.
- Undertake capture-recapture primary sessions with 6 nocturnal searches in each of the three capture-recapture plots.
- Analyse data from the capture-recapture primary sessions and prepare a report with recommendations for any required improvements in the methods.

Hochstetter's Frogs

- Identify suitable treatment and non-treatment areas where streams have similar characteristics (e.g., wet-width, flow rates, substrate, elevation and vegetation type).
- Randomly select 45 transects in each of the three areas.
- Locate and mark the transects.
- Record details of transect characteristics.
- Undertake 6 nocturnal searches of each of the transects.
- Analyse data from the transect searches and prepare a report with recommendations for any required improvements in the methods.

Appendices

APPENDIX A: CAPTURE-RECAPTURE METHODS FOR MONITORING ARCHEY'S FROGS

Standard Capture-recapture Method for *Leiopelmid* frogs

Capture-recapture has been used to monitor populations of Archey's frogs and other *Leiopelmid* frogs for several decades (Bell, 1994, 1997; Bell et al., 2004; Bell, 2010b; Cisternas, 2018b; Germano et al., 2023; Haigh et al., 2007; Hotham et al., 2023; Lettink, 2012b). Early monitoring studies used capture-recapture of toe-clipped individuals found during daytime searches of frog retreat sites in a single 10 x 10 m plot (Bell et al., 2004). More recently, capture-recapture using photographic identification of individuals found during night-time searches of 10 x 10 m plots has been established as the standard method for monitoring populations of Archey's frogs (Cisternas, 2018b; Germano et al., 2023; Haigh et al., 2007; Hotham et al., 2023; Lettink, 2012b). The method can provide a range of demographic estimates for plot populations including abundance, survival, fecundity and recruitment. With large enough sample sizes estimates can be derived for different age-classes. The disadvantages of the capture-recapture method in comparison to other methods stem from its cost and complexity, which limit the number of plots that can be sampled. Typically there are only one or two plots assigned to a treatment (Cisternas, 2018b; Germano et al., 2023). Demographic estimates from capture-recapture are for frogs inhabiting the plots and extrapolating the results to surrounding areas requires caution. Inferences about the population in the wider area surrounding plots are further compromised by the need to select plot locations that have high numbers of frogs to achieve robust population estimates. Despite its disadvantages, the capture-recapture method is a good option for monitoring Archey's frog.

Spatially Explicit Capture-recapture

Spatially explicit capture-recapture models were recently used to estimate population density and rate of change for a translocated population of Archey's frogs (Cisternas et al., 2022). The spatially explicit capture-recapture field method is similar to the capture-recapture method but includes recording accurate location information for each capture event. Spatially explicit capture-recapture analytic methods are theoretically superior to standard capture-recapture methods for monitoring plot populations in unbounded plots where individuals can leave the plot, because they account for temporary immigration across plot boundaries (i.e. the edge effect) (Royle et al., 2013). However, there are drawbacks to its use. Obtaining accurate capture locations of frogs in damp forest at night is difficult and time-consuming in large plots (>800 m^2) typically required for accurate demographic estimates. The task becomes impracticable when there are large number of captures during a search night. There also concerns about the analytic method's current implementation in *secr* (Efford, 2017). During a study on *Powelliphanta* (Lloyd, 2017), plot population estimates from *secr* were 30 to 40% higher than estimates from standard capture-recapture analyses, which is implausible, because edge effect bias capture-recapture estimates upwards. The *secr* package also performed poorly in a simulation study, producing population estimates between 29% and 60% (mean 45%) higher than the simulated population density (Lloyd, 2017). Despite the documented drawbacks of spatially explicit capture-recapture, given its apparently successful use of by Cisternas et al. (2022), recording capture locations during standard capture-recapture field work on Archey's frogs seems worthwhile, as it will allow comparison between results from standard and spatially explicit capture-recapture models.

Capture-recapture Field Method

To minimise possible spread of the amphibian chytrid fungus and other pathogens, recommended hygiene and handling protocols for native frogs (Appendix C) will be adhered to during all capture-recapture field-work.

