Using passive detection devices to monitor occupancy of ship rats (*Rattus rattus*) in New Zealand temperate rainforest

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Abstract: Reliable estimates of invasive pest mammal abundance and distribution in New Zealand are vital for effective conservation management of endangered native species. In this study, passive detection devices were used to monitor site occupancy by ship rats *(Rattus rattus)* in temperate rainforest in the Eglinton Valley, Fiordland, New Zealand. Ship rat occupancy was monitored on three grids of c. 100 ha each, containing 50 tracking tunnels spaced at 150-m intervals, for seven nights each in November 2004, January 2005 and March 2005. Site occupancy estimates were obtainable for only one of these grids, Walker Creek, where estimates increased by a factor of 2.5 over the total sampling period. Detection rates were highest within forest and forest-edge habitats, and on nights with rainfall. In March 2005, 48 ship rats were caught in an effective trapping area of 132 ha. Removal trapping gave an estimated density of 0.38 rats ha^{-1} (0.36–0.48 rats ha^{-1}, 95% confidence interval). Given the linear relationship between ship rat tracking and trapping rates, we are confident the reported trends in occupancy are realistic, and more accurate than tracking rate estimates. Improving the current monitoring methods so that the probability of detection can be estimated would be a good first step towards more accurate estimates of ship rat distribution.

Keywords: beech forest; detection probability; *Fuscospora; Lophozonia; Nothofagus*; removal trapping; rodents; site occupancy; tracking tunnels

Introduction

Introduced ship rats (*Rattus rattus*) in New Zealand periodically irrupt when beech (*Fuscospora* spp; *Lophozonia* sp.) undergo mast seed-fall events (e.g. King & Moller 1997; Studholme 2000; Blackwell et al. 2001). The rats have substantial impacts on native biodiversity during these irruptions, preying on native vertebrate and invertebrate species (e.g. Dilks et al. 2003; Innes 2005; McQueen & Lawrence 2008). If ship rats are to be controlled, monitoring methods will need to estimate trends in rat population abundance or distribution prior to an irruption event, as well as measuring the effectiveness of the rat control. However, monitoring ship rats at low densities is difficult because of low detection probability and patchy distribution (Wilson et al. 2007). Nevertheless, effective protection of native species may require detecting changes in rat populations when they are in low numbers.

The methods currently used to monitor changes in ship rat abundance in beech forest have several limitations. For example, footprint-tracking tunnels are commonly used to index the relative abundance of ship rats on grids or line transects (e.g. Brown et al. 1996; Innes et al. 2010). However, because there is no measure of probability of detection associated with these indices (e.g. Anderson 2003; MacKenzie & Kendall 2002), it is difficult to determine whether changes in index values reflect actual changes in numbers or a change in ability to detect individuals (Yoccoz et al. 2001; MacKenzie et al. 2003). Likewise, a failure to detect rats does not mean that they are absent. Therefore, indices are only useful for detecting large changes in numbers and/or when rat populations are at relatively high densities. Traditional empirical modelling techniques that adjust for detection probability (e.g. mark–recapture and distance sampling) are more robust (e.g. Thompson et al. 1998; Buckland et al. 2001; Borchers et al. 2002). However, such methods do not provide a suitable alternative in beech forest because of low rat capture or recapture rates and assumption violations (e.g. Efford 2004; Efford et al. 2006; Wilson et al. 2007).

One potential solution when species are at low density is site-occupancy modelling (MacKenzie et al. 2006), which has been used elsewhere to monitor changes in species of nocturnal and small mammal species including ship rats (e.g. Watkins et al. 2010; De Bondi et al. 2010; Fauteux et al. 2013). Instead of measuring changes in relative abundance, site occupancy is a measure of changes in the proportion of sample units a species occupies (MacKenzie et al. 2006). Compared with traditional indices, site occupancy enables detection probability to be separated from variations in the size of animal populations that are being monitored (Efford & Dawson 2012). Occupancy uses multiple presence/absence surveys of a sample unit to estimate the number of sites occupied by a species in an area (MacKenzie et al. 2006). Adequate revisitation rates by the target species are also needed, otherwise the amount of sampling effort required increases, and could make the technique logistically unfeasible (MacKenzie & Royle 2005). Knowledge of spatial movement patterns of the target species that is being monitored, as well as the effective sample plot size of the detection device that is being used, are also important to ensure estimates of detection probability and occupancy are correct (MacKenzie & Royle 2005; Efford & Dawson 2012).

