Halo Project Tracking Tunnel Monitoring: 2018-2020

Prepared for the Halo Project

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Contents

Summary

Background

Community-led predator trapping, designed for best practice stoat and possum control, began in the Halo Project's 3,900 ha Inner Halo in 2017. Although increasing numbers of predators are being caught, trapping does not give an indication of how many – and what species of – predator remain in the area. Monitoring mammalian predators using tracking tunnels met the Halo Project's criteria for reliable, cost-effective monitoring that could involve the local community in data collection.

Objectives

This study aimed to ascertain the relative abundance of mammalian predator species in the Inner Halo's main habitat types – pastoral farmland; indigenous forest and scrub; and exotic forest using 1-night (rodent) and 21-night (mustelid) tracking indices. As stoats are the main focus of the trapping programme, there was also a desire to examine whether trapping was reducing stoat levels. However, evaluating interim results part way through this study revealed that the number of mustelid detections was too low to be able to detect changes in stoat levels over time. This study therefore focused on using 1-night indices to address the first main aim above. The 21-night indices have been included for completeness.

Methods

- Ten tracking tunnel (TT) lines were set up following DOC protocols for monitoring mustelids in proportion to the main types of habitat available.
- Monitoring sessions were run approximately every 3 months between April 2018 and February 2020.
- 1-night tracking rates were obtained from baiting 10 TT per line with peanut butter at each end of the tunnel.
- From autumn 2018 – summer 2019, 21-night tracking indices were obtained from baiting every other TT along a line with fresh rabbit meat in the centre of the tunnel.
- Ten chew cards were deployed along each TT line to provide a possum activity index over 8 nights.
- Relative abundance indices were calculated for each species as the average percentage of tunnels tracked (or chew cards bitten) by that species per line.

Results

- Average 1-night rat tracking rates in the Inner Halo ranged from 6 to 19% per session, with the average across all monitoring sessions being 12% (± 2% SE). No obvious seasonal pattern was apparent.
- Rats were much more likely to be recorded in forest habitats compared with pastoral farmland. Relative abundance was highest in the indigenous forest, where tracking

rates often averaged 20 – 30%. Two indigenous forest lines and one exotic forest line had the highest tracking rates, averaging between 20 – 55% across all monitoring sessions.

- Average 1-night mice tracking rates in the Inner Halo tended to be between 20-30% throughout the seasons. Relative abundance across all monitoring sessions averaged 20 ± 3%.
- Mice were much more likely to be recorded in forest habitats compared with pastoral farmland. Relative abundance was similar in indigenous and exotic forest.
- Excluding the winter hibernation periods, 1-night tracking rates for hedgehogs were similar across seasons, averaging 10 ± 1.5% over the study period.
- There was no clear pattern for hedgehog habitat preference with 1-night indices; however, relative abundance reached their highest levels in exotic forest.
- Mustelids were recorded from four lines in total over the duration of this study. Most records were considered to be probable stoats although ferrets were recorded also.
- The relative abundance of mustelids was low during the four 21-night monitoring sessions, reaching a maximum of 2% during winter 2018.
- Mustelid tracking rates averaged 3 – 7% in exotic forest, which was higher than the other two habitat types. No mustelids were recorded from indigenous forest during the 21-night monitoring sessions.
- Feral cats were recorded during 21-night monitoring sessions in indigenous forest only. Their highest relative abundance occurred in summer 2019 (7% ± 7% SE).
- Cats tracked tunnels more than 250 m from the forest edge.
- 21-night tracking indices for hedgehogs gave a clearer picture that this species was relatively more abundant in pastoral farmland and exotic forest habitats than in indigenous forest.
- CC recorded possum presence from 10 – 50% of lines per session. Relative abundance on two of the indigenous forest lines was moderate to high.
- There was no obvious relationship between possum relative abundance indices and rat 1-night TT indices, but sites with high levels of possum chews recorded very low levels of rat bites on CC.

Conclusions

- Rat tracking rates were similar to those measured on the Otago Peninsula, 2012-2017.
- Average tracking rates in indigenous forest habitat was similar to levels in other southern South Island forests (measured in 2014).
- Rat tracking rates in 2 indigenous forest sites regularly exceeded the 30% threshold recommended for managing sensitive threatened species.
- Tracking rates suggest that ferret and stoat relative abundance in the Inner Halo is low. However, stoats are regularly trapped in the Inner Halo. It is likely that tracking tunnels were not effective at detecting stoats when they were present.

- Using 14- or 21-night indices improved stoat detections compared with using just 7-nights.
- Rat indices from chew cards set for 8 nights are not a reliable indicator of rat density when possums are at high relative abundance.

Recommendations

- Because of the risks posed to indigenous biodiversity by high rat levels, rodent monitoring should be expanded in the Halo area. DOC guidelines suggest using 15-20 TT lines a minimum of 200 m apart to monitor rodents in an area the size of the Inner Halo.
- It is recommended to target rats for control in areas where tracking rates regularly exceed 30% and to monitor the effectiveness of rat control in those areas specifically. For more statistical power to compare effects of rat control, monitoring should include non-treatment sites without rat control.
- Future predator monitoring should target habitats of interest and species of interest. Low relative abundances of rats and mustelids in pastoral farmland habitat in the Halo means monitoring for these species should focus on forest sites. Exceptions would be in non-forest areas inhabited by vulnerable indigenous species such as lizards.
- Do not use chew cards to measure rodent indices if possum activity is expected to be high.
- Tracking tunnels are not recommended for monitoring mustelids in the Inner Halo. However, if they are used in the future then running them for at least 14 nights is recommended to increase the number of stoat detections.
- To assess the effectiveness of predator control it is recommended that predator monitoring be undertaken in conjunction with biodiversity outcome monitoring.

Background

Introduced mammalian predators, especially ship rats (*Rattus rattus*), stoats (*Mustela erminea*) and brushtail possums (*Trichosurus vulpecula*), are recognised to be the main cause of the current decline in populations of native species in NZ forests[1]. Predator control programmes have become increasingly common throughout NZ, especially following the launch of Predator Free 2050, an aspirational goal to rid NZ of introduced mammalian predators by 2050.

The Halo Project

The Halo Project, established by the Landscape Connections Trust (LCT), covers a 55,000 ha area around Orokonui Ecosanctuary, 20km north of Dunedin (Fig. 1). Its main objectives are to connect people to their local environment, enhance the health of ecosystems, protect and restore indigenous biodiversity, and support the local economy. Community-led mammalian predator trapping networks started in 2017, initially focussing on the 3,900 ha Inner Halo area. In October 2018, the Halo Project became one of the delivery partners for Predator Free Dunedin (PFD) and community trapping initiatives have since spread to Port Chalmers and Aramoana, and will eventually reach north Dunedin.

The Inner Halo

The main habitat types that make up the Inner Halo are pastoral farmland, exotic forest and indigenous forest and scrub (especially of kānuka and broadleaf)[2] .

In February 2018, 15 Community trapping groups were operating 307 traps in two thirds of the Inner Halo area and had caught 270 predators[3]. By November 2019, trapping networks covered the Inner Halo area and beyond, there were 790 active traps on the ground and 1807 pests had been caught[4] (Fig. 2). Trapping is designed for best practice stoat and possum control. However, other mammalian predator species are also caught in the traps; most frequently ship rats and hedgehogs (*Erinaceus europaeus*)[5]. Despite having a widespread presence in the Inner Halo area[6], feral cats (*Felis catus*) are not targeted by the trapping programme although a small number of cats have been caught in traps.

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[1] Innes J et al. 2010. Predation and other factors currently limiting New Zealand forest birds. NZ J Ecology, 34: 86–114.

[2] Wildland Consultants. 2016. Habitat relationships of forest birds in a mixed production landscape in East Otago. Contract report no. 3412a prepared for Landscapes Connection Trust, Dunedin.

[3] The Halo Project newsletter: February 2018. Available from: https://www.haloproject.org.nz/resources

[4] The Halo Project newsletter: November 2019. Available from: https://www.haloproject.org.nz/resources

[5] Unpubl. data from Trap.NZ (1 March 2017 – 1 November 2019; accessed 19 April 2020)

[6] Veale AJ. 2019. Review of camera trapping pilot study and recommendations for monitoring mustelids in the Halo. Unpublished Predator Free Dunedin report.

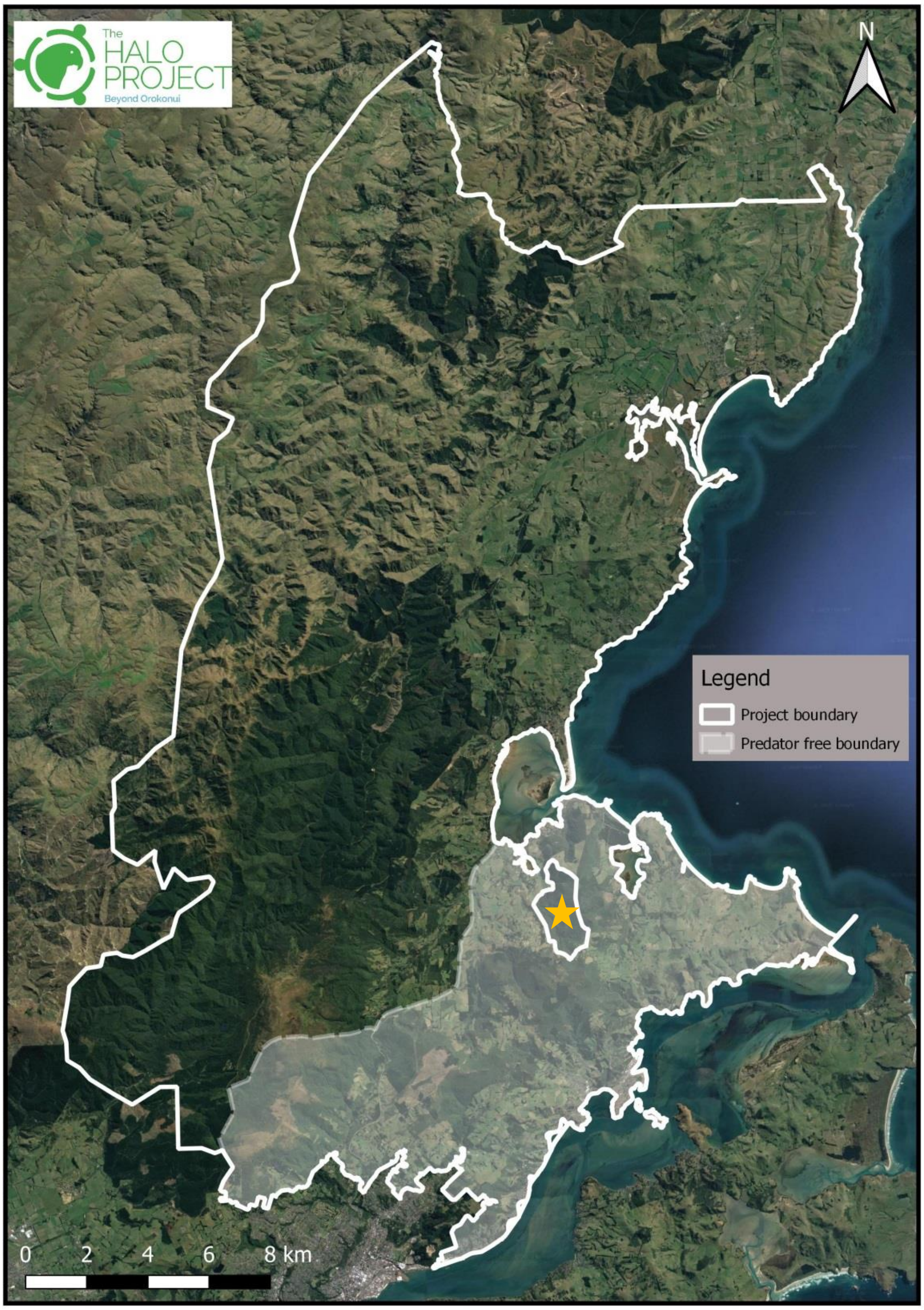

Fig. 1: The 55,000 ha Halo Project area, which includes the Predator Free area around Orokonui Ecosanctuary (marked with an orange star), north of Dunedin.

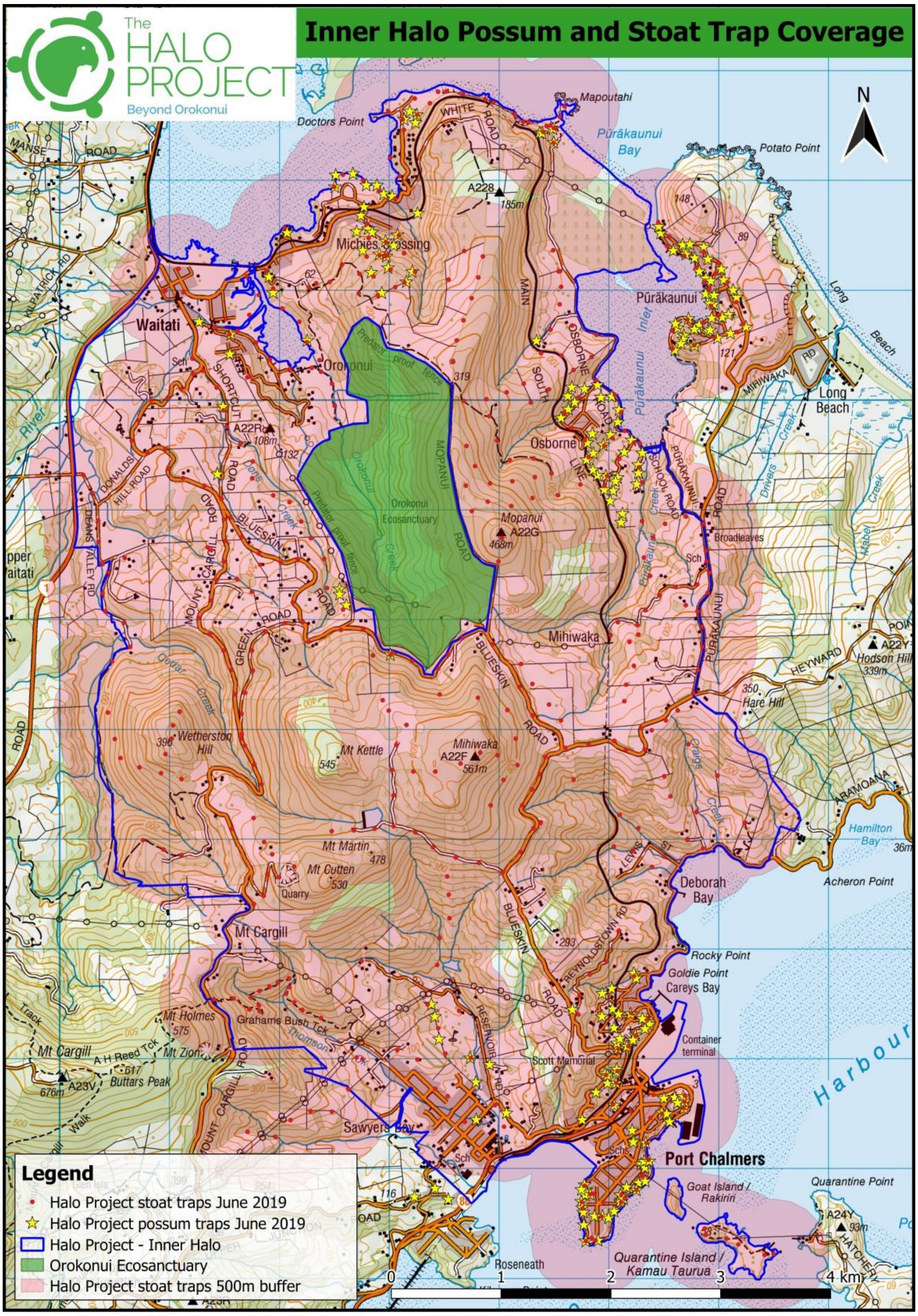

Fig. 2: Stoat and possum trap locations in the 3,900 ha Inner Halo project area around Orokonui Ecosanctuary, June 2019.

