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RESEARCH

Measuring rat relative abundance using camera traps and digital strike counters for Goodnature A24 self-resetting traps

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Abstract: Invasive ship rats (*Rattus rattus*) pose a threat to the biota of Goat Island (9.3 ha), New Zealand. In June 2016 we installed 10 Goodnature A24 CO_2 powered self-resetting rat and stoat traps equipped with digital strike counters (Goodnature Ltd., Wellington, NZ) to control rat numbers on the island. The self-resetting traps were monitored with motion-activated cameras to develop a measure of rat abundance from camera traps. All devices were checked on 10 occasions from August 2016 to October 2017. The videos revealed high rat activity on the island, which reduced over time. Counting only the number of videos that showed rats did not result in any loss of information when compared to more laboriously counting individual rats in videos and was therefore the preferred method for obtaining an index of relative rat abundance. We also found that digital strike counters designed to record the number of times an A24 is triggered, accurately reflected the number of individuals killed by A24s. However, measuring rat abundance in number of rat videos per 100 camera nights was shown to be of greater value when rat abundance was low and A24s failed to detect the remaining individuals.

Keywords: camera, invasive rats, index of abundance, *Rattus rattus*, relative abundance, self-resetting traps

Introduction

Early detection of invaders as well as invasive species control and eradication programmes require reliable monitoring (Pichlmueller & Russell 2018). In particular, monitoring tools must be able to detect individuals at low population densities and species which are reluctant to interact with detection devices or are elusive. In New Zealand, tracking tunnels are a widely used method for monitoring relative abundance