The main objective of this study was to demonstrate the use of passive detection devices to estimate site occupancy of ship rats in a New Zealand beech forest. We monitored changes in site occupancy over three seasons (spring, summer

and autumn) at three grids and conducted removal trapping to estimate ship rat abundance at the end of this period. We used site occupancy modelling to identify potential predictors that could improve ship rat detection rates and describe habitat use patterns. We discuss whether we were able to meet the requirements of the site occupancy method and implications for monitoring ship rats in beech forest.

Methods

Study site

Research was carried out in a cold temperate beech forest in the Eglinton Valley (Fiordland National Park, New Zealand; 44º58' S, 168º00' E), which is a U-shaped glaciated valley with steep sides and a flat floor 0.5–2 km wide. Three study grids (~130 ha each) were distributed through the valley from south to north: Walker Creek (45º05' S, 167º57' E); Knobs Flat (44º57' S, 168º01' E) and Plato Creek (44º54' S, 168º02' E). The study grids were on glacial terraces bisected by gullies and dominated by mature red beech (*Fuscospora fusca*, previously *Nothofagus fusca*), with mountain (*F. cliffortioides*, previously *N. solandri* var. *cliffortioides*) and silver beech (*Lophozonia menziesii*, previously *N. menziesii*) (Heenan & Smissen 2013) along the forest edge and modified tussock grassland dominated by *Festuca rubra* and *Anthoxanthum odoratum* along the border.

Monitoring methods

Three 100-ha grids were set up using GPS, and on each grid 50 footprint-tracking tunnels (C.A. Gillies & D. William unpubl. report 2003) were placed at 150-m intervals. The tracking tunnels were set by inserting a plastic tray with an inkpad in the middle, and paper cards on either side to record the tracks. These were baited with peanut butter in the centre of the inkpad, and the presence of ship rat tracking was recorded each day for seven consecutive nights. We used three tracking sessions of seven consecutive nights each in November (spring) 2004, January 2005 (summer) and March (autumn) 2005 in a non-mast season.

After the final tracking session rats were trapped from the Walker Creek grid using snap traps (Victor®). A single snap-trap was placed within 1 m of each tracking tunnel station (N = 50 traps) and baited with a mixture of peanut butter and rolled oats. Tracking tunnels remained active concurrently with the removal trapping so the two indices could be compared. Traps were set for a total of eight nights, with numbers of ship rats captured recorded daily.

At Walker Creek each trap and tracking tunnel station was also defined in terms of broad habitat type (forest interior, forest edge, grassland); three lower understorey (0.5–3.0 m vegetation height) composition variables; canopy dominant species (red beech, hardwood species mountain beech, none); percentage red beech; and number of plant species.

Site occupancy analysis

A multi-season site occupancy model (MacKenzie et al. 2003, 2004, 2006) was used to estimate occupancy (ψ), colonisation (γ) and local extinction (ε) probabilities while allowing for the imperfect detection of ship rats. This model uses the observed sequence of detections and non-detections of rats at each of the 50 tracking tunnels to provide estimates of the occupancy-related parameters. By checking tunnels for multiple nights within a sampling period, it was possible to account for imperfect detection of rats at sites (i.e. sites where rats are present, but never detected in the tunnel).