Measuring predator abundance

Although increasing numbers of predators are being caught in the Inner Halo, trapping does not give an indication of how many – and what species of – predator remain in the area.

Information on the abundances of each predator species and which habitats they are found in is important to (1) assist targeted predator control; (2) help assess whether trapping is reducing predator levels at the landscape scale.

There are several methods of measuring predator levels that are independent of trapping results. They each have their pros and cons in terms of cost, ease of use and reliability[7]. When this study was initiated in mid-2017, priorities for the Halo Project were for a reliable, cost-effective monitoring method that would enable active participation by the local community. Monitoring mammalian predators using tracking tunnels met these criteria the best.

Tracking tunnel (TT) indices

As the name suggests, tracking tunnels (TT) consist of a baited tunnel containing an ink pad in the middle section with card either side to record the footprints of animals that pass through, which can be identified to species (Fig. 3).

Tracking tunnel methodology assumes that tracking tunnel indices are linearly related to the abundance or density of the species being tracked.

Department of Conservation (DOC) standardised methods specify 10 TT spaced 50 m apart along a line and baited with peanut butter for one night to obtain a rodent index, and 5 TT spaced 100 m apart along a line and baited with fresh rabbit for 3 nights to provide a mustelid index[8]. Although the standardised procedures are not designed to monitor hedgehogs, it is possible to obtain an index of hedgehog relative abundance also using the above methods. Feral cats and possums occasionally track the tunnels, but are generally too large to fit inside. Another benefit of TT is that they also detect the presence of lizards and insects[9,10].

Disadvantages of using TT for monitoring include that TT indices provide a coarse index of species relative abundance only, which means quite large changes in tracking rates need to be observed before a statistically significant difference is found. As with all index methods, relative abundance is measured rather than population density and there is not a direct relationship between the number of tunnels tracked and the number of predators present.

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[7] Warburton B & McNutt K. 2015. Introduction to animal pest monitoring v1.1. Unpublished DOC report Available from: www.doc.govt.nz/our-work/biodiversity-inventory-and-monitoring/

[8] Gillies CA & Williams D. 2013. DOC tracking tunnel guide v2.5.2: Using tracking tunnels to monitor rodents and mustelids. DOC Science & Capability Group, Hamilton: www.doc.govt.nz

[9] Jarvie S & Monks JM. 2014. Step on it: can footprints from tracking tunnels be used to identify lizard species? NZ J Zoology, 41: 210–217.

[10] Watts C et al. 2008. Tracking tunnels: a novel method for detecting a threatened New Zealand giant weta (Orthoptera: Anostostomatidae). NZ J Ecology, 32: 92–97.

Although variability in detectability can be controlled to some extent by using standardised methods, indices do not reflect differences in detectability. For example, there is evidence that mice tracking rates increase in the absence of rats[11] and that rat tracking rates are inversely proportional to the relative abundance of possums in an area[12]. Although a recent TT study on Otago Peninsula did not find that rat tracking rates increased following widespread possum control, the study recommended monitoring for possum presence if using TT to obtain rodent indices[13].

In addition, although sensitive at detecting rodents when these animals are at low density, TT are not good at detecting stoats at low densities. At present, no reliable standardised method exists for measuring stoat relative abundance when these animals are at low density. Two possibilities for improving TT detection rates include increasing the number of TT lines within the study site, or monitoring for periods longer than 3 nights. Twenty one-night surveys improved mustelid detection in alpine areas compared with 3 nights[14].

Not all footprints recorded by TT can be identified to species. It is not possible to differentiate reliably between Norway (*Rattus norvegicus*) and ship rats. Also, footprints of weasels (*Mustela nivalis*) and stoats, and stoats and ferrets (*Mustela furo*) overlap in size[15]. Although prints longer than 20 mm can be confidently assigned to ferrets and prints shorter than 10 mm are likely to have been made by a weasel, it is not possible to unequivocally differentiate the tracks of the 3 species and therefore it is usual to label those prints as having been made by a 'mustelid'.

Fig. 3: Tracking tunnel and insert tracked by rats.

[11] Bridgman L et al. 2018. Interactions between ship rats and house mice at Pureora Forest Park. NZ J Zoology, 45: 238–256.
[12] Griffiths JW & Barron MC. 2016. Spatiotemporal changes in relative rat (*Rattus rattus*) abundance following large-scale pest control. NZ J Ecology, 40: 371–380.
[13] Wilson D. 2017. Abundance of rats (*Rattus* species) following brushtail possum control operations on the Otago Peninsula. Otago Peninsular Biodiversity Group: http://www.predatorfreepeninsula.nz/
[14] Rawlence TE. 2019. The efficacy of aerial 1080 poison applied on a landscape scale to control alpine predators and the reproductive response of rockwren (*Xenicus gilviventris*). MSc. Thesis, University of Otago.
[15] Ratz H. 1997. Identification of footprints of some small mammals. Mammalia, 61: 431–441.

Objectives

At the initiation of this study in mid-2017, community-led trapping efforts were in their early stages. There was not a clear understanding of which mammalian predator species were most abundant in the Inner Halo, and whether their relative abundances varied with habitat. As stoats were the main focus of the predator trapping, there was also a desire to examine whether the trapping programme was reducing stoat levels.

Therefore, the two 2 original aims of this study were:

(1) To ascertain the relative abundance of mammalian predator species in the Inner Halo's main habitat types.

(2) To assess whether the relative abundance of stoats decreased over time.

A further aim of this study was to involve and upskill the local community in biodiversity monitoring by providing training and equipment.

Modification of the original aims

The first monitoring session occurred in April 2018. In March 2019, the interim results from the first four monitoring sessions were evaluated. Despite using 21 nights of monitoring to increase the chance of detecting stoats, the number of mustelid detections was considered too low to be able to detect changes in stoat levels over time. Given the high level of volunteer commitment required to undertake the 21 nights of monitoring and that a separate camera trapping trial was underway to monitor stoats, it was decided to discontinue the mustelid monitoring and focus instead on using 1-night (rodent) indices to address aim (1) above.

As the Halo trapping network was not designed to control rats, mice or hedgehogs specifically, the relative abundance of these species was not expected to decrease over time.

Methods

Tracking tunnel line locations

Tracking tunnel lines were set up following DOC protocols for monitoring mustelids[16]. Ten lines were set up in the Inner Halo in proportion to the main types of habitat available (as mapped by Wildland Consultants[2]) – pastoral farmland; indigenous forest and scrub; and exotic forest (Fig. 4). Lines were at least 1000 m apart from each other at their closest points and, as much as possible, ran in a random direction within the habitat type. Some lines were not able to be run in a random direction: Lines 3 – 6 had to take farm operations into consideration and therefore tended to run along fencelines at the edges of paddocks; Lines 8 and 9 followed public walking tracks as the topography at those sites would have made it hazardous operating randomly-placed lines. TT lines did not run along ecotone boundaries or trapping lines, but traps were in the vicinity of TT lines, and the number of traps in the Inner Halo increased over the period of this study as the trapping network grew.

Fig. 4: Location of the 10 tracking tunnel monitoring lines in the Inner Halo (boundaries in orange). Lines are coloured according to habitat: green = exotic forest; yellow = pastoral farmland; blue = indigenous forest.

[16] Gillies CA & Williams D. 2013. DOC tracking tunnel guide v2.5.2: Using tracking tunnels to monitor rodents and mustelids. DOC Science & Capability Group, Hamilton: www.doc.govt.nz

Setting up the tracking tunnels

Each line consisted of 10 standard-sized tunnels made from black corflute (Pest Control Research, Christchurch) spaced 50 m apart. All lines, with the exception of Lines 5 and 6, were set up 3-4 weeks before the first monitoring session to give animals the opportunity to get used to the tunnels. Lines 5 and 6 were set up at least 3 weeks before the second monitoring session. Tunnels were placed on flat ground, secured firmly with metal pegs and their location marked with flagging tape and a handheld GPS.

Volunteer training

Over the duration of the study, more than 30 community volunteers participated in collecting TT and chew card data. Volunteers received training prior to their first monitoring sessions in how to operate the TT lines so that standardised procedures were followed and criteria important for the collection of good quality data were met (for example, how to ink the inserts; securely anchor the TT; keep the tunnel entrances clear of obstructions; which days to check the tunnels; footprint identification). Instructions, health and safety information, data sheets, maps and footprint identification cards were provided to be taken into the field. Reminders were sent regularly and refresher training was also available.

Monitoring sessions

Monitoring sessions were run approximately every 3 months between April 2018 and February 2020 (Table 1). The start day for each survey session was dependent on the first night having fine weather.

Table 1: Dates of Inner Halo predator monitoring sessions.

Season	1-night TT	21-nights TT	8-nights CC
Autumn 2018	28–29 April	29 April – 20 May	28 April – 6 May
Winter 2018	28–29 July	29 July – 19 Aug	28 July – 5 Aug
Spring 2018	10–11 Nov	11 Nov – 2 Dec	10–18 Nov
Summer 2019	26–27 Jan	27 Jan – 17 Feb	26 Jan – 3 Feb
Autumn 2019	11–12 May	N/A	11–19 May
Winter 2019	27–28 July	N/A	27 July – 4 Aug
Spring 2019	2–3 Nov	N/A	2–10 Nov
Summer 2020	1–2 Feb	N/A	1–9 Feb

One-night (rodent) indices

On Day 1 of each monitoring session, inserts (card with black track ink (Pest Control Research, Christchurch) applied in the central third of the card) were secured with drawing pins in the 10 TT on each line and a small blob of peanut butter was smeared on each end of the insert. TT were revisited on the following day (Day 2), and at each TT, a record was made for whether tracks or scat or chew marks were seen on the insert, along with whether bait was present or absent and the status of the TT (i.e. whether an animal would have been able to leave tracks on the insert). Inserts with tracks were removed from the TT and the tracks identified. Tracks that were not able to be identified were recorded as 'unidentified'.

Monitoring sessions that ran from autumn 2018 to summer 2019 continued on Day 2 with 21-night mustelid indices (see below). TT monitoring sessions from autumn 2019 onwards finished on Day 2, and inserts and bait were removed from all 10 TT on each line. The tunnels were left *in situ*.

21-night (mustelid) indices

On Day 2, every other TT along each line (TT2, 4, 6, 8 and 10) had their inserts and uneaten peanut butter removed and were effectively 'closed' for the remainder of the monitoring session although they were left *in situ*. The remaining 5 TT had a fresh insert added if necessary and the peanut butter lure was replaced with a small (c.2 cm) piece of fresh rabbit meat in the centre of the inkpad. These TT were checked, re-inked and rebaited 2 or 3 times over the following 21 nights. As previously, at each check, any inserts with tracks, scat or chew marks were removed and the species was recorded along with whether bait was present or absent and the status of the tracking tunnel. At the end of the monitoring session (Day 23), inserts were checked for tracks and all inserts and uneaten bait were removed from the tunnels. The tunnels were left *in situ*.

Chew cards (CC)

Chew cards (CC) consist of a piece of folded corflute containing palatable paste as bait inside the internal channels[17]. Bite marks in the corflute can be identified to species. The sole purpose of the CC was to provide an index of possum activity along the TT line, as recommended by Wilson (2017)[18]; however, CC are equally palatable to rodents, and other animals to a lesser extent, and therefore can be used to obtain indices for these species also.

On Day 1, 10 chew cards (Connovation Ltd, Auckland) were deployed along each TT line at 50 m intervals. One CC was nailed to a tree or fence post in between each TT along the line (i.e. about 25 m from each TT), 30 cm off the ground (Fig. 5). Occasionally, when trees or wooden fence posts were not available, CC had to be anchored to metal warratahs using a cable tie. Locations of CC were marked with flagging tape. CC were not always placed in exactly the same location each monitoring session, but most locations would have been within the same vicinity and all locations would have been discoverable by the same individual possum. CC were left *in situ* for 8 nights. On Day 9, TT operators removed all CC from the line and recorded the status of the CC (i.e. whether the CC remained anchored to the tree and had been available to bite) and the identification of any species that had left bite marks on the cards.

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[17] Sweetapple P & Nugent G. 2011. Chew-track-cards: a multiple-species small mammal detection device. NZ J Ecology, 35: 153-162.

[18] Wilson D. 2017. Abundance of rats (*Rattus* species) following brushtail possum control operations on the Otago Peninsula. Otago Peninsular Biodiversity Group: http://www.predatorfreepeninsula.nz/

Fig. 5: Chew card mounted with offset nail (© Landcare Research).

Data entry

All TT and CC data were entered onto an online Google form. Following this, TT operators returned their data sheets, tracked inserts and CC to Halo Staff for verification and safe keeping.

Verification of species identification

If the TT operator was uncertain of the correct identification for tracks and bite marks, photos of the tracks and/or the actual inserts and CC were sent to Halo staff and GP for expert species identification. In addition, GP verified other identifications by subsequently checking inserts and CC. Tracks and bite mark that could not be identified were classed as 'unidentified'.

Data analysis

Tracking tunnels

The index of relative abundance for a certain species is defined as the average percentage of tunnels tracked by that species per line. For each species, the % tracking rate for each line was calculated as the number of TT tracked by that species as a proportion of the total number of TT available to be tracked on that line. 'Tracking' included the presence of footprints, scat or bite marks of a species on the insert.

Whether TT were available to be tracked on each line was established from the TT status recorded in the field. For each species, the number of TT available was calculated by multiplying the number of tracking tunnels which had been disturbed before that species of animal could leave tracks on the inserts (e.g. inserts had been pulled completely out of the tunnels; waterlogging had caused black track ink to run across both sides of the insert) by 0.5 and subtracting this from the total number of tracking tunnels on that line. Tracking tunnels that were missing or had not been baited were omitted from analyses.

For each species, the number of TT on a line that had been tracked by that species was divided by the number of TT available to that species, and multiplied by 100 to obtain the % tracking rate for that line.

