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RESEARCH

The relationship between *Rattus rattus* trap capture rates and microhabitat in Mt Aspiring National Park

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Abstract: The role of vegetation in the relationship between microhabitat and ship rat (*Rattus rattus*) distribution remains poorly understood. We used three years of trapping data (2017–2020) to calculate capture rates for 97 traps in the Makarora Valley and Haast Pass areas of Mt Aspiring National Park and determined aspects of the vegetation surrounding traps that influenced capture rates. The presence of fruiting understory plants—round-leaved coprosma (*Coprosma rotundifolia*), horopito (*Pseudowintera colorata*), and wineberry (*Aristotelia serrata*)—had weakly significant and positive associations with rat captures, whereas increasing density of large (> 200 mm DBH) mountain beech (*Fuscospora cliffortioides*) trees had a negative association, which was highly significant. Future research should incorporate methodology that links seasonal food abundances to capture rates and explores the influence of edge effects.

Keywords: beech forest, capture rate, microhabitat, *Rattus rattus*, trapping

Introduction

The introduction of ship rats (*Rattus rattus*) throughout New Zealand (NZ) was the likely cause of several avian extinctions from the 19th century onwards (Atkinson 1973; Bell et al. 2016). Ship rats continue to impact native bird populations through predation and food competition on the mainland (Innes et al. 2010). Consequently, controlling and eradicating rats and other introduced mammalian predators in NZ has become a priority.

Control operations use kill traps and/or poison baits. Trapping enables local communities to participate in conservation efforts: for example, the Central Otago Lakes Branch (COLB) of the conservation organisation Forest & Bird has, since 1998, managed a trap network targeting ship rats and mustelids in the beech forest of the Makarora Valley, Mt Aspiring National Park, with the aim of protecting the local population of mōhua/yellowhead (*Mohoua ochrocephala*), a hole-nesting bird which has declined across its fragmented range since the start of the 20th century (O'Donnell et al. 2002). Some of these declines appeared to correspond with local irruptions of ship rats due to beech masts (e.g. Studholme 2000), and predation of mōhua by rats has also been observed (Dilks et al. 2003).

The concept of microhabitat has been subject to inconsistent and competing definitions Jorgensen (2004). We use the definition of Morris (1987), i.e. that a microhabitat consists of the "physical/chemical variables that influence the allocation of time and energy by an individual within its home range [i.e. the macrohabitat]". Two studies in NZ have explored the relationship between microhabitat features and ship rat captures in beech and hardwood-podocarp forests, but significant variation between sites and variable scales of measurement have prevented broader conclusions about the capture-habitat relationship (Christie et al. 2006; Metsers 2007), with the result that the influence of vegetation remains unclear, despite its importance given that ship rats are arboreal (Hooker & Innes 1995), and omnivorous (Daniel 1973; Sweetapple & Nugent 2007; McQueen & Lawrence 2008).

We tested variables relating to local vegetation around traps against ship rat trap records collected from the Makarora COLB network between 2017–2020. Variables were based on either hypotheses constructed from existing literature, or on the results of studies in similar environments.

Methods

Study area

The COLB Makarora Valley network (44° 9′ S 169° 16′ E) consists of 13 trap-lines, clustered around the Haast Pass, Blue Pools, and Makarora West township areas (Fig. 1). Makarora Valley is primarily vegetated by silver beech (*Lophozonia menziesii*) forest, which extends from the valley floor (300 m a.s.l.) up to elevations around 1140 m a.s.l. (Wardle 2001). In the sub-canopy common plants include broadleaf (*Griselinia littoralis*), Hall's totara (*Podocarpus laetus*), lancewood (*Pseudopanax crassifolius*), marbleleaf (*Carpodetus serratus*), mountain toatoa (*Phyllocladus alpinus*), and patē (*Schefflera digitata*). *Coprosma* spp. are dominant in the understory with horopito (*Pseudowintera colorata*) and weeping mapou (*Myrsine divaricata*) also present. There is a history of farming

