Modelling the habitat–capture relationship of ship rats (*Rattus rattus*) on the Forest & Bird Makarora-Haast Pass trap network

Report prepared for Forest & Bird, Central Otago Lakes (COLB) branch

Image: Muddy Creek seen from the Boat Line

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Summary

This report was produced as part of the Forest & Bird Central Otago Lakes (COLB) project "Why do some rat traps catch more rats?", funded by the Curious Minds Participatory Science Platform. This research aimed to investigate the relationship between ship rat captures and micro-habitat factors on the Makarora-Haast Pass trap network. There has been limited research into this relationship within New Zealand environments, particularly beech forests, and current information suggests that regional variation plays a large role in what habitat factors are significant. Therefore, there is a need for a Makarora-specific study to inform future trapping practices within the area.

Vegetation and geological surveys were conducted for 96 of the 302 DOC 150/200 traps active in the network. Factors relating to beech trees (density and DBH) and the presences of several understory species were measured within a 20-metre radius around each trap, along with distances to natural and artificial features (such as water sources). These were then compared to corrected trapping index (CTI) values calculated from historical trapping data collected from 2017–2020. Selected factors were then inputted into a negative binomial generalized linear model, and stepwise AIC selection was undertaken to refine the model.

It was found that the density of mature beech trees and the presence of several plant species (round-leaf coprosma, horopito, and wineberry) were related to CTI values. The results are somewhat consistent with previous research in beech research, though the effect of regional variation appears to be reinforced. Overall, the results can provide some more guidance for future COLB trap-work, though additional research using an experimental design may be necessary to gain a more thorough picture of the nature of habitat-capture relationships in Makarora.

Background

Introduced mammalian predators pose serious threats to New Zealand's indigenous biodiversity (Dowding & Murphy, 2001; O'Donnell et al., 2017), having been implicated in the population declines of several species (Innes et al., 2010). In response, government agencies and other various groups have been implementing measures to control predator populations throughout the country (Russell & Stanley, 2018). At present, control measures for small mammals, such as rodents and mustelids, primarily consist of kill-trapping and poisons, either through aerial drops or bait stations (Parkes et al., 2017).

Trapping has become a way for communities to get involved with local conservation efforts (e.g. Shanahan et al., 2018). One such example is the Central Otago Lakes branch (COLB) of Forest & Bird, which actively manages a trap network throughout the Makarora Valley. The major drawback to trapping, however, is cost: ground control measures can cost considerably more per hectare than aerial control (Parliamentary Commissioner for the Environment, 2011). Recent technological developments have looked to increase the efficiency and effectiveness of traps. Such examples include self-resetting traps, which ideally would reduce the labour costs involved with regularly checking traditional single-catch traps (Carter et al., 2016). However, another potential way to increase the effectiveness of trap networks is to optimise the placement of trap networks, to target higher densities of mammalian predators. Detection devices such as tracking tunnels and chew-cards can indicate the relative abundances of introduced mammals (Gillies, 2013). However, the costs of implementing these devices could potentially be avoided by examining habitat around current trap sites – from which factors that may be linked to higher rat captures could be inferred. COLB received funding from the Curious Minds Participatory Science Platform to explore whether this can be achieved for the Makarora Valley. This report documents the outcome of that work.

At present, there is relatively little literature available that investigates the relationship between rat captures and habitat factors between trap sites in New Zealand environments. One study has suggested that the structural complexity of forests may influence ship rat abundances (Harper et al., 2005). Christie et al. (2006) conducted an exploratory analysis of trap capture data for two hardwood–podocarp forests. Factors were mostly measured as binary variables (presence/absence). The general findings were that many factors contributed to trapping capture patterns, including canopy and sub-canopy heights, forest maturity, and edge effects (Christie et al., 2006). Interestingly, the study found no effect of slope on

captures, different to the findings made by King et al. (1996), where traps on steeper slopes in tawa-podocarp forest tended to catch more ship rats. This suggests a degree of regional variation may be at play with habitat–capture relationships.

Other research has focused on beech forest specifically. At Nelson Lakes National Park, it was found that elevation played a role in rat captures, which was thought to be linked to altitudinal patterns of beech seed production (Christie et al., 2017). A separate study by Metsers (2007) explored habitat factors in considerable detail, within several beech-dominated valleys of the Mt. Aspiring National Park. Rather than adopting the presence/absence approach of Christie et al. (2006), they incorporated height tiers and abundances into their modelling. Their best predictive model suggested relationships between rat captures and the ground-level abundances of beech and *Coprosma* plants. However, they found that habitat–capture relationships varied significantly between sites, preventing broad generalisations about beech forests as a whole (Metsers, 2007). Overall, it appears unlikely that conclusions from other locations, even within the same habitat, can be applied to the COLB trap network, necessitating the need for a Makarora-specific study.