Three broad types of exploratory analyses of the rat data were conducted: (1) analysis to investigate general trends in occupancy over the three sampling periods (seasons); (2) detection data were pooled to determine whether less effort (i.e. tunnels checked only every second day) would provide similar results (assuming negligible degradation of bait over two nights); and (3) the effect of potential habitat-related covariates on the occupancy, colonisation and local extinction probabilities. For each analysis, Akiake's Information Criterion (AIC) was used to rank models (Burnham & Anderson 2002). Those with low AIC values were considered the most parsimonious. AIC model weights were also calculated to indicate the level of support for each model (Burnham & Anderson 2002). All analyses were conducted using the multi-season model within PRESENCE 6.1 (http://www.mbr-pwrc.usgs.gov/software/presence.html).

The time intervals between the three sampling periods were not equal (approximately 12 and 6 weeks respectively). Therefore models constraining colonisation and/or local extinction probabilities to be equal between periods one and two, and periods two and three, would not be biologically reasonable (i.e. assuming the probability of a site being colonised during the 6-week interval was the same as the probability for the preceding 12-week interval does not seem reasonable). Consequently, a 'dummy' sampling period was added to the data between the first and second sampling periods to create three intervals of equal length. This results in colonisation and local extinction probabilities being estimated at a 6-week-interval scale. But because no data were actually collected in the dummy sampling period, it was not possible to separately estimate colonisation and local extinction probabilities for the intervals immediately before and after the dummy period; so these probabilities were set equal in all models. Furthermore, detection probabilities within the dummy sampling period must be set equal to zero. This was achieved by inserting the 'survey' outcomes for the dummy sampling period as missing values for all sites (MacKenzie et al. 2006), and arbitrarily constraining the detection probabilities within the dummy period to be equal to any other estimable detection probability. Which detection probabilities within the dummy period are set to equal will have no effect on the analysis as the inserted missing values effectively force the dummy-period detection probabilities to be zero.

Trapping removal estimator

Estimates of rat density from removal trapping were obtained from maximum likelihood methods recommended by Williams et al. (2002). Estimates were obtained with Program MARK 3.0 (White & Burnham 1999) assuming a closed population model with zero recapture probability. In order to calculate density, a boundary strip (Dice 1938) was added to the three-forested edges of the 100-ha grid to calculate the effective trapping area. The boundary strip was estimated from the mean radius (r = 99 m) for the mean ship-rat home range size (1 ha) recorded at Walker Creek in the same season but following year (Smith et al. 2009). Therefore, the effective trapping area for the Walker Creek grid was estimated to be 132 ha. Grassland was omitted from the effective trapping area, because it was unused by ship rats (Smith et al. 2009; this study). The statistical relationship between density and tracking rate, recorded over successive nights of the removal trapping, was estimated using linear regression.

Results

No rats were tracked on the Knobs Flat grid, and only two tunnels were tracked during the March tracking session at the Plato Creek grid. Only the data from Walker Creek could be analysed using site occupancy methods. At Walker Creek 22%, 46%, and 66% of the 50 tunnels were tracked by ship rats for the 7-day sessions in November, January, and March respectively. Once a tunnel was tracked, tracking continued each subsequent night. In all three tracking sessions, the number of new tunnels tracked by rats commenced levelling off at five nights (Fig. 1), meaning no new information was gained after five nights.

Site occupancy modelling

Preliminary analyses (not presented here) of the rat data using site occupancy modelling indicated that the daily probability of first detecting rats differed for each sampling period (0.20, 0.24 and 0.52 respectively). Once detected, the odds of detecting rats in a tracking tunnel were (approximately) 10.0 times greater (approximate 95% confidence interval of 5.5–18.2). Overnight rain also increased the probability of detecting rats by a factor of 1.7 (95% confidence interval of 1.0–2.9).

Six models representing various hypotheses about how occupancy changed over time were considered (Table 1). The first, third and fourth models used the original parameterisation where occupancy (ψ) in the first sampling period was estimated (denoted by $\psi(1)$), and colonisation (γ) and local-extinction (ε) probabilities were allowed to either differ for the two intervals between the three real sampling periods (denoted by the t in parentheses following the respective parameters) or to be equal (denoted by the '·' in parentheses). The second, fifth, and sixth models used an alternative parameterisation where the probability of occupancy was estimated directly for each sampling period along with colonisation probabilities (note local-extinction probabilities were derived parameters in these cases so no ε term appears in the model names; Table 1).

