

Efficacy of chew-track-card indices of rat and possum abundance across widely varying pest densities

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Abstract: Chew-track-cards (CTCs) are potentially a cost-effective way to estimate the relative abundance of invasive rats and possums in New Zealand, but previous research suggested that their high sensitivity may limit use to low-density populations. Using a short two-night deployment period, we compared CTC indices of rat and possum abundance with a footprint tracking rate (RTR) index of rat abundance and a wax tag bite rate index (WTI) of possum abundance in 11 forest remnants that varied widely in rat and possum abundance (RTR and WTI of 0–100% over two nights). The CTC indices were strongly correlated with the WTI and RTR and were no more sensitive than these measures, and they showed little indication of saturation at high pest abundances. We found no evidence that rat interference altered possum bite rates, as had been observed for longer deployment periods. CTCs, deployed for two nights, are a promising tool for use over a wide range of pest abundances. Further research is required to examine whether rat interference is ever sufficiently high to obscure possum sign, and to confirm that the index can reflect meaningful variation in population density.

Keywords: monitoring, *Rattus rattus*, relative abundance, rodents, *Trichosurus vulpecula*

Introduction

Predation and competition from invasive rats (*Rattus rattus*, *R. norvegicus*, *R. exulans*) and possums (*Trichosurus vulpecula*) threaten many of New Zealand's native species (Craig et al. 2000; Innes et al. 2010a). The abundance of possums and rats is now routinely monitored as part of ecosystem health assessments (e.g. Craig Bishop, Auckland Council, pers. comm.; Elaine Wright, Department of Conservation, pers. comm.), for prioritisation of pest control operations (Sweetapple & Nugent 2011), and to understand the impacts of pest mammals on native species (e.g. Innes et al. 1999; Sweetapple et al. 2002; Boulton et al. 2008). Because the absolute abundance of small-mammal populations is extremely difficult to measure cost-effectively (Blackwell et al. 2002), this monitoring typically relies on estimating relative abundance using several indices: rat relative abundance using the proportion of tracking tunnels that contain rat footprints (rat tracking rate or 'RTR'), and possum relative abundance using the proportion of wax blocks that contain possum bite marks (wax-tag index or 'WTI') or the proportion of leg-hold traps that catch possums (residual trap catch index or 'RTCI'). Nationally standardised protocols have been developed for calculating these indices (NPCA 2010, 2011; Gillies & Williams 2013).

Chew-track-cards (CTCs) were recently developed as an alternative tool for monitoring the distribution and relative abundance of small-mammal populations in New Zealand (Sweetapple & Nugent 2011). Because CTCs are inexpensive, lightweight, compact, and able to monitor multiple species simultaneously, the CTC index of relative abundance (i.e. the proportion of CTCs bitten by a given species) is a time- and cost-effective alternative to existing indices (Sweetapple & Nugent 2011). CTCs are now commercially available (e.g. Connovation's 'Chew Card'), and they are increasingly being

used to index rat and possum abundance in New Zealand (Sweetapple & Nugent 2011; Craig Bishop, Auckland Council, pers. comm.).

Sweetapple and Nugent (2011) deployed CTCs at pest-controlled sites with low-density rat and possum populations, and showed that under these circumstances the CTC index of rat and possum abundance often correlated well with other indices (WTI, RTCI, and faecal pellet count index for possums, and an RTR index for rats). Explanatory power (R^2 value) for these correlations was typically within 60–80%. However, because of the high sensitivity of CTCs, Sweetapple and Nugent (2011) predicted that the CTC index may saturate, preventing differences in abundance from being discriminated at higher population densities. Sweetapple and Nugent (2011) deployed CTCs for a relatively long period (typically a week or more), and they suggested shorter deployment may avoid saturation at sites with higher pest abundance. These authors also found that rat interference on CTCs affected the probability that the bites of other species would be detected, and cautioned that the CTC index of possum abundance may be unreliable at sites with high rat abundance.