The geological factors in Christie et al. (2006) were generally measured at a scale of 50 m, while vegetation factors were measured at a 100 m scale. Depending on the number of variables to be measured, such a scale may be impractical for pest managers and trappers to conduct widespread surveys with. Additionally, they concluded that this scale may be too broad to identify relationships with finer-scale aspects of the habitat (Christie et al., 2006). As a result, the additional aim of this research was to investigate if significant habitat factors could be identified at a comparatively smaller scale, to enable the Forest & Bird COLB to more easily survey new trap locations. Furthermore, the factors were to be measured in simple variables that could be easily measured by volunteers (e.g. presence/absence) or estimated through GIS software (e.g. distance to natural/artificial features, elevation).

Methods

Study site

The study concentrated on a network of traps managed by the Forest & Bird Central Otago Lakes branch (COLB) within the Makarora Valley and Haast Pass areas, Otago (Figure 1). The Makarora Valley follows the Makarora River as it flows southwest into the northern end of Lake Wanakā. Significant rivers of the Makarora River catchment include the Blue

and Young Rivers. Most of the valley lies within the Mt. Aspiring National Park. Forest vegetation is prominent throughout the valley, mainly consisting of silver beech *Nothofagus menziesii* (Wardle, 2001). Common understory plants include *Coprosma* spp., horopito *Pseudowintera colorata* and weeping mapou *Myrsine divaricata* (pers. obs.). Tōtara *Podocarpus laetus* and mountain toatoa *Phyllocladus alpinus* are also present (Wardle, 2001).

Much of the lowland areas in the southern half of the valley are farmed. Some formerly farmed areas, such as at Cameron Flat, are in various stages of succession, such as bracken fern. State Highway 6 runs along the eastern side of the Makarora River and up through the Haast Pass. The highway runs through the small village of Makarora, at the base of Mt. Shrimpton.
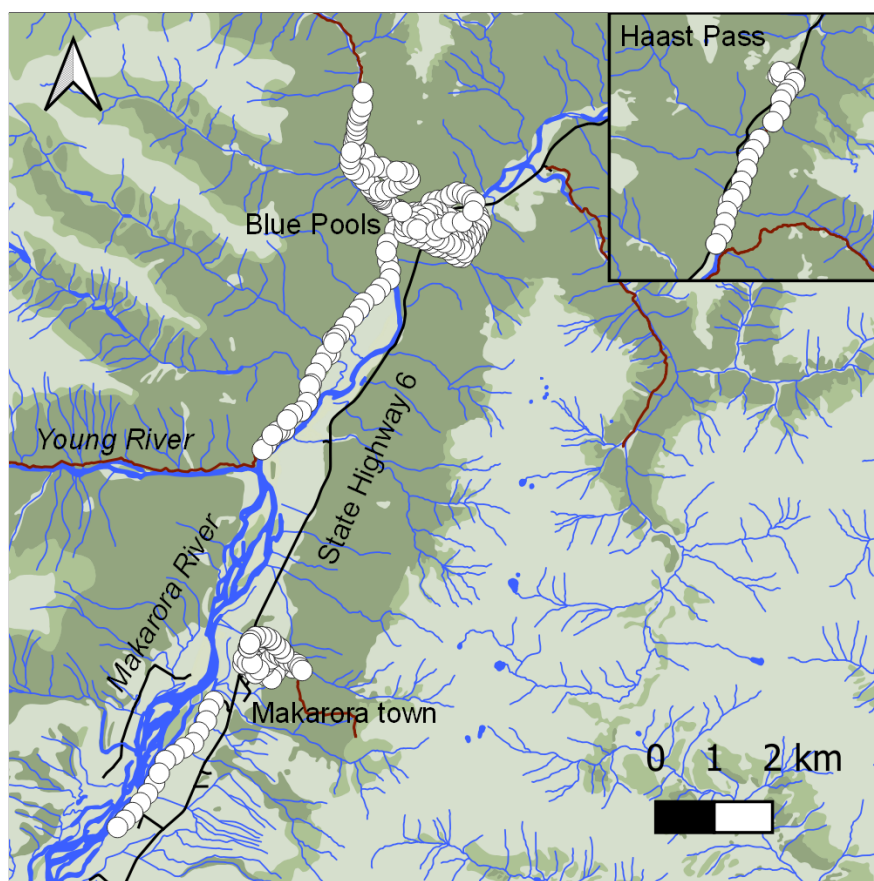

Figure 1.   Map of the Makarora Valley, showing the Forest & Bird trap network (white circles), roads (black), and major walking tracks (brown).

The Makarora-Haast Pass Forest & Bird trap network consists of a total of 302 DOC 150/200 traps over 13 trap lines, grouped into three general areas: the township area (Makarora River, Nature Walk, Jack Lange, Pipson Creek Grid, Wonder Line), the Blue Pools

area (Blue-Young, Blue Loop, Boat Line, Cameron-Blue, Camp Flat, Muddy Creek Grid), and the Haast Pass area (Bridle Track, Haast Pass Lookout). Two of the lines are laid in a grid format (Muddy Creek and Pipson Creek), whereas the other trap lines generally follow walking or tramping tracks (e.g. Blue-Young, Camp Flat, Haast Lookout) or natural features (e.g. Makarora River). Trapping work was initiated in the 1990s, with additional lines having been added in subsequent years (Wildland Consultants, 2020). The network utilises a mix of trap types, including traditional DOC 150/200 traps (both single and double units) and self-resetting GoodNature™ traps. Data from the latter traps were not used in this analysis; as they are self-resetting, it was often impossible to know what animal had been caught. Based on catch data, it is assumed that the main species of rat in Makarora is the ship rat *Rattus rattus*, although one kiore *R. exulans* was caught in 2006 near Haast Pass (Golding & Harper, 2008).

