Waikato Regional Council Technical Report 2022/07

Herpetofauna survey of geothermal ecosystems in the Waikato region

www.waikatoregion.govt.nz
ISSN 2230-4363 (Online)

Waikato
REGIONAL COUNCIL
Te Kaunihera ā Rohe o Waikato

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December 2022

Document #: 23070944

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Acknowledgement

Many thanks to the landowners and managers who permitted access to the sites used in this study, as well as to Rhys Burns (Department of Conservation), Moniqua Nelson-Tunley (WRC) and Jim McLeod (WRC) for their expert guidance, and assistance in the field. Thank you Gotcha 2020 Ltd for the rapid delivery of their easy to assemble Black Trakka™ tracking tunnels, and to the Waikato Regional Council for the opportunity to work on this project over the summer. Lastly, a special thank you to Katherine Luketina, for her guidance and direction in both the writing of this report and the design of this study.

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Abstract

The indigenous ground dwelling fauna of geothermal ecosystems in the Taupo Volcanic Zone is relatively poorly understood. A tracking tunnel survey was conducted with the aim of identifying the ground-dwelling vertebrates living in geothermal habitats at four sites in the Taupo Volcanic Zone, with the specific intent of locating and identifying native lizard populations at these sites. 162 tracking cards were collected from a total of 60 tracking tunnels over a period of 40 days. The tracks recorded on the tracking cards were identified, and Chi squared (X^2) analysis was performed to identify the strength of the relationships between the type of prints detected, the vegetation type at the tunnel, and the site from which the tunnels were collected. In total, the prints of six different terrestrial vertebrate species and groups of vertebrates were identified. The common brushtail possum (*Trichosurus vulpecula*), the European hedgehog (*Erinaceus europaeus*), various rat species (*Rattus* sp.), an unidentified mustelid species (*Mustela* sp.), house mice (*Mus musculus*) and an unidentified skink species, likely indigenous, (*Oligosoma* sp.) were detected at these sites. Print detection exhibited a relationship with both site and with vegetation type, though it was unclear whether site related factors or vegetation related factors had the more significant effect on the distribution of terrestrial vertebrates. This study is the first of its kind to find evidence of a lizard association with a geothermal habitat in New Zealand. Additional research will be necessary to identify the species of the lizard detected.

Executive summary

A study was undertaken using tracking cards to identify the presence of indigenous lizard populations at a few key geothermal ecosystems in the Waikato region, to establish whether native lizard populations could exist within geothermal habitats. The tracking cards also recorded prints of mammalian pest populations at these ecosystems. How pest populations varied with vegetation class and site was evaluated.

Skinks were detected in geothermal kānuka scrub at Craters of the Moon in the Taupo Volcanic Zone (TVZ), but not at any of the other sites investigated. This demonstrates that lizards can exist within geothermal habitats but does not allow us to make any assumptions about their distribution. Exotic vertebrates were frequently detected at all four sites. Depending on the location and on the species, detection of exotic vertebrates varied both with vegetation and with site. No estimates could be made of true population distributions of either lizards or pest mammals.

As lizards have been proven to have a habitat in at least one geothermal ecosystem in the TVZ, further studies into pest distribution in geothermal areas, as well as increased pest control measures for small mammals, are advised. Further study will be necessary to identify the type and distribution of the skinks detected at Craters of the Moon, as will study to detect lizard populations at other sites in the Taupo Volcanic Zone. A more statistically rigorous sampling model could also be used in order to more accurately identify population distributions of pests at the geothermal sites.

1 Introduction

The Taupo Volcanic Zone (TVZ) in the northern half of the North Island of New Zealand is home to unique geothermal ecosystems and habitats. These ecosystems are generally defined by heated, geothermally acidified and mineralised soils, as well as frequent exposure to geothermal fluid and gas. The vegetation of geothermal ecosystems in the Taupo Volcanic Zone is reasonably well defined (Smale and Fitzgerald, 2014) (Wildlands Consultants, 2014a, 2021), as is the biota of geothermal waters in the region (Duggan and Boothroyd, 2002, 2003); the terrestrial fauna of these ecosystems, however, is relatively poorly understood. Though some study has been conducted on terrestrial macro-invertebrates in geothermal ecosystems, (Willoughby and Beard, 2013), no studies so far have been done on the distribution of terrestrial vertebrates in geothermal ecosystems of the TVZ. Wildlands Consultants in their 2014 report "Priorities for pest plant control, pest animal control, and fencing at geothermal sites in the Waikato Region" (Wildlands Consultants, 2014b) assessed the threat presented to geothermal ecosystems in the Taupo Volcanic zone by pest animals such as possums, deer, and pigs. This report was an assessment of threat, rather than of distribution, so assessments were often made based on "knowledge of what pest animals were likely to be at or near a given site" (Wildlands 2014b), or what pest species the site would be particularly vulnerable too. Assessments for this report were often made over a single site visit and did not consider the threat presented by small terrestrial vertebrates, such as rats, mice, and mustelids.

Of the terrestrial vertebrates with the potential to be endemic to geothermal ecosystems, indigenous lizards are a good candidate for study. They, along with frogs, have short ranges (Hitchmough *et al.,* 2021) so the detection of an individual within a geothermal ecosystem will imply the existence of a permanent population within that ecosystem. These localised populations will have a more intimate relationship with the geothermal ecosystems than far ranging birds or bats. As many indigenous lizards native to the TVZ are also nationally endangered (Hitchmough *et al.,* 2021), determining whether these species have populations in geothermal habitats is an essential step in the protection and management of both geothermal ecosystems, and of indigenous lizard populations.

According to Van Winkel *et al*. (2018) there are a range of species of native lizard that inhabit the region. Three of these are gecko species, the elegant gecko, *Naultinus elegans,* the forest gecko, *Mokopirakau granulatus* and the Raukawa Gecko, *Woodworthia maculata.* Geckos are largely arboreal so are unlikely to be detected in the scrubland characteristic of a geothermal ecosystem. The skink species, *Oligosoma polychroma (*northern grass skink) *Oligosoma ornatum* (ornate skink), *Oligosoma striatum* (striped skink) and *Oligosoma aff. infrapunctatum "crenulate"* (crenulate skink). Populations of all these species have been recorded either near geothermal ecosystems, or in scrub and brush that bears similarity to geothermal kānuka, mingimingi and kānuka scrub. None of those species has had populations recorded in geothermal habitats. The invasive Rainbow Skink (*Lampropholis delicata)*

New Zealand lizard species such as those listed above tend to be highly elusive (Bell, 2009) so detecting and monitoring New Zealand geckos and skinks visually is difficult. Nonvisual methods like pitfall traps, g-minnow traps and tracking tunnels must be employed to identify and categorise skink and gecko populations. Of these methods, tracking tunnels are cheap, low maintenance, are quick to install and uninstall, and can be left in the field for extended periods of time without needing to be retrieved. In addition, they do not involve the risks to animals that trapping or handling bring and require less in the way of regulatory approval. Lettink et al. (2022), proved that tunnels were significantly more effective at detecting Indigenous skink populations compared to other trapping methods. Tunnels are the ideal method for detecting and locating populations, as they can be quickly deployed over a large area, where they can collect data over a long period of time without having to be checked on more

than once a fortnight. Though tunnels are ideal for establishing the presence of a population, it can be difficult to distinguish between the tracks recorded on a tracking card of species within the same family. For skinks (Jarvie., 2012; Lettink et al. 2022) there is currently no reliable method of identifying species from tracking card prints, though foot size has been used to identify different species of geckos from their prints (Jarvie., 2012). To identify the species of a given population, more intensive monitoring methods like g-minnow and pitfall traps for lizards, or camera traps and, mechanical traps and bait stations for mammals, must be employed. As tracking tunnels cannot easily select for any given species, data on exotic vertebrate populations, including stoats, ferrets, weasels, rats, mice and possums, and even on terrestrial invertebrate populations is also collected in studies that use them. Tracking tunnels can also struggle in that they do not detect 100% of all animals in the area around the tunnel. Because of this, reports on studies that use tunnels can typically only discuss species distribution in terms of likelihood of detection (MacKenzie *et al*., 2002), though probabilistic corrections may be applied if detection rate can be estimated.

This survey used tracking tunnels to determine the existence and distribution of any populations of native lizards, and potentially of mammalian pest species at four geothermal systems within the Taupo Volcanic Zone. Tracking card data was cross-referenced with vegetation data, (Wildlands Consulting 2014a, 2021), to determine which vegetation classes were most likely to harbour lizards and mammalian pests.

2 Methods

2.1 Site Selection

Four geothermal ecosystems in the Waikato region were selected based on geographical spread, the ease by which they could be accessed, and on the diversity of their geothermal vegetation. They were monitored for a period of 40 days between 9 December 2021 and 21 January 2022. These ecosystems were Waikite geothermal ecosystem (WKT), the Longview Road geothermal ecosystem (LVR) in the Reporoa Geothermal System, the Orakei Korako geothermal ecosystem (ORK) and the Craters of the Moon geothermal ecosystem (CTM) in the Wairakei-Tauhara Geothermal System (See Figure 1).