For 1-night rodent indices, the tracking rates were obtained from the single night of monitoring using peanut butter as bait.

For 21-night mustelid indices, the tracking rates were obtained from the 21 nights of monitoring using rabbit meat as bait. In this case, the number of TT which had tracked a specific species in each 7-day period was summed and then divided by the total number of available TT in the 21 day period. For example, if one TT had tracked a mustelid in the first 7-day period and two TT had tracked mustelids in the second 7-day period and all five TT on the line had been available to track throughout the 21-day period (3 periods of 7 days), the % tracking rate of mustelids would be: (1+2)/(3x5) = 20%.

In the autumn and winter 2018 monitoring sessions, TT with rabbit bait were checked after 3, 7, 14 and 21 nights whereas the spring 2018 and summer 2019 monitoring sessions did not include a 3-night check. Therefore, the 3 night check was assimilated into the 7 night check in the autumn and winter 2018 sessions; if a TT had recorded a species after 3 nights and also after 7 nights then that species was said to have been recorded only once by that TT over a 7-night period.

Only 2 out of 4 pastoral farmland lines were set up to collect data in the autumn 2018 monitoring session. Furthermore, unforecast rain on the first night of the first monitoring session in autumn 2018 affected the 1-night indices for this session and only mice were recorded. Data from this night are presented in this report but cannot be used in comparisons with 1-night indices from subsequent monitoring sessions which occurred in fine weather. They were also not included in the average tracking rates for each line. In the winter 2018 session, 1-night data were not available for Line 1 (exotic forest). Weather conditions during the 21-night monitoring sessions were generally favourable.

1-night indices
The % tracking rate of rats, mice and hedgehogs for each line in each monitoring session was used to calculate the following 1-night and 21-night indices:

- Index of relative abundance for the Inner Halo (Lines 1 – 10): average (± SE) tracking rates per monitoring session.
- Index of relative abundance for each habitat type (exotic forest: Lines 1 – 2; pastoral farmland: Lines 3 – 6; indigenous forest: Lines 7 – 10): average (± SE) tracking rates per monitoring session.
- Index of relative abundance for each Line: average (± SE) tracking rate across 7 monitoring sessions (winter 2018 – summer 2020).

21-night indices

The % tracking rate of mustelids, cats and hedgehogs for each line in each monitoring session was used to calculate the following:

- Index of relative abundance for the Inner Halo (Lines 1 – 10): average (± SE) tracking rates per monitoring session
- Index of relative abundance for each habitat type (exotic forest: Lines 1 – 2; pastoral farmland: Lines 3 – 6; indigenous forest: Lines 7 – 10): average (± SE) tracking rates per monitoring session.
- Index of relative abundance for each Line: average (± SE) tracking rate across 4 monitoring sessions (autumn 2018 – summer 2019).

In addition:

- For each monitoring session, the % of lines tracked by mustelids was calculated for each 7-night period within the 21-night session. These data were used to examine the cumulative length of time it took to detect the mustelids in this study.

Chew cards

Chew cards were used to calculate relative abundance indices for possums, rats and mice. Chew card indices for a species were defined as the % of CC on a line that were bitten by that species as a proportion of the total number of CC available to be bitten on that line.

For each species, the number of CC available was calculated by multiplying the number of chew cards which had been disturbed before that species of animal could leave bite marks on the cards (e.g. CC pulled off their anchor point) by 0.5 and subtracting this from the total number of CC on that line. Chew cards that were missing were omitted from analyses.

To look more closely at the relationship between rat and possum relative abundance indices when possum activity was high (CC index >50 %), possum CC indices were plotted against rat relative abundance indices for Lines 7 and 9. We were interested to examine whether high possum activity levels were associated with lower indices of rat relative abundance.

Assumptions

The general assumptions for using TT methodology are outlined in Gillies (2013)[19].

The standardised protocols described earlier were used for the duration of the project in order to reduce variation in detectability as much as possible. However, some brief variations to protocols were made over the course of this study because of the number of people involved with collecting the data and the length of the monitoring sessions. Variations included applying peanut butter bait to the centre of the ink pad rather than at the ends of the inserts (3 lines - 4 occasions in total); anchoring CC to the ground with wire pegs instead of 30 cm off the ground (1 line on 1 occasion); not folding the CC in half before

[19] Gillies C. 2013. Animal pests: tracking tunnel indices of small mammal abundance v 1.0. Department of Conservation publication DOCDM-322684. 10pp. Available from: www.doc.govt.nz.

anchoring them (1 line on 1 occasion); operating the TT mustelid index for 20 or 22 nights instead of 21 (3 lines on 1 occasion); not fully inking the middle third of the insert (5 lines – 11 occasions in total). In addition, after the first four monitoring sessions, the peanut butter used as bait was switched from a cheaper variety to a better quality brand (Bay Rd, Dunedin). Although these variations had the potential to affect the detectability of the species being monitored, the fact that these variations occurred in a minority of cases and that obviously different tracking rates were not observed from lines where variations occurred meant we considered it reasonable to assume that these variations did not greatly influence the overall tracking rates recorded.

Results

One-night (rodent) indices

Species recorded during 1-night indices were predominately rats, mice and hedgehogs (Appendix A). A mustelid (probable stoat) tracked one TT on Line 10 in summer 2019 and either a small ferret or a stoat tracked two TT on Line 5 in summer 2020. Possums were recorded from up to four TT along Line 9 on four occasions and once from one TT on Line 7. Unidentified tracks made up less than 1% of all records.

Rats

Rat tracking rates in the Inner Halo averaged 6 – 19% per session, with an average across the whole study of 12% (± 2% SE; Fig. 6A). No obvious seasonal pattern was apparent. The highest rate was recorded in winter 2018, but this might be partly because no data were available from one typically 'less ratty' line during this session. About 15% of tunnels were tracked during autumn 2019 and summer 2020. The lowest tracking rates, 6% and 7%, occurred in summer and winter 2019 respectively.

Rats were more likely to be recorded in forest habitats compared with pastoral farmland (Fig. 6B). With the exception of winter 2018, rat relative abundance was highest in the indigenous forest, where tracking rates often averaged between 20 – 30% and were 23% (± 2.5%) overall. The exceptionally high tracking rate of 70% in the exotic forest habitat in winter 2018 probably reflects that only one – particularly ratty – line operated in this habitat during this session. In all other monitoring sessions, rat tracking rates in the exotic forest averaged less than 15%.

Tracking rates for each line averaged over 7 monitoring sessions showed that Lines 2 (20 ± 9%; exotic forest), 7 (55 ± 6%; indigenous forest) and 9 (28 ± 7%; indigenous forest) had the highest relative abundances of rats (Fig. 7). All three lines were to the south of Orokonui Ecosanctuary. Tracking rates on Line 7 reached 70% in three of the monitoring sessions. The two remaining indigenous forest lines had relatively low overall tracking rates (Line 8: 6 ± 3%; Line 10: 3 ± 2%). The remaining exotic forest line and all pastoral farmland lines had very low rat relative abundances (<3%); no rats were recorded at all from Lines 3 and 6.

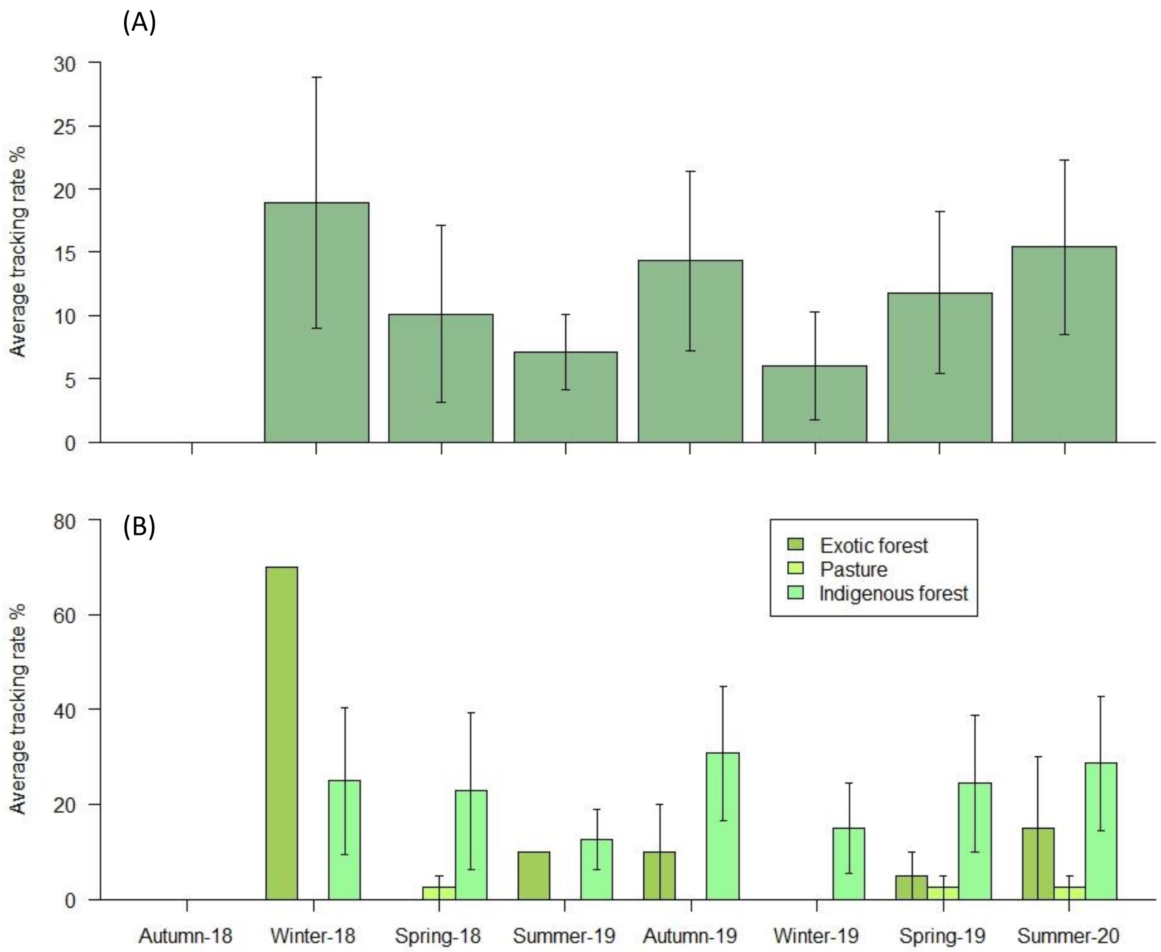

Fig. 6: Relative abundance of rats (% tracking tunnels (TT) tracked by rats in one night) each season between 2018 – 2020 in the Inner Halo, north of Dunedin. Tracking rates in Autumn 2018 were affected by rain and are not comparable with those from subsequent monitoring sessions. (A) Overall relative abundance (rat tracking % average ± SE across all 10 TT lines); (B) relative abundance average ± SE in each of 3 main habitat types (Exotic forest = 2 TT lines (with exception of Winter 2018 = 1 TT line); Pasture = 4 TT lines (with exception of Autumn 2018 = 2 TT lines); indigenous forest = 4 TT lines).

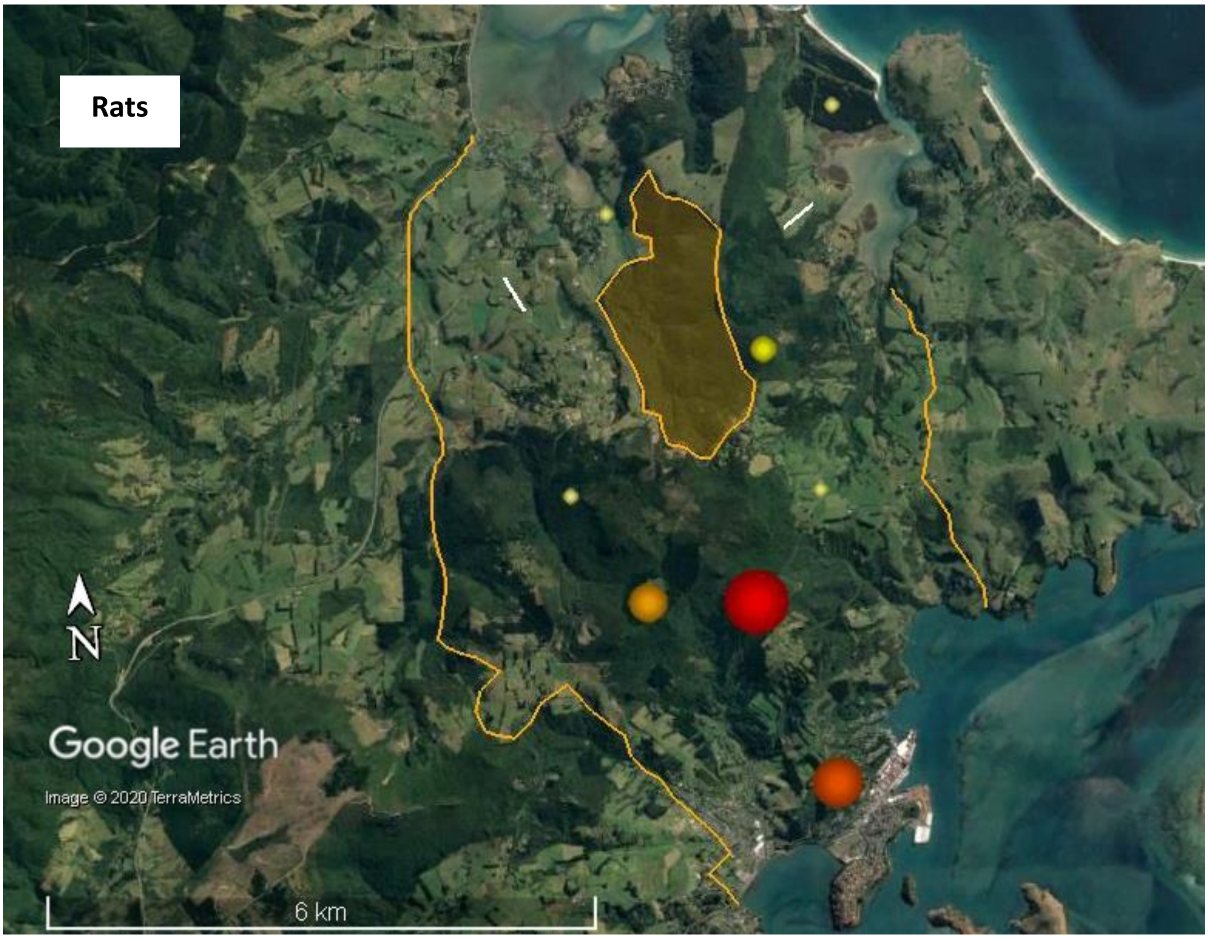

Fig. 7: Average 1-night rat tracking rates for each tracking tunnel line in the Inner Halo across 7 monitoring sessions, 2018-2020. Tracking rates: 0% = white line; >0 – 5% = small pale yellow; >5 – 10% = yellow; >10 – 25% = orange; >25 – 50% = dark orange; >50 – 75% = red. Boundary lines of Orokonui Ecosanctuary (shaded area) and the Inner Halo are shown in orange.