Trap surveys

Many of the traps in the network did not meet the criteria for sampling. Traps were not sampled if they did not have catch data going back to at least August 2017. The two grid lines (Muddy Creek, Pipson Creek) were not surveyed due to the difficulty in accounting for the grid effect (i.e. the difference in catch rate between traps on the outside of the grid vs. traps in the centre of the grid). Overall, surveys were conducted for 101 traps. However, some surveys were excluded due to missing data ($n = 4$) or having had caught no rats in the 2017–20 time period ($n = 1$). The latter would have created issues when used in the negative binomial regression, as the logarithm of zero cannot be taken. Therefore, only 96 surveys could be used in the analysis, consisting of the Blue-Young ($n = 33$), Boat Line ($n = 35$), Bridle Track ($n = 20$), Camp Flat ($n = 5$), and Haast Pass Lookout ($n = 3$) lines. This represented 31.7% of the total DOC 150/200 trap network in Makarora.

For each of the sampled trap locations, vegetation and geological surveys were completed. Vegetation surveys were conducted within a 20-metre radial plot, while geological variables were measured immediately around the trap location. Initially, the vegetation survey was conducted as a modification of the 'Recce' survey (described in Hurst & Allen, 2007). All species present within the plot were recorded, along with the respective height tiers they were present in. In addition, notes were made about the topography (e.g. undulation, slope) immediately surrounding each site. These surveys were conducted for about 30 traps, with the data being used in an exploratory analysis to suggest factors to be

measured in a refined survey. This survey was subsequently used to assess the remainder of the trap sites. The refined vegetation survey generally took 30 minutes per trap site. A copy of the trap site survey is included in Appendix A.

Plant species

For the remainder of the surveys, the height tier system described in the Recce method was simplified to 5 tiers: A (ground cover, <0.3 m), B (shrubs, 0.3–2 m), C (small trees, 2–5 m), D (larger trees, 5–12 m), and E (canopy and emergents, 12+ m). Relative abundance of plants within the survey plots was not recorded because this was likely to have significantly changed over the survey period, particularly for ground-cover species. Additionally, there were concerns over possible observer error resulting from subjectivity. Because *Coprosma* spp. were nearly ubiquitous throughout the plots, it was decided not to group them as Metsers (2007) had done. Rather, two common and easy-to-identify species were selected to represent the group: round-leaf coprosma *C. rotundifolia* and karamū *C. lucida*.

Beech trees

Beech trees (Nothofagaceae) were measured in detail due to their importance to the ecology of ship rats. Ship rats are arboreal and will typically den in beech trees (Pryde et al., 2005). Furthermore, beech masting events (mass seeding events) have been linked to large increases in ship rat populations (King & Moller, 1997). Within each survey plot, the number of beech trees taller than 2 m was recorded and grouped into two size classes: 'younger' trees (<200 mm DBH) and 'mature' trees (≥200 mm DBH). A square-root transformation was applied to the younger trees count as the data was skewed. The DBH of the largest beech tree in the plot was also recorded. As with other plant species, the height tiers were taken for beech.

Mistletoe

Beech trees are parasitised by mistletoes *Peraxilla* spp. (de Lange, 2021). Epiphytes can be used by ship rats as nesting spots (Hooker & Innes, 1995). I theorized that there also may be an indirect relationship between trap captures and the presence of mistletoes, based on the fact that the plants are primarily dispersed and pollinated by birds (Ladley & Kelly, 1995). If there is extensive predation of these pollinators by ship rats, then it may be expected that fewer mistletoes will be present around these areas (Robertson et al., 1999).

Geology

At each site, two aspects of the geology immediately surrounding the trap were recorded: landform and rock type. The landform was categorized into alluvial fan, flat terrace, bedrock, talus, rockfall, and road-fill. The rock type was categorized into sand, gravel, boulders, schist, and silt. These factors were measured as it was theorized that there may be an indirect link to rat populations – given that geology influences plant communities (Cottle), and may therefore impact what local food sources are available. However, these variables returned high variance inflation factor (VIF) values, so were excluded from the model fitting.

Topography

The distances from each trap site to the nearest water source (including streams, rivers, lakes and swamp) and the nearest road were calculated using QGIS 3.10 (QGIS Development Team, 2019). Water and road data were sourced from the LINZ Data Service (https://data.linz.govt.nz/), licensed for reuse under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

Slope data for each site was inferred from the NZSoSDEM v1.0 digital elevation model (Columbus et al., 2011), and square-root transformed. Elevation data were also collected, as Christie et al. (2017) found that rat captures decreased with increasing altitude in Nelson Lakes National Park. However, this could not be used as a variable in the analysis as the data was non-normal, and proved resistant to both log and square-root transformations.