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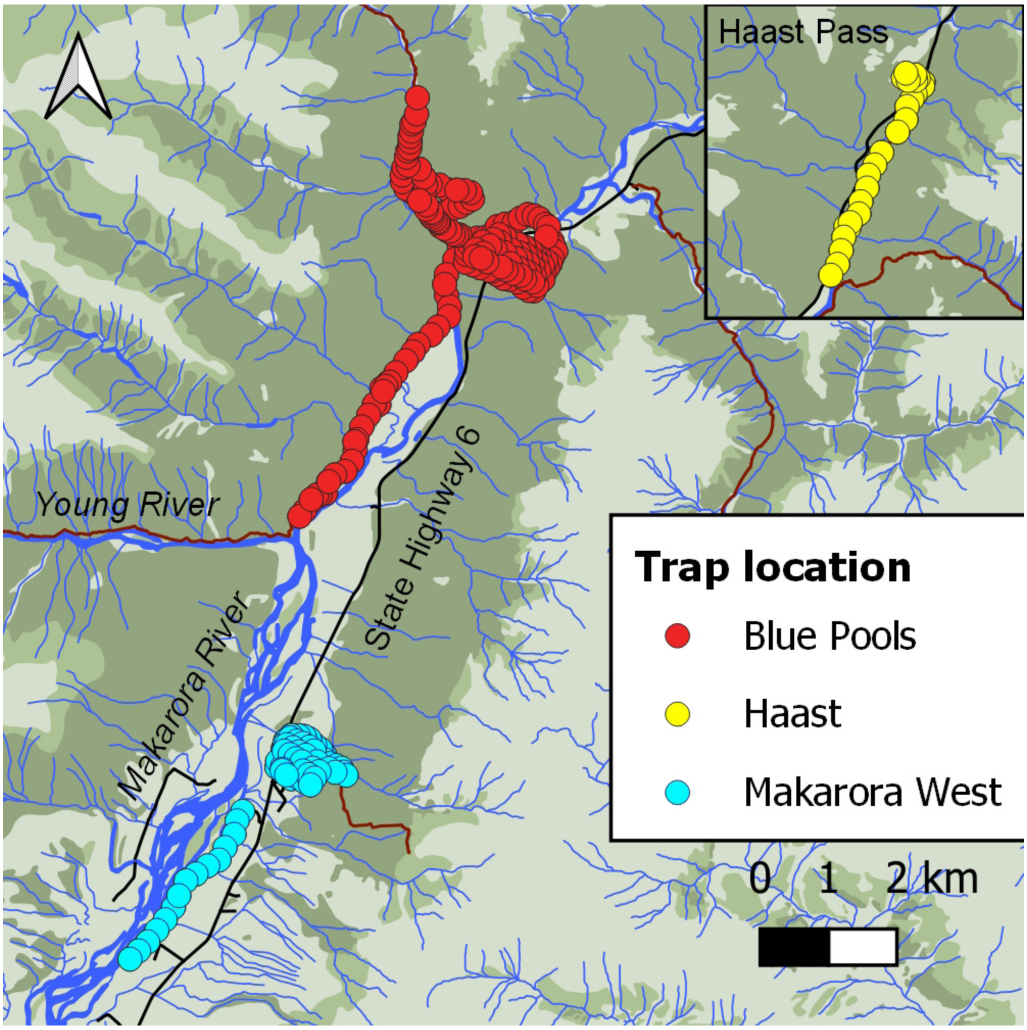

Figure 1. Map of the trapping network in the Makarora Valley, operated by the Central Otago Lakes branch of Forest and Bird, showing the distribution of DOC 150 and 200 traps (n = 306). Dark green indicates areas of beech forest, and medium green represents areas of scrub. State Highway 6 is represented by the black line, and dark red lines represent walking tracks. Haast Pass (inset) is approximately 9 km NE of the Blue Pools section.

in the lowlands of the valley. Some pasture is maintained, but other sections have been replaced by bracken fern (*Pteridium esculentum*) or regenerating beech forest.