Mice

Mice tracking rates in the Inner Halo tended to average from 20-30% throughout the seasons, with the exception of January 2019 when they were a relatively low 5% (Fig. 8A). Relative abundance across all monitoring sessions averaged 20 ± 3% (± SE). Lines 1 and 8 recorded mouse tracking rates as high as 90% in one monitoring session.

As with rats, mouse relative abundance was higher in forest habitats compared with pastoral farmland (Fig. 8B). However, unlike rats, average relative abundance was slightly higher in the exotic forest (average 39 ± 9%) compared with the indigenous forest (25 ± 4%). The exotic forest average tracking rate was higher because two sessions included 70% tracking rates. If these two sessions were excluded, average tracking rates in these two habitats were similar.

Tracking rates for each line averaged over 7 monitoring session revealed that mouse relative abundance was highest at Line 1 (30 ± 14%; exotic forest), Line 2 (41 ± 9 %; exotic forest), Line 8 (57 ± 12%; indigenous forest) and Line 10 (27 ± 9%; indigenous forest), situated in all directions around Orokonui Ecosanctuary (Fig. 9). Relative abundance of farmland pastoral lines ranged from 0% (Line 5) to 19 ± 5% (Line 4) and was relatively low along the other 2 indigenous forest lines (Line 7: 6 ± 3%; Line 9: 10 ± 3%).

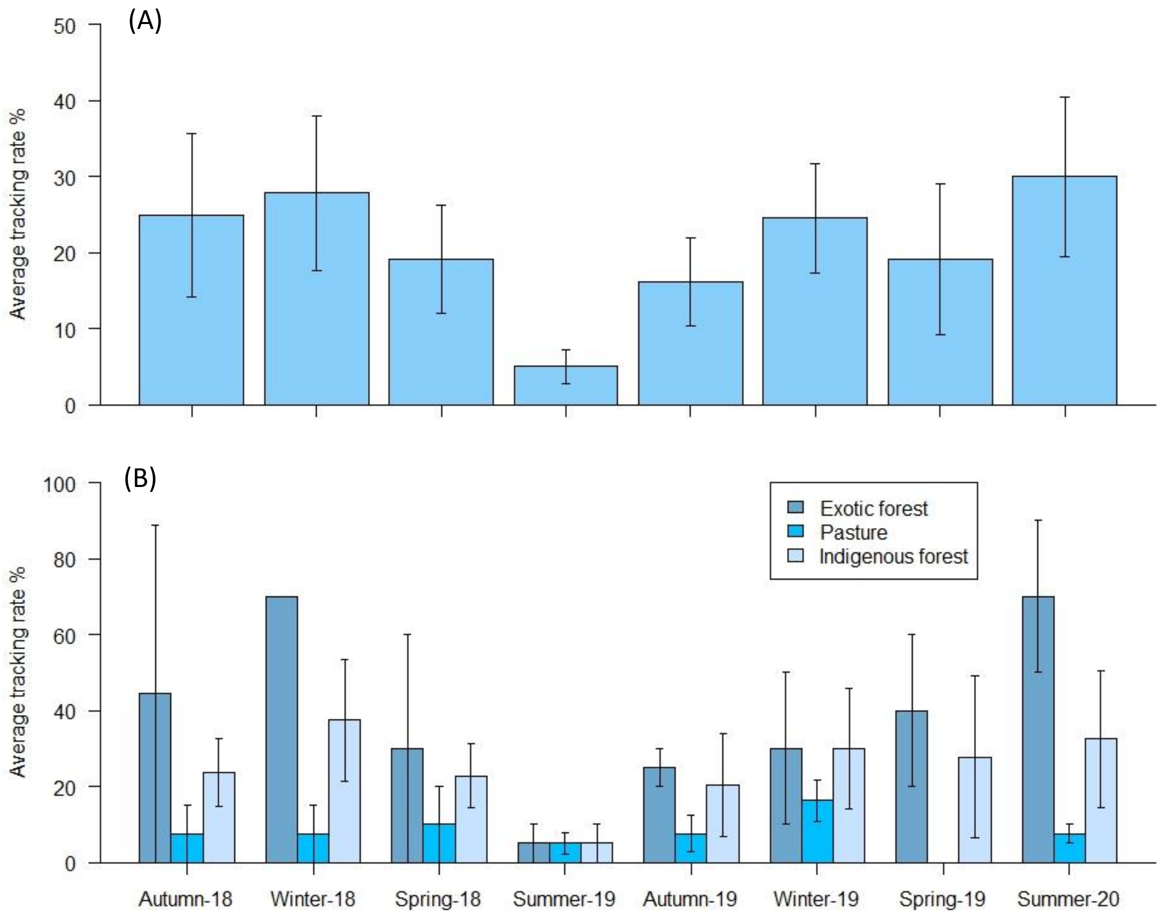

Fig. 8: Relative abundance of mice (% tracking tunnels (TT) tracked by mice in one night) each season between 2018 – 2020 in the Inner Halo, north of Dunedin. Tracking rates in Autumn 2018 were affected by rain and are not comparable with those from subsequent monitoring sessions.
(A) Overall relative abundance (mouse tracking % average ± SE across all 10 TT lines); (B) relative abundance average ± SE in each of 3 main habitat types (Exotic forest = 2 TT lines (with exception of Winter 2018 = 1 TT line); Pasture = 4 TT lines (with exception of Autumn 2018 = 2 TT lines); indigenous forest = 4 TT lines).

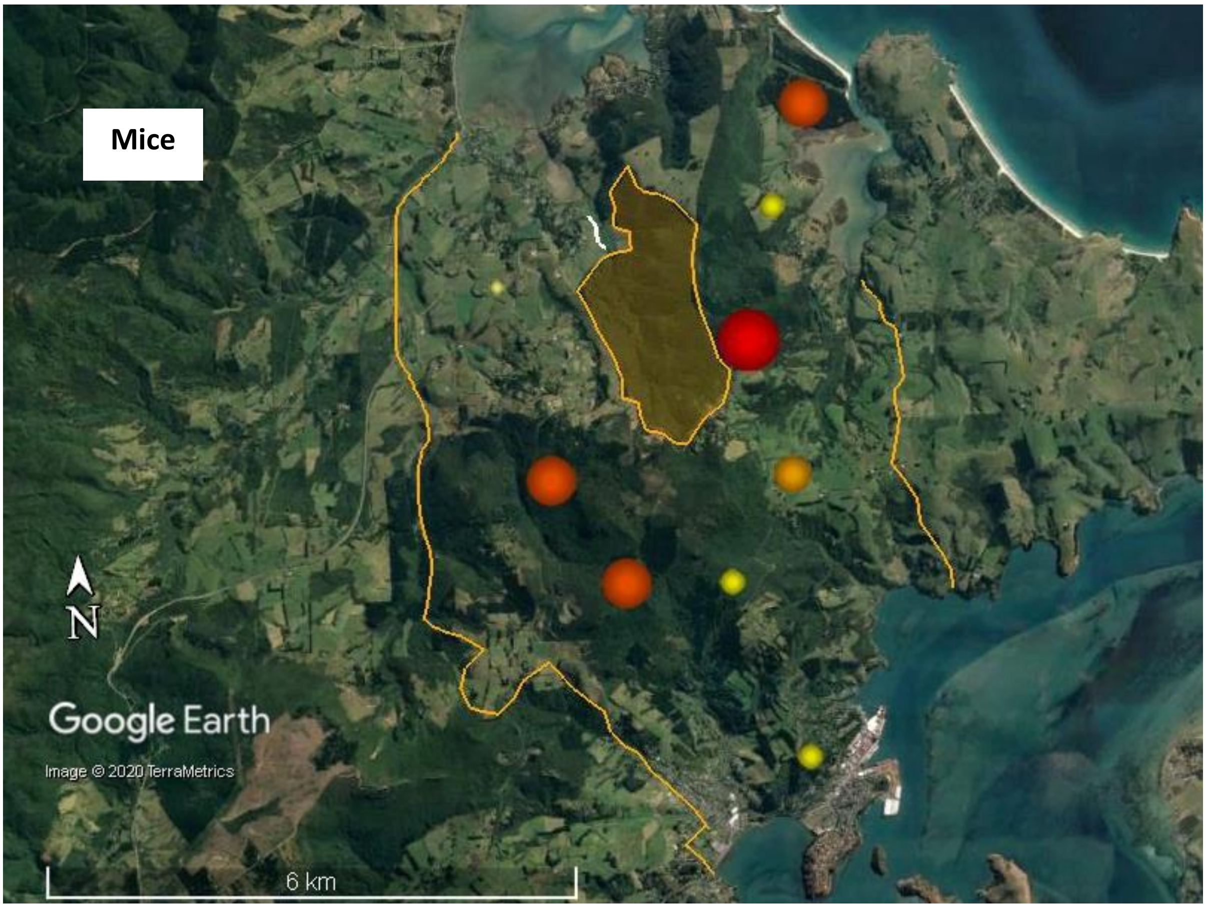

Fig. 9: Average 1-night mouse tracking rates for each tracking tunnel line in the Inner Halo across 7 monitoring sessions, 2018-2020. Tracking rates: 0% = white line; >0 – 5% = small pale yellow; >5 – 10% = yellow; >10 – 25% = orange; >25 – 50% = dark orange; >50 – 75% = red. Boundary lines of Orokonui Ecosanctuary (shaded area) and the Inner Halo are shown in orange.

Hedgehogs

Average hedgehog tracking rates in the Inner Halo ranged from 0%, as expected during winter hibernation, to a high of 15 ± 5% (± SE) in summer 2020 (Fig. 10A). Excluding the winter hibernation periods, tracking rates for the Inner Halo were similar across seasons, averaging 10 ± 1.5% over the study period.

Hedgehogs were found in all 3 habitat types and did not show an obvious habitat preference (Fig. 10B). However, hedgehog relative abundance reached its highest in exotic forest in the autumn 2019 and summer 2020 monitoring sessions. Both of the exotic forest lines recorded hedgehog tracking rates of 50% on one monitoring occasion.

The lines with the highest relative abundance of hedgehogs over the course of the study were Line 2 (exotic forest; 16 ± 6%) and Line 3 (pastoral farmland; 16 ± 7%; Fig. 11). Tracking rates on most other lines averaged 5 – 10%. No hedgehogs were recorded on Lines 6 (pastoral farmland) and 8 (indigenous forest).

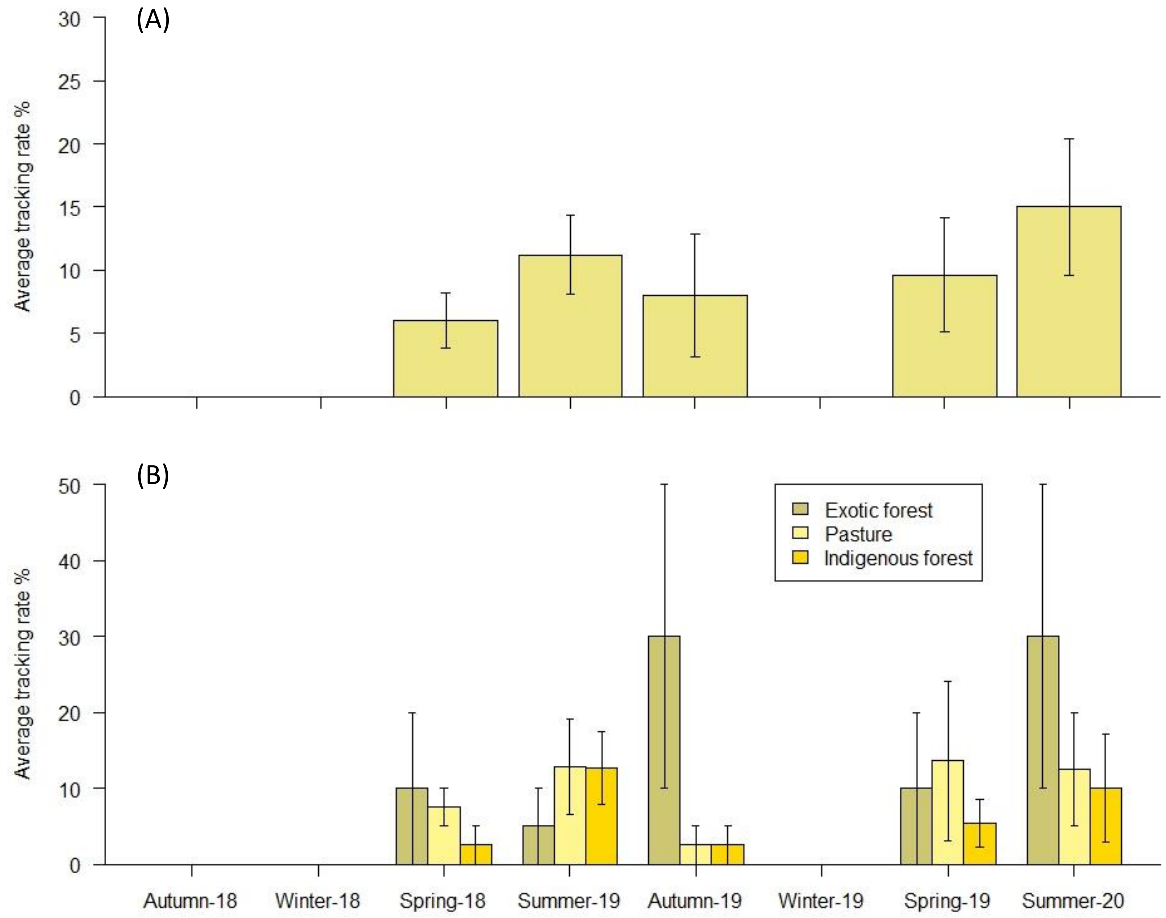

Fig. 10: Relative abundance of hedgehogs (% tracking tunnels (TT) tracked by hedgehogs in one night) each season between 2018 – 2020 in the Inner Halo, north of Dunedin. Tracking rates in Autumn 2018 were affected by rain and are not comparable with those from subsequent monitoring sessions. (A) Overall relative abundance (hedgehog tracking % average ± SE across all 10 TT lines); (B) relative abundance average ± SE in each of 3 main habitat types (Exotic forest = 2 TT lines (with exception of Winter 2018 = 1 TT line); Pasture = 4 TT lines (with exception of Autumn 2018 = 2 TT lines); indigenous forest = 4 TT lines).