A total of 60 tracking tunnels with inked tracking cards were installed in geothermal vegetation over this period, in a range of sites selected in the field to represent a range of vegetation types and degrees of geothermal influence. Forty-seven tunnels were installed on the initial visit to the sites on 9 - 10 December 2021; 5 at Waikite, 8 at Longview Rd, 12 at Orakei Korako, and 22 at Craters of the Moon, where lizards had been recently sighted. A further 13 tunnels were installed on subsequent visits to the sites in areas where data were sparse, or results were promising. On 20 - 21 December 2021, 2 tunnels were added at the Longview Road site, one at Orakei, and 5 at Craters of the Moon. On 10 - 11 January 2022, 5 more tunnels were installed at Waikite. In total 162 tracking cards were collected from the four sites.

Map 1: Locations of ecosystems sampled in the TVZ. 20/01/22. Google Earth images map.

2.2 Data Collection

Tracking cards were collected from the tunnels thrice during the 40-day monitoring period. On 20 - 21 December 2021, and on 10 – 11 and 20 – 21 January 2022. Precise location (±5 metres) for each tunnel was recorded using the New Zealand Topo Maps app on a smartphone.

Vegetation class at each tracking tunnel was described in the field, and cross referenced with data from Wildlands Consulting technical reports (2014a, 2021). In total, six main vegetation classes were sampled in this study.

1. Indigenous fernland
2. Indigenous treeland
3. Manuka-dominant scrub
4. Mingimingi-dominant scrub
5. Kānuka-dominant scrub
6. Loamfield

Where there was discrepancy between the 2014 Wildlands report vegetation class and the observed vegetation, vegetation class was redefined based on field observations, using classes described by Wildlands, 2014. Occasionally vegetation at a tunnel location was part of a unique microhabitat that was localised to a single site, this often resulted in cases where one tunnel was the only site with a certain vegetation class. Where this occurred, vegetation class at the site was re-categorised into one of the six vegetation classes in this study, based on similarities in vegetation, and on proximity to sites with well-defined vegetation.

For the purposes of this report class “Kānuka-dominant scrub” is a merged class consisting of both prostrate kānuka scrub from the 2014 report and geothermal kānuka scrub from the 2021 report. geothermal kānuka has been defined as its own species since it was identified as prostrate kānuka in Wildlands 2014a, (de Lange, 2014) and while not all prostrate kānuka identified by that survey is genetically distinct “geothermal kānuka”, the vegetation types are similar enough to combine into a single class for the purpose of this report.

2.3 Data Analysis

The tracks of rat species, mice (*Mus musculus*), the common brushtail possum (*Trichosurus vulpecula)* mustelids, European hedgehogs (*Erinaceus europaeus)*, Oligosoma skink species and gecko species can all be easily distinguished on inked tracking cards. (Agnew, 2009) For each tracking card, presence, and absence of each of these groups were recorded (See Table 1). Though prints of terrestrial invertebrates (beetles, weta, cockroaches and others) were found on many cards, identifying the differences between families of insect from the tracks is often imprecise, and the tracks of these species were not analysed in this study.

For each tracking card and each tunnel, the vegetation class, broad vegetation description, tunnel location and the animals detected were described qualitatively. The number of cards from each site, the number of cards collected from each vegetation type, and the number of cards on which a given species was detected were recorded as discrete variables.

Chi Squared (X^2) tests were used to determine the significance of the association between the site and vegetation class of a given card, and the detection of the various species identified in this study. For each species or group of animals detected, two expected distribution tables were created, showing how many animals of each species would be detected in each vegetation type and at each site assuming that detection was random, with a fixed probability across all locations. For each combination of spices, a Chi squared statistic (X^2) was calculated:

$$X^2 = \sum \frac{(Observed\ detection - Expected\ detection)^2}{Expected\ detection}$$

This chi squared statistic for each species was compared to the chi squared statistic at the 95th percentile of the random distributions, (p = 0.05). Distributions with X^2 values higher than the X^2 where p=0.05 were considered to contain statistically significant relationships. The parameters of a chi squared (X^2) test can be denoted by:

The following notation is used in this report to describe the conditions behind statements of significance. X^2 (*degrees of freedom*, N = *number of samples total*) = *Chi squared for these parameters*, p = *selected confidence level*.

3 Results

3.1 Vegetation Assessment

There were several trap locations in this study where significant changes to the vegetation were observed since 2014. There were also a number of locations at The Craters of the Moon site where traps were placed outside of the area defined by the Wildlands 2021 report. The following changes were made from the Wildlands Vegetation Reports (2014a, 2021) for the purposes of this analysis.

- **Waikite: WKT03** and **WKT04** are in kānuka scrub. Replanting has changed the vegetation class here from exotic species dominant scrub since the vegetation was last defined in 2014.
- **Waikite: WKT10** is in a narrow band of rank exotic grass scrub/ indigenous *Christella dentata*/Tūrutu fernland on the edge of a stream. This is a small ecosystem isolated from the surrounding sedge by a fenceline and rank exotic grass pasture that has become established since 2014.

- **Orakei Korako: ORK01** rests very near the edge of a small (<4 m across, < 1 m deep) patch of indigenous sedgeland in between a geyser and a wide sinter terrace. This was the only site in sedge observed in this study and has been reclassified to sinter, due to the tunnel's proximity to this habitat.
- **Orakei Korako:** Localised patches of Indigenous fernland were noted to be dotting the mānuka scrub at Orakei Korako in the Wildlands report, (2014a) but were too small to be mapped. **ORK08** and **ORK12** are in this habitat type.
- **Orakei Korako: ORK11** is also in indigenous fernland in the mouth of a geothermal cave. The shelter at the cave's entrance has provided habitat for a stand of diverse indigenous ferns.
- **Craters of the Moon:** Geothermal kānuka dominant shrub at **CTM11** has been reclassified to kānuka dominant scrub, as it was the only site of this type sampled in the entire study, and was similar to the low, sparse kānuka scrub elsewhere at Craters of the Moon.
- **Craters of the Moon: CTM16, CTM18** and **CTM20** were on the edges of the geothermal habitat and the surrounding indigenous treeland and mingimingi scrub. They have been classified using Wildlands (2014a) as a reference.
- **Craters of the Moon:** Prickly mingimingi scrub was a vegetation class defined in Wildlands, 2021. It is a subclass of mingimingi dominant scrub, so has been treated as mingimingi dominant scrub for the purpose of this study **(CTM27, CTM02)**

3.2 Tracking Card Data

A total of 162 tracking cards were gathered from sites at Waikite, Longview Rd, Orakei Korako, and Craters of the Moon (Figure 1). Of these cards, 20 were taken from Waikite (WKT), 28 from Longview Rd (LVR), 38 from Orakei Korako (ORK), and 76 from Craters of the Moon (CTM).

Table 1: Number of cards with tracks belonging to M musculus, Rattus sp., T vulpecula, Skink sp., and E europaeus collected from the Craters of the Moon (CTM), Longview Rd (LVR), Orakei Korako (ORK) and Waikite (WKT) geothermal ecosystems between 9 December 2021 and 21 January 2022.

Site	*Mus musculus*	*Rattus sp.*	*Trichosurus vulpecula*	*Erinaceus europaeus*	Mustelid Sp	Skink sp.	Number of Cards
CTM	28	29	2	0	1	1	76
LVR	15	0	4	0	0	0	28
ORK	13	15	2	0	0	0	38
WKT	1	5	12	4	0	0	20
Total	**57**	**49**	**20**	**4**	**1**	**1**	**162**

Of the groups identified in this study, Mice were present at all sites, and detected with a moderate frequency at all sites other than Waikite. Rats were detected at all sites in moderate numbers other than at Longview Road, where they were not detected at all, the brushtail possum was detected at all sites, though it was uncommon at Orakei Korako and Craters of The Moon. The European hedgehog, and an unspecified mustelid were detected at Waikite only, in low numbers. Geckos were not detected at any sites, and skinks were detected only once, at Craters of the Moon.

Of the vegetation classes sampled in this study, Mingimingi-dominant and kānuka-dominant scrub were the most common, followed by Mānuka-dominant scrub. Loamfield and indigenous fernland were the least sampled of the vegetation types in this study, and sampled slightly more frequently were indigenous treeland and manuka dominant scrub in that order.

The tracking card data from each of the sites can be cross-referenced with vegetation class data to compare the abundance of the four different groups detected under different types of plant coverage.

Table 2: Number of cards with tracks belonging to M musculus, Rattus sp., T vulpecula, Skink sp , and E europaeus collected from vegetation classes indigenous fernland (IF), indigenous treeland (IT), loamfield (LO), manuka dominant scrub (MaS), mingimingi dominant scrub (MiS) and kanuka dominant scrub at Craters of the moon, Longview Road, Orakei Korako and Waikite geothermal ecosystems.

Vegetation Class	*Mus musculus*	*Rattus sp.*	*Trichosurus vulpecula*	*Erinaceus europaeus*	*Mustelid Sp*	*Skink sp.*	Number of Cards
Indigenous fernland	0	3	0	0	0	0	10
Indigenous treeland	2	10	8	4	1	0	18
Loamfield	7	2	0	0	0	0	9
Mānuka-dominant scrub	13	7	2	0	0	0	22
Mingimingi-dominant scrub	17	14	3	0	0	0	42
Kānuka-dominant scrub	18	13	7	0	0	1	61
Grand Total	**57**	**49**	**20**	**4**	**1**	**1**	**162**

The skink at Craters of the Moon was detected in geothermal kānuka-dominant scrub. As only one individual was identified, no comment may be made on the variation of detection for this species.

Table 3: Waikite tracking tunnel, vegetation, and vertebrate tracking data summary. Vegetation class sourced from both field observations and Wildlands (2014a). Vegetation and site descriptions collected in the field. Presence of lizards from Skink species (S sp.), and of mammals: Mus musculus (MM), Trichosurus vulpecula (TV), Rattus species (R sp.), Mustella species, (M sp.) and Erinacheus europea recorded at each site.