Trap records

The COLB trapping network consists of approximately 650 DOC 150 (https://www.doc.govt.nz/documents/conservation/threats-and-impacts/animal-pests/doc150-predator-trap.pdf) and DOC 200 traps (https://www.doc.govt.nz/documents/conservation/threats-and-impacts/animal-pests/doc200-predator-trap.pdf) in both single and double-set tunnel designs, self-resetting GoodNature™ rat and brushtail possum (*Trichosurus vulpecula*) traps, and Trapinator™ possum traps, baited with eggs and Erayz jerky blocks (Connovation Ltd, Auckland, New Zealand). For this analysis, only DOC traps (n = 302) were considered; GoodNature™ traps were excluded as it is difficult to identify captures due to the trap immediately releasing the carcass after activation, thus allowing it to be scavenged. Traps were checked, baited, and re-set by volunteers approximately once a month with any captures or misfires recorded. Traps with records back to August 2017, until October 2020 when our study began, were included in analyses (n = 97). Although this subset excludes data from some of the oldest trap-lines, it minimises cumulative changes in microhabitat between start and end dates, particularly due to the beech mast in 2017. The density of beech seedlings can increase significantly following seedfall events (e.g. Stewart 1995), and the dynamics of how these can affect understorey plant composition are not well understood. The dataset includes the 2019 beech mast.

The relationship between captures and microhabitat likely differs between types of trap placement (linear or grid) due to trap competition. Because our model can predict only one type of relationship, we chose to include only linearly placed traps. Traps were also excluded if missing data (n = 4), which would have precluded the use of a rate-based model. Overall, of the 97 traps that were used in the analysis, 24 were from the Haast Pass area and 73 from the Blue Pools area: 72 traps were single-set models, while 25 were double-set traps.

A modification of the index of abundance described by Cunningham et al. (1996), hereafter referred to as the 'corrected trap index' or CTI, was applied to the August 2017–October

2020 records from each trap. The original index was used as a measure of trap effort across a trap-line over a single trapping session; here we have used it to describe the trap effort for a single trap over several consecutive sessions. The CTI for a given trap x is calculated using Eq. (1):

$$CTI_x = \frac{n_c}{TN_x} \times 100 \; (1) \qquad (1)$$

where n_c is the total number of ship rat captures, and TN_x is the corrected trap nights at trap x. The latter value is calculated using Eq. (2):

$$TN_x = \sum_1^k \left(t_y - \tfrac{1}{2}t_y c_y\right) = \left(t_1 - \tfrac{1}{2}t_1 c_1\right) + \left(t_2 - \tfrac{1}{2}t_2 c_2\right) + \ldots + \left(t_k - \tfrac{1}{2}t_k c_k\right) \qquad (2)$$

where t_y is the time period (nights) between the y^{th} trap check and the $y{-}1^{th}$ check, k is the total number of trap checks, and c_x is a binary value for the y^{th} trap check where 1 = capture (including bycatch) or misfire, and 0 = no capture (i.e. trap still set). A trap that has fired cannot catch animals until it is re-set, so the formula assumes that a trap has been closed for half of the time between consecutive checks if it has fired (Nelson & Clark 1973). For double-set trap units the corrected trap nights were summed for each separate trap then combined along with the number of captures into a single CTI value for the entire unit. A test inclusion of trap type as a predictor variable in the global model did not indicate that double-set traps affected capture rate, when other environmental factors were accounted for.

Selection & measurement of microhabitat factors

Between November 2020 and February 2021, within a twenty-metre radial survey plot of each trap, we measured the following microhabitat factors: (1) the density of 'mature' (DBH > 200 mm) beech trees, (2) the DBH (mm) of the largest beech tree in the survey plot, (3) the presence of epiphytic mistletoe (*Peraxilla* spp.), and (4) the presence of a selected range of berry-bearing understory & ground-based plants (Table 1).

Microhabitat factors 1–3 primarily relate to the availability of potential arboreal nesting locations. In forests, ship rats spend at least part of their lives arboreally (Hooker & Innes 1995), although this could vary with forest type (cf. Dowding & Murphy 1994). A mature beech tree with a larger DBH is more likely to present more suitable canopy nesting locations than a younger tree. Additionally, epiphytic species may have crevices ideal for nests, hence the selection of *Peraxilla* spp., which is a common beech epiphyte.