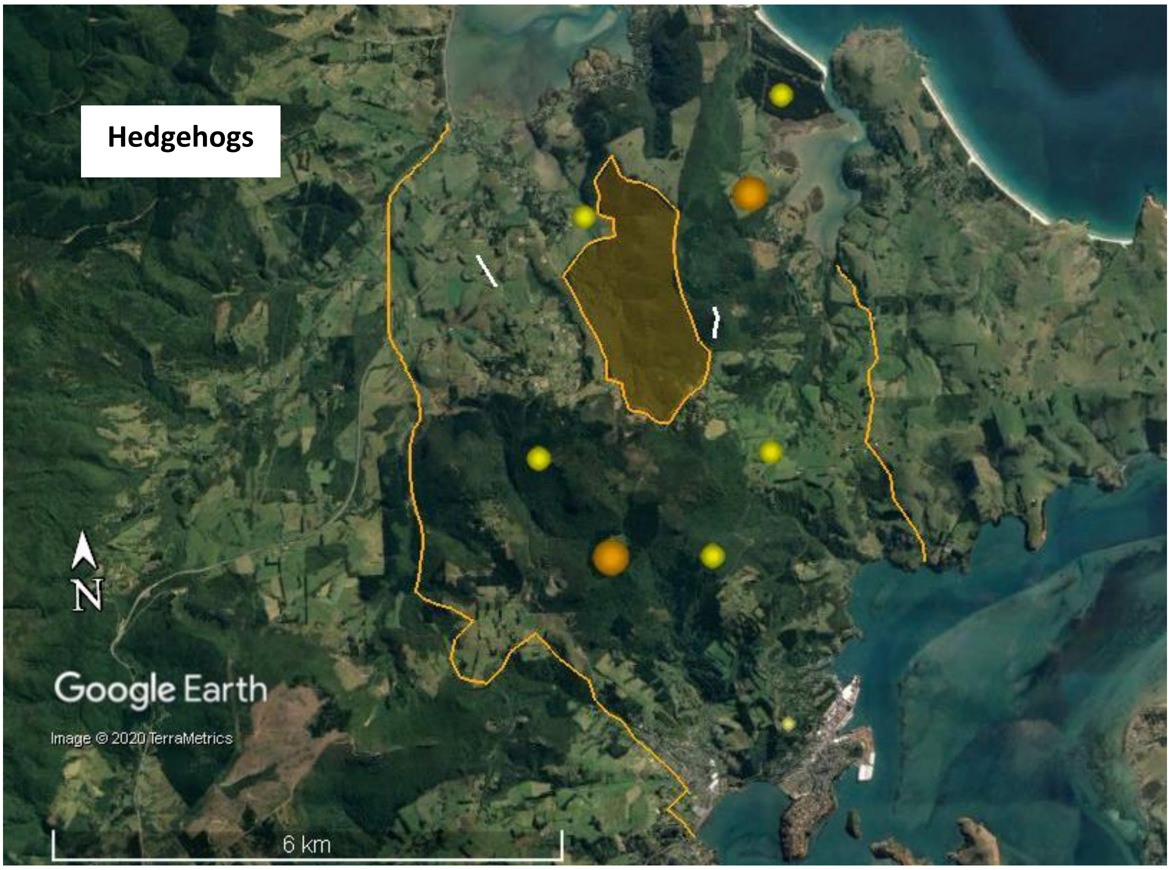

Fig. 11: Average 1-night hedgehog tracking rates for each tracking tunnel line in the Inner Halo across 7 monitoring sessions, 2018-2020. Tracking rates >0% represented by coloured circles: 0% = white line; >0 – 5% = small pale yellow; >5 – 10% = yellow; >10 – 25% = orange. Boundary lines of Orokonui Ecosanctuary (shaded area) and the Inner Halo are shown in orange.

21-night (mustelid) indices

Mouse, rat, hedgehog, mustelid (probable stoat, stoat/weasel and ferret), cat and possum tracks were recorded during the four 21-night monitoring sessions between autumn 2018 and summer 2019 (Appendix A). Unidentified tracks made up 4.9% of all records.

Mustelids

Mustelid relative abundance was low during the four 21-night monitoring sessions, reaching a maximum of 2% (± 1.5% SE) during winter 2018 (Fig. 12A). Tunnels in exotic forest were more likely to be tracked than those in the other habitat types, with exotic forest tracking rates averaging between 3 – 7% (Fig. 12B). A ferret (or ferrets) tracked one TT on pastoral farmland Line 5 on two occasions during the winter 2018 monitoring session. Probable stoats (but possibly also a weasel) were recorded from both the exotic forest lines during the period of the study, particularly from Line 2 south of Orokonui Ecosanctuary (Fig. 13). Mustelid tracks were recorded on this line during every monitoring period. On the other exotic forest line, one mustelid tracked one TT in summer 2019. No mustelid tracks were recorded in the indigenous forest during the 21-night indices.

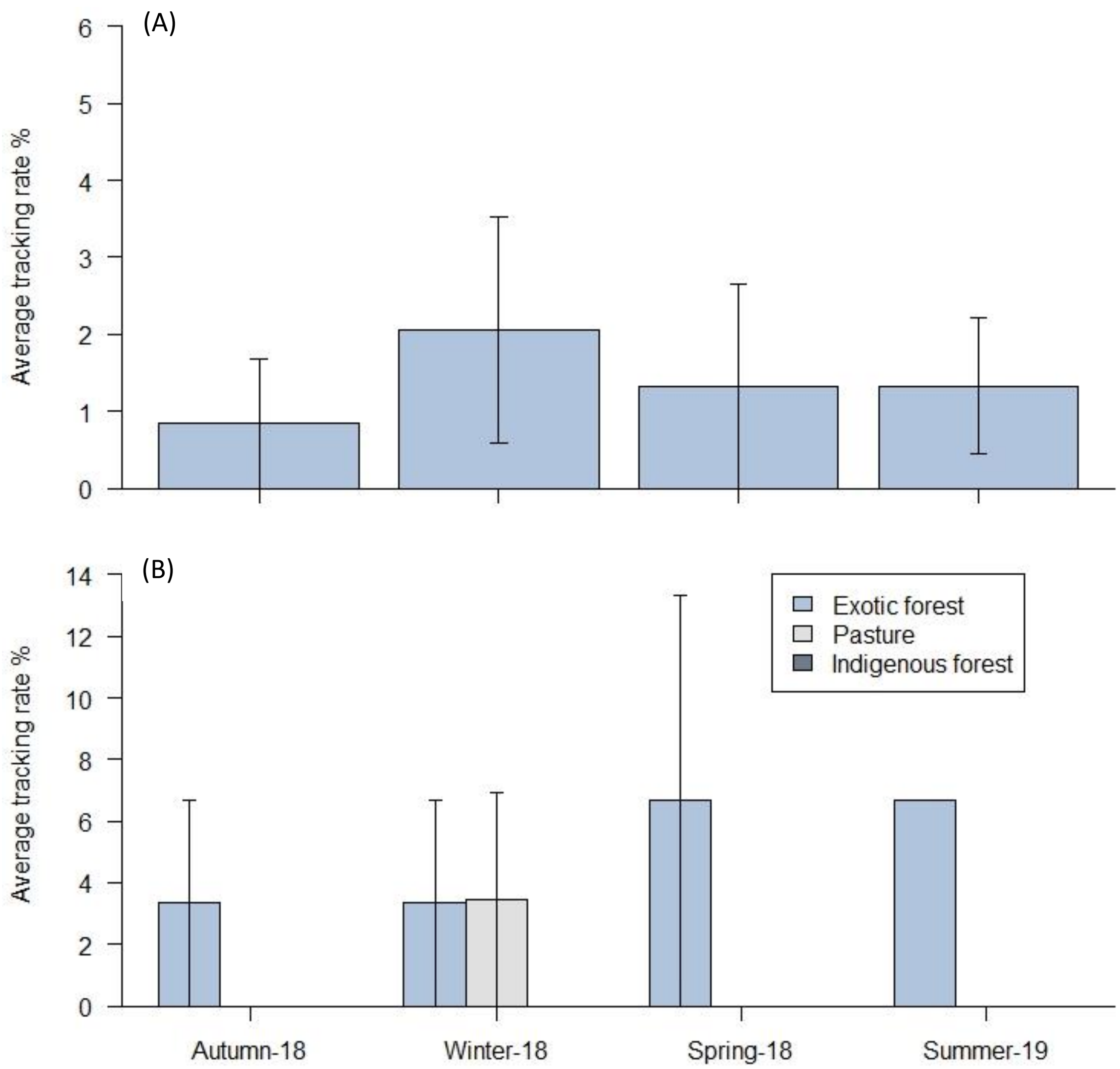

Fig. 12: Relative abundance of mustelids (% tracking tunnels (TT) tracked by mustelids in 21 nights) each season between 2018 – 2019 in the Inner Halo, north of Dunedin. (A) Overall relative abundance (mustelid tracking % average ± SE across all 10 TT lines); (B) relative abundance average ± SE in each of 3 main habitat types (Exotic forest = 2 TT lines; Pasture = 4 TT lines (with exception of Autumn 2018 = 2 TT lines); indigenous forest = 4 TT lines).

Fig. 13: Average 21-night mustelid tracking rates for each tracking tunnel line in the Inner Halo across 4 monitoring sessions, 2018-2019. Tracking rates >0% represented by coloured circles: 0% = white line; >0 – 5% = small pale yellow; >5 – 10% = yellow. Boundary lines of Orokonui Ecosanctuary (shaded area) and the Inner Halo are shown in orange.

Feral cats

Feral cats were recorded in all monitoring sessions except winter 2018 (Fig. 14A). Their highest relative abundance occurred in summer 2019 (7 ± 7%; mean ± SE). All feral cat records were from two indigenous forest lines (Lines 7 and 10; Fig. 14B). In addition, cats were suspected at a third indigenous forest site (Line 9) on 3 occasions but as they did not leave unequivocal prints they were classed as 'unidentified' there.

Cat tracking rates averaged 8 ± 6% on Lines 7 and 10 over the course of the study (Fig. 15). Both lines recorded cats during two monitoring sessions, with cats tracking tunnels more than 250 m from the forest edge at both sites.

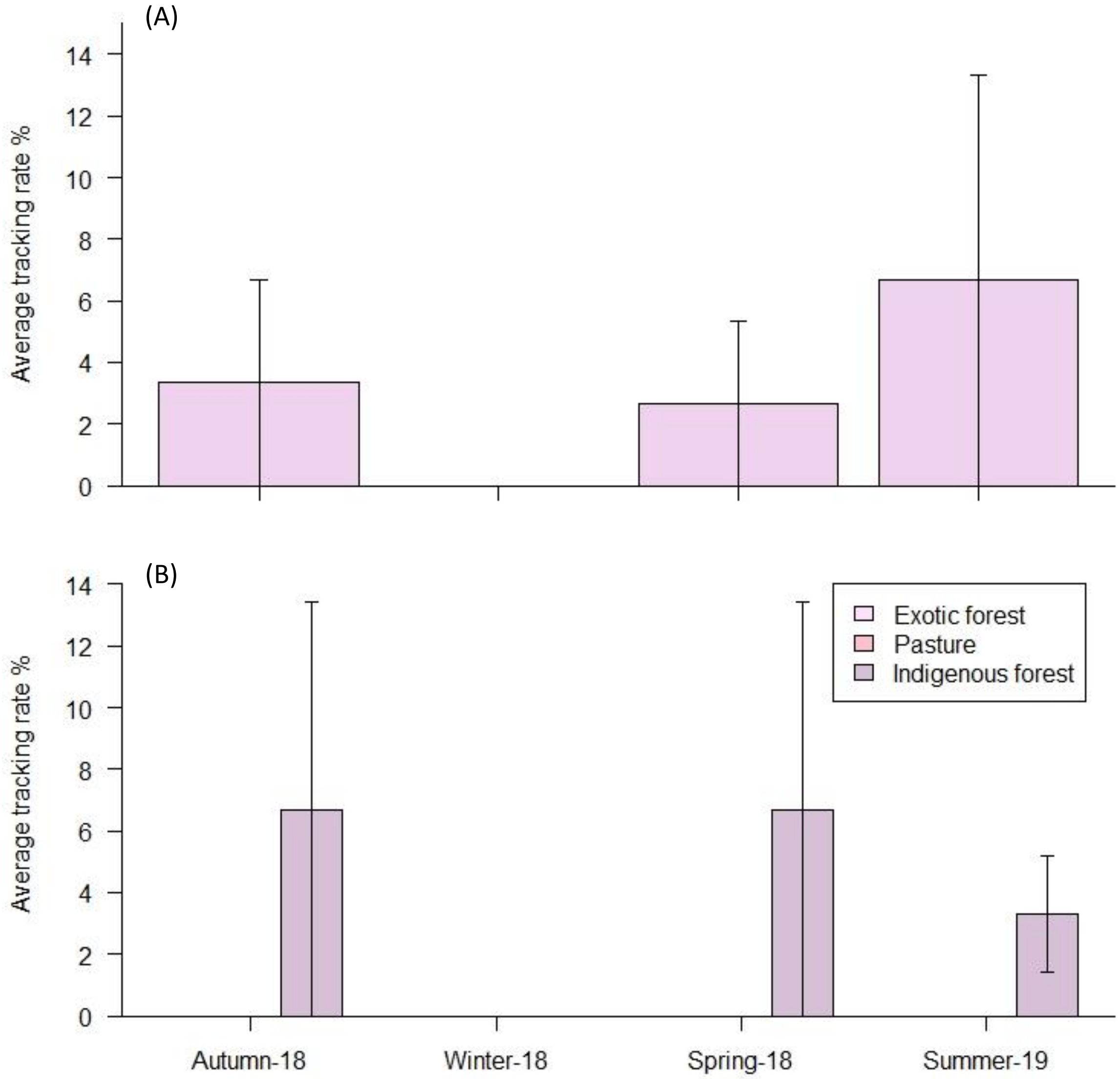

Fig. 14: Relative abundance of feral cats (% tracking tunnels (TT) tracked by cats in 21 nights) each season between 2018 – 2019 in the Inner Halo, north of Dunedin. (A) Overall relative abundance (cat tracking % averaged across all 10 TT lines); (B) relative abundance averaged in each of 3 main habitat types (Exotic forest = 2 TT lines; Pasture = 4 TT lines (with exception of Autumn 2018 = 2 TT lines); indigenous forest = 4 TT lines).

Fig. 15: Average 21-night feral cat tracking rates for each tracking tunnel line in the Inner Halo across 4 monitoring sessions, 2018-2019. Tracking rates >0% represented by coloured circles: 0% = white line; >5 – 10% = yellow. Symbol ** = location of probable cat tracks. Boundary lines of Orokonui Ecosanctuary (shaded area) and the Inner Halo are shown in orange.

Hedgehogs

Excluding the winter hibernation period, hedgehog relative abundance from 21-night indices ranged from 19 – 35% (Fig. 16A). Autumn 2018 data were available for the 21-night indices and show the relative abundance of hedgehogs during this session was similar to spring 2018 levels. The 21-night indices by habitat show a trend of lower relative abundance in indigenous forest compared with the other two habitat types (Fig. 16B). Relative abundance in the exotic forest and pastoral farmland habitats frequently averaged 50% or higher.