Table 1. Summary of model selection procedure for exploratory modelling of ship rat (*Rattus rattus*) detection data. ΔAIC is the absolute difference in AIC values compared to the top-ranked model, w is the AIC model weight and *NPar* is the number of parameters in the model. For the model parameters, ψ is occupancy probability, γ is colonisation probability, ε is extinction probability and p is detection probability. Terms in the parentheses indicate what factors are being included for each parameter type in that model, with a ' · ' indicating the parameter is constant, t indicating it is sampling-period specific, and T indicating a linear trend. Model names that do not include ε are re-parameterised models that allow occupancy to be estimated directly for each sampling period.

Model	ΔAIC	w	*NPar*
$\psi(1)\,\gamma(\cdot)\,\varepsilon(\cdot)\,p\,(t+redetect+rain)$	0.00	0.44	8
$\psi(T)\,\gamma(\cdot)\,p\,(t+redetect+rain)$	0.91	0.28	8
$\psi(1)\,\gamma(t)\,\varepsilon(\cdot)\,p\,(t+redetect+rain)$	1.91	0.17	9
$\psi(1)\,\gamma(t)\,\varepsilon(t)\,p\,(t+redetect+rain)$	3.61	0.07	10
$\psi(T)\,\gamma(t)\,p\,(t+redetect+rain)$	5.03	0.04	9
$\psi(\cdot)\,\gamma(\cdot)\,p\,(t+redetect+rain)$	8.87	0.01	7
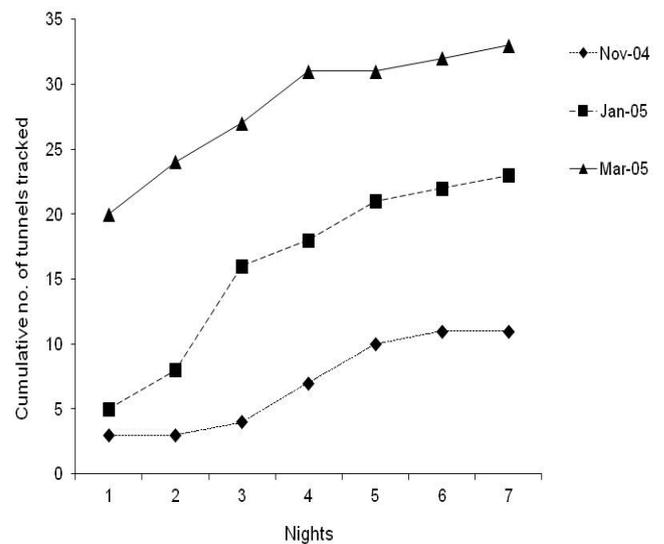
Figure 1. Cumulative number of tunnels tracked by ship rats (*Rattus rattus*) at Walker Creek, Eglinton Valley, Fiordland, over three (November 2004, January and March 2005) 7-day sampling sessions.

Occupancy probability was modelled with a linear trend (on the logistic scale; $\psi(t)$), or as a constant in all sampling periods ($\psi(\cdot)$). The first three models ranked in Table 1 all had a reasonable level of support, given the data suggesting ambiguity on which model might be considered 'best'. However, all models resulted in similar inference about changes in occupancy; hence we based our inference solely upon the top-ranked model. The estimated probability of occupancy in the first sampling period was 0.27 (SE = 0.08; Table 2), with estimated colonisation and local-extinction probabilities (standardised to approximately 6-week intervals between sampling periods) of 0.28 (SE = 0.06) and 0.04 (SE = 0.03), respectively. From these estimates, the probability of occupancy in each period was calculated (MacKenzie et al. 2003, 2006; Table 2), suggesting an increase in occupancy.

A less intensive monitoring regime was simulated by pooling the data to reflect three checks: one every second day over a 6-day period. We fitted the top-ranked model to the pooled data and found the estimated probabilities of occupancy, colonisation and local extinction in the first sampling period were 0.42 (SE = 0.21), 0.20 (SE = 0.10) and 0.03 (SE = 0.03), respectively. While these estimates differ from those obtained using the 7-day dataset, there was still a clear indication of an increase in occupancy over time (Table 2), but larger standard errors suggest a greater level of uncertainty and reduced inferential power.