The fruiting understorey plants we selected were shining karamū (*Coprosma lucida*), round-leaved coprosma (*Coprosma rotundifolia*), broadleaf, horopito, and wineberry (*Aristotelia serrata*). Stomach content analyses indicate that fruits and seeds contribute to ship rat diets in New Zealand forests (Daniel 1973; Sweetapple & Nugent 2007; Clapperton et al. 2019), so the presence of these species within a plot may suggest increased food availability for ship rats. Furthermore, the larger species (e.g. marbleleaf) may indicate less canopy cover from the more dominant beech and thus fewer canopy nesting opportunities.

Model construction and fitting

Given the sample size of 97 traps, we were limited to a maximum of ten predictor variables per regression model to avoid biasing coefficients (Peduzzi et al. 1996). Using the *gamlss* package (Rigby & Stasinopoulos 2005) in R 4.2.2. (R Core Team 2022), we constructed generalised linear models (GLM) with CTI as the response variable using the gamlss function, setting the distribution as negative binomial. This was used over a Poisson distribution, as the data were over-dispersed. Because the trapping data were in the form of a rate (i.e. captures per 100 corrected trap nights), the GLM incorporated an offset parameter: ln(100TN_x). We constructed four models: a global model (incorporating all predictor variables), an aboreal-nesting model (incorporating mature beech stem density, DBH of the largest beech, *Peraxilla* spp., and marbleleaf), a food-availability model (incorporating all understorey plants), and a null model (offset parameter only, no predictor variables). The significance of individual predictor variables was considered weak if $p < 0.10$, moderate if $p < 0.05$, and strong if $p < 0.01$.

Results

Between August 2017 and October 2020, traps ($n = 97$) caught a median of seven ship rats (range 1–25). Traps were open for a median of 1160 trap nights (range 616–1493). The median corrected trapping index (CTI) was 0.70 captures per100 trap nights (Fig. 2). CTI values ranged from 0.09 to 2.1 (Fig. 3).

Directly comparing AICc values against the global model (Table 2), the aboreal-nesting model (Table 3) is competitive

Table 1. Predictor variables used in the global generalised linear regression model (and sub-set models) of ship rat capture rates at traps in the Makarora Valley and Haast Pass in August 2017–October 2021.

Predictor	Form	Aboreal-nesting model	Food-availability model
Number of beech trees with DBH > 200 mm in survey plot	Count	X	
DBH of the largest beech tree in survey plot (mm)	Continuous	X	
Presence of mistletoe *Peraxilla* sp. in survey plot	Binary	X	
Presence of marbleleaf *Carpodetus serratus* in survey plot	Binary	X	X
Presence of round-leaved coprosma *Coprosma rotundifolia* in survey plot	Binary		X
Presence of groundcover (< 30 cm) karamū *Coprosma lucida* in survey plot	Binary		X
Presence of broadleaf *Griselinea littoralis* in survey plot	Binary		X
Presence of mountain horopito *Pseudowintera colorata* (> 30 cm height) in survey plot	Binary		X
Presence of wineberry/mako *Aristotelia serrata* in survey plot	Binary		X