Tunnel	Vegetation Class	Description	Lizard Sp.	Mammal Sp.
WKT01	Indigenous treeland	Rautawhiri/kānuka/karamu/rank exotic grass tree land. Site beneath low kānuka scrub beside rank exotic grass field.	N/A	*MM*, R sp., TV, M.sp., EE
WKT02	Indigenous treeland	Rautawhiri/kānuka/karamu/rank exotic grass tree land. Site on bare leaf litter below tall (>3m) rautawhiri	N/A	TV
WKT03	Kānuka-dominant scrub	Rautawhiri/kānuka/karamu/rank exotic grass tree land (replanting). Site in kānuka/karamu between the geothermal stream and exotic pasture.	N/A	R sp., TV
WKT04	Kānuka-dominant scrub	Kānuka/karamu/wheki/rank exotic grass tree land (replanting). Site in kānuka/karamu treeland between the geothermal stream and exotic pasture. *Christella dentata* grows along the bank of the river here.	N/A	TV
WKT05	Indigenous treeland	Rautawhiri/kānuka/karamu/rank exotic grass tree land. Tunnel in rank exotic grass under moderately tall (>2m) rautawhiri/ kānuka	N/A	R sp., TV, EE
WKT06	Kānuka-dominant scrub	Kānuka/rank exotic grass scrub (overgrown since previous assessment) Site in rank exotic grass, between bare geothermal earth (sinter) and kānuka shrubland.	N/A	N/A
WKT07	Kānuka-dominant scrub	Kānuka/rank exotic grass shrubland. Site on a small island of kānuka and rank exotic grass surrounded by bare geothermal earth and geothermal water on all sides.	N/A	N/A
WKT08	Kānuka-dominant scrub	Kānuka/rank exotic grass/blackberry-bracken shrubland. Tunnel under kānuka overgrown by bracken (*Pteridium esculentum)* and rank exotic grass. Beside hot stream, downstream of a large mass of blackberry scrub.	N/A	N/A
WKT09	Kānuka-dominant scrub	Tunnel on bare earth/kānuka leaf litter beneath kānuka scrub, on far side of geothermal stream from the fence line.	N/A	TV
WKT10	Indigenous fernland	Site in localised *Christella* dentata-Tūrutu fernland/Rank exotic grass nestled tightly between a fenceline/ rank exotic grass pasture and geothermal water (geothermal stream)	N/A	N/A

Table 4: Longview Road tracking tunnel, vegetation, and vertebrate tracking data summary. Vegetation class sourced from both field observations and Wildlands (2014a). Vegetation and site descriptions collected in the field. Presence of lizards from Skink species (S sp.) and of mammals: mouse species (Mus musculus), Trichosurus vulpecula (TV), Rattus species (R sp.), Mustella species, (M sp.) and Erinacheus europea recorded at each site.

Tunnel	Vegetation Class	Notes	Lizard Sp.	Mammal Sp.
LVR01	Mingimingi-dominant scrub	On loose leaf litter and bare earth, on the border of dense geothermally influenced mingimingi-mānuka scrub and sinter terrace. Red *Trentepholia* algae abundant on present on dry brush.	N/A	N/A
LVR02	Mingimingi-dominant scrub	Site on loose leaf litter, on the border of dense mingimingi-mānuka scrub and sinter terrace. Red *Trentepholia* algae abundant.	N/A	*MM*, TV
LVR03	Mingimingi-dominant scrub	On loose leaf litter/ bare earth, on the border of dense mingimingi-mānuka scrub and sinter terrace. Red *Trentepholia* algae abundant	N/A	N/A
LVR04	Mingimingi-dominant scrub	In prickly mingimingi scrub on dead branches, beside between sinter terrace and geothermal water. Red *Trentepholia* algae abundant	N/A	*MM*, TV
LVR05	Mingimingi-dominant scrub	Tunnel on sinter/bare earth, directly beneath over-hanging mānuka-mingimingi scrub on the bank of geothermal water. *Trentepholia* algae present	N/A	*MM*
LVR06	Mingimingi-dominant scrub	Tunnel beneath mingimingi scrub on loose leaf litter/bare earth. *Trentepholia* algae present on scrub.	N/A	*MM*
LVR07	Mingimingi-dominant scrub	On moss (*Leucobryum javense)* under mānuka-mingimingi scrub covered thickly in *Trentepholia* algae. On edge of sinter terrace/bare earth	N/A	*MM*
LVR08	Loamfield	Wedged between sinter and *Trentepholia* laden mānuka-mingimingi scrub, near geothermal water.	N/A	*MM*
LVR09	Mānuka-dominant scrub	Tunnel on mossy ground *(Chiloscyphus semiteres)* in tall (4 m) mānuka-mingimingi scrub, near the edge of dry, bare geothermal earth.	N/A	*MM*, TV
LVR10	Mānuka-dominant scrub	Site deep into dense, tall (4m), *Trentepholia*-laden, mānuka, scattered mingimingi also present. On dry *Chiloscyphus semiteres* moss.	N/A	*MM*, TV

Table 5: Orakei Korako tracking tunnel, vegetation, and vertebrate tracking data summary. Vegetation class sourced from both field observations and Wildlands, (2014a). Vegetation and site descriptions collected in the field. Presence of lizards from Skink species (S sp.), and of mammals: mouse species (Mus sp.), Trichosurus vulpecula (TV), Rattus species (R sp.), Mustella species, (M sp.) and Erinacheus europea recorded at each site.

Tunnel	Vegetation	Notes	Lizard Sp.	Mammal Sp.
ORK01	Loamfield	Indigenous sedgeland/mānuka-mingimingi scrub. Localised patch of wīwī sedge and mānuka scrub on the edge of nonvegitated raw-soilfield. Tunnel placed in the sedge, surrounded by sinter on two sides 4 m distant from active feature.	N/A	*Mus* sp., R sp.
ORK02	Mānuka-dominant scrub	Tunnel on mossy (*Dicranoloma* sp.) ground in diverse (Exotic pine)/mānuka-mingimingi scrub. Scattered karamū and exotic pines present amongst the kānuka, near *Dicranopteris* fernland	N/A	*Mus* sp., R sp.
ORK03	Mānuka-dominant scrub	Site in dense Mānuka-mingimingi scrub above sinter terrace, beside geothermal stream on mossy *Dicranoloma* sp. ground. Scattered *Dicranopteris* and tūrutu present.	N/A	*Mus* sp., R sp.
ORK04	Mānuka-dominant scrub	Tunnel in dense, dry mingimingi on bare geothermal earth, scattered *Dicranopteris* fern present.	N/A	*Mus* sp.
ORK05	Mānuka-dominant scrub	Site on bare earth beneath dense mingimingi scrub. scattered *Dicranopteris* and *Gleichenia* fern also present.	N/A	*Mus* sp.
ORK06	Mānuka-dominant scrub	Site on thick leaf litter uphill from the track, at the terminus of a narrow chute. Vegetation is dry mānuka scrub, with patches of *Dicranopteris* and *Gleichenia.*	N/A	*Mus* sp., R sp.
ORK07	Mānuka-dominant scrub	Mānuka-mingimingi scrub. Sparse mingimingi and tall (4 m) mānuka scrub. Tunnel mossy (*Dicranoloma* sp.) ground in thick tūrutu brush.	N/A	N/A
ORK08	Indigenous fernland	Tunnel in localised *Dicranopteris* dominant fernland, on *Dicranoloma* sp. moss with scattered mānuka and karamū scrub	N/A	N/A
ORK09	Kānuka-dominant scrub	Site on loose bark under log on the border between geothermal kānuka-dominant scrub and mingimingi-mānuka scrub.	N/A	TV, R sp.
ORK10	Kānuka-dominant scrub	Site on *Dicranoloma* moss in moderately tall (>3 m) geothermal kānuka-dominant scrub, scattered mingimingi-mānuka present near tunnel as well.	N/A	R sp.
ORK11	Indigenous fernland	Indigenous wheki/ mamaku/ ponga/ *Dicranopteris* fernland. Site in the mouth of a cave on heated rocky earth surrounded by a range of fern species. Primarily D*icranopteris linearis*, wheki and ponga fern. Directly adjacent to fumarole.	N/A	R sp.
ORK12	Indigenous fernland	Tunnel under large indigenous pine (rimu) in sparse *Dicranopteris* fernland. Surrounded by mānuka-dominant/mingimingi scrub. Scattered Japanese honeysuckle, rewarewa and karamu among other broadleaf species present.	N/A	N/A
ORK13	Kānuka-dominant scrub	Tunnel on bare earth/sparse *Dicranoloma* moss in kānuka-dominant scrub with sparse mingimingi and tūrutu scattered through.	N/A	TV

Table 6: Craters of the Moon tracking tunnel, vegetation, and vertebrate tracking data summary. Vegetation class sourced from both field observations and Wildlands, (2021). Vegetation and site descriptions collected in the field. Presence of lizards from Skink species (S sp.) and of mammals: mouse species (Mus sp.), Trichosurus vulpecula (TV), Rattus species (R sp.), Mustella species, (M sp.) and Erinacheus europea recorded at each site.