To examine the utility of CTCs for indexing rat and possum abundance beyond low-density pest-controlled populations, we deployed CTCs for two nights at sites covering a wide range of rat and possum relative abundances. We chose this deployment period after a region-wide pest monitoring programme by Auckland Council, based on a three-night deployment of CTCs, appeared to provide a reasonable balance between detection and saturation rates for both rats and possums, although still had occasional problems with index saturation (Craig Bishop, Auckland Council, pers. comm.). We calculated the rat and possum CTC indices for each of our sites, as well as an RTR index of rat abundance and a WTI of possum abundance. Our aims were to determine, for our two-night deployment period,

(1) how well the CTC index correlated with these other indices of rat and possum abundance, (2) the sensitivity of the CTC index compared with these other indices, in particular whether the CTC index became ‘saturated’ and uninformative beyond certain levels of rat and possum abundance, and (3) whether rat interference on CTCs affected the possum CTC index.

Methods

Rat and possum monitoring

We estimated relative abundance of rats and possums in 11 remnants of native forest (hereafter ‘sites’) across the Northland, Auckland, and Waikato regions of New Zealand. We selected sites that maximised variation in rat and possum densities, which we achieved by selecting sites that varied between no control and intensive ongoing control of rats and possums (Table 1). Livestock-exclusion fences were in place at all forest remnants.

Within each site we established 100-m-long transects, set parallel to the forest edge. Each site contained one transect 10 m in from the forest edge (with the exception of a single site that was wetland at 10 m from the forest edge), and where sites were large enough we placed additional transects at 50 m (five sites) and 200 m (one site) from the forest edge, giving a total of 16 transects (Table 1). Transects were laid out in this way because the study formed part of a wider investigation into the influence of edge effects on pest mammal distributions in forest remnants.

Each transect contained six monitoring stations, spaced 20 m apart. At each station we deployed one footprint

tracking tunnel (‘Black Trakka’, Gotcha Traps, Auckland, New Zealand), one wax tag (‘Possum Detecta’, Connovation, Auckland, New Zealand), and one CTC (‘Chew Card’, Connovation), approximately 3 m apart. Tracking tunnels were baited with peanut butter (Gillies & Williams 2013), wax tags were nailed on trees at c. 30 cm above ground and with a 5:1 flour:icing sugar ‘blaze’ (i.e. a trail of flour–icing sugar mix leading from the ground to the wax tag; NPCA 2010), and CTCs were nailed on trees at c. 20 cm above ground and baited with Connovation’s ‘FeraFeed 213 paste’ (a mix of peanut butter, icing sugar, and Lucerne chaff). In total, the study involved 96 monitoring stations (16 transects containing six stations each). Monitoring devices were left in place for two consecutive rain-free nights between May and June 2012.

This spacing, number, and deployment period of devices deviated from the nationally standardised protocols for calculating WTI and RTR. These protocols call for a 10-m spacing of wax tags over three or seven nights and a 50-m spacing of tracking tunnels over one night, respectively, with tens of devices deployed along multiple transects (NPCA 2010; Gillies & Williams 2013). Our deviations from the standardised protocols were necessitated by logistical constraints. Firstly, these protocols require relatively large areas of forest in order to fit the required number and spacing of devices (Innes et al. 2010b), whereas many of our sites were small forest remnants (Table 1). Inclusion of these small remnants was necessary because larger sites with no recent history of pest control were extremely rare in our study region. A 20-m spacing of monitoring stations allowed us to fit enough devices into our small forest remnants to calculate each index with reasonable resolution. An alternative protocol has been developed

Table 1. Characteristics of forest remnants sampled in this study. Sites are ordered by increasing intensity of pest control.