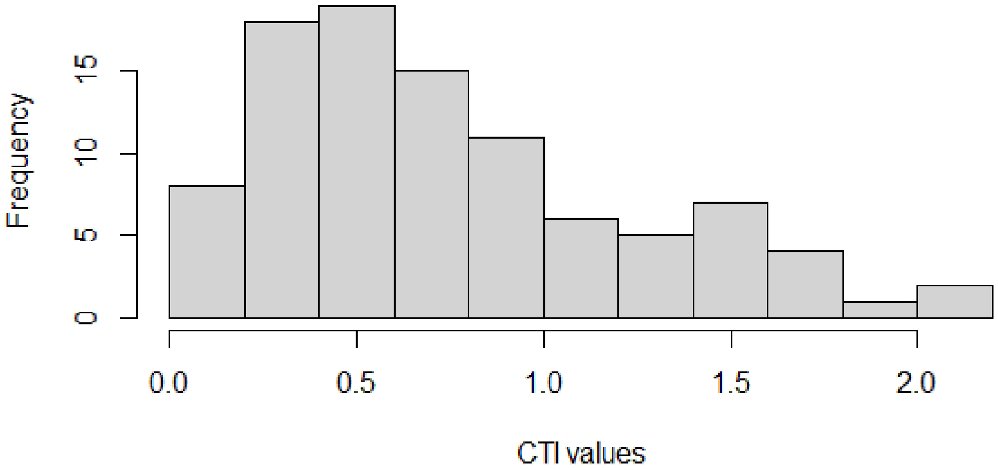

Figure 2. The distribution of corrected trap index (CTI) values calculated for each of the $n = 97$ sampled traps from the Makarora Valley network operated by the Central Otago Lakes branch of Forest and Bird, over the August 2017–October 2020 period.

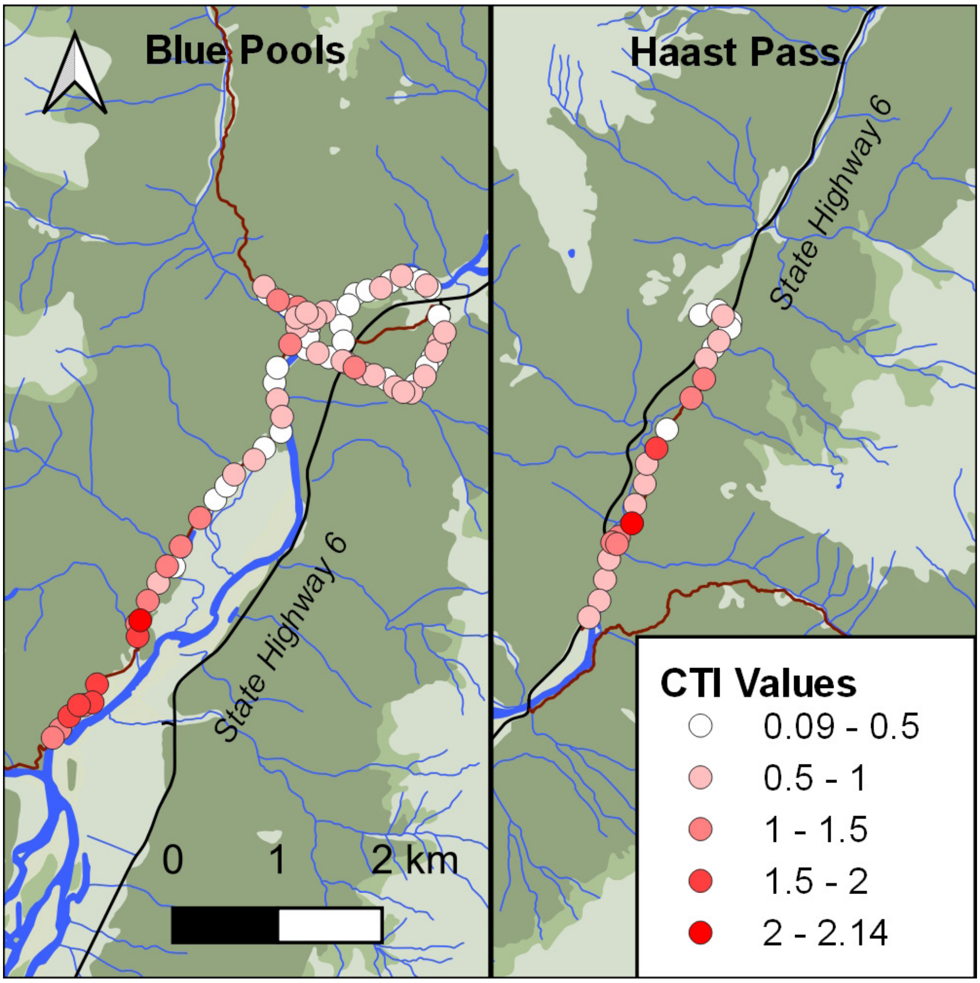

Figure 3. Map of corrected trap index (CTI) values for ship rat captures in 97 traps in the Blue Pools and Haast Pass areas of the Makarora Valley network from August 2017–October 2020. State Highway 6 is represented by a black line, and walking tracks by a dark red line.