Plot Marking

Capture-recapture plots will be permanently marked using Gallagher Poly Wire (a long-lasting polyethylene farm fencing materials) anchored on 300 mm metal standards around the outer boundaries. Each of the plots will be divided into 10 x 10 m sub-plots with subplot boundaries also permanently marked using poly wire on metal standards. Sub-plots should have prominent identity labels (e.g. 11, 12 13, 21 ... 33).

Seasonal Sampling Schedule

Primary capture-recapture sessions will be undertaken in each of the three capture-recapture plots annually, during late summer and early autumn (i.e. March to May). This timing avoids the breeding and parental care period during October–February (Bell, 1978; Bell, 1985; Bell, 2010a; Thurley & Bell, 1994), when brooding adult males will not be available for capture, and increases the probability that overnight climate conditions will be suitable for frogs to be active on the surface, with minimum overnight temperature > 10°C and relative humidity > 90% (Bell, 1978; Cree, 1989; Ramírez, 2017).

Nocturnal Search Schedule

Each primary capture-recapture session for a plot will entail at least 3 nocturnal searches of the plot (i.e., secondary sessions), but ideally there should be 5 nocturnal searches, during a primary session, to achieve higher accuracy and precision in the demographic estimates (Lloyd, 2024b). In the standard recommended capture-recapture method for *Leiopelmid* frogs plot searches within a primary session are undertaken on consecutive nights. Searching the same plot on successive nights is convenient for field workers but adds unnecessary complication and delays to the analyses. To analyse *Leiopelmid* frog capture-recapture data for searches undertaken on successive nights, Pledger and Bell (2008) used temporary emigration models, which require results from three consecutive primary sessions (i.e. years or seasons) to obtain population estimates for the middle primary session. The temporary emigration model uses a parameter describing the proportion of frogs remaining in retreat sites overnight and not available for capture throughout the middle primary session (Bell, 2010b; Haigh et al., 2007; Pledger & Bell, 2008).

In the proposed modified capture-recapture method to be used at Wharekirauponga, successive searches of a plot will be spaced at least three nights apart to ensure sampling independence, but ideally less than two weeks apart to minimise frog dispersal and mortality between searches. This schedule avoids the unnecessary complication and delay in obtaining demographic estimates from a temporary emigration model caused by searching on successive nights. It also avoids unnecessary random errors introduced by the need to estimate the extra parameter describing the proportion of frogs remaining in retreat sites overnight. Another advantage of spacing successive searches of a plot at least three nights apart is that searches in the three capture-recapture plots can be undertaken on successive nights, thereby reducing the confounding effect of differences in seasonal timing among primary sessions in the three plots, which will occur when successive searches in a plot are undertaken on consecutive nights.

Nocturnal Search Conditions

Nocturnal searches will begin 30 minutes after dusk (end of civil twilight) ends and finish no later than 30 minutes before dawn (start of civil twilight) begins. During the proposed March to May search season, this allows nightly search durations of up to 9 hours. To achieve high capture probabilities, searches will only be undertaken on nights when weather conditions favour frog above-ground activity, with minimum overnight temperatures > 10°C and minimum overnight relative humidity > 90% (Bell, 1985; Cree, 1986; Ramírez, 2017).

Environmental Monitoring

Temperature and relative humidity in each of the plots will be recorded at 30-minute intervals using data-loggers (e.g., Onset Hobo Pro v2 temp/RH Logger) placed 300 mm above the ground, just outside of each of the plots. The data-loggers will be left in place at the plots throughout the entire monitoring programme, with data downloaded at 3-monthly intervals. Additional information on rain and wind during and immediately before nocturnal searches will be recorded by field staff.

Search Method

Searchers should all have a powerful waterproof (IP68) headlamp (e.g. Fenix HP25R v2 or Fenix HP16R) and a powerful hand torch. All searchers in a team should have headlamps with a similar light output. During each nocturnal plot search, the entire plot will be searched systematically once to find and capture any emerged Archey’s frogs visible on the ground or in vegetation up to eye level. Searching will include carefully lifting fern fronds and parting the stems and leaves of restiads (sedges, rushes and grasses), but not more intrusive habitat disturbance such as lifting logs or rocks.