Hedgehogs were recorded from all tracking tunnel lines except Line 8 (Fig. 17). Their relative abundance was highest overall on the exotic forest Line 2 (40 ± 14%; mean ± SE) and pastoral farmland Line 3 (38 ± 13%).

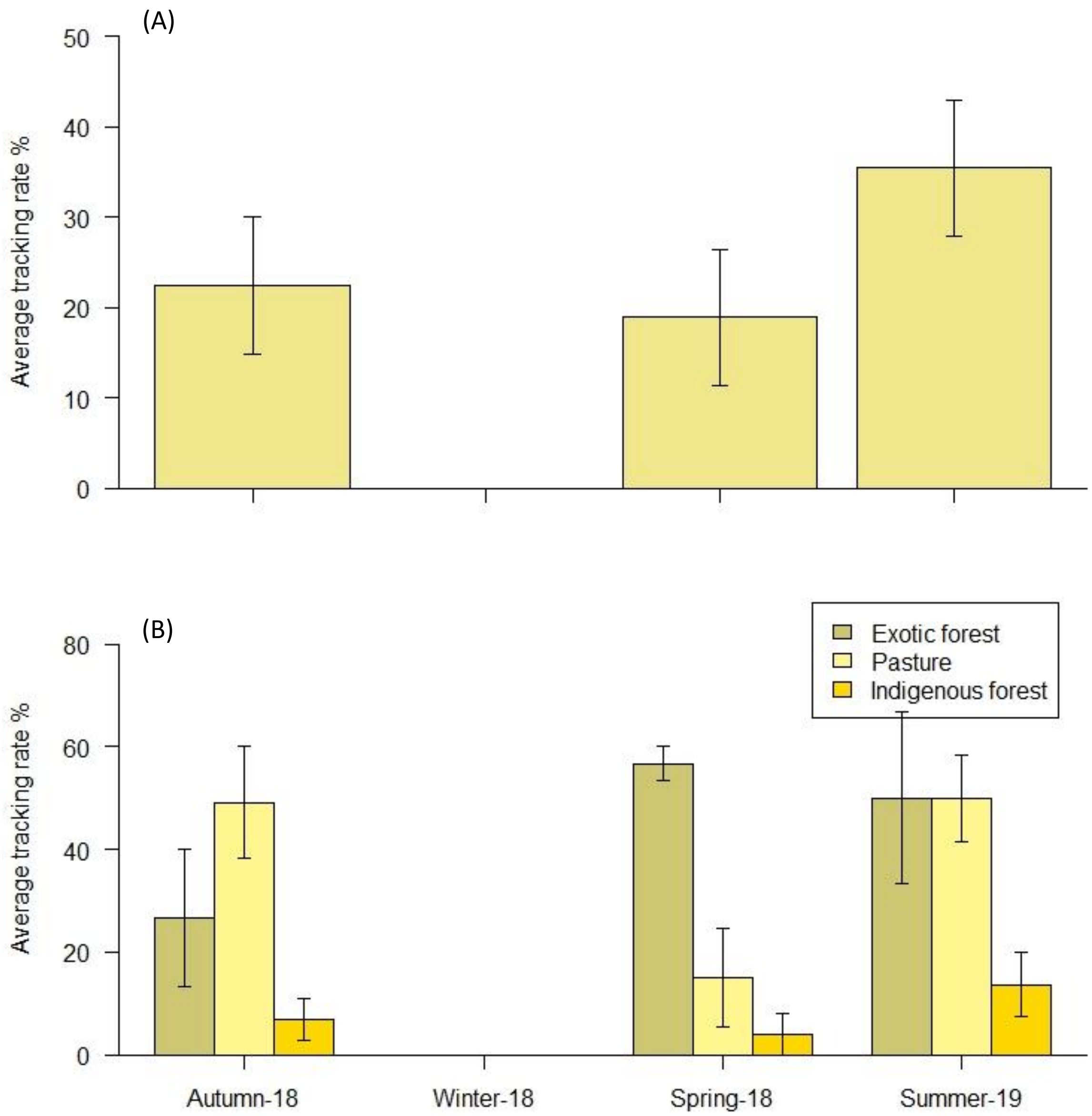

Fig. 16: Relative abundance of hedgehogs (% tracking tunnels (TT) tracked by hedgehogs in 21 nights) each season between 2018 – 2019 in the Inner Halo, north of Dunedin. (A) Overall relative abundance (hedgehog tracking % averaged across all 10 TT lines); (B) relative abundance averaged in each of 3 main habitat types (Exotic forest = 2 TT lines; Pasture = 4 TT lines (with exception of Autumn 2018 = 2 TT lines); indigenous forest = 4 TT lines).

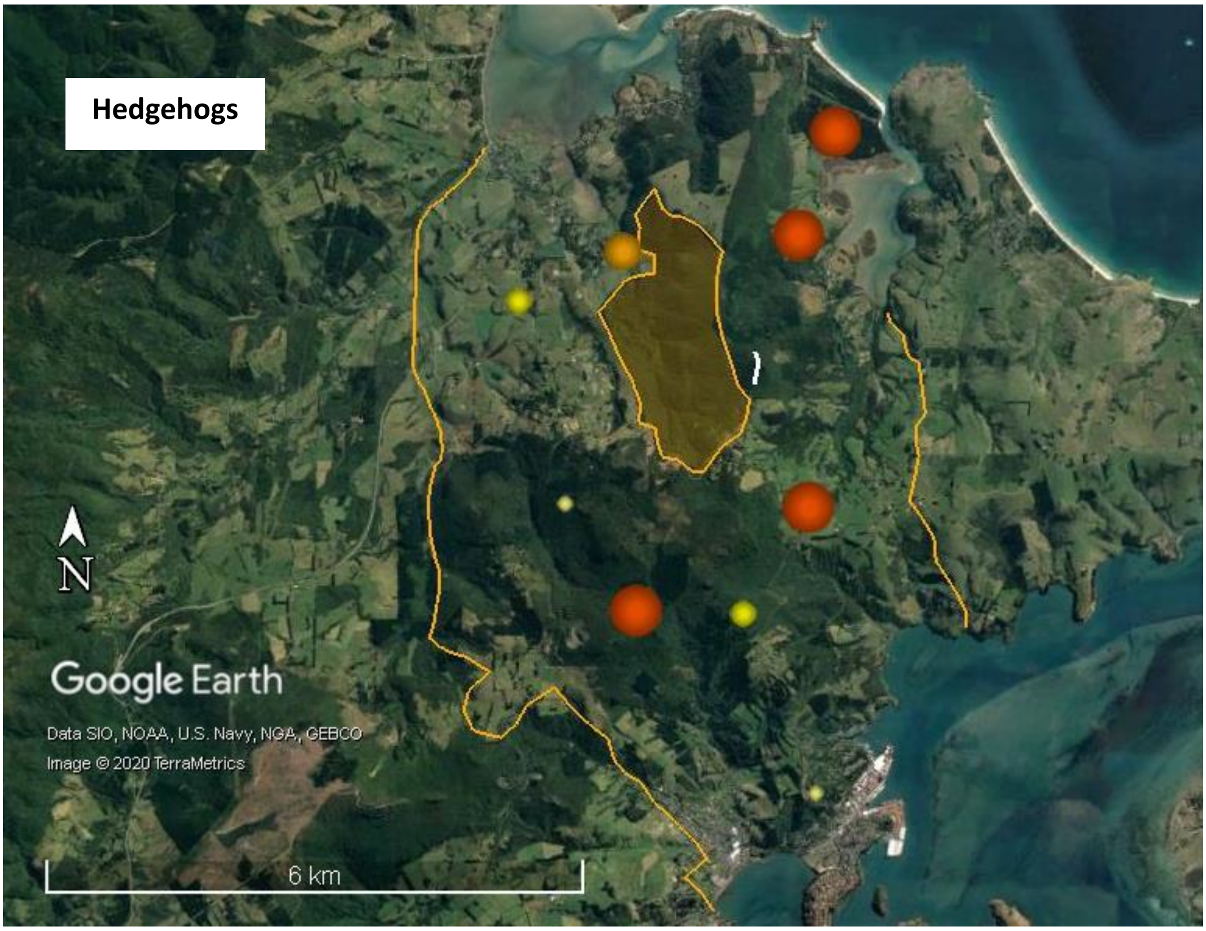

Fig. 17: Average 21-night hedgehog tracking rates for each tracking tunnel line in the Inner Halo across 4 monitoring sessions, 2018-2019. Tracking rates >0% represented by coloured circles: 0% = white line; >0 – 5% = small pale yellow; >5 – 10% = yellow; >10 – 25% = orange; >25 – 50% = dark orange. Boundary lines of Orokonui Ecosanctuary (shaded area) and the Inner Halo are shown in orange.

Cumulative % lines tracked by mustelids

Mustelids were detected during all four of the 21-night monitoring sessions. They were recorded on 2 out of 10 TT lines after two 21-night monitoring sessions, but it took four sessions to detect mustelids on 3 lines.

If TT had operated for just 7 nights per session, mustelids would have been recorded from 2 lines during 2 sessions (Fig. 18). It was not until 14 nights of monitoring that mustelids were detected on 3 lines. For 2 out of 4 sessions, all mustelid detections were made within 14 nights. For the other 2 sessions, mustelid presence was detected on new lines at 21 nights.

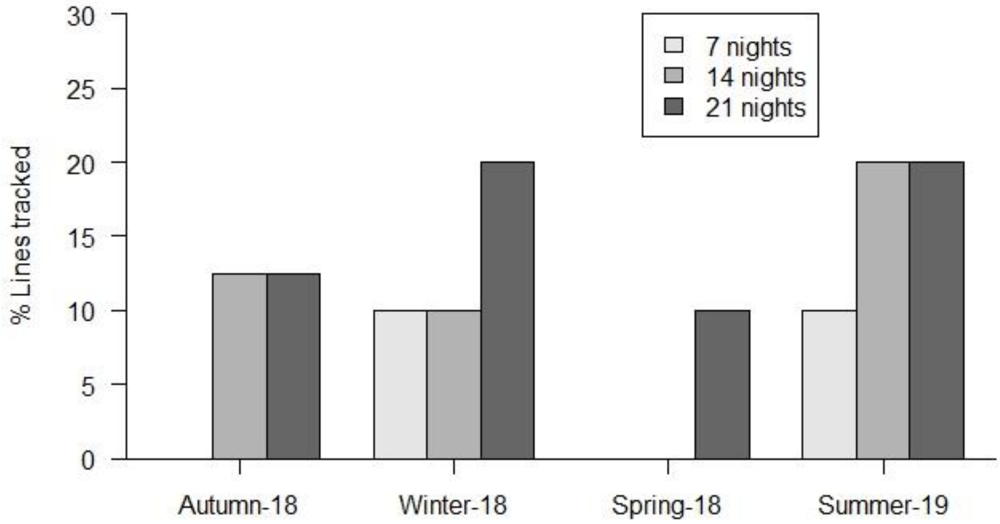

Fig. 18: Proportion of 10 tracking tunnel lines (Autumn-18 = 8 lines) in the Inner Halo which tracked mustelids during 4 monitoring sessions in 2018 - 2019. Tunnels were checked for tracks every 7 days for a 21-day period.

Possum indices (chew cards)

CC were chewed mainly by possums, rats and mice, but cards were also bitten by stock, hedgehogs, probable mustelids and unidentified animals (possibly birds; Appendix B).

CC recorded possum presence from 10 – 50% of lines per session, with the highest levels recorded between spring 2018 and winter 2019 (Table 2). On most lines, possum relative abundance across all monitoring sessions was very low (Fig. 19). However, relative abundance on two of the indigenous forest lines (Lines 7 and 9) reached moderate to high levels, and on Line 9 in particular was frequently over 50%.

Table 2: Relative abundance of possums (% of available chew cards with bite marks) along 10 lines in the Inner Halo. Ten cards were spaced at 50 m intervals and left for 8 nights. ( ) = number of available chew cards; NA = no data; * left for 7 nights. Lines with ≥50% relative abundance during monitoring sessions are shaded in grey.

Line #	Autumn 2018	Winter 2018	Spring 2018	Summer 2019	Autumn 2019	Winter 2019	Spring 2019	Summer 2020
L1	10% (10)	0% (10)	0% (10)	0% (10)	30% (10)	10% (10)	0% (10)	0% (10)
L2	0% (10)	0% (10)	0% (9)	0% (9)*	0% (10)	0% (8)	0% (9)	0% (10)
L3	0% (10)	10% (10)	20% (10)	0% (10)	10% (10)	0% (10)	0% (10)	0% (10)
L4	0% (10)	0% (10)	0% (10)	0% (10)	0% (10)	0% (9)	0% (10)	0% (9)
L5	NA	0% (10)	0% (9)	0% (10)	0% (10)	0% (10)	0% (7)	0% (5)
L6	NA	0% (4)	0% (4)	0% (9)	0% (10)	0% (9)	0% (10)	0% (10)
L7	10% (10)	0% (10)	10% (10)	30% (10)*	50% (10)	44% (9)	33% (9)	0% (9)
L8	0% (10)	0% (10)	10% (10)	0% (10)	0% (10)	0% (10)	0% (10)	0% (10)
L9	0% (9)	10% (10)	50% (10)	60% (10)	83% (6)	100% (10)	50% (10)	89% (9)
L10	0% (10)	0% (10)	10% (10)	0% (10)	0% (10)	0% (10)	0% (10)	0% (10)

Fig. 19: Average % of chew cards with possum bite marks at each tracking tunnel line in the Inner Halo across 8 monitoring sessions, 2018-2020. For each monitoring session, 10 chew cards were placed at 50 m intervals along each line and left for 8 nights. Relative abundance >0% represented by coloured circles: 0% = white line; >0 – 5% = small pale yellow; >5 – 10% = yellow; >10 – 25% = orange; >50% = red. Boundary lines of Orokonui Ecosanctuary (shaded area) and the Inner Halo are shown in orange.

Comparison with rat indices

There was no obvious relationship between possum CC indices and rat 1-night TT indices on Lines 7 and 9 (Fig. 20). However, rat relative abundance obtained from chew cards was 0% when possum relative abundance exceeded 80% on Line 9. It is unclear whether rat CC indices were reduced when possum CC indices were between 50 – 80% as there were insufficient data in this range. Possum CC indices below 50% did not seem to affect rat CC indices.