| Site | Location | Area (ha) ^a | Forest type | Distance of transect(s) from forest edge | Pest control |
|---------------------------|----------------------|------------------------|----------------------|--|--|
| Puoto 1 | Kaipara (Northland) | 1.7 | Podocarp–broadleaved | 10 m | None |
| Puoto 2 | Kaipara (Northland) | 5.2 | Kahikatea | 50 m ^b | None |
| Flexman Scenic Reserve | Rodney (Auckland) | 2.6 | Podocarp–broadleaved | 10 m, 50 m | None |
| Whitikahu | Taupiri (Waikato) | 1.5 | Kahikatea | 10 m | None |
| Coulthards Scenic Reserve | Franklin (Auckland) | 11.9 | Podocarp–broadleaved | 10 m, 50 m | None since at least 2007 |
| Paerata Scenic Reserve | Franklin (Auckland) | 2.0 | Podocarp–broadleaved | 10 m | None since at least 2007 |
| Simpkin Rd | Kaipara (Northland) | 10.4 | Podocarp–broadleaved | 10 m | Occasional possum control |
| SH2 | Hauraki (Waikato) | 1.4 | Tawa–broadleaved | 10 m | Occasional possum control |
| Orchard Rd | Hauraki (Waikato) | 0.9 | Kahikatea | 10 m | Occasional possum control |
| Bald Hill | Franklin (Auckland) | 1.6 | Podocarp–broadleaved | 10 m, 50 m | Rat and possum bait stations, ~1 per ha, replenished quarterly |
| Ark in the Park | Waitakere (Auckland) | 13,207 | Podocarp–broadleaved | 10 m, 50 m, 200 m | Intensive ongoing control of rats, possums, and mustelids |

^aMeasured from the New Zealand Land Cover Database 2 using ArcMap 10.0.

^bNo 10-m transect at this site because of unsuitable habitat (wetland).

Kahikatea = *Dacrycarpus dacrydioides*; Tawa = *Beilschmiedia tawa*

for deploying tracking tunnels in relatively small forest remnants, whereby tunnels are placed on a 50-m grid (Innes et al. 2010b) rather than along a transect (Gillies & Williams 2013). However, this protocol would also have resulted in an insufficient number of monitoring stations at our smallest sites. Secondly, because our aim was to compare the sensitivity of CTCs to the other devices, we deployed all devices for the same length of time (Sweetapple & Nugent 2011). This period was determined by our hypothesised optimal CTC deployment period of two nights.

We examined CTCs for the presence of rat or possum bite marks, wax tags for the presence of possum bite marks, and tracking tunnels for the presence of rat footprints. We pooled transects within sites, which was necessary for the statistical approach we took (see below), then calculated our rat CTC index, possum CTC index, and WTI for each site as the proportion of devices bitten, and our RTR index as the proportion of tunnels tracked.

Statistical analyses

We analysed relationships between the CTC index and our WTI and RTR index with simple linear regression. We logit-transformed RTR and WTI to ensure they had a linear relationship with their respective CTC index, and then modelled RTR as a function of rat CTC index and WTI as a function of possum CTC index. We chose this transformation because it is generally the most appropriate for modelling proportional data (Warton & Hui 2011), and because it produced models that met the assumptions of linear regression as judged by plots of model residuals. Although RTR and WTI were also proportional data, we did not transform these indices because linear regression does not require normally distributed predictor variables. We used the R^2 value produced (i.e. proportion of variance in WTI or RTR explained by CTC index) to examine how well the rat CTC index could predict RTR, and how well the possum CTC index could predict WTI. We had initially attempted to model relationships among indices using mixed-effects models with site as a random factor (avoiding the need to pool data) and generalised linear models (avoiding the need to transform data prior to analysis), but we were unable to produce models that met the assumptions of these approaches despite attempting a comprehensive range of fitting procedures.

To compare the sensitivity of the CTC indices with RTR and WTI, we visually inspected scatterplots of rat CTC index versus RTR, and possum CTC index versus WTI, to see whether values for the CTC index tended to reach 100% (i.e. saturate) before those for the RTR or WTI. We also used paired Wilcoxon signed-rank tests to test if rat CTC index or possum CTC index was on average higher or lower than RTR or WTI from the same site. We used paired Wilcoxon tests rather than paired t -tests because we could not meet the latter's assumption of normally distributed differences among pairs of observations, even after trying a range of data transformations.

We tested for an effect of rats on the efficacy of the possum CTC index in our study by regressing the residuals of our possum CTC model against the rat CTC index. This tested whether discrepancies between values of WTI predicted by the possum CTC index and values of WTI observed in the data could be explained by rates of rat interference on CTCs. All analyses were carried out in R v2.15.1 (R Core Team 2012).

Results

As expected from their differing degrees of mammalian pest control (Table 1), there was wide variation in the relative abundance of rats and possums across sites, ranging between 0% and 100% for both RTR and WTI (Fig. 1a, b). Our regression models suggested that CTC indices were strongly correlated with RTR and WTI. For rats, the CTC index explained a high proportion of variance in RTR, and this relationship was highly significant ($R^2 = 0.70$, $P = 0.001$; Fig. 1a). For possums the relationship was even stronger, with the CTC index explaining 94% of the variance in WTI ($R^2 = 0.94$, $P < 0.0001$; Fig. 1b).