During a plot search, each of the 10 x 10 m sub-plots will be searched separately by a team of three or more people moving slowly and methodically alongside each other along search lanes in the sub-plot. When search teams include 6 or more searchers, sub-plots can be searched simultaneously. The order that sub-plots in a plot are searched and direction searchers take should vary randomly between search nights. Frogs seen on the plot boundary should only be captured if more than half of the frog is within the plot.

Capture and Processing

Search teams will carry a supply of clean ziplock plastic bags and marker tags arranged in pairs, with both bag and tag in a pair labelled with the same unique identification number. When a frog is found, it will be caught, placed in one of the labelled bags and the labelled tag from the pair of tags used to mark the capture location. Details recorded immediately after a frog's capture are the time of capture, the identification number of the bag and tag, the sub-plot identity and a brief description of the capture location, to ensure the frog is returned to its exact capture location. To reduce the risk of disease transmission, new nitrile gloves will be used for handling each frog. Captured frogs will be weighed and snout-vent-length measured before being processed for identification purposes. Snout-vent-length will be used to assign individuals to age classes (i.e. juvenile, sub-adult and adult). Weights and snout-vent-length will provide the basis for condition scores. Weight records also provide a useful method for identifying errors in snout-vent-length records. The process used for identifying individual frogs is to be decided on, but will be either photographic or using DNA methods, as discussed in a following section. After processing, frogs will be released at their exact capture locations.

Recording Exact Capture Locations

Exact capture locations will be recorded to allow spatially explicit capture-recapture analyses. of the data. There are practical difficulties in determining accurate capture locations in damp forest at night and some experimentation will be required to establish a satisfactory method. Measuring perpendicular distances to two adjacent plot boundaries with a tape measure is time consuming and results in considerable disturbance. A faster and less disruptive alternative could be using a laser distance measuring device (e.g. Leica Disto X310) to measure distances to adjacent plot corner markers. Another option is using a handheld gps unit with sub-metre accuracy e.g. (Trimble Geoexplorer 6000 Series) but experience shows that diffraction of satellite radio signal by the wet forest canopy reduces location accuracy, so that it can 20–30 minutes to obtain an accurate location for each capture. (Lloyd, 2017).

Photographic Methods for Individual Identification

In the standard capture-recapture method for Archey's frogs, individual frogs are identified from photographs of the unique distinctive patterns of individual's natural skin markings (Germano et al., 2023; Haigh et al., 2007; Hotham et al., 2023). Captured frogs are photographed in a specially designed photo-stage with mirrors placed to allow lateral, dorsal and frontal views of the frog to be captured in a single digital image. To reduce disturbance to the plot and captured frogs, frogs will be photographed without removing them from the plot. In the office, after field work, the images are archived in a digital photo library and individual frogs identified manually by matching their distinctive patterns (Bradfield, 2004). Currently photographic matching for Archey's frogs is undertaken manually, which can be extremely time-consuming(Lettink, 2012a). However, manual matching might eventually be replaced by using pattern-recognition software. Incorrect photographic identification of individuals can occur as a result of similar markings on several individuals, or if individual's markings change over time (Bradfield, 2004). Incorrect identifications from skin marking patterns is unlikely to be a serious problem for closed population estimates from individual primary sessions but could compromise open population demographic estimates from long-term monitoring.

DNA Methods for Individual Identification

In recent years DNA (deoxyribonucleic acid) methods have been used in capture-recapture studies for identifying individuals of species where marking is impracticable (Frasier et al., 2020,; Li, Li, Chen, Xiong, & Hu, 2020; López-Bao et al., 2018; Stephen N. Atkinson et al., 2021; Wegge, Bakke, Odden, & Rolstad, 2018; Woodruff, Lukacs, & Waits, 2018) including frogs (Bina Perl et al., 2018). DNA profiling is a well-established methodology used widely to identify individuals for criminal cases and other types of forensics uses in both humans and animals (Kanthaswamy, 2015; Linacre, 2021). For native frogs, the sampling method would be simple and rapid, entailing buccal swabbing (Ambu & Dufresnes, 2023; Broquet, Berset-Braendli, Emaresi, & Fumagalli, 2007; Goldberg, Kaplan, & Schwalbe, 2003; Martin & Maddock, 2019). Swab samples can be placed in 70–95% ethanol in the field and kept in a standard domestic freezer for long-term storage.