Statistical analyses

Historical trapping data

Catch data from August 2017 to October 2020 was collected for each of the surveyed traps from the Animal Pests Trapping database managed by the Department of Conservation. A broad timeline was obtained to dilute the effects of seasonal behaviour among ship rats and the effect of an aerial 1080 poison drop that occurred in late-2019. A corrected trapping index (CTI) was calculated for each trap using Equation 1, as described in Cunningham et al. (1996):

$$\mathrm{CTI} = \frac{n_c}{\mathrm{TN}_c} \times 100$$

(1)

where n_c is the total number of ship rat captures, and TN_c is the corrected trap nights, calculated by using Equation 2:

$$\text{TN}_c = \sum_1^k (t_x - \frac{1}{2}t_x c_x)$$
$$= (t_1 - \frac{1}{2}t_1 c_1) + (t_2 - \frac{1}{2}t_2 c_2) + ... + (t_1 - \frac{1}{2}t_k c_k) \quad (2)$$

where t_x is the time period (nights) between the xth trap check and the $x - 1^{th}$ check, k is the total number of trap checks, and c_x is a binary value for the xth trap check where 1 = capture (including bycatch) or misfire, and 0 = no capture (i.e. trap still set). This formula corrects for the fact that a trap that has fired is no longer able to catch an animal until it is reset during the following trap session, assuming that a fired trap has been closed for half the time (Nelson & Clark, 1973). For 'double' traps (trap boxes with two traps, one at either end), the total corrected trap nights were summed for each trap, then combined along with the number of captures into a single CTI value.

The usage of the index for this study differs slightly from that of Cunningham et al. (1996), in that the original index was a measure of the combined trapping effort across an entire trap line throughout a single trapping session. In this study, the index is used to measure the trapping effort for a single trap for multiple trapping sessions.

Selection of initial predictor variables

A common rule-of-thumb for constructing linear regression models is the '1:10' rule, where a minimum of 10 samples per predictor variable is generally considered necessary to avoid biased coefficients (Peduzzi et al., 1996). Based on this rule, the study was limited to using ten predictor variables given the initial sample size of 100 traps. The level of detail within the survey necessitated combining and excluding certain variables. The final predictors selected for the initial model were based on two criteria: (1) perceived ecological/biological importance to ship rats, and (2) significant linear correlations with trap rate. Correlations were calculated using Pearson's (r) correlation coefficient. Variance inflation factors (VIF) were calculated for each predictor in the initial and final models using the *regclass* package (Petrie, 2020), as a test for multicollinearity. Table 1 lists the ten final variables.

Table 1.   Predictor variables used in the initial regression model.

Predictor	Code	Form
Number of mature beech trees in plot	BEECH_M	Count
DBH of the largest beech tree in plot, *mm*	DBH_LARGEST	Continuous
Presence of mistletoe *Peraxilla* sp. in plot	PERAXILLA	Binary
Presence of round-leaf coprosma *Coprosma rotundifolia* in plot	RL_COPROSMA	Binary
Presence of groundcover (<30cm) karamū *Coprosma lucida* in plot	KARAMU_GRD	Binary
Presence of marbleleaf *Carpodetus serratus* in plot	MARBLELEAF	Binary
Presence of broadleaf *Griselinea littoralis* in plot	BROADLEAF	Binary
Presence of sub-canopy (>30cm) horopito *Pseudowintera colorata* in plot	HOROPITO_SUBC	Binary
Presence of wineberry/mako *Aristotelia serrata* in plot	WINEBERRY	Binary
Distance to nearest water source, *m*	DIST_WATER	Continuous

Model construction and selection

I fitted the predictor variables to the capture rate data to a generalized linear model (GLM) with a negative binomial (NB-2) distribution in R 4.0.3 (R Core Team, 2021) using the *gamlss* package (Rigby & Stasinopoulos, 2005). A Poisson GLM was not used as the dataset was overdispersed. Because the data was in the form of a rate, an offset parameter $ln(100TN_c)$ was included to allow the model to account for the differences in trapping effort

between traps. After the initial model was fitted, a two-direction stepwise AIC selection process was used to select a final model. This was done using the stepAIC() function provided in the *MASS* package (Venables & Ripley, 2002).