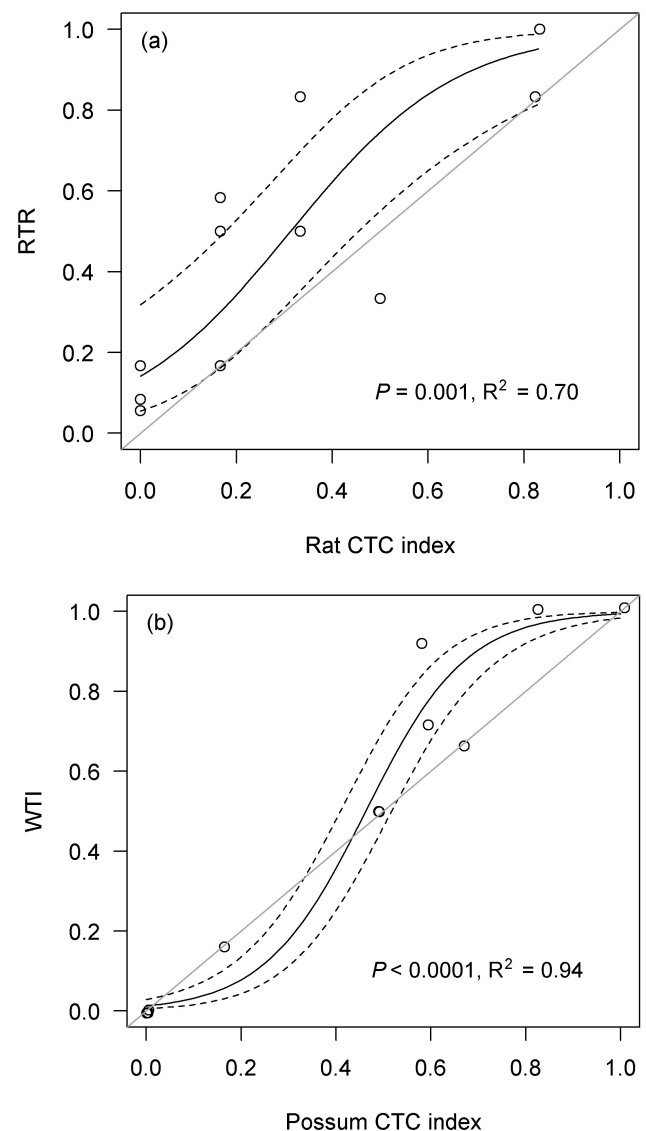


Figure 1. Relationships between chew-track-card (CTC) indices of rat and possum abundance and indices based on established tools. (a) Relationship between CTC and tracking tunnel rate (RTR) indices of rat abundance. (b) Relationship between CTC and wax tag bite rate (WTI) indices of possum abundance. R^2 and P -values were calculated using linear regression of logit-transformed RTR and WTI on CTC index. The solid and dashed black lines show back-transformed fitted values and 95% confidence bands, respectively, from the regression models. The grey lines depict a hypothetical 1:1 relationship between indices, and indicate whether observed values for the CTC index are more sensitive (below the line) or less sensitive (above the line) than RTR or WTI.

We tested whether the strong correlation between the possum CTC index and WTI may have partly been due to four sites with ‘double zeros’ (where possum abundance was so low that no wax tags or CTCs were bitten) or ‘double ones’ (where possum abundance was so high that all wax tags and CTCs were bitten). This produced a perfect correlation among these sites, even though interference rates of the two devices may not have correlated closely with one another at intermediate relative abundances. However, the CTC index still had a high ability to predict WTI when these four sites were removed and the analysis was rerun ($R^2 = 0.78$, $P = 0.008$). ‘Double zeros’ and ‘double ones’ did not occur for the rat data.