If DNA profiling can be used for identifying individual native frogs, both Archey's and Hochstetter's frog populations could be estimated using capture-recapture methods. For Archey's the capture-recapture method would be as described above but with DNA profiling replacing photographic identification of individuals. For Hochstetter's frogs, the proposed survey method with replicate searches along transects for N-mixture modelling could be augmented by DNA profiling of individual frogs found along transects to allow capture-recapture analyses of the survey results.

DNA profiling utilises unique patterns of polymorphisms of multiple genetic markers to identify individuals. Recent studies of genetic variation in *Leiopelmid* frog populations (Clay et al., 2010; Easton, 2018; Gleeson, Clay, Gemmell, Howitt, & Haigh, 2010) used microsatellites: short tandem repeats (STR) of 3–7 base pairs in regions of non-coding DNA (Butler, 2018). However, low genetic diversity in the Whareorino Archey's frog population studied meant that the number of polymorphic STR markers was too low for individual identification of Archey's frogs with the sequenced STR markers. Reduced-representation sequencing (Çilingir & Dennis Hansen, 2022; Hohenlohe, Funk, & Rajora, 2021) can generate many more polymorphic markers than the microsatellite method. The Centre for Reproduction and Genomics, University of Otago uses reduced-representation sequencing (RRS) routinely for individual identification of livestock and would be interested in and able to undertake RRS analyses for a population study on Archey's frogs (pers. com. Prof. N. Gemmell). Ballpark cost estimates for RRS analyses are between $50 and $100 per buccal swab sample, with some additional initial setup costs. The maximum total number of captures from three 30 x 30 m capture-recapture plots, with 5 nocturnal searches a year is likely to be about 400, which gives a maximum annual cost for RRS analyses of between $20,250 and $40,500.

The advantages of DNA profiling with RRS instead of photographic identification are:

- RRS provides more reliable identification, because DNA profiles don't change over time and if sufficient loci are used there is vanishingly small probability of multiple individuals having the same profile.
- buccal swabbing for DNA profiling entails shorter handling time for captured frogs in the field.

- identifying individuals from DNA profiles is less time consuming than the manual task of photograph matching as software is available for matching individual's DNA profiles.
- RRS provide more information about the study population than just the demographic estimates obtained from capture-recapture with photographic identification. Genetic information from RRS can be used to investigate effective population size (N_e), kinship and dispersal patterns, the population's recent demographic history and genetic diversity.
- Determining kinship will be valuable for investigating whether translocated frog are breeding successfully.

The disadvantages of using DNA profiling are:

- RRS is untested for Archey's and Hochstetter's frogs; and
- RRS entails the additional expense of routine laboratory work. However, the expense of laboratory work will be offset against the expense of manual photographic matching.

If DNA profiling with RRS is used for individual identification, photographic identification and DNA profiling should both be used during the first season to compare the performances of the two methods.

Capture-recapture Analyses

Analytic models and software for capture-recapture data are constantly evolving. It is therefore unwise to be prescriptive about the methods to be used for future analyses. Briefly there are three classes of capture-recapture analyses: closed population, open population and robust design (Cooch & White, 2018; Lettink, 2012b; Williams et al., 2001). Robust design analyses combine closed and open population analyses. Both closed population and robust design analyses will be used to analyse capture-recapture data from the monitoring programme.