Results

Trapping data

For the 97 surveyed traps, the median number of rat captures was 7 (range 1–25) over the period August 2017–October 2020. The median number of trap nights was 1160 (range 616–1493), giving a median corrected trapping index (CTI) of 0.70 captures/100 nights (range 0.09–2.1). Figure 2 presents a histogram of the CTI values, and a boxplot grouped by trap line. Because of the small sample size for the Haast Pass Lookout ($n = 3$) and Camp Flat ($n = 5$), interpretation of these lines shouldn't be attempted. The remaining lines appear to have relatively similar CTI values.
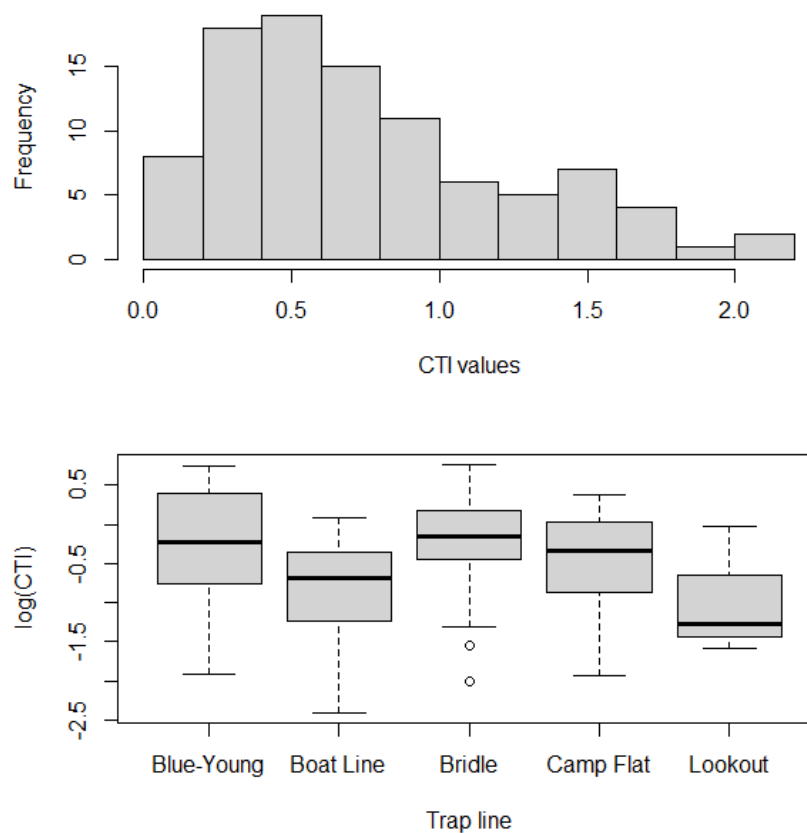
Figure 2.   Histogram of the corrected trap index (CTI) values for surveyed traps in the Makarora-Haast Pass trap network (top), and boxplot of the CTI values by trap line (bottom).

A map of the surveyed traps with respective CTI values is shown in Figure 3. Many of the larger CTI values came from traps on the Blue-Young and Bridle Track lines.
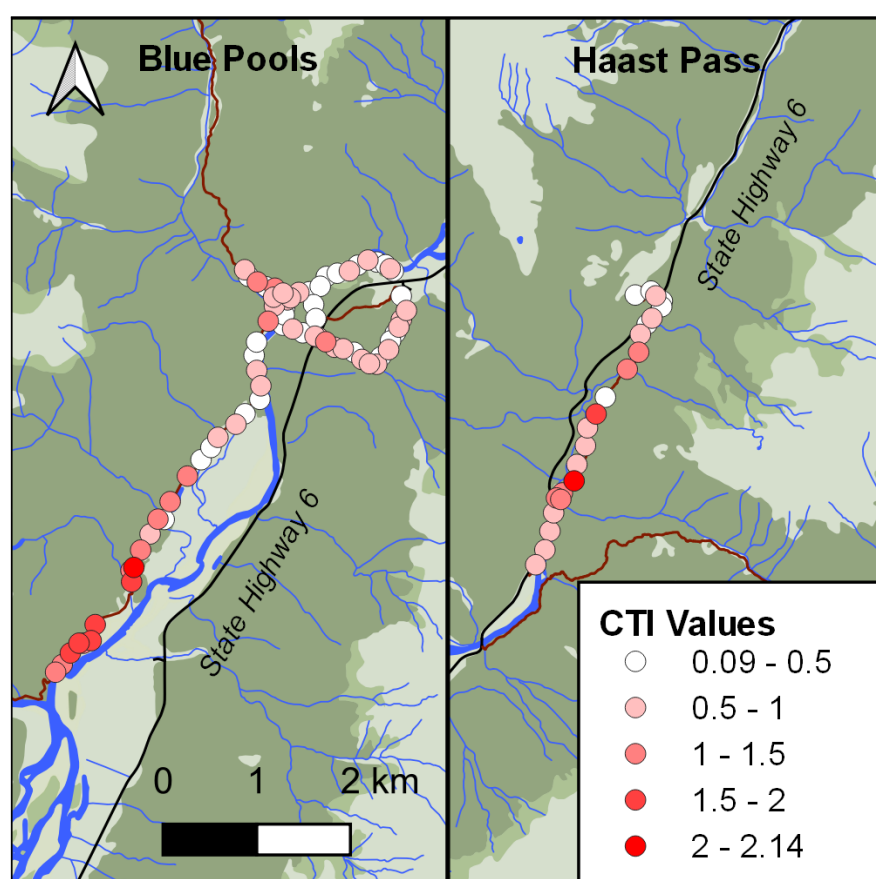

Figure 3.   Corrected trap index (CTI) values for surveyed traps in the Makarora-Haast Pass trap network.