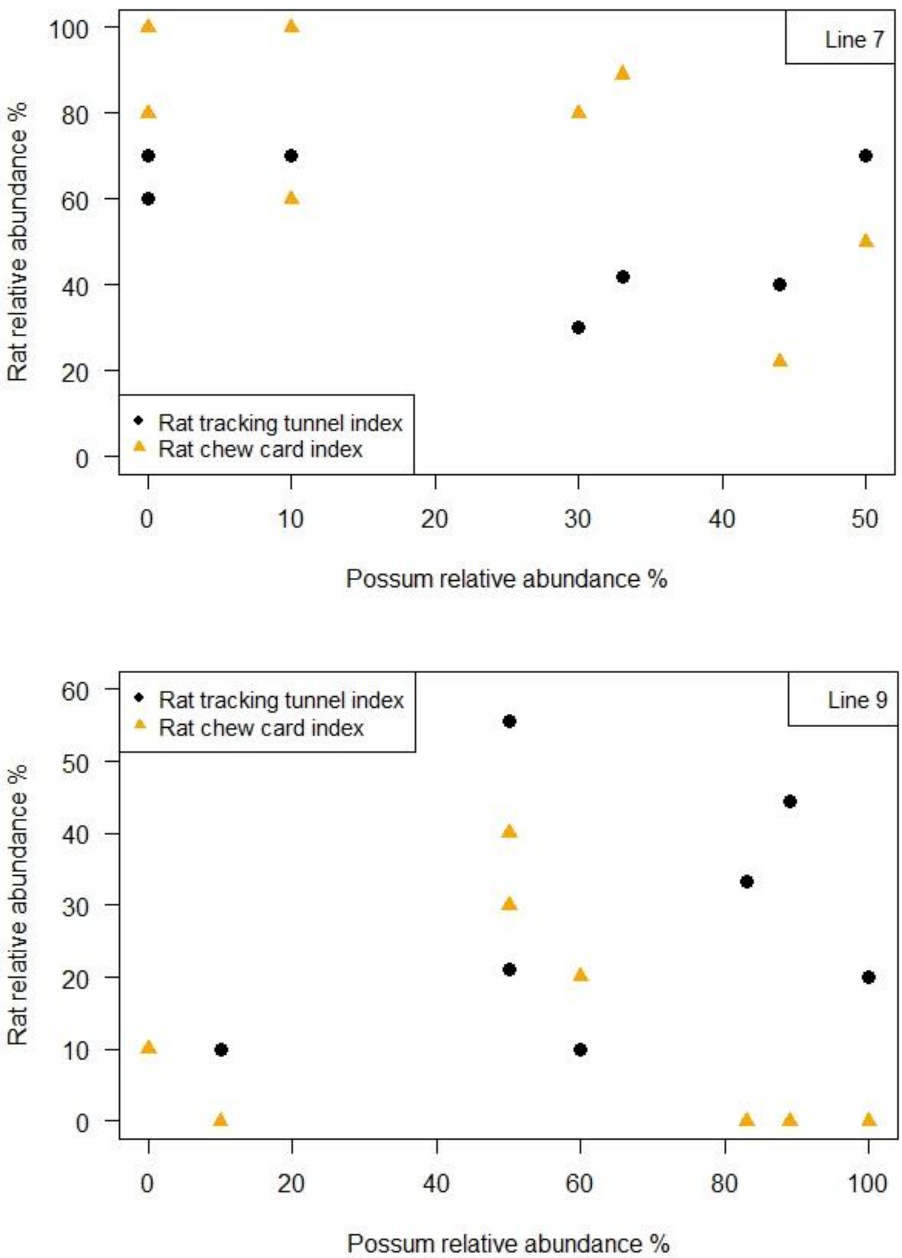

Fig. 20: The relationship between possum relative abundance (% of available chew cards bitten by a possum in 8 nights) and rat relative abundance measured in 2 ways: (1) 1-night tracking tunnel index (% of available tunnels tracked by a rat in one night); (2) 8-night chew card index (% of available chew cards bitten by a rat in 8 nights) for two monitoring lines in the Inner Halo, monitored 8 times between 2018-2020. Tracking tunnel index data were not available for one monitoring session.

Conclusions

Rodents

One-night TT indices did not reveal an obvious seasonal pattern for rat relative abundance. Tracking rates in the Inner Halo averaged 6 – 19% across all lines during the course of the study and 12% overall. This overall average is similar the 10% average measured on the less-forested Otago Peninsula between 2012 – 2017[20].

The recommended threshold for one-night TT rat indices for most threatened species that are sensitive to mammalian predators (for example, mohua *Mohoua ochrocephala*) is 30% and it is 5% for those species that are especially sensitive[20]. Rats were much more abundant in Inner Halo forest habitat, especially indigenous forest, compared with pastoral farmland sites. Average tracking rates in indigenous forest were often between 20 – 30%. For comparison, rat tracking rates measured in 12 southern South Island forests in 2014, prior to 1080 application, averaged 25% (± 5% SE)[21].

Two indigenous forest lines and one exotic forest line had the highest tracking rates, averaging from 20 – 55% across all monitoring sessions. Rats regularly tracked over 30% of tunnels on Lines 7 and 9. It may not be coincidence that a recent survey of South Island robins (*Petroica australis*) in the Inner Halo found no evidence of robins establishing populations at these sites[22].

Mouse relative abundance in the Inner Halo generally averaged 20 – 30% across all lines and showed no obvious seasonal trends. As with rats, mouse relative abundance was highest in forested areas, with broadly similar tracking rates in exotic and indigenous forest habitats. The lower mouse tracking rates on Lines 7 and 9 compared with the other forest lines was possibly a result of the higher rat relative abundance there. Ship rats are predators of house mice. Mice also become more detectable in the absence of rats[23]. Interestingly, the exotic forest Line 2 recorded relatively high tracking rates of both rats and mice. Possibly there was abundant food available and/or niche partioning that enabled both species to coexist in that habitat[24].

In April 2018, at the beginning of this study, Dunedin was reported to be suffering from extremely high numbers of rats and mice following a long hot summer[25]. Unfortunately, rain

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[20] Wilson D. 2017. Abundance of rats (*Rattus* species) following brushtail possum control operations on the Otago Peninsula. Otago Peninsular Biodiversity Group: http://www.predatorfreepeninsula.nz/

[21] Elliott G & Kemp J. 2016. Large-scale pest control in New Zealand beech forests. Ecological Management & Restoration, 17: doi: 10.1111/emr.12227.

[22] Pickerell G. 2020. Halo Project robin survey: 2018-2019. Unpublished report for The Halo Project, Dunedin.

[23] Bridgman L et al. 2018. Interactions between ship rats and house mice at Pureora Forest Park. NZ J Zoology, 45: 238–256.

[24] Shiels AB et al. 2013. Dietary niche differentiation among three species of invasive rodents (*Rattus rattus*, *R. exulans*, *Mus musculus*). Biological Invasions, 15: 1037–1048.

[25] Otago Daily Times article. 30 April 2018. Smell a rat? Here comes winter. www.odt.co.nz.

affected the 1-night tracking indices in autumn 2018 and no rats were recorded, but relatively high rat and mice indices were recorded in winter 2018, possibly indicating autumn rat tracking rates would have been high also. This is supported by the chew card indices for rats, which indicated a higher relative abundance from autumn 2018 through to summer 2019 before chew rates declined. Climate change projections for Otago indicate an increase in annual mean temperatures and more hot days by 2090[26], which could result in more frequent increases in rodent abundance.

Hedgehogs

There are no standardised methods for measuring hedgehog relative abundance in New Zealand and it was uncertain whether 1 night of tracking would provide an accurate picture of relative abundance for this species. Therefore, two relative abundance indices were calculated for hedgehogs in the Inner Halo: 1-night and 21-night tracking rates. Both indices confirmed that hedgehogs were present in all three habitat types and that Lines 2 and 3 had the highest relative abundance. However, while the 1-night index did not show an obvious habitat preference, the 21-night index showed more clearly that relative abundances were higher in pastoral farmland and exotic forest habitats compared with indigenous forest. Although another study also found hedgehogs were more abundant in older exotic plantations compared with indigenous forest[27], it is unknown whether this reflects a real habitat preference. There is a lack of published studies using 1 or 21-night tracking tunnel indices with which to compare the relative abundances from this study.

Mustelids and cats

One-night and 21-night indices detected mustelids on only four lines in the Inner Halo over the two years of this study. Stoats (and/or possibly a weasel) were detected from Lines 1, 2 and 10; ferrets (and/or possibly a stoat) were detected on Line 5. Line 2 in exotic forest had the highest relative abundance of mustelids.

Tracking rates suggest that stoat relative abundance in the Inner Halo is low. However, stoats are regularly trapped in the Inner Halo. Several stoats were caught in the vicinity of Lines 1, 3, 4, 5 and especially Lines 2 and 7 during the course of this study[28] and Orokonui Ecosanctuary has trapped more than 20 stoats around the outside of its fenceline each year from 2017-2019 (Orokonui Ecosanctuary, unpubl. data). Possibly stoat distribution is spatially patchy and the TT lines by chance did not sample in areas with higher stoat relative abundances. Alternatively, stoats were present but not detected by the TT. TT are unreliable

[26] NIWA. 2019. Climate change predictions for the Otago region. Report prepared for Otago Regional Council. www.orc.govt.nz.

[27] King CM et al. 1996. Distribution and abundance of small mammals in relation to habitat in Pureora Forest Park. NZ J Ecology, 20: 215–240.

[28] 1 April 2018 – 29 Feb 2020 data from Trap.NZ [accessed 29 May 2020].

for detecting stoats, especially when stoats are at low density[29], so this last explanation is likely to be a significant factor.

Ferrets are commonly found in open habitats and were expected to track tunnels along the four pastoral farmland lines more than the forest lines[30]. Ferrets were recorded only from along the pastoral farmland Line 5. With the exception of Line 5, tracking tunnel lines in pastoral farmland tended to run through the middle of pasture areas where there was little cover, and this might explain why ferrets were not detected more often[31]. It is also possible that low tracking rates reflected a low density of animals rather than poor detectability alone. This is supported by trap data that show few ferrets were caught in the Inner Halo during the course of this study[28].

Despite using 21 nights of TT monitoring instead of the standard 3 nights, mustelid detection remained low. Mustelids were detected in all four 21-night TT monitoring sessions and it took four sessions to record stoat presence on 3 lines. If monitoring sessions had lasted for 7 nights only, mustelids would have been recorded on just 2 lines in 2 sessions. Monitoring sessions lasting 14 nights would have recorded mustelids on 3 lines in 3 of the sessions. This indicates that increasing the number of nights per monitoring session was beneficial for detecting stoats and that 14 or more nights of monitoring are warranted. However, the logistical feasibility of using TT monitoring periods longer than 14 days needs to be considered.

In August 2019, 6 months after the final 21-night monitoring period of this study, a trial camera trap study was undertaken where 3 cameras were placed along each of the TT lines for approximately 3 weeks[32]. On the whole, the camera trap study supported the TT monitoring findings that ferrets and stoats in the Inner Halo were present at relatively low levels overall and/or are difficult to detect, and that stoat relative abundance was higher in forest sites and along Line 2 in particular. But the camera study provided evidence that stoat presence was more widespread in indigenous forest sites than the TT monitoring had shown 6 – 18 months prior. Clearly, monitoring mustelids with camera traps is more effective and efficient in terms of detection rates and time spent in the field compared with TT monitoring, but looking through photos is resource demanding and requires expertise, which might limit community involvement in pest monitoring if cameras are the primary monitoring tool used in the future.

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[29] Smith DHV & Weston KA. 2017. Capturing the cryptic: a comparison of detection methods for stoats (*Mustela erminea*) in alpine habitats. Wildlife Research, 44: 418–426.

[30] Clapperton BK. 2001. Advances in New Zealand mammalogy 1990-2000: Feral ferret. Journal of the Royal Society of New Zealand, 31(1): 185–203.

[31] Ragg JR & Moller H. 2000. Microhabitat selection by feral ferrets (Mustela furo) in a pastoral habitat, East Otago, New Zealand. NZ J Ecology, 24: 39–46.

[32] Veale AJ. 2019. Review of camera trapping pilot study and recommendations for monitoring mustelids in the Halo. Unpublished Predator Free Dunedin report.

TT detected feral cats from two indigenous forest lines and possibly from a third. The three lines had relatively high tracking rates of rats and/or mice at the time, which might explain the cat presence there. However, cats were not recorded from exotic forest Line 2, which also had high rodent indices. Cats were recorded in TT that were over 250 m from the forest edge. Line 10 went through relatively open forest (with the understorey recently decimated by wild pigs *Sus scrofa*) and Line 9 followed a walking track which allowed easy access into the bush. Line 7 on the other hand, went through forest with a reasonable amount of understorey.

Trail cameras are an effective method for detecting cats and the camera trap study in August 2019 recorded them from 6 lines on 27 occasions[32]. Half of the sightings were from Line 9 alone, but there were 8 sightings along pastoral farmland Line 3 also. The other lines where cats were recorded were exotic forest Line 1, pastoral farmland Line 6, and indigenous forest Lines 7 and 10.

Chew cards indices for possums

Chew cards detected possums on between 10 and 50% of monitoring lines during the course of this study with highest possum relative abundance on indigenous forest Lines 7 and 9. On Line 9, at the northern edge of Port Chalmers, possum relative abundance regularly exceeded 50%. OSPRI has been undertaking possum control in the Inner Halo since 2018 and this is reflected in the general low levels of possum bite indices at the other 8 lines. But the OSPRI possum control area does not include Port Chalmers township.

The camera trap study recorded half of the possums (25) along pastoral farmland Line 3 over three weeks, but on no other pasture lines[32]. Of the forested lines, Lines 2 and 9 had the highest number of sightings, followed by Lines 1, 7 and 8. In contrast, CC on Line 3 were bitten by possums on only four occasions over the duration of this study. Possibly possums were adverse to going too close to the electrified fence that the CC were attached to (although it is unknown how often this fence was 'live') or there was a flurry of possum activity at this site during August 2019.

High levels of possum activity in an area can result in lower rat relative abundances being measured either because possums outcompete rats for resources resulting in fewer rats being present, or because rat behaviour is altered resulting in reduced detectability[33]. With the latter, low rat abundance indices might not be correlated with low rat densities. Examining the rat TT and CC indices obtained in this study on the two lines with the highest possum relative abundances gave no reason to think that possum levels had affected rat tracking rates. However, rat CC indices were reduced when possum relative abundances ≥80%. This was possibly as a result of possum interference with the CC before rats could bite

[33] Griffiths JW & Barron MC. 2016. Spatiotemporal changes in relative rat (*Rattus rattus*) abundance following large-scale pest control. NZ J Ecology, 40: 371–380.

them. Rat indices from CC set for 8 nights therefore are not a reliable indicator of rat density when possum relative abundance is high.

Recommendations for future monitoring

It is recommended that rodent monitoring is expanded in the Halo area. Ship rats, stoats and possums are the introduced predators having the most impact on native species in NZ forests[34]. Predator Free Dunedin focus is on the control of stoats and possums, but it is important to consider the damage high levels of rats have on indigenous flora and fauna. Ship rats can be responsible for high levels of nest predation and have been implicated in dramatic declines in robin, mohua, bat and invertebrate populations in the South Island[35]. If rodent populations in the Halo fluctuate widely, then indigenous species might be more at risk from predation following rodent population declines if mustelids and cats, the main rodent predators, are forced to switch to alternative food sources[36]. Furthermore, it is unknown whether sustained stoat and possum control in the Halo area may lead to increased rodent numbers over time because of a mesopredator release[37].