(ΔAICc = +1.51), with the food-availability model (Table 4) being less competitive (ΔAICc = +3.80), while the null model (intercept estimate = −0.2838; standard error = 0.0669; t-value = −4.24; p-value < 0.01) was substantially uncompetitive (ΔAICc = +21.9). Based on Akaike weights (w), the global model is the most plausible (w = 0.617), though this does not provide enough certainty for it to be the single best model (w < 0.9; as per Portet 2020). The arboreal-nesting model had the second-highest probability (w = 0.291), while the weights of the food-availability model (w = 0.0921) and null model (w < 0.01) indicated low plausibility. In the global model, mature beech stem density was strongly negatively significant, while the presences of *Peraxilla* spp., round-leaved coprosma, and horopito were weakly significant (negatively for *Peraxilla*, and positively for the two plant species). In the aboreal-nesting model, mature beech stem density was also a

Table 2. Variables used in the global model for predicting ship rat captures at traps in the Makarora Valley, with respective coefficient estimates, standard errors, t-values, and p-values.

Model variables	Estimate	Standard error	t-value	p-value
Intercept	−0.860	0.264	−3.26	< 0.01
Count of large beech stems (DBH > 200 mm)	−0.0284	0.0107	−2.65	< 0.01
DBH of the largest beech tree (mm)	0.0529	0.0543	0.974	0.333
Presence of *Peraxilla* mistletoe	−0.353	0.184	−1.92	0.0583
Presence of round-leaved coprosma	0.213	0.122	1.74	0.0855
Presence of karamū	0.138	0.148	0.934	0.353
Presence of marbleleaf	0.0753	0.153	0.493	0.623
Presence of broadleaf	0.146	0.183	0.796	0.428
Presence of horopito	0.294	0.174	1.68	0.0964
Presence of wineberry	0.227	0.142	1.60	0.114

Table 3. Variables used in the arboreal-nesting model for predicting ship rat captures at traps in the Makarora Valley, with respective coefficient estimates, standard errors, t-values, and p-values.

Model variables	Estimate	Standard error	t-value	p-value
Intercept	−0.363	0.182	−1.99	0.0493
Count of large beech stems (DBH > 200 mm)	−0.0375	0.011	−3.57	< 0.01
DBH of the largest beech tree (mm)	0.064	0.0563	1.14	0.258
Presence of *Peraxilla* mistletoe	−0.359	0.181	−1.99	0.0495
Presence of marbleleaf	0.396	0.125	3.16	< 0.01

Table 4. Variables used in the food availability model for predicting ship rat captures at traps in the Makarora Valley, with respective coefficient estimates, standard errors, t-values, and p-values.

Model variables	Estimate	Standard error	t-value	p-value
Intercept	−1.103	0.224	−4.93	< 0.01
Presence of round-leaved coprosma	0.305	0.122	2.49	0.0146
Presence of shining karamū	0.0288	0.142	0.202	0.840
Presence of marbleleaf	0.118	0.155	0.763	0.448
Presence of broadleaf	0.173	0.190	0.911	0.365
Presence of horopito	0.347	0.180	1.93	0.0569
Presence of wineberry	0.324	0.143	2.27	0.0255

highly significant negative predictor, alongside the presence of marbleleaf (negative), while *Peraxilla* spp. continued to be moderately negatively significant. In the food-availability model marbleleaf was no longer significant. Round-leaved coprosma, horopito, and wineberry were all moderately positive significant predictor variables in this model.

Discussion

Our analyses suggest that factors relating to arboreal habitat may affect ship rat captures more than plant communities on the ground, but it was difficult to relate the microhabitat around a trap to the trap's ship rat capture rate when measured at a fine scale (20 m radius). Our analyses suggest that the global model is the most plausible; however, the arboreal-nesting model is also competitive. While the arboreal-nesting model benefits from being more parsimonious, the relevance of understory plant communities in the spatial distribution of ship rats cannot be discounted. Other studies, such as those of Christie et al. (2006) and Metsers (2007), have identified associations between certain fruiting plants known to be consumed by rodents and rat distributions within forest systems. We feel that the weakly significant fruiting plant predictor variables in our global model underline this importance; therefore, we consider the global model to be the most appropriate model to describe ship rat captures in the beech forest of Mt Aspiring National Park.