Tunnel	Vegetation	Notes	Lizard Sp.	Mammal Sp.
CTM01	Kānuka-dominant scrub	Tunnel on geothermally heated bare earth under low geothermal kānuka scrub, with scattered *Dicranopteris* fern present near tunnel.	N/A	*Mus* sp.
CTM02	Mingimingi-dominant scrub	(Mānuka)/rank exotic grass/karamu/prickly mingimingi-geothermal kānuka scrub. Tunnel beneath a log in prickly mingimingi-mānuka. Distinct stands of rank exotic grass and scattered karamu in surrounding scrub.	N/A	*Mus* sp.
CTM03	Kānuka-dominant scrub	Tunnel on *Dicranoloma? moss* in low geothermal kānuka scrub. To the south of the track	S sp.	*Mus* sp.
CTM04	Kānuka-dominant scrub	Site on bare earth/loose leaf litter directly beside track, under the edge of the boardwalk in low geothermal kānuka scrub.	N/A	*Mus* sp., R sp.
CTM05	Kānuka-dominant scrub	Tunnel in the shade of very low (<30 cm high) geothermal kānuka scrub, on *Dicranoloma? sp. moss*. Scattered *Lycopodiella* sp. also present in scrub.	N/A	*Mus* sp.
CTM06	Loamfield	Site on heated bare sand/geothermal sinter under wooden boardwalk, beside low geothermal kānuka scrub.	N/A	*Mus* sp.
CTM07	Kānuka-dominant scrub	Site in very low (<30 cm high) geothermal kānuka scrub on bare geothermal earth/sinter between two fumaroles.	N/A	*Mus* sp.
CTM08	Kānuka-dominant scrub	Tunnel on bare geothermal earth in low (<30 cm high) geothermal kānuka scrub, near the top of a shallow rise leading down into a gully. Lichen abundant on nearby bare ground	N/A	N/A
CTM09	Kānuka-dominant scrub	Tunnel on bare geothermal earth/*Dicranoloma? sp.* moss in low (<30 cm high) geothermal kānuka scrub, near the top of a shallow rise leading down into a gully. Lichen abundant on nearby bare ground.	N/A	*Mus* sp.
CTM10	Kānuka-dominant scrub	Site in geothermal kānuka-tūrutu scrub directly adjacent to wooden boardwalk. On the border of prostrate (<0.5m) geothermal kānuka/*Lycopdiella* shrubland	N/A	*Mus* sp., R sp.
CTM11	Kānuka-dominant scrub	Site in sparse, prostrate geothermal kānuka shrubland with abundant *Lycopodiella* sp. club moss. Tunnel placed on geothermally heated bare earth in a narrow ditch at the bottom of a low mound.	N/A	*Mus* sp.

Tunnel	Vegetation	Notes	Lizard Sp.	Mammal Sp.
CTM12	Mingimingi-dominant scrub	Mingimingi-whauwhaupaku-karamū-geothermal kānuka/ bracken scrub. Site on mossy (*Dicranoloma? sp.)* ground under tall (2m) kānuka on the border between diverse Mingimingi-whauwhaupaku-karamū-geothermal kānuka scrub and geothermal kānuka scrub with patches of heated bare earth.	N/A	*Mus* sp., R sp.
CTM13	Mingimingi-dominant scrub	Mingimingi-whauwhaupaku-karamū-geothermal kānuka/ bracken scrub. Site on mossy (*Dicranoloma sp.)* ground under tall (2m) kānuka on the border between diverse Mingimingi-whauwhaupaku-karamū-geothermal kānuka scrub and pure geothermal kānuka scrub with patches of heated bare earth.	N/A	*Mus* sp., R sp.
CTM14	Kānuka-dominant scrub	Tunnel on loose leaf litter in prostrate geothermal kānuka scrub, directly adjacent to exposed gravel walkway.	N/A	*Mus* sp., R sp.
CTM15	Mingimingi-dominant scrub	Site at the top of a tall rise on mossy (*Dicranoloma sp.)* ground under kānuka in mixed Mingimingi-whauwhaupaku-karamū-geothermal kānuka scrub. Scattered *Nephrolepis flexuosa* and Tūrutu present around tunnel	N/A	*Mus* sp., R sp.
CTM16	Indigenous Treeland	Tunnel on loose leaf litter/roots at the border of mixed Rautawhiri-wheki-whauwhaupaku-karamū treeland broadleaf treeland and geothermal kānuka scrub.	N/A	R sp., TV
CTM17	Kānuka-dominant scrub	Tunnel on *Dicranoloma sp.* moss in tangled geothermal kānuka- tūrutu scrub. Directly adjacent to the trail.	N/A	*Mus* sp., R sp.
CTM18	Indigenous Treeland	Tunnel on lose leaf litter in mingimingi-mānuka-wheki-whauwhaupaku karamū-geothermal kānuka-bracken treeland on the northern border of the geothermal habitat. Composition similar to mingimingi scrub, but broadleaf species more dominant than in pure mingimingi	N/A	*Mus* sp., R sp.
CTM19	Kānuka-dominant scrub	Site on loose leaf litter in geothermal kānuka scrub with scattered tūrutu and mingimingi	N/A	R sp.
CTM20	Indigenous treeland	Site nestled under log on loose leaf litter in mixed mingimingi-mānuka-wheki-whauwhaupaku-karamū-geothermal kānuka/bracken scrub.	N/A	R sp.
CTM21	Kānuka-dominant scrub	Site on bare earth/loose leaf litter in very low (<30 cm) geothermal kānuka-mingimingi scrub. At top of ridge above large geothermal vent.	N/A	N/A
CTM22	Mingimingi-dominant scrub	Site on bare earth/leaf litter in Mingimingi-mānuka-whekī-whauwhaupaku-karamū-geothermal kānuka/bracken scrub.	N/A	R sp.
CTM23	Kānuka- dominant scrub	Tunnel on bare heated geothermal earth under low (<30 cm) geothermal kānuka, scattered tūrutu and mingimingi present in nearby scrub.	N/A	N/A

Tunnel	Vegetation	Notes	Lizard Sp.	Mammal Sp.
CTM24	Mingimingi-dominant scrub	Site on *Dicranoloma sp.* moss amongst tūrutu brush in Mingimingi-whauwhaupaku-karamū-geothermal kānuka/bracken scrub.	N/A	*Mus* sp.
CTM25	Mingimingi-dominant scrub	Site on loose leaf litter/heated geothermal earth under geothermal kānuka in Mingimingi-whauwhaupaku-karamū-geothermal kānuka/bracken scrub directly adjacent to multiple fumaroles. No bracken or whauwhaupaku nearby.	N/A	R sp.
CTM26	Kānuka-dominant scrub	Tunnel on *Dicranoloma sp.* moss in kānuka-dominant scrub just north of the trail. Scattered tūrutu present in scrub.	N/A	*Mus* sp.
CTM27	Mingimingi-dominant scrub	Site on loose leaf litter beside tūrutu brush in tall (>4m) (Mānuka)/prickly mingimingi-geothermal kānuka scrub. Down a shallow slope from the main gravel track along a clear pig track.	N/A	R sp., TV

3.3 Waikite

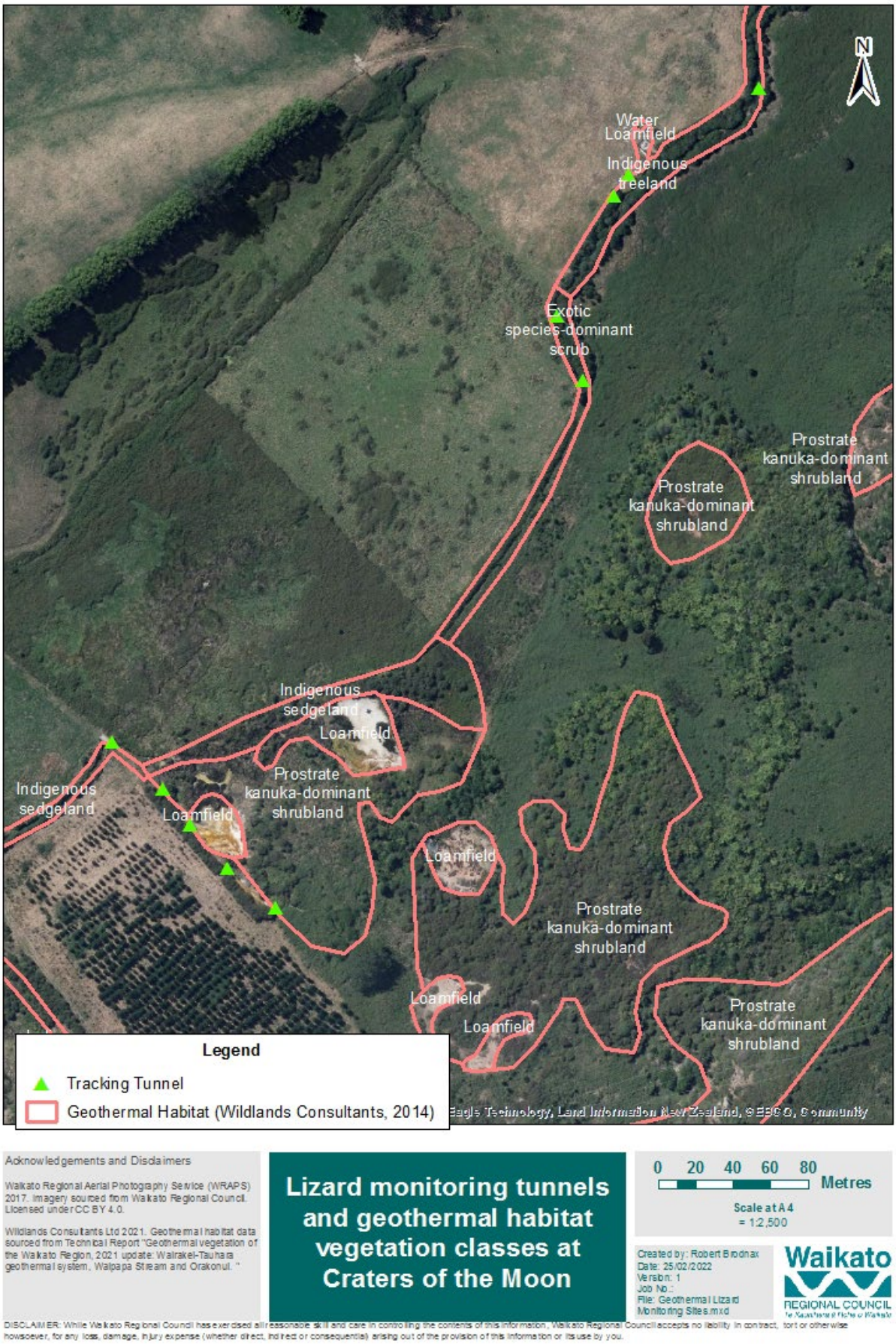
The Waikite valley geothermal ecosystem is unique in that it is dominated by a large wetland, fed partially from geothermal vents that are scattered up valley from the wetland. Around these vents, the ecosystems have traditionally been dominated by either prostrate kānuka and mānuka scrub or surrounded by exotic pasture (Wildlands, 2014a). At this site, several observed vegetation class differed from the Wildlands report. Recently, wetland restoration in the Waikite valley has resulted in significant changes to this vegetation (Reeves *et al*. 2018, Cashmore and Thompson 2021). Extensive kānuka plantings along the Otamakokore stream above the wetland have converted blackberry scrub and pasture to kānuka treeland, in other places, where pasture has been fenced off and not replanted or inundated, bracken and blackberry scrub has become dominant.