Trap survey results

Figure 4 shows the Pearson's (r) correlation matrix between TRAP_RATE (the corrected trapping index, CTI) and the variables selected from the trap surveys for the initial model. BEECH_M, RL_COPROSMA, MARBLELEAF, WINEBERRY, HOROPITO_SUBC and KARAMU_GRD were found to have significant ($p < 0.05$) associations, although these were generally weak to moderate in strength. WINEBERRY had the strongest association with CTI ($r = 0.41$), closely followed by RL_COPROSMA ($r = 0.40$). All significant associations with CTI were positive, except for BEECH_M ($r = -0.33$) –

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suggesting that an increase in the density of 'older' (≥200 mm DBH) beech trees is associated with a decrease in CTI.
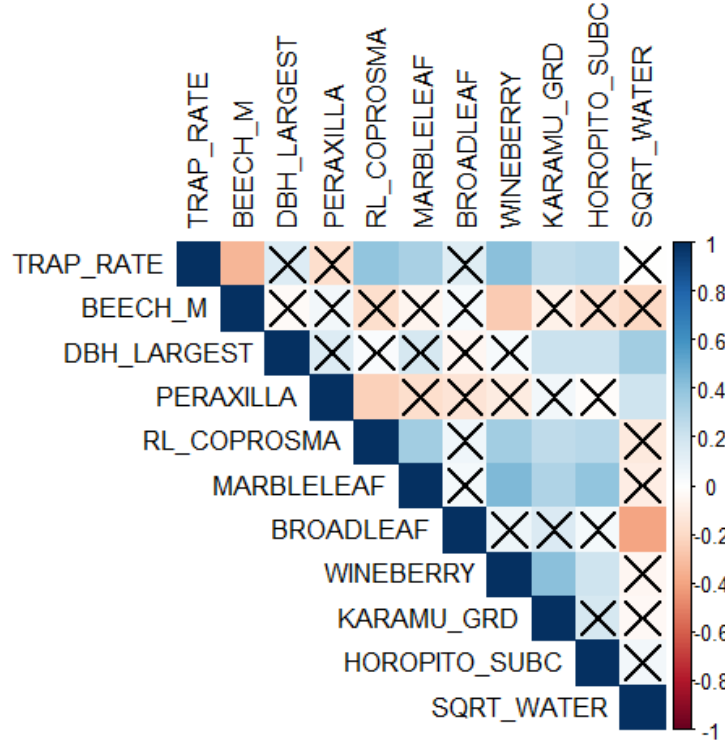

Figure 4.   Correlation matrix of the capture rate and selected predictor variables. Non-significant correlations (p > 0.05) are crossed out. Positive associations are shown in blue and negative associations in red, with colour intensity indicating the strength of the association.

Statistical analyses

After the initial NB2 generalized regression model was fitted with all of the initial predictors listed in Table 1, stepwise AIC selection was undertaken to determine the final model. This model is shown in Equation 3:

$$\text{CTI}_i = \text{NB}(\mu_i, k) \tag{3}$$

$$\text{E}(\text{CTI}_i) = \mu_i$$

$$log(\mu_i) = \beta_0 + \beta_1 \text{BEECHM}_i + \beta_2 \text{RLCOPROSMA}_i \\ + \beta_3 \text{HOROPITOSUBC}_i + \beta_4 \text{WINEBERRY}_i + \sigma_\varepsilon + log(\text{TN}_c 100_i)$$

where β_0 is the model intercept, β_j is the respective coefficient for variable j, σ_ε is the error and dispersion parameter, and $\log(TN_c 100_i)$ is the offset parameter.

The final 4-predictor model gave an AIC of 553.17, compared to the initial 10-predictor model's value of 559.97. Table 2 lists the final predictors with their respective estimates and statistics.

Table 2. Predictors used in the stepwise model with respective estimates, standard errors, *t*-values and p-values.

	Estimate	Standard error	t-value	*p*-value
Intercept	-0.567	0.170	-3.340	<0.01
BEECH_M	-0.0248	0.010	2.380	0.019
RL_COPROSMA	0.324	0.118	2.752	<0.01
HOROPITO_SUBC	0.260	0.150	1.734	0.086
WINEBERRY	0.320	0.126	2.536	0.012

Discussion

This study aimed to identify links between habitat factors and the rate of ship rat captures in the Makarora-Haast Pass trap network at a scale that could be approachable for trappers to optimise trap placement. Few relationships between vegetation factors and capture rate could be identified when measured within the immediate vicinity (20 m) of trap sites. Factors that appeared significant at this scale were the density of beech trees (with DBH ≥200 mm) and the presence of certain ground and sub-canopy plants (round-leaf coprosma, horopito, and wineberry). The distance of a trap site to a water source did not appear to have any association with the capture rate.