Ten models each containing only one or none of the four habitat covariates for occupancy and colonisation were fitted to the rat data from the three sampling sessions. The only other variation in model structure was allowing colonisation probability to differ between sampling sessions. The models that include the habitat-related covariates were a much better fit to the data, with the 'broad habitat type' covariate providing the highest ranked models and together containing essentially all the AIC model weight ($w = 0.96$; Table 3). The analysis supports the hypothesis that grassland was infrequently used habitat by ship rats in this valley. Occupancy in the grassland

Table 2. Estimated probability of occupancy (± 1 SE) by ship rats (*Rattus rattus*) in the three sampling periods using the highest ranked model from Table 1, ψ (1) γ (.) ε (.) p (*t + redetect + rain*). 'Ship rat' denotes data collected daily for a 7-day period; and 'Pooled ship rat' denotes data pooled to reflect three checks: one every second day over a 6-day period.

	Sampling session		
Data	November 2004	January 2005	March 2005
Ship rat	0.27 (0.08)	0.60 (0.06)	0.69 (0.07)
Pooled ship rat	0.42 (0.21)	0.60 (0.08)	0.66 (0.07)

Table 3. Summary of model selection procedure for modelling of ship rat (*Rattus rattus*) detection data including habitat-related covariates. Four covariates were considered: broad habitat type (BH; interior, edge or grassland); dominant lower-understorey species (DLU; red beech, hardwood, mountain beech and none (in grassland)); percent red beech in lower understorey (%RB); and number of species in lower understorey (NS). ΔAIC is the absolute difference in AIC values compared with the top-ranked model, *w* is the AIC model weight, and *NPar* is the number of parameters in the model. For the model parameters, ψ is occupancy probability, γ is colonisation probability, ε is extinction probability, and *p* is detection probability. Terms in the parentheses indicate what factors are being included for each parameter type in that model, with a '·' indicating the parameter is constant, *t* indicating it is sampling-period specific, and T indicating a linear trend.

Model	ΔAIC	*w*	*NPar*
ψ (BH) γ (BH) ε (.) p (*t + redetect + rain*)	0.00	0.67	12
ψ (BH) γ (*t* + BH) ε (.) p (*t + redetect + rain*)	1.69	0.29	13
ψ (DLU) γ (DLU) ε (.) p (*t + redetect + rain*)	7.43	0.02	14
ψ (DLU) γ (*t* + DLU) ε (.) p (*t + redetect + rain*)	8.43	0.01	15
ψ (%RB) γ (%RB) ε (.) p (*t + redetect + rain*)	9.75	0.01	10
ψ (%RB) γ (*t* + %RB) ε (.) p (*t + redetect + rain*)	11.70	0.00	11
ψ (1) γ (·) ε (.) p (*t + redetect + rain*)	12.86	0.00	8
ψ (NS) γ (NS) ε (.) p (*t + redetect + rain*)	14.35	0.00	10
ψ (1) γ (*t*) ε (.) p (*t + redetect + rain*)	14.77	0.00	9
ψ (NS) γ (*t* + NS) ε (.) p (*t + redetect + rain*)	16.30	0.00	11
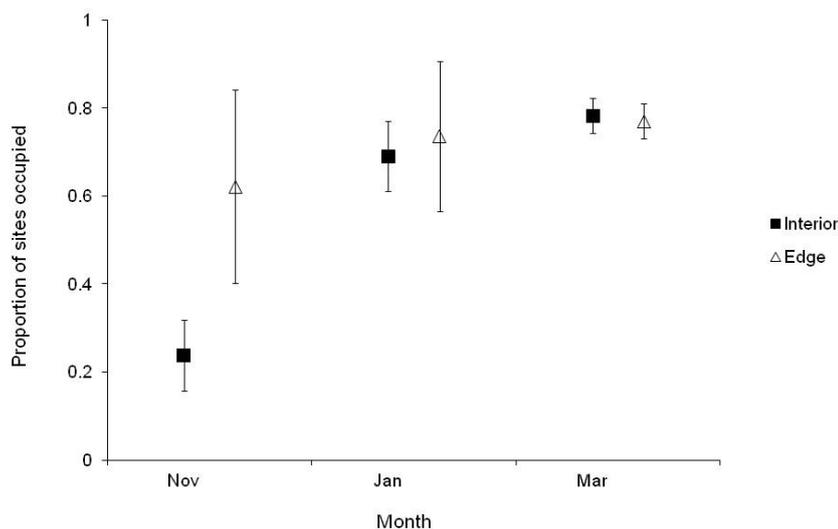
Figure 2. Proportion of sites occupied by ship rats (*Rattus rattus*) in forest-interior and forest-edge habitats at Walker Creek, Eglinton Valley, Fiordland, over three consecutive (November 2004, January and March 2005) sampling sessions. Error bars are ± 1SE.