For rats, CTCs were generally less sensitive than tracking tunnels for indexing relative abundance, with the rat CTC index averaging 58% ($\pm 14\%$ SE) of RTR. This difference in sensitivity was apparent on a scatterplot of rat CTC index versus RTR, with the majority of points falling above the 1:1 line (Fig. 1a), and was statistically significant (paired Wilcoxon signed-rank test, $Z = 2.23$, $P = 0.02$, d.f. = 11). For possums, CTCs were of similar sensitivity to wax tags, with the possum CTC index averaging 93% ($\pm 4\%$ SE) of WTI. This difference was not statistically significant ($Z = 1.73$, $P = 0.25$, d.f. = 11). The possum CTC index reached 100% (i.e. saturated) at one site, and the rat CTC index nearly saturated ($>80\%$) at two sites. However, there was no evidence that the CTC index saturated before WTI or RTR; in fact, inspection of scatterplots suggested that RTR and WTI may have been more prone to saturate than their corresponding CTC index (Fig. 1a, b).

There was no evidence of a correlation between rat CTC index and the residuals of our regression model for WTI against possum CTC index ($R^2 = 0.01$, $P = 0.75$; Fig. 2), suggesting

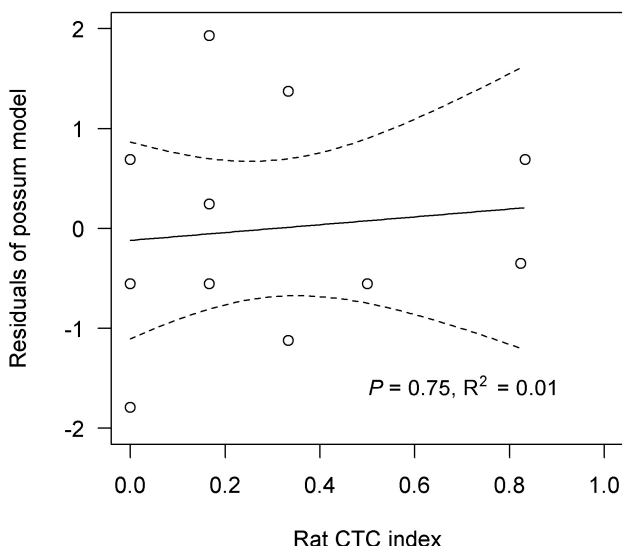


Figure 2. Discrepancies in the relationship between a chew-track-card (CTC) index of possum abundance and a wax tag bite rate index of possum abundance (WTI) as a function of rat interference rates on CTCs. The possum CTC index was initially modelled as a function of WTI using linear regression, and the figure plots the residuals of this model against rat interference rates on CTCs. The hypothesis that rat interference depresses the possum CTC index relative to WTI implies that high values of the rat CTC index should be associated with large negative residuals. R^2 and P -values were calculated by linear regression of the residuals on rat CTC index. The solid and dashed black lines show fitted values and 95% confidence bands from this model, respectively.

that rat interference on CTCs did not affect the ability of the possum CTC index to predict WTI under the range of rat interference rates we observed.

Discussion

Conservation managers and researchers working with limited resources in New Zealand require tools that can cost-effectively and reliably index the abundance of rats and possums. Sweetapple and Nugent (2011) found that CTCs were more cost-effective than existing tools, but questioned CTC reliability beyond sites with low-density populations because (1) their high sensitivity may predispose the CTC index to saturation, and (2) high rates of rat interference may affect the possum CTC index. Our results suggest that these issues can be avoided by shortening the deployment period of CTCs to two nights. We found that CTCs, deployed for two nights across sites with widely varying pest relative abundances (as measured by CTC indices, RTR and WTI), produced index values that did not saturate for rats and did not saturate for possums except at a single site. The CTC index was no more sensitive than indices based on tracking tunnels or wax tags, and CTC values correlated strongly with the RTR and WTI. We also found no evidence that rat interference affected the possum CTC index's ability to predict WTI. Overall, our data suggest that a two-night deployment period provides an appropriate balance between detection and saturation probabilities across a wide range of pest relative abundances.