Tracking tunnels were laid both along the banks of the Otamakokore stream, which flows with mixed geothermal and fresh water, and along the banks of a tributary of the stream that is almost pure geothermal water, just above the wetland, in scrub and tree land around the geothermal vents.

Vegetation: Site dominated by diverse indigenous treeland and geothermal kānuka-dominant scrub. Scattered patches of rank exotic grass, blackberry-bracken scrub and indigenous fernland present.

Terrestrial Vertebrates: *Trichosurus vulpecula* detected at most tunnels, localised *Rattus* sp. *Erinaceus europaeus*, *Mus musculus* and *Mustella* sp. at some sites.

Figure 1: Waikite site WKT01. Tunnel visible under kānuka scrub, beside rank exotic grass and mingimingi scrub. Rautawhiri/karamu dominant mixed indigenous treeland in the background, to the other side of the geothermal stream.



Map 2 Waikite site and tunnel map. Broad vegetation class tags taken from Wildlands Consulting (2014a) "Geothermal vegetation of the Waikato Region".

3.4 Longview Road

The Longview Road geothermal ecosystem is part of the Reporoa geothermal system. It is a small area of geothermal surface features, surrounded by exotic pasture and dominated by mingimingi scrub, mānuka scrub, and bare silica terrace. Red *Trentepholia* alga is abundant where scrub is dry or dead. The Longview Road site has the most homogenous vegetation of the four sites investigated in this study, with only three terrestrial habitat classes present (Wildlands Consultants, 2014a).

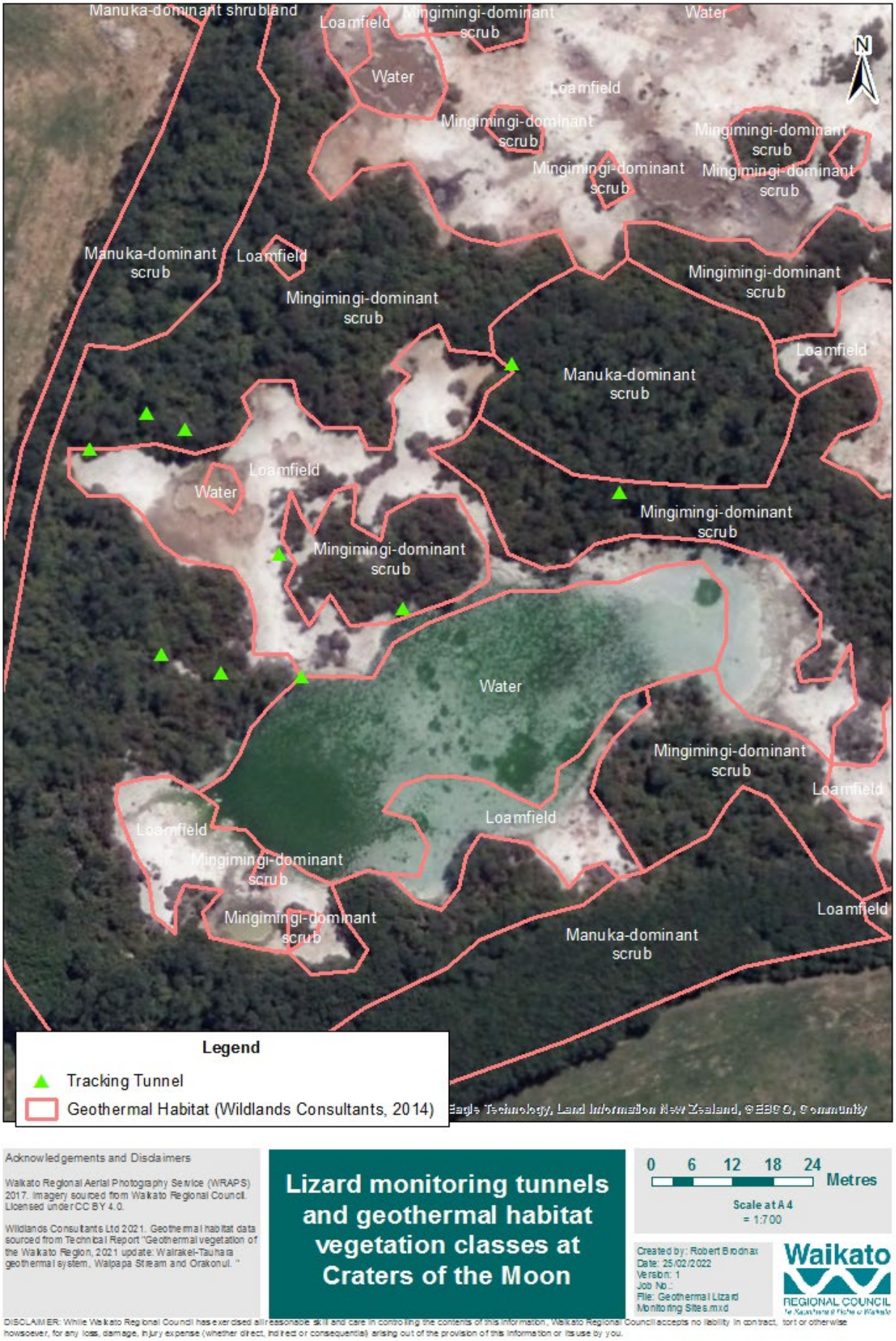
The Longview Road geothermal ecosystem is entirely on private land and was accessed via a narrow path southwest of the ecosystem. The mingimingi scrub at Longview Road is particularly dense. Due to the dangers of traveling through dense vegetation over potentially unstable ground, it is safest to traverse this site via the silica pavements around the geothermal pools. Only a limited area of the geothermal ecosystem could be easily accessed in this way, so sampling sites were all relatively close to the accessway in the southwest corner of the system

Samples were taken from mingimingi and mānuka scrub from around the edges of the silica terrace in the southwest corner of the system, near a large green pool.

Vegetation: Mingimingi-mānuka scrub, mānuka mingimingi scrub, geothermal bare earth.

Terrestrial Vertebrates: Mice (*Mus musculus*) detected on just over half of all cards. *Trichosurus vulpecula* detected occasionally in scrub. No rats (*Rattus sp.*) detected at any tunnels.

Figure 2: Longview Road site LVR05. Thin unconsolidated layer of exsolved silica overlies the mud between geothermal water and red Trentepholia-laden mingimingi mānuka scrub



Map 3: Longview Road site and tunnel map. Broad vegetation class tags taken from Wildlands Consulting (2014a) "Geothermal vegetation of the Waikato Region".