was estimated to be zero in the first sampling session, and there was no colonisation of the sites. The small (*n* = 6) number of tracking tunnels in this habitat may have influenced this result. Occupancy was estimated to be higher at edge than interior sites in the first sampling session, although interior sites had a higher rate of colonisation (Fig. 2).

Rat removal estimator

In total, 48 ship rats were trapped (33 adults, 15 juveniles) at 25 stations on the Walker Creek grid. The total number of

rats trapped remained similar for the first three nights before declining abruptly; 11, 11, 13, 4, 3, 2, 2, and 2 rats were killed on successive days of removal trapping. The minimum observed density in the study area was 0.36 rat ha^{-1} (48 in 132 ha). Maximum likelihood methods estimated actual density at 0.38 rat ha^{-1} (51 in 132 ha), with an upper bound of 0.48 rat ha^{-1} (upper 95% confidence limit). Although no more rats were trapped, the continued presence of rat tracks in the tracking tunnels, albeit at a much reduced level, at the end of the removal period suggests that our estimate of ship

rat density may be an underestimate.

The relationship between density (rats ha^{-1}) and tracking was explored by regressing nightly tracking rate against the absolute density of rats calculated to have still been present on each successive night of the removal trapping. This regression explained 84% of the variance ($P < 0.001$; Fig. 3), suggesting that footprint tracking tunnels give a reasonable indication of rat density. However, captures of more than one rat at a trap suggest that multiple rats may have visited a tracking tunnel. Furthermore, continued footprint tracking suggested that some resident rats remained. Trap competition with mice (*Mus musculus*) may also have been a problem, as mouse trapping rates remained stable over the rat trapping removal period; 20, 16, 11, 13, 11, 5, 5, and 5 mice were killed on successive days of removal trapping.
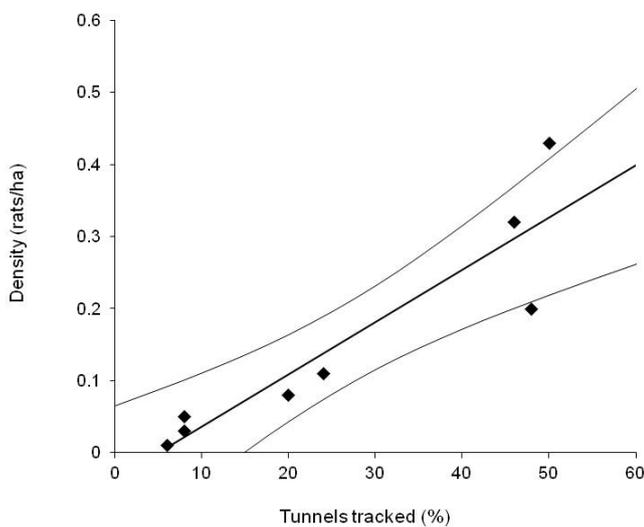
Figure 3. Relationship between nightly tracking rate and density of ship rats (*Rattus rattus*) in successive nights, from using removal trapping in Fiordland. The bold middle-line represents a linear regression of best fit ($y = 0.0073x − 0.0366$), with the upper and lower lines denoting 95% confidence limits.