Metsers (2007) identified the abundance of beech (mountain beech *Fuscospora cliffortioides* and red beech *F. fusca*) and small-leaved *Coprosma* spp. as ground cover as

being relevant factors for trap capture elsewhere in the Mt. Aspiring National Park. These plant species were also found to be significant in this research, although differences in the measurements taken make comparisons difficult. At the least, the two studies seem to agree on the significance of coprosmas. In Makarora-Haast Pass, the presence of round-leaf coprosma (regardless of height tier) was associated with an increase in CTI. Metsers (2007) suggests that the association between coprosmas and captures may be an indirect relationship, where coprosma abundance reflects microclimate conditions caused by the structure of the beech canopy. The research at Makarora-Haast Pass found that the density of mature beech did negatively influence CTI. It is difficult to interpret the biological significance of this for rats, however, given that no other beech tree measure was found to be significant to CTI. Furthermore, my results do not add any weight to Metsers's theory, ass neither mature beech density nor DBH of the largest tree had any significant correlations with the presence of round-leaf coprosma. Potentially, mature beech density may instead either influence some other aspect of the understory structure (a positive correlation with wineberry was identified), or the availability of resources for rats up in the canopy, such as nesting sites. The amount of time that ship rats spend above ground seems to vary considerably: a tracking study in a kauri forest found that rats spent only 6.5% of their time in trees (Dowding & Murphy, 1994), whereas 73% of fixes from ship rats in a lowland forest were above ground (Hooker & Innes, 1995). A possibility is that the provision of more suitable nesting spots could increase the likelihood of a rat occupying that area; the resulting formation of a home range may then reduce the visitation of other rats to the trap site. Tracking studies have generally shown that male ship rat home ranges tend to overlap, but female home ranges tend to be more exclusive (Hooker & Innes, 1995), though this may be seasonally dependent (Dowding & Murphy, 1994). Ultimately, there is too little information here to make much interpretation about why this association is present. Future research may choose to integrate radio-tracking or explore other aspects of the beech canopy (such as light gaps).

Ship rats have an omnivorous diet, consisting of a mix of invertebrates & vertebrates (including birds and mammals), as well as plant material, including leaves, fruit, and seed (Clout, 1980; McQueen & Lawrence, 2008). In the lowland forest of the Orongorongo Valley, Daniel (1973) found that identified *Coprosma* spp. material contributed 4% to the winter diet of rats. Wineberry *Aristotelia serrata* was also consumed, though it contributed a smaller percentage. Another study in a podocarp-broadleaf forest found that fruit contributed to about a quarter of the diet of ship rats; of which, horopito was one of the most commonly consumed (Sweetapple & Nugent, 2007). All of the aforementioned species were found to have

significant relationships with capture rates in Makarora, however, it is unclear whether this is direct (i.e. due to food preferences) or indirect (e.g. presence of plants indicating some other habitat factor, such as microclimate). Tree fuschia *Fuchsia excorticata* and patē *Schefflera digitata* material was also found in ship rat stomachs (Daniel, 1973; Sweetapple & Nugent, 2007), though neither species occurred frequently enough in the survey plots to make meaningful inferences about potential associations to capture rates.

The lack of relationship between CTI and distance to water sources is consistent with the results of previous studies. The mean distance of trap sites to water sources was 97.7 m. The average home range length of ship rats in a kauri forest in Northland was 174 m (Dowding & Murphy, 1994), and 170 m in tawa/kohekohe forest in the Bay of Plenty (Hooker & Innes, 1995). It is therefore highly likely that ship rats would have ample access to water regardless of location in the Makarora Valley. Future research may choose to look at specific types of water sources (for example, the effect of proximity to a major river like the Makarora River as opposed to streams), as it may be related to plant community structure. However, this could be difficult to infer from the current trap network given that most trap sites are positioned near the river. The placement of experimental trap sites may be needed to explore this further in-depth.

The lack of a significant relationship between captures and the presence of mistletoes (*Peraxilla* spp.) could be explained by the survey scale. Given the relative lack of mistletoe plants in Makarora, it may be likely that differences between trap sites are a result of random chance, and that a broader scale is required to pick up any trends. This may also be true in regards to the populations of bird pollinators, as bellbirds can travel distances of over 500 m for food (Spurr & Borkin, 2010). Therefore, these effects may have to be explored at a trap-line scale. Additionally, other species in the ecosystem may play a more important role. Possums *Trichosurus vulpecula* have been found to negatively influence the distribution of mistletoe (Sessions et al., 2001), and so may play more of an important role in the presence of mistletoe in Makarora. Possum catch data may need to be analysed in conjunction with rat data to confirm or reject this hypothesis. Broadleaf *Griselinia littoralis* is also a common epiphyte in the Makarora beech forest, however, incorporating it into the dataset did not create a significant correlation with CTI. Ship rats can also nest in tree hollows (Hooker & Innes, 1995), so this may additionally explain why the capture rate is not affected by epiphyte presence.

While the analysis has indicated several habitat factors to be significant in the capture rates of ship rats in the Makarora trap network, caution is necessary when interpreting the

results. Because vegetation factors were only measured at the end of the capture data period, it could be expected that some of the measurements may have changed slightly over that period. Additionally, there may be a question of whether the detected associations would also be reflected in "pre-trap" populations. In other words, there is no way of telling whether the presence or absence of certain plant species is a direct result of trapping – for example, reduced abundances of rats may enable the successful seedling establishment of those plants (Wilson et al., 2003). But given the relatively slow growth rate of beech trees (diameter growth rate 1–5 mm/year; Richardson et al., 2011), the beech data can be assumed to be relatively sound for the 2017–20 trapping data period.