Closed population analyses provide plot population size estimates from a single primary session, which comprises a series of secondary sessions (in this case nocturnal searches) undertaken during a short period of a few weeks. Closed population analyses are based on the assumption that plot populations are closed, without mortality, recruitment, immigration, or emigration, during a primary session. Open population and robust design analyses provide a range of demographic estimates including population size during primary sessions and estimates of population change, survival, fecundity, recruitment between primary sessions. However open population and robust design analyses can only be used for analyses of data collected from three or more primary sessions. As a consequence, only closed population analyses will be used for analyses of data from the first two primary sessions of the monitoring programme. Goodness-of-fit tests will be used to assess how well capture–recapture models fit the data (Choquet, Lebreton, Gimenez, Reboulet, & Pradel, 2009).

Currently, analyses of capture-recapture data is most commonly undertaken using the R-package *RMark* (Laake & Rexstad, 2018) as an interface for the software *MARK* (Cooch & White, 2018). *RMark* provides a wide range of models for analysing capture-recapture data and will almost certainly be used for analysing data from the monitoring programme.

However, recent developments in Bayesian analyses of capture-recapture data using the R-package *nimble* (Gimenez, 2023) make Bayesian analyses an attractive proposition for undertaking parallel analyse for comparisons with analyses using *RMark*. A list of other software available for analysing capture-recapture data can be found at: http://www.phidot.org/software/. Spatially-explicit capture-recapture analyses will also be undertaken using both the R-package *secr* (Efford, 2017), based on maximum likelihood, and Bayesian analyses (Kery & Royle, 2016; Royle & Young, 2008) using the R-package *nimble* (Gimenez, 2023). The R-package *capwire* may be for estimating population census size from DNA profiles (Miller, Harper, P., Hofmeyr, & Funston, 2014; Pennel, Stansbury, Waits, & Miller, 2013).

Analyses of the capture-recapture data and reporting results from the analyses will be undertaken annually to deliver timely, reliable and information on the effects of vibration and pest control on the local Archey's frog population.

Appendix B: Replicate Count Method for Monitoring Hochstetter's Frogs

To minimise possible spread of the amphibian chytrid fungus and other pathogens, recommended hygiene and handling protocols for native frogs (Appendix C) will be adhered to during all field work on Hochstetter's frogs.

Replicate counts of Hochstetter's frogs along stream transects were used during summer 2023–2024 in a pilot study for a BACI programme to monitor potential effects of stream flow reductions on Hochstetter's frog populations in the Wharekirauponga catchment (Lloyd, 2024a; van Winkel, 2024). The method with minor modifications to sampling design and survey methods, outlined in Lloyd (2024a), will be used to monitor the effects of dewatering .

Survey Design

- Daytime searches to find Hochstetter's frogs in their daytime refuges will be undertaken along 20 m long transects in streams.
- There will be 45 transects randomly selected in each of the treatment and non-treatment areas.
- Each transect will be searched a minimum of 6 times with at least one day between replicate searches of a transect.
- To ensure search effort is the same during each replicate search of a transect, the same, or similar, number of refuges should be searched during each replicate search of the transect. The number of refuges searched on different transects will vary according to the nature of the transect.

Replicate Count Field Method

Details of the field survey method adapted from van Winkel (2024).

1. Two searchers search each transect.
2. Searchers travel to the downstream end of a transect and use a tape measure to mark out the 20 m length of the transect.
3. On the first search of a transect, the start, midpoint and end of the transect is marked with flagging tape for subsequent searches. A marker with the Transect Identity is placed at the start of the transect.
4. One searcher begins searching upstream from the downstream end of the transect, while the other begins searching upstream from 10 m above the downstream end.
5. The searchers move slowly upstream looking for frogs in their daytime refuges, beneath rocks, in rock crevices, leaf litter packs and debris dams, etc. Headlamps are used during searches to increase visibility and detection.
6. The number of refuges searched is counted using handheld counters.
7. After refuges are searched, they are carefully reinstated to their original condition.
8. When a frog is encountered:
    a. the time of the observation is noted,
    b. the frog's position along the tape measure,
    c. the frog's size is measured, without touching or handling it, by hovering a ruler over the frog and estimating its snout-urostyle length (SUL), i.e., tip of snout to base of hind limbs/tip of ischium to the nearest 5 mm.
9. Where SULs cannot be accurately measured, estimated SULs are recorded. Estimated SULs are excluded from SUL analyses but used to assign frogs to age classes.
10. Frog's age classes are assigned from their SUL: Juvenile < 18 mm, Sub-adult 18 – 24 mm, Adult 25 – 39 mm, and Mature Adult Female > 39 mm.