3.5 Orakei Korako

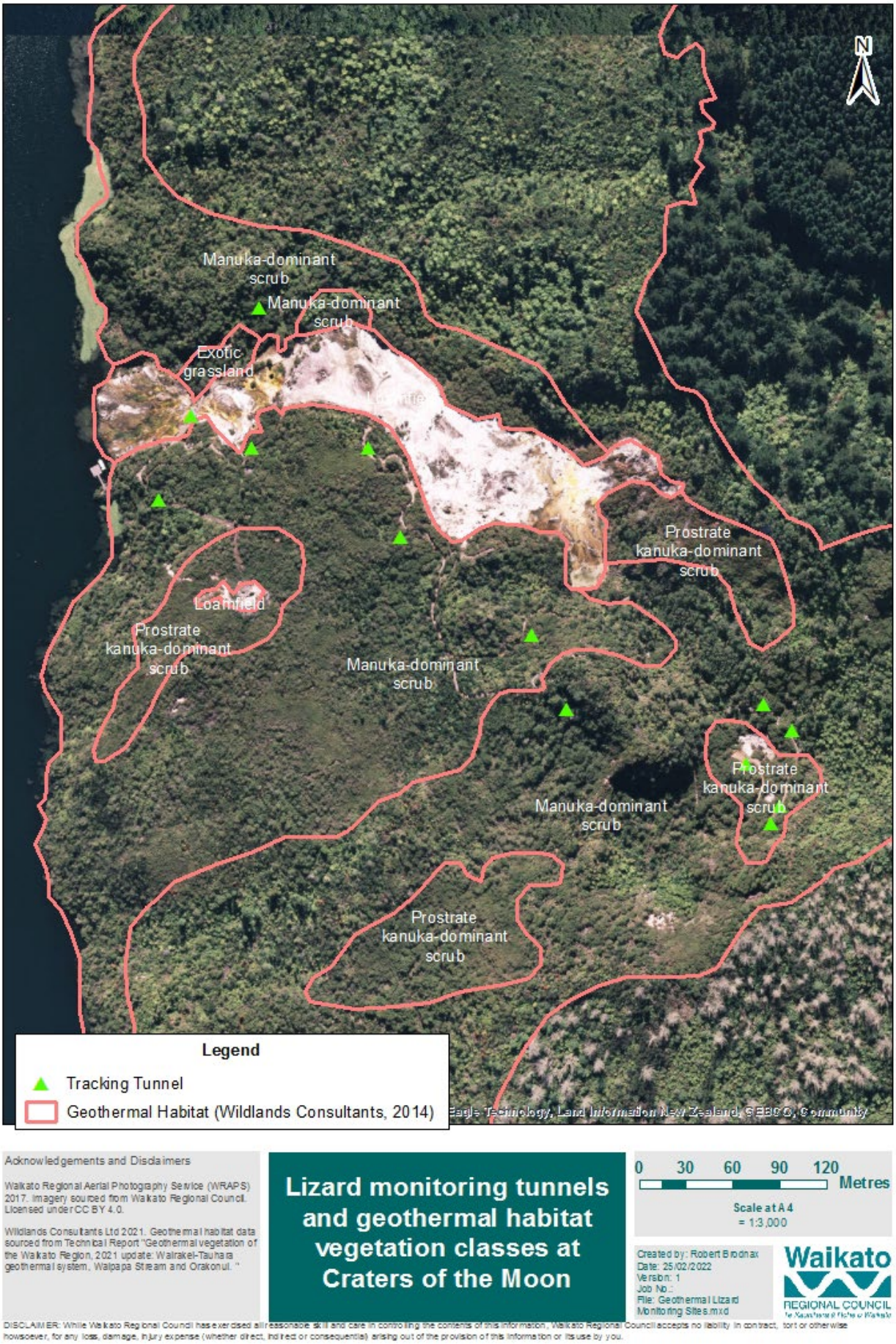
The Orakei Korako geothermal ecosystem consists of a wide range of geothermal habitats, surrounding a series of geothermal sinter terraces, dotted with vents, pools and geysers. Water flows down the sinter terraces in a combination of rivulets and cascades, with a few isolated patches of sedgeland dotting the banks. On the cliffs and hills around the terraces, prostrate kānuka, kānuka and mingimingi scrub dominate on exposed heated ground, separated by occasional stands of broadleaf forest and fernland, where there is shelter or patches of cooler earth. The nationally vulnerable geothermal fern *Dicranopteris linearis* is particularly abundant here and is found both forming large patches of indigenous fernland dotting the site and scattered individual plants through other scrub. To the north and to the east of the ecosystem, exotic pines occasionally present, mixed with bracken, mānuka and kānuka.

The ecosystem is on the true right of the Waikato River and is only easily accessible by boat. Tunnels here were placed entirely within the area that the Orakei Korako Geothermal Park and Cave tourist facility operates, along tourist access routes and off to the side of the main tracks.

Vegetation: Mānuka-mingimingi scrub, prostrate kānuka, scattered patches of indigenous fernland, exotic pine, bare geothermal earth.

Terrestrial Vertebrates: *Rattus* species detected at just under half of all sites in all vegetation types. *Mus* species at just over a third of sites, and preferentially in mānuka-dominant scrub X^2 *(3, N=38) =* 7.8147, $p<0.05$. *Trichosurus vulpecula* detected twice in geothermal kānuka-dominant scrub.

Figure 3: Orakei Korako site ORK01, tracking tunnel in sedge and manuka scrub on the edge of sinter/geothermal water



Acknowledgements and Disclaimers

Waikato Regional Aerial Photography Service (WRAPS) 2017. Imagery sourced from Waikato Regional Council. Licensed under CC BY 4.0.

Wildlands Consultants Ltd 2021. Geothermal habitat data sourced from Technical Report "Geothermal vegetation of the Waikato Region, 2021 update: Wairakei-Tauhara geothermal system, Waipapa Stream and Orakonui. "

Lizard monitoring tunnels and geothermal habitat vegetation classes at Craters of the Moon

0 30 60 90 120 Metres

Scale at A4 = 1:3,000

Created by: Robert Brodnax
Date: 25/02/2022
Version: 1
Job No.:
File: Geothermal Lizard Monitoring Sites.mxd

Waikato Regional Council

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Map 4: Orakei Korako and tunnel map. Broad vegetation class tags taken from Wildlands Consulting (2014a) "Geothermal vegetation of the Waikato Region"

3.6 Craters of the Moon

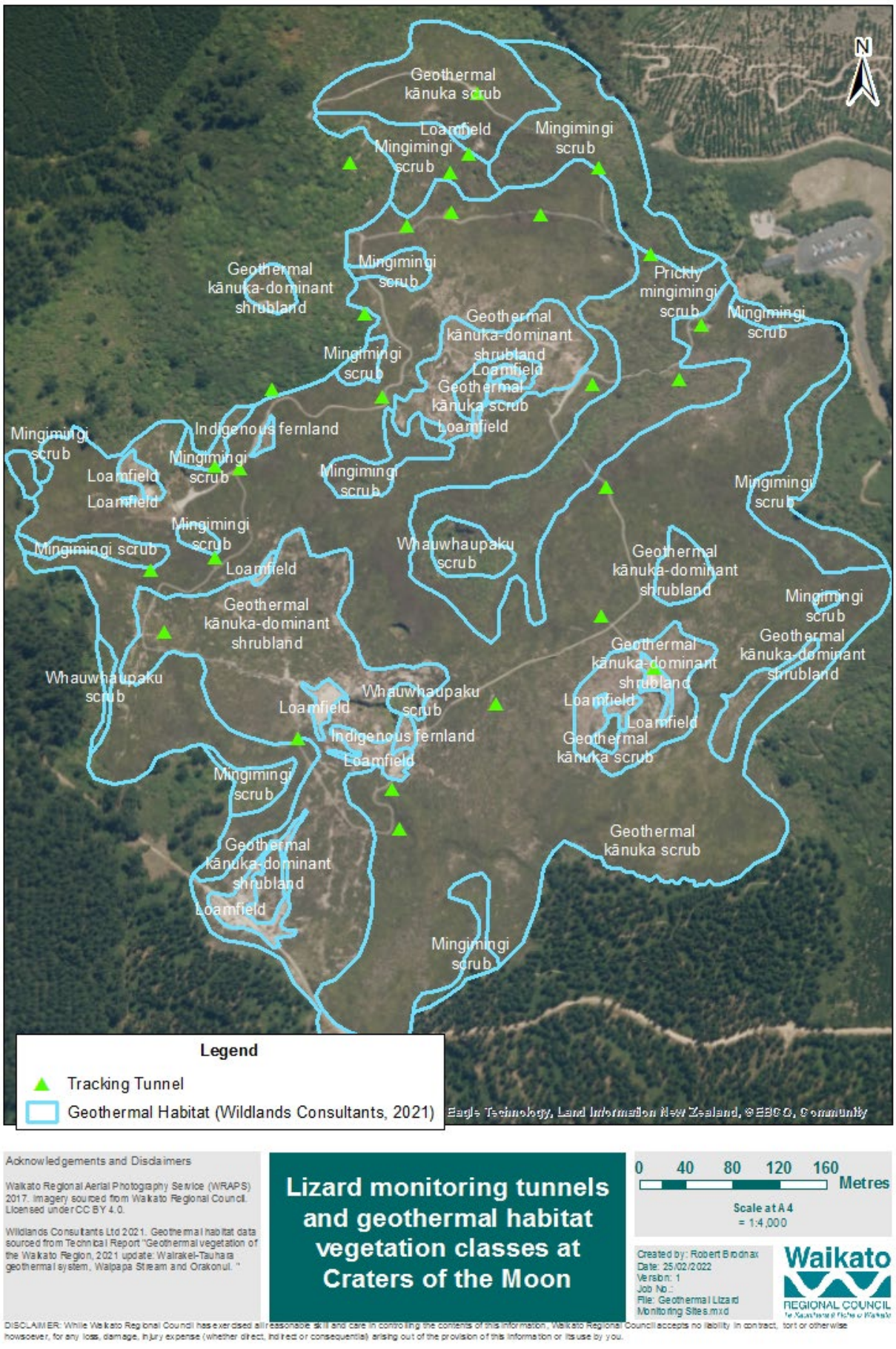
The Craters of the Moon geothermal ecosystem is a large, flat area, dominated by geothermal kānuka scrub and dotted with large open fumaroles. On hills where geothermal warming of the soil is low, and around the edges of the ecosystem, scrub can be quite diverse, with whauwhaupaku (five-finger), bracken and *Dicranopteris linearis* fern, wheki (tree fern), karamu, and monoao present alongside the mingimingi and kānuka scrub. Exotic vegetation such as rank exotic grass, Chinese privet and wilding pine are occasionally found near the edges of the ecosystem.