The effects of reinvasion following 1080 poison treatment in 2019 were not considered in this analysis. A study of rat abundances following a 1080 drop in the Tararua Forest Park suggested that subsequent increases in rats within the treatment area may be caused by the movement of individuals from adjacent non-treatment areas (Griffiths & Barron, 2016). Some of the highest CTI values were from the southern end of the Blue-Young line, which lies adjacent to farmland that was not part of the treatment area. This may potentially act as a source of reinvasion (Breedt & King, 2021). Therefore, the effect of this may account for some of the unexplained variation in the model. Incorporating a model that can account for temporal patterns of captures may allow for a better understanding of the effects of reinvasion.

It was also difficult to incorporate some habitat factors in the analyses, due to the non-random distribution of traps within the Makarora Valley. Because most of the traps that met the sample criteria were located at the floor of the valley rather than on the slopes, associations between habitat and elevation could not be made out. Additionally, the majority of traps tended to follow walking tracks (for the convenience of the trappers), so no interpretations of the distance to tracks could be made either. I would recommend that future research undertakes an experimental approach rather than an observational one (i.e. creating a new trap network rather than relying on pre-existing networks); a good study design will consider trap placement in relation to these factors. Camera traps are a viable way of estimating relative abundances on a landscape scale (Breedt & King, 2021); future research could test this methods' applicability at a refined scale.

The research presented here, combined with previous studies, has highlighted some aspects of the beech forest environment that could influence the capture rate of ship rats. This information could prove useful for trappers to help optimise their trap networks if the goal is simply to reduce population numbers in Makarora and other parts of Mt. Aspiring National

Park. But as Breedt & King (2021) discuss, it is critical not to conflate trap captures with abundances. If trapping is to be undertaken with a goal to *completely* eradicate rats from a landscape, then a systematic approach at the trap level (i.e. grid trapping) is more important than optimisation. Optimising trap sites based on perceived habitat-scale influences may result in small pockets of rats that could then rapidly reinvade adjacent exterminated areas (King et al., 2011). Forest & Bird have been making steps towards this in Makarora, with the establishment of the Muddy Creek and Pipson Creek grids in recent years.

This research has reaffirmed the difficulty in identifying relationships between habitat factors and the capture of ship rats. Many factors play a role in population dynamics, including stochasticity (Leirs et al., 1997), and not all can be easily measured or inferred. Ship rats appear to have a relatively broad niche breadth and ability to adapt to a range of habitats (Harper et al., 2005). Therefore, important limiting factors to ship rat populations could be less apparent at these scales. This may explain the variation in vegetation–capture relationships between studies. Nonetheless, the results presented here may provide trappers with some guidance on habitat influences within the Makarora Valley. Future research may obtain a clearer view of how ship rat populations are influenced by implementing an experimental study design over an observational one, which would then widen the range of factors that can be measured. Ultimately, the contexts in which this information should be used will depend on the short and long-term goals of the Makarora-Haast Pass trap network. I recommend that COLB, where practical, continue with the rolling out of trapping grids.

Acknowledgements

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Appendix

Appendix A: Revised vegetation survey for traps

Trap line and number:		Date surveyed:	
BEECH TREES			
Number of beech with DBH <200mm:		Number of beech with DBH ≥200mm:	
DBH of the largest beech:		Tiers* present:	
SITE NOTES			
Canopy cover (%):		Fern cover (%):	
Epiphytes (state species, and number of each):		Other notes (e.g. water present in plot, outside forest):	
COMMON FLORA (WRITE TIERS* PRESENT IN FOR EACH)			
ROUND-LEAF COPROSMA (*Coprosma rotundifolia*)		KARAMŪ (*Coprosma lucida & robusta*)	
MARBLELEAF (*Carpodetus serratus)*		WEEPING MĀPOU (*Myrsine divaricata*)	
MOUNTAIN TOATOA (*Phyllocladus alpinus*)		MIRO (*Prumnopitys ferruginea*)	
BROADLEAF (*Griselinia littoralis*)		LANCEWOOD/HOROEKA (*Pseudopanax crassifolius)*	
WINEBERRY/MAKO (*Aristotelia serrata*)		MOUNTAIN HOROPITO (*Pseudowintera colorata*)	
TŌTARA (*Podocarpus totara & laetus*)		HAUMAKŌROA (*Raukaua simplex*)	
LESS COMMON FLORA (WRITE TIERS* PRESENT IN FOR EACH)			
SYCAMORE (*Acer pseudoplatanus*)		PATĒ/SEVEN FINGER (*Schefflera digitata*)	
OTHER PODOCARPS (*Rimu, Kahikitea, etc. - SPECIFY*)		MATAĪ (*Prumnopitys taxifolia*)	
TREE FUSCHIA (*Fuchsia excorticata*)		*Any interesting species not specified (e.g. five-finger):*	

*TIERS:

A – *Ground tier*, <30cm; **B** – *Small shrubs*, 30-2m; **C** – *small trees*, 2-5m; **D** – *medium trees*, 5-12m; **E** – *canopy and emergent*, 12+ m