Discussion

The aim of this study was to determine whether passive detection devices could be used to estimate occupancy of ship rats in beech forest when ship rats were at low densities. However, due to low ship rat densities, occupancy estimates were obtained only from the Walker Creek grid, where rat occupancy increased by a factor of 2.5 over the three sampling periods. This increase followed seasonal patterns recorded for ship rats in other New Zealand forests (e.g. Daniel 1972; Harper et al. 2005; Innes 2005), although even the highest density of 0.38 rats ha^{-1} in March 2005 was much lower than estimates recorded for podocarp and mixed beech forest (2.9 ha^{-1}, Dowding & Murphy 1994; 6.7 ha^{-1}, Brown et al. 1996; 5 ha^{-1} 2003; 9 ha^{-1} 2004, Wilson et al. 2007). Given the linear relationship between ship rat tracking and trapping rates, we are confident the reported trends in occupancy are realistic, and provide a more accurate estimate of ship rat activity than tracking rates.

At a local scale, the intensive grid at Walker Creek showed a better approximation of rat activity than the single tracking-

tunnel line that was part of a widely dispersed, extensive, valley monitoring regime. Rat activity at the standard tracking tunnel line through the middle of the study block only increased by a factor of 0.1 between November and February (G. Hill, Department of Conservation, unpubl. data), compared with a factor increase of 2.5 measured by the grid. This is not surprising given the occupancy sampling effort was much more intensive. However, this highlights the risk that widely dispersed lines may fail to detect localised outbreaks of rats and this could have a detrimental effect on native species. For instance, at Walker Creek, native bird species such as robin (*Petroica australis*) declined dramatically during the study period (Greene & Pryde 2012), while mōhua (*Mohoua ochrocephala*), a species sensitive to predators (Elliott 1996; Dilks et al. 2003), was absent. Both of these species maintain their presence in other parts of the Eglinton Valley where rats were less numerous (this study). Inadequate knowledge of rat numbers at a local scale could result in extirpation of a species, even in a non-mast year, especially when a native species is patchily distributed and occurs at low densities within a valley system.

Ship rats are traditionally hard to detect in beech forest between mast years (e.g. King 1983; O'Donnell et al. 1996; Dilks et al. 2003), so identifying factors that improve detection probability would be extremely useful. We found the presence of overnight rain significantly improved the probability of ship rat detection. Few studies have examined the influence of weather on ship-rat capture probability, but some have noted increased capture rates of ship rats in winter (e.g. Daniel 1978; Alterio et al. 1999; Efford et al. 2006). Ship rats are relatively small mammals, with a fast metabolism (Innes 2005), so inclement weather conditions (i.e. cold temperatures and rain) may increase their need for food and the probability that they will enter a baited tracking device. Such behaviour highlights the importance of measuring weather conditions when monitoring ship rats.

We found that four key components required consideration when using the site occupancy method. These were (a) spatial layout of the sampling area, (b) size of the effective sampling area, (c) sample period for each session (MacKenzie & Royle 2005; MacKenzie et al. 2006; Efford & Dawson 2012), and (d) heterogeneity of the sample habitat. In this study, distance between tracking tunnels (150 m) was based on published home-range sizes for ship rats (e.g. Innes 2005), although a later radio-tagging study at the same site recorded ship rats regularly moving distances of greater than 150 m (Pryde et al. 2005; Smith et al. 2009). As occupancy is a species-level metric, whether multiple tracking tunnels are within the home range of a single individual or different individuals is largely irrelevant as in either case the area around the tracking tunnel is occupied by the species.