On the low ground around the fumaroles, where much of the ground is heated, geothermal kānuka is the dominant species. Kānuka scrub/shrub grows between 0.3 and 4 m tall here and is scattered with local patches of bare geothermal earth, *Dicranopteris linearis and Nephrolepis flexuosa* fern, *Lycopodiella cernua* (clubmoss), and other mosses, lichens and algae including *Trentepholia.* (Wildlands Consultants, 2021)

Vegetation: Geothermal kānuka scrub, mingimingi-whauwhaupaku-karamū-geothermal kānuka/ bracken scrub (mingimingi-dominant), indigenous treeland, geothermally influenced bare earth.

Terrestrial Vertebrates: *Oligosoma* sp. detected in geothermal kānuka-dominant scrub. *Mus musculus* and *Rattus* sp. detected in all vegetation types at just over a third of all sites. Rats detected preferentially in more diverse scrub (mingimingi scrub/treeland) X^2 *(3, N=76) =* 7.8147, $p<0.05$. *Trichosurus vulpecula* detected infrequently in diverse scrub.

Figure 4: Craters of the Moon site CTM07. Tunnel in low geothermal kānuka scrub amidst patches of lichen and geothermally influenced bare earth



Map 5: Craters of the Moon site and tunnel map. Broad vegetation class tags taken from Wildlands Consultants (2021) "Geothermal vegetation of the Waikato Region, 2021 update"

3.7 Statistical Analysis

Tracking tunnels were successfully able to detect the presence of lizards in a geothermal habitat at Craters of the Moon in the Taupo Volcanic Zone. Only one lizard was detected, so there is no way to draw any conclusions about the size or distribution of any lizard populations in the ecosystem. Pest species, (hedgehogs, rats, mice, mustelids, and possums), were also detected in geothermal ecosystems. Hedgehogs and mustelids were detected exclusively at Waikite. The proportion of cards that detected possums was highest at Waikite, with 60% of the cards collected from that site having possum print. Mouse detection at Waikite was the lowest of all four sites, though this may be because possum damage to the cards prevented mice from being detected. Mice were detected on the highest proportion of cards from Longview Road, with just over 54% of all cards from that site showing signs of mice. At Longview Road possums were detected on the second highest proportion of cards, with 14% of Longview Road sites showing possum sign. Rats were not detected at Longview Road. At the two tourist sites, Orakei Korako and Craters of the Moon, there was no significant variation in detection of any species with site, X^2 (2, N = 114) = 3.841 p>0.05. At Orakei Korako, 39% of cards detected rats, 31% of cards detected mice and 5% detected possums, at Craters of the Moon 38% of cards detected rats, 36% detected mice, and 3% detected possums.

Using chi squared (X^2) tests, the statistical significance of the variation of one discrete variable with another can be determined. This method determines the probability of an observed distribution occurring if there is no relationship between variables, and the true distribution is random. This probability can be used as a measure of significance. Analysing the data from all sites and vegetation classes together, detection of *Mus musculus*, *Rattus* sp., hedgehogs (*Erinaceus europaeus)*, and of possums (*Trichosurus vulpecula)* varied significantly both with site, X^2 (3, N = 168) = 7.15, p<0.05, and with vegetation X^2 (7, N = 168) = 11.07, p<0.05.

While detection of mammalian pests varied significantly across all four sites, at individual sites, correlation between detection and vegetation was inconsistent. At Longview Road, there was no clear relationship between detection and vegetation for any vertebrates, X^2 (2, N = 28) = 5.99, p<0.05. At Waikite there was no significant variation in detection with vegetation for all pests other than *Erinaceus europaeus* X^2 (2, N = 20) = 5.99, p<0.05, with twice as many hedgehogs detected in indigenous treeland than would be expected given a random distribution. There was statistically significant variation in mouse species *(Mus musculus)* detection with vegetation at Orakei Korako, X^2 (3, N = 38) = 7.81, p<0.05. With mice detected in fernland and on Loamfield far more commonly than they would have been if detection had been completely random. In contrast, at Craters of the Moon only *Rattus sp.* detection varied significantly with vegetation, X^2 (3, N = 76) = 7.81, p<0.05. Rats were found more frequently in diverse mingimingi scrub and Indigenous treeland than would be expected given a random distribution.

Similarly, variation in detection of groups of vertebrates with site was only statistically significant (p<0.05) under certain vegetation classes. For example, in mingimingi-dominant scrub, *Mus musculus*, *Trichosurus Vulpecula,* and *Erinaceus europaeus,* detection showed no significant variation with site, X^2 (2, N = 42) = 3.84, p<0.05 but *Rattus* sp. detection did. In kānuka-dominant scrub, *Mus musculus* and *Trichosurus vulpecula* detection varied significantly between sites, X^2 (3, N = 61) = 5.99, p<0.05, while *Rattus* sp. and *Erinaceus europaeus* detection did not, as Craters of the Moon was the only site where mice were detected in kānuka dominant scrub, and Waikite and Orakei Korako were the only sites where *Trichosurus* was detected in the vegetation class.

Wildlands Consultants' 2014 report "Priorities for pest plant control, pest animal control, and fencing at geothermal sites in the Waikato Region" identified key sites which it deemed were under significant threat from pest animals, including possums, which were identified in this study. Though Wildlands Consultants 2014b focused primarily on larger terrestrial mammals, such as pigs and deer, interesting comparisons can be drawn between its risk assessment at the four sites and the detection of mammalian pests in tracking tunnels. Waikite and Orakei Korako were both classified as under "medium" threat from pest animals by Wildlands (2014b), and

Longview Rd and Craters of the Moon were classified as under low risk. In this study, the detection of possums at Waikite was significantly higher than at any of the other sites (3, N = 168) = 7.15, $p<0.05$, including Orakei Korako, which was under a similar level of threat in Wildlands (2014b). There was no significant variation between possum detection at Orakei Korako and Craters of the Moon, $X^2(2, N = 114) = 3.841$ $p>0.05$, despite threat at the two sites being different in 2014. Assuming detection is directly correlated to population of a mammal species, threat at Orakei Korako may have dropped to low since 2014, as wilding pine removal and pest control have provided greater protection to native geothermal habitats, but threat at Waikite seems to have remained high.

4 Discussion

It is very likely that factors related to both site location and management and to vegetation coverage influence the population distributions and thereby the detection rates of pest species in the Taupo Volcanic Zone, though this cannot be confirmed given the lack of stratification in the sampling method employed by this study. Studies on the factors controlling pest species distribution in New Zealand bush suggest that distribution of a species can be related to any number of factors simultaneously. Watkins (2007) determined that in native ecosystems around Pureora, mouse, stoat, and rat detection were affected by habitat. The same study also found that detection of pest species varied not only between habitats, but also spatially within habitats at both Pureora and in Fiordland. Breedt (2017), and Breedt and King (2021) in their studies of pest species distributions in the Waikato Region, estimated that pest species populations varied significantly between locations, land use classes, and vegetation types. They found that pest populations varied spatially within blocks of similar vegetation at the same site. Innes *et al*. (2010) found that management of pasture adjacent indigenous ecosystems and ecosystem fragments, like the one at Waikite, can have a significant effect on mammalian pest population distribution. They found that rats were far more common in fenced, pasture adjacent, forest fragments like the Waikite site, rather than in unfenced fragments, or in large stands of indigenous forest.

Elsewhere in the world, Madden *et al*. (2019) used a tracking tunnel study to find any associations between vegetation coverage and rodent populations on St Eustatius Island in the Caribbean Netherlands. They found correlation between vegetation diversity and rodent population, with rodents preferring denser rainforest to sparse scrub. Our study recorded a similar trend in *Rattus* species detection, both overall, and specifically within the Craters of the Moon ecosystem, where Rattus species were detected more frequently in diverse, mingimingi-dominant scrub than would be expected if their distribution within the ecosystem was random.

As the sampling methods employed in this study were not truly random and samples were not stratified for either site or for vegetation type, it is impossible to determine whether factors relating to site, or factors relating to vegetation type had the more significant effect on detection rates for the of mammalian pests. Nor is it within the scope of this study to identify the nature of any interdependency between vegetation type and site which may be affecting the relationships observed. Expanding the scope of the sampling, including some sort of stratification based on vegetation class and site, and increasing the randomness of the method by which tracking tunnel sites are selected could be potential avenues for further study. Another potential avenue of investigation could involve using the probabilistic model developed by Mackenzie. (2002) to convert detection data into population distributions of the pest species detected.

5 Conclusions and Recommendations

5.1 Conclusions

The primary goal of this study was to determine the existence of any populations of indigenous lizards in geothermal ecosystems at Waikite, Orakei Korako, Longview Road, and Craters of the Moon in the Taupo Volcanic Zone. The study identified a potential population of (likely native) skinks, in geothermal kānuka scrub at Craters of the Moon. Large skink tracks were recorded in low geothermal kanuka scrub on 11 January 2022 at Craters of the Moon, Taupo. No evidence was found of indigenous lizards at any of the other sites investigated in this study. This is the first lizard sighting associated with a geothermal site recorded in New Zealand.