These results appear to corroborate those of Metsers (2007) elsewhere in Mt. Aspiring National Park in that in both studies small-leaved *Coprosma* spp. and beech tree abundance were related to ship rat captures. Metsers (2007) suggested that the relationship between captures and *Coprosma* spp. was indirect because the abundance of those plants would be related to the structure of the beech canopy. Alternatively, the association between ship rat captures and *Coprosma* spp. could be driven by resource availability. Ship rats have an omnivorous diet that includes invertebrates, vertebrates, and plant material (Clout 1980; McQueen & Lawrence 2008). The plant species that we found to be associated with ship rat trap capture rates contribute to the diet of ship rats in other areas, e.g. horopito in a podocarp-broadleaved forest (Sweetapple & Nugent 2007), and *Coprosma* spp. and wineberry in lowland forest (Daniel 1973). Given the wide scope of food consumed by ship rats, food is probably driving this association. Measuring seasonal changes in fruit availability against capture rates could provide further insights.

The negative influence of large beech stem density on ship rat capture rates could be due to resource availability. An increasing density of larger beech stems could provide more suitable arboreal nesting locations for ship rats. The resulting formation or extension of a home range might potentially reduce visitation by other individuals, thus reducing the trap capture rate. The negative association between the presence of arboreal *Peraxilla* mistletoes with capture rates could be because the presence of this species was a proxy for nesting site availability. Alternatively, the increased availability of arboreal habitat may mean ship rats spend less time on the ground, resulting in reduced capture rates. More information on the ranging behaviour of ship rats in beech forests is necessary. Aside from a pilot study (Pryde et al. 2005), there are no home range studies in this environment.

Using historical capture data from a pre-existing trap-line presents some challenges and limitations. The effect of walking tracks could not be determined as trap-lines followed these tracks to give trappers ease of access. This issue would be solved by the experimental placement of traps. Because the microhabitat variables were measured at the end of the trap capture data period, it is possible that some aspects of these variables might not entirely reflect the environment at the start. We measured the microhabitat in ways that were unlikely to have changed significantly over a 2-year period (e.g. presence/absence of large established plants). Another consideration is the impact of ship rats on microhabitats. The reduction of ship rat densities through intensive trapping may increase seedling establishment (Wilson et al. 2003), thus altering the vegetation community around traps. Our use of a short time period minimised this risk. Continual monitoring throughout the data collection period may assist in accounting for these effects.

Identifying relationships between ship rat capture rates and the surrounding microhabitat within NZ forests is challenging. Ship rats have a relatively broad niche and can adapt to a range of conditions (Harper et al. 2005). Beech forest plant communities are relatively homogenous. Four of the six understory plant species were present in over 50% of survey plots, adding to the difficulty of being able to define the scale at which the microhabitat should be measured. Indirect influences on capture rates must also be considered. Individual ship rat behaviour (e.g. trap-shyness, variability in home range size) could impact capture probability; this could conflate data returned from areas of low ship rat densities. Inconsistent distances between traps may also reduce the likelihood of an individual encountering a trap. Furthermore, trap location in relation to forest edges and the overall boundary of the trap network might be important (Christie et al. 2006). Habitat adjacent to trapped areas can potentially act as sources of reinvasion. Rat abundance following an aerial 1080 toxin drop in the Tararua Forest Park increased in the treatment area due to movement of individuals from adjacent non-treatment areas (Griffiths & Barron 2016). In 2019, an aerial 1080 toxin drop to control introduced mammalian predators took place in the Makarora Valley. High CTI values were recorded adjacent to farmland that was not part of the treatment area, suggesting that the pasture acted as a source for reinvasion. Local abundances of other introduced mammalian predators may also affect ship rat densities (Efford et al. 2006). These regional effects must be properly accounted for in future research so that broader conclusions and comparisons about capture-microhabitat relationships can be made with more certainty.

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