Size of the effective sampling area of the detection devices can induce errors in estimating detection probabilities if the effective sampling area of a detection device is too small or large relative to the home range size of the target animal (MacKenzie & Royle 2005; Efford & Dawson 2012). For example, tunnels too close together might attract individuals to neighbouring devices. The 150-m spacing used in this study should have been adequate to avoid rats detecting and tracking adjacent devices, so the results of this study should have been spatially independent, thereby avoiding errors in detection probability. Furthermore, the size of the effective sampling area needs to be the same for each device (MacKenzie et al. 2006). Although the size of the effective sampling area around

our baited tracking tunnels is not clear, it should not vary noticeably, because each tunnel is the same in terms of design and bait type. Thus, occupancy should not be interpreted as an 'effective area occupied' (i.e. how many square metres), but 'fraction of point locations occupied' (MacKenzie et al. 2006).

The sampling period for each session needs to be long enough to undertake repeat surveys of each sample unit but short enough so there is no systematic shift in rat distribution during the monitoring period (MacKenzie et al. 2006). This is because, with the occupancy method, closure is at the scale of the rats' use of space, not in terms of changes in the number of rats in the survey region (MacKenzie et al. 2002, 2006). Repeat visits from the target animal are also required for the site occupancy method to work (MacKenzie et al. 2006; Efford & Dawson 2012). The seven repeat surveys of each tunnel station in this study should have ensured that any rat present on the grid was detected and be short enough so that a systematic shift in distribution could not occur. This is consistent with period of 3–7 days as the standard for grid-based density estimates of ship rats in beech forest (e.g. Brown et al. 1996; Blackwell et al. 2002; Wilson et al. 2007). No systematic shift in ship rat tracking was detected during the sampling period. Furthermore, ship rats tracked tunnels every subsequent night following their initial visit, and the tracking rate levelled off at five nights for all three of the sampling sessions at Walker Creek. This suggests that, in our study, tunnels only needed to be active for five nights to get adequate occupancy estimates for ship rats.

Habitat was an important component of ship-rat occupancy patterns, but with a seasonal influence. Forest-edge habitats had consistently high-use levels through all seasons, while use of the forest interior was initially low but increased from spring through autumn. The relationship between ship rat abundance and the distribution of mature forest is well recognised in New Zealand (e.g. King et al. 1996; Harper et al. 2005; Christie et al. 2006) and overseas (White et al. 1997; Cox et al. 2000). Ship rats are arboreal omnivores and their distribution is most likely linked to food availability and shelter (Innes 2005). Forests provide ship rats with trees for nesting, as well as a variety of food sources (Dowding & Murphy 1994; Innes 2005). However, in other studies, forest-edge habitats are either generally not favoured, or had no effect on capture probabilities of ship rats (e.g. King et al. 1996; White et al. 1997; Christie et al. 2006). Edge habitats likely have greater food availability than the beech forest interior, because of their greater plant and invertebrate diversity (e.g. Montgomery et al. 2003), while still providing the shelter ship rats require. Failure to detect ship rats in adjacent grassland habitat during this study was not surprising. While ship rats are capable of occupying grassland, their presence is much less common when compared with forest habitats (e.g. Pye et al. 1999; Innes et al. 2010; King et al. 2011).

Conclusions

We found that when ship rats were at low densities in beech forest, passive detection devices were a good tool for estimating ship rat occupancy. Given the linear relationship between ship rat tracking and trapping rates, we are confident the reported trends in occupancy are realistic and provide a more accurate estimate of ship rat activity than tracking rates. Furthermore, at a local scale, the intensive grid gave a better approximation of rat distribution than the single tracking-tunnel line that was part of a widely dispersed, extensive, valley monitoring regime. Utilising grids to monitor ship rats could be beneficial

for patchily distributed populations of native species, which may be impacted by localised outbreaks of rats in non-mast years. While we were able to meet the requirements of the site occupancy method, the design and layout requirements needed may differ for estimating ship rat occupancy in different habitat types. This is because ship rats display seasonal shifts in habitat selection, and because ship rat abundance and home range size vary according to forest type (Innes 2005). Improvements in detection probability with the presence of rain highlight the importance of measuring weather conditions when monitoring ship rats. Improving the current indices so that the probability of detection can be estimated would be a good first step towards more accurate estimates of ship rat distribution.

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