While we found that our CTC indices were strongly correlated with indices based on tracking tunnels and wax tags, we caution that these results provide only suggestive evidence that CTC indices can reflect meaningful variation in the underlying quantities of interest (such as absolute density or predation risk). Firstly, the CTC indices, WTI, and RTR are all relative indices, and there are well-recognised biases with extrapolating this type of index to absolute density. For example, interference rates can vary independently of density as a result of activity rates of the target species, interference by individuals across multiple devices, food availability, and behavioural suppression by predators and competitors (Sarrazin & Bider 1973; King & Edgar 1977; Quy et al. 1993; Brown et al. 1996; Blackwell et al. 2002; Whyte 2013). Secondly, for logistical reasons, we deployed wax tags and tracking tunnels using methods that deviated from nationally standardised protocols (NPCA 2010; Gillies & Williams 2013). While the standardised versions of WTI and RTR have been shown to reflect meaningful variation in pest abundance or impacts (e.g. Innes et al. 1999; Armstrong et al. 2006), our versions of these indices have not. Given the strong correlations we observed between our WTI and RTR indices and the CTC indices, it seems likely that the CTC indices would also correlate with the standardised versions of WTI and RTR. However, this assumption remains untested. Thirdly, as in previous studies of the relationships between relative abundance indices (Brown et al. 1996; Blackwell et al. 2002; Sweetapple & Nugent 2011), the correlations we observed may have been artificially increased by the fact that CTCs, wax tags, and tracking tunnels were placed in close proximity to one another at each monitoring station. This approach allows device sensitivity to be compared while controlling for within-patch variation in pest density or activity rates, but bait consumption at one device might nevertheless increase searching intensity or decrease neophobia around the other devices. Fourthly, we did not record any rat or

possum interference at 3 of our 11 sites, suggesting that CTC indices based on a two-night deployment – while providing a good balance between detection and saturation probabilities when monitoring rat and possum abundance across sites with widely varying pest densities – may be relatively insensitive when monitoring occurs exclusively within low-density pest-controlled populations. In these cases, the longer deployment periods used by Sweetapple and Nugent (2011) may be more appropriate.

The fitted values from our statistical models suggested a sigmoidal relationship between RTR and rat CTC index, and between WTI and possum CTC index. However, we logit-transformed our CTC indices prior to statistical modelling to linearise their relationships with RTR and WTI, and this forced their back-transformed relationships with RTR and WTI to be sigmoidal. The logit is generally the best transformation for proportional data (Warton & Hui 2011), and appeared to be appropriate in our case, producing valid models (confirmed by inspection of model residuals) and fitted values that represented the relationships between RTR, WTI, and the CTC indices relatively well. Nonetheless, we had no theoretical reason for believing there would be sigmoidal relationships among indices, and statistical models based on a larger number of data points may have indicated that these relationships were somewhat different. Thus, although our models showed there were strong positive relationships between RTR and rat CTC index, and between WTI and possum CTC index, we stress that the specific shape of these relationships remains uncertain.

Although we found no evidence that rat interference on CTCs affected the efficacy of the possum CTC index, our rat CTC index did not exceed 80% across the sites sampled. This may have limited our ability to detect an effect of rat interference, which might only occur at higher rat activity rates. These moderate interference rates were potentially the result of the short deployment period of CTCs, rather than an intrinsically low abundance of rats at our sites, because (1) we sampled sites that had no recent history of rat control, and (2) many of these had high rat abundance as measured by our RTR index ($\geq 50\%$ at six sites, reaching 100% at one site). Nevertheless, at some point rat interference must reduce the ability of CTCs to index possum abundance. Whereas possum bites create dents in CTCs but do not remove any material, rats physically remove sections of CTCs, removing bait, reducing the size of the detection surface, and potentially removing pre-existing possum bites at high rat-bite intensities. A key question that remains is how frequently (if ever) rat interference on CTCs deployed for two nights reaches high enough levels to significantly affect the possum CTC index.

In conclusion, we find that CTCs are a promising tool for the cost-effective indexing of rat and possum abundances over widely varying pest densities. Our results suggest that perceived problems with CTC sensitivity beyond low-density populations may be avoided by calculating CTC indices based on a two-night deployment period, rather than the deployments of one week or more that have been used previously for monitoring (Sweetapple & Nugent 2011). However, further research to examine whether rat interference ever reaches sufficiently high levels to significantly affect the possum CTC index, and a calibration study comparing CTC index values to known pest abundance, would be useful before considering the two-night CTC index a robust alternative to existing indices.

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