Information to be Recorded

Frog Observations

The following details should be recorded for each frog:

1. Transect identity and geographic location.
2. Date and time of observation.
3. Frog's snout-urostyle length (SUL).
4. Frog's position along the tape measure.
5. Details of the frog's refuge.

Survey Conditions

During each search of a transect, the following details should be recorded:

1. Transect identity and geographic location.
2. Date.
3. Searcher's names for each 10 m transect section of the transect.
4. Start time and end time for each 10 m section of the transect.
5. Search duration for each 10 m section of transect.
6. General weather conditions (e.g., cloud cover, rainfall, wind speed and direction).
7. Air temperature and relative humidity at the start of the survey.
8. Water temperature at the start of the survey.

Transect Characteristics

During the first search of each transect, the following details should be recorded:

1. Transect identity and geographic location.
2. GPS coordinates & elevation of the downstream end of the transect.
3. Average canopy cover (%) along each 10 m section of the transect.
4. Vegetation type (using NZLRI or similar) for each 10 m section of the transect.
5. Representative photographs of the 10 m sections of transect.
6. Substrate types every 2 m along the transect using types listed on the field datasheet.
7. The number of refuges searched.

During each search of a transect, the following stream characteristics should be measured and recorded every 2 m along the length of the transect:

1. Stream wetted width.
2. Water depth. For wide streams, record a series of depth measurements every 200 mm across the width of the stream.
3. Water velocity, measured with a flow meter placed 60% of the water depth below the water surface (i.e., 40% of the water depth above the stream bed).

Technical Gear Required for Transect Searches

Technical gear required for the transect searches are: wet-weather field datasheets or a waterproof digital device for recording data, GPS with maps, thermometer, relative humidity meter, 20 m or 50 m tape measure, headlamps, handheld counters, 100 or 150 mm clear plastic rulers and flow meters.

APPENDIX C: NATIVE FROG HYGIENE AND HANDLING PROTOCOL

Native frog hygiene and handling protocols

Background

Over the past 25 years' amphibian populations have declined throughout the world and disease is considered to play a major role. One disease we have in New Zealand which is thought to be a major threat to frogs is the amphibian chytrid fungus. Given the transmission risk of the fungus and other diseases, strict hygiene and handling protocols are required to ensure the safety of our native frog populations. This document provides information on how to:

- Minimise any possible spread of the amphibian chytrid fungus and other pathogens.
- Avoid artificially increasing contact between frogs.
- Achieve the highest level of hygiene protocol that is effective and practical in the field.
- Safely handle frogs for research purposes.

Principles

- Transmission risk can be managed/reduced through good hygiene practices.
- New or disinfected equipment /footwear should be used at every new site.
- New or disinfected equipment should be used for each frog, where practicable.

> **What should I do before entering known frog habitat?**
>
> Before you enter known frog habitat ensure all your foot wear, gaiters and equipment are clean, e.g. free of dirt/mud and dry. Foot wear, gaiters and equipment will also be disinfected. You can ensure that your clothing and equipment is safe to take into frog areas by following simple hygiene protocols.

Site hygiene

- Remove all dirt/mud from footwear, gaiters and field equipment. Pay particular attention to field gear likely to come in contact with amphibians, soil/ground, freshwater, and/or that is already dirty e.g. boot soles.
- Disinfect all field gear. Mud/dirt etc. will be cleaned off first before disinfecting.
- Wash and dry everything. *Important* Chytrid fungus cannot survive drying out so it is very important that cleaned items are dried.
- Store gear in a clean dry area away from soil to avoid recontamination.
- *Important* If you have been to an area infected with the amphibian chytrid fungus you will clean and disinfect all your gear. Gear will also be cleaned between each field trip into the same native frog area, regardless of whether you are going in the same way or not.

Tips

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