The secondary goal of this study was to monitor any exotic vertebrates at the sites investigated. Exotic species were detected at all four of the sites investigated in this study. Mice (*Mus musculus*), and rats (*Rattus* sp.) were the most common species detected, while *Trichosurus vulpecula* (Brush tailed possums) were detected infrequently at all sites except Waikite, where they were detected often, and the European hedgehog (*Erinaceus europaeus*) was detected at Waikite. Detection of these species varied inconsistently with both site and vegetation type both at individual sites and across all four sites. More intensive sampling with a higher degree of rigour in randomisation will be necessary to establish population distributions for these species within and between geothermal ecosystems.

5.2 Further Study

This preliminary study was only capable of collecting rough information on the distribution of both indigenous and exotic vertebrates at sites in the TVZ. Further study could expand upon this research in one of three ways:

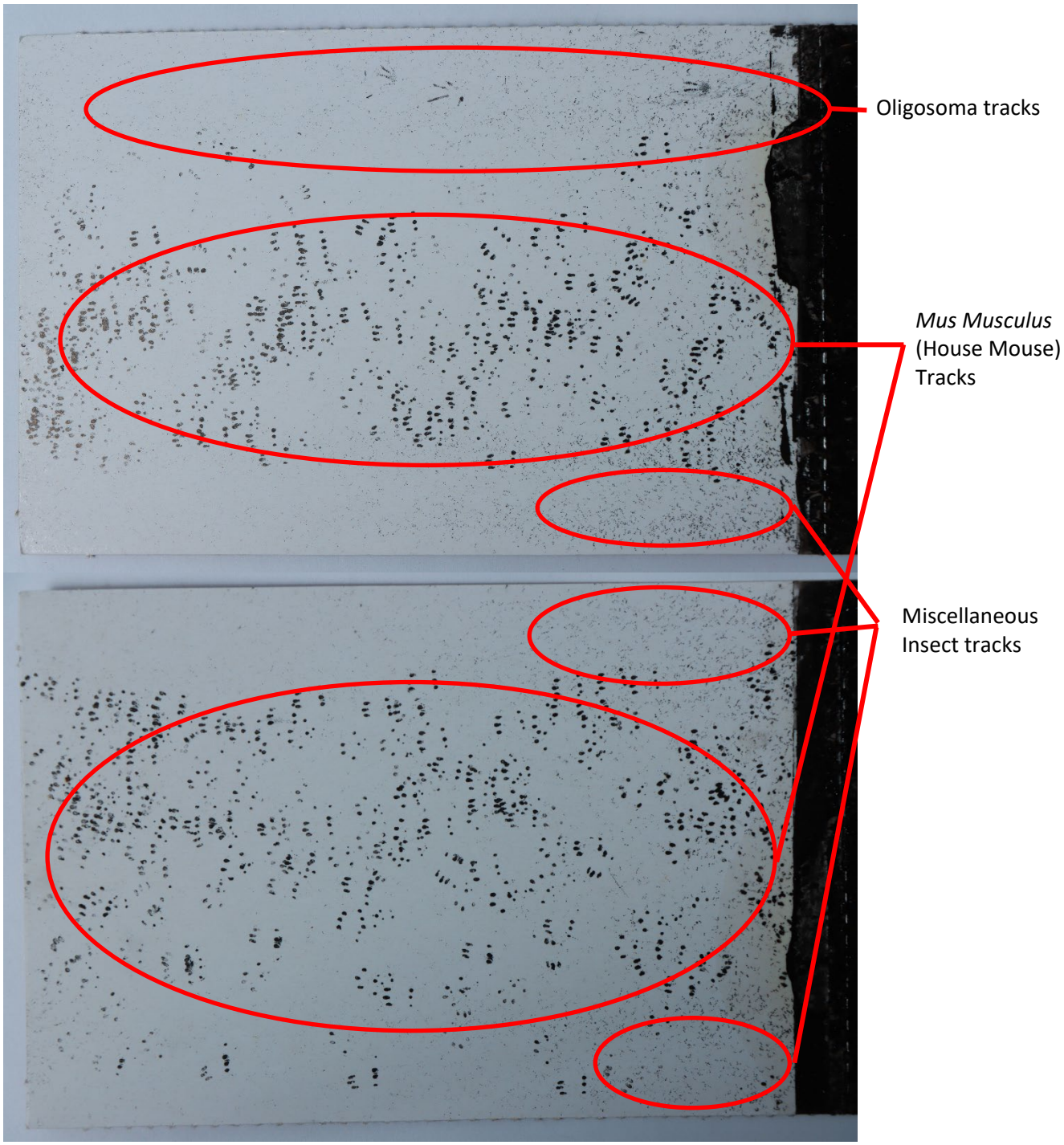
1. Expand the scope of the study to include geothermal habitats beyond the four investigated, with the aim to identify potential lizard populations in other geothermal habitats in the region
2. Intensify tracking at key sites using more rigorous randomisation and stratification techniques for sampling, to build a better picture of the distribution of exotic vertebrates within geothermal ecosystems
3. Revisiting Craters of the Moon with either pitfall traps or g-minnow traps to identify the species and distribution of the skink population detected there.

The presence of pest mammals at Waikite, Longview Rd, Orakei Korako and Craters of the Moon presents a threat to indigenous lizard and bird populations at these sites. If further study into the lizard populations at Craters of the Moon and other sites can prove that there are significant indigenous lizard populations endemic to geothermal ecosystems, intensifying trapping and other pest control efforts in and around geothermal areas could ensure that indigenous lizard populations have stable habitats in future.

6 Appendices

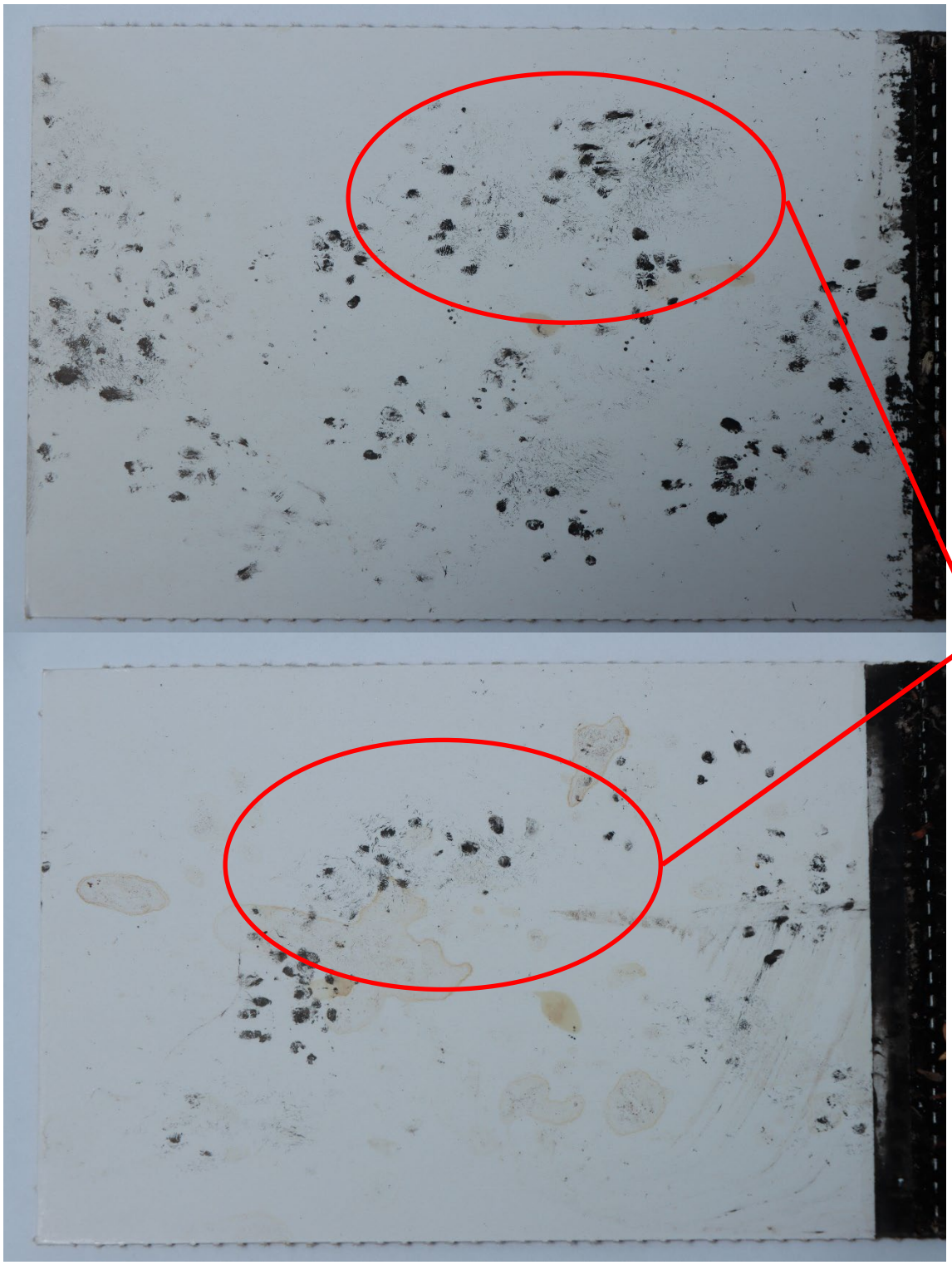
6.1 Example Tracking Cards

CTM03: 21/12/21



ORK09: 09/12/21

WKT: 10/01/21



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