This study was designed to monitor mustelids and so TT lines were set up a minimum of 1 km apart. Because rats have smaller home ranges than mustelids and can be patchily distributed through the landscape, effective rodent monitoring requires the use of more monitoring devices spaced closer together. DOC guidelines suggest using 15-20 TT lines a minimum of 200 m apart to monitor rodents in an area the size of the Inner Halo[38].

It is recommended to target rats for control in areas where tracking rates regularly exceed 30%. Rodent monitoring at these sites is considered essential for assessing the effectiveness of the control measures. Self-resetting A24 traps have been deployed recently (1 per ha) in the 178 ha Mihiwaka area in the vicinity of Lines 2 and 7. DOC guidelines suggest operating 6 – 8 rodent monitoring lines for areas <300 ha in size. The shape and topography of the Mihiwaka site mean that only 4 or 5 monitoring lines might be possible. As with all standardised rodent TT monitoring, lines should be more than 200 m apart at their closest point and sample representative habitat. For more statistical power to compare effects of predator control, rodent monitoring should include non-treatment sites without rodent control.

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Future predator monitoring should target habitats of interest and species of interest. Pastoral farmland habitat had low levels of rodents and mustelids and therefore future monitoring for these predators should focus on forest sites. However, predator monitoring (including for hedgehogs), is recommended for non-forest habitats that support populations of indigenous species, for example lizards, which are vulnerable to predation.

Examining relative abundance indices for rats in the presence of possums suggests it would be advisable to monitor rats using tracking tunnels rather than chew cards if possum activity is expected to be high.

Tracking tunnels are not recommended for monitoring mustelids in the Inner Halo. However, if they are used in the future then running them for at least 14 nights is recommended to increase the number of stoat detections.

Relative abundance indices of predators, such as those obtained from tracking tunnels and chew cards, are just one tool for informing managers of the effectiveness of predator control measures. The indices assume that detectability remains constant across space and time but this might not be the case in reality. Therefore, to assess the effectiveness of predator control it is recommended that predator monitoring be undertaken in conjunction with biodiversity outcome monitoring (e.g. nest monitoring) of indigenous species.

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Appendix A: Tracking tunnel indices

Table A.1: Summary of 1-night TT indices (proportion of TT per line tracked by each species in 1 night of monitoring using peanut butter as bait). Habitat: Exotic = exotic forest; Indigen = indigenous forest and scrub. Abbreviations: N/A = TT not set.

Monitoring session	Line	Habitat	Rat	Mouse	Hedgehog	Possum	Mustelid	Cat	Unident.
Autumn 2018	L1	Exotic	0	0.89	0	0	0	0	0
	L2		0	0	0	0	0	0	0
	L3	Pasture	0	0.15	0	0	0	0	0
	L4		0	0	0	0	0	0	0
	L5		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	L6		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	L7	Indigen	0	0.11	0	0	0	0	0
	L8		0	0.2	0	0	0	0	0.1
	L9		0	0.14	0	0	0	0	0
	L10		0	0.5	0	0	0	0	0
Winter 2018	L1	Exotic	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	L2		0.7	0.7	0	0	0	0	0
	L3	Pasture	0	0	0	0	0	0	0
	L4		0	0.3	0	0	0	0	0.1
	L5		0	0	0	0	0	0	0
	L6		0	0	0	0	0	0	0
	L7	Indigen	0.7	0.1	0	0	0	0	0
	L8		0.2	0.7	0	0	0	0	0
	L9		0.1	0.1	0	0	0	0	0
	L10		0	0.6	0	0	0	0	0
Spring 2018	L1	Exotic	0	0	0	0	0	0	0
	L2		0	0.6	0.2	0	0	0	0
	L3	Pasture	0	0	0.1	0	0	0	0.1
	L4		0	0.4	0.1	0	0	0	0
	L5		0.1	0	0.1	0	0	0	0.2
	L6		0	0	0	0	0	0	0
	L7	Indigen	0.7	0	0.1	0	0	0	0
	L8		0	0.3	0	0	0	0	0
	L9		0.21	0.21	0	0.11	0	0	0.21
	L10		0	0.4	0	0	0	0	0
Summer 2019	L1	Exotic	0.1	0	0	0	0	0	0
	L2		0.1	0.1	0.1	0	0	0	0
	L3	Pasture	0	0.1	0.3	0	0	0	0
	L4		0	0.1	0.1	0	0	0	0
	L5		0	0	0.11	0	0	0	0
	L6		0	0	0	0	0	0	0
	L7	Indigen	0.3	0	0.2	0	0	0	0
	L8		0	0	0	0	0	0	0
	L9		0.1	0.2	0.2	0.2	0	0	0
	L10		0.11	0	0.11	0	0	0	0
Autumn 2019	L1	Exotic	0	0.2	0.1	0	0	0	0
	L2		0.2	0.3	0.5	0	0	0	0
	L3	Pasture	0	0.1	0	0	0	0	0
	L4		0	0.2	0	0	0	0	0
	L5		0	0	0.1	0	0	0	0
	L6		0	0	0	0	0	0	0
	L7	Indigen	0.7	0	0	0	0	0	0
	L8		0.1	0.6	0	0	0	0	0
	L9		0.33	0.11	0	0	0	0	0
	L10		0.1	0.1	0.1	0	0	0	0

Monitoring session	Line	Habitat	Rat	Mouse	Hedgehog	Possum	Mustelid	Cat	Unident.
Winter 2019	L1	Exotic	0	0.5	0	0	0	0	0
	L2		0	0.1	0	0	0	0	0
	L3	Pasture	0	0.25	0	0	0	0	0
	L4		0	0.2	0	0	0	0	0
	L5		0	0	0	0	0	0	0
	L6		0	0.2	0	0	0	0	0
	L7	Indigen	0.4	0	0	0	0	0	0
	L8		0	0.7	0	0	0	0	0
	L9		0.2	0.1	0	0.4	0	0	0
	L10		0	0.4	0	0	0	0	0
Spring 2019	L1	Exotic	0	0.2	0	0	0	0	0
	L2		0.1	0.6	0.2	0	0	0	0
	L3	Pasture	0	0	0.44	0	0	0	0
	L4		0.1	0	0	0	0	0	0
	L5		0	0	0.1	0	0	0	0
	L6		0	0	0	0	0	0	0
	L7	Indigen	0.42	0.21	0.11	0.11	0	0	0
	L8		0	0.9	0	0	0	0	0
	L9		0.56	0	0.11	0	0	0	0
	L10		0	0	0	0	0	0	0
Summer 2020	L1	Exotic	0	0.9	0.5	0	0	0	0
	L2		0.3	0.5	0.1	0	0	0	0
	L3	Pasture	0	0.1	0.3	0	0	0	0
	L4		0.1	0.1	0.2	0	0	0	0
	L5		0	0	0	0	0.2	0	0
	L6		0	0.1	0	0	0	0	0
	L7	Indigen	0.6	0.1	0.1	0	0	0	0
	L8		0.1	0.8	0	0	0	0	0
	L9		0.44	0	0	0.22	0	0	0
	L10		0	0.4	0.3	0	0	0	0

Table A.2: Summary of 21-night TT indices (proportion of TT per line tracked by each species in 21 nights of monitoring using fresh rabbit meat as bait). Habitat: Exotic = exotic forest; Indigen = indigenous forest and scrub. Abbreviations: N/A = TT not set; * = 22 nights of monitoring.

Monitoring session	Line	Habitat	Rat	Mouse	Hedgehog	Possum	Mustelid	Cat	Unident.
Autumn 2018	L1	Exotic	0.20	0.67	0.13	0	0	0	0
	L2		0.6	0.87	0.4	0	0.07	0	0
	L3	Pasture	0	0.2	0.6	0	0	0	0
	L4		0.07	0.44	0.39	0	0	0	0
	L5		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	L6		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	L7	Indigen	0.53	0.33	0	0	0	0.27	0.07
	L8		0.14	0.76	0	0	0	0	0
	L9		0.28	0.14	0.14	0	0	0	0.21
	L10		0.33	0.67	0.14	0	0	0	0
Winter 2018	L1	Exotic	0.07	0.4	0	0	0	0	0
	L2		0.87	0.53	0	0	0.07	0	0
	L3	Pasture	0.2	0	0	0	0	0	0
	L4		0	0.7	0	0	0	0	0.07
	L5		0	0	0	0	0.14	0	0
	L6		0	0	0	0	0	0	0
	L7	Indigen	0.8	0.07	0	0.07	0	0	0
	L8		0.33	0.6	0	0	0	0	0
	L9		0.53	0.2	0	0	0	0	0.13
	L10		0.07	0.73	0	0	0	0	0
Spring 2018	L1	Exotic	0.28	0.27	0.6	0	0	0	0.14
	L2*		0.07	0.73	0.53	0	0.14	0	0.07
	L3	Pasture	0	0	0.4	0	0	0	0.2
	L4		0.07	0.53	0.2	0	0	0	0.07
	L5		0	0.2	0	0	0	0	0
	L6		0	0	0	0	0	0	0
	L7	Indigen	0.93	0.16	0.16	0	0	0	0
	L8		0.53	0.4	0	0	0	0	0
	L9		0.73	0.53	0	0	0	0	0
	L10		0.13	0.73	0	0	0	0.27	0.13
Summer 2019	L1	Exotic	0.2	0	0.33	0	0.07	0	0
	L2		0.33	0.33	0.67	0	0.07	0	0.13
	L3	Pasture	0	0.2	0.53	0	0	0	0.2
	L4		0	0.33	0.53	0	0	0	0
	L5		0	0.2	0.67	0	0	0	0.07
	L6		0	0	0.27	0	0	0	0
	L7	Indigen	0.33	0	0.2	0	0	0.07	0.27
	L8		0	0.4	0	0	0	0	0
	L9		0.07	0.27	0.34	0	0	0	0.07
	L10		0	0.07	0.07	0	0	0.07	0.07

Appendix B: Chew card indices

Table B.1: Summary of 8-night CC indices (% of available CC bitten per line) for rats *Rattus* spp. for 10 monitoring lines in the Inner Halo. ( ) = number of available chew cards; N/A = no data; * = 7 nights of monitoring.

Line #	Autumn 2018	Winter 2018	Spring 2018	Summer 2019	Autumn 2019	Winter 2019	Spring 2019	Summer 2020
L1	10% (10)	10% (10)	40% (10)	10% (10)	0% (10)	0% (10)	20% (10)	0% (10)
L2	40% (10)	80% (10)	44% (9)	11% (9)*	0% (10)	12% (8)	11% (9)	20% (10)
L3	0% (10)	0% (10)	0% (10)	10% (10)	0% (10)	0% (10)	0% (10)	0% (10)
L4	0% (10)	0% (10)	0% (10)	0% (10)	0% (10)	0% (9)	0% (10)	0% (9)
L5	N/A	0% (10)	0% (9)	0% (10)	0% (10)	0% (10)	0% (7)	0% (5)
L6	N/A	0% (4)	0% (4)	0% (9)	0% (10)	0% (9)	0% (10)	0% (10)
L7	60% (10)	80% (10)	100% (10)	80% (10)*	50% (10)	22% (9)	89% (9)	100% (9)
L8	10% (10)	30% (10)	70% (10)	0% (10)	0% (10)	0% (10)	0% (10)	0% (10)
L9	11% (9)	0% (10)	30% (10)	20% (10)	0% (6)	0% (10)	40% (10)	0% (9)
L10	20% (10)	10% (10)	10% (10)	0% (10)	0% (10)	0% (10)	0% (10)	0% (10)

Table B.2: Summary of 8-night CC indices (% of available CC bitten per line) for mice (*Mus musculus*) for 10 monitoring lines in the Inner Halo. ( ) = number of available chew cards; N/A = no data; * = 7 nights of monitoring.

Line #	Autumn 2018	Winter 2018	Spring 2018	Summer 2019	Autumn 2019	Winter 2019	Spring 2019	Summer 2020
L1	50% (10)	70% (10)	30% (10)	0% (10)	60% (10)	100% (10)	40% (10)	70% (10)
L2	30% (10)	40% (10)	55% (9)	44% (9)*	100% (10)	87% (8)	89% (9)	80% (10)
L3	10% (10)	0% (10)	0% (10)	0% (10)	0% (10)	0% (10)	0% (10)	20% (10)
L4	40% (10)	20% (10)	30% (10)	30% (10)	50% (10)	11% (9)	10% (10)	0% (9)
L5	N/A	0% (10)	0% (9)	0% (10)	10% (10)	0% (10)	0% (7)	0% (5)
L6	N/A	0% (4)	0% (4)	0% (9)	20% (10)	0% (9)	0% (10)	0% (10)
L7	40% (10)	10% (10)	40% (10)	10% (10)*	10% (10)	22% (9)	22% (9)	0% (9)
L8	90% (10)	80% (10)	20% (10)	60% (10)	70% (10)	80% (10)	90% (10)	100% (10)
L9	22% (9)	20% (10)	30% (10)	0% (10)	0% (6)	20% (10)	20% (10)	0% (9)
L10	70% (10)	80% (10)	40% (10)	0% (10)	0% (10)	70% (10)	10% (10)	70% (10)

Table B.3: Summary of 8-night CC indices (% of available CC bitten per line) for hedgehog/mustelid/other (excluding stock) for 10 monitoring lines in the Inner Halo. ( ) = number of available chew cards; N/A = no data; * = 7 nights of monitoring.

Line #	Autumn 2018	Winter 2018	Spring 2018	Summer 2019	Autumn 2019	Winter 2019	Spring 2019	Summer 2020
L1	0% (10)	0% (10)	0% (10)	10% (10)	0% (10)	0% (10)	0% (10)	10% (10)
L2	0% (10)	0% (10)	22% (9)	0% (9)*	0% (10)	0% (8)	11% (9)	0% (10)
L3	0% (10)	0% (10)	0% (10)	10% (10)	0% (10)	0% (10)	0% (10)	50% (10)
L4	20% (10)	0% (10)	0% (10)	20% (10)	0% (10)	11% (9)	10% (10)	33% (9)
L5	N/A	0% (10)	30% (9)	0% (10)	10% (10)	0% (10)	0% (7)	20% (5)
L6	N/A	0% (4)	0% (4)	0% (9)	0% (10)	0% (9)	0% (10)	0% (10)
L7	30% (10)	20% (10)	0% (10)	0% (10)*	0% (10)	0% (9)	0% (9)	0% (9)
L8	0% (10)	0% (10)	0% (10)	0% (10)	0% (10)	0% (10)	0% (10)	0% (10)
L9	0% (9)	0% (10)	10% (10)	0% (10)	0% (6)	0% (10)	10% (10)	0% (9)
L10	0% (10)	0% (10)	0% (10)	0% (10)	0% (10)	0% (10)	0% (10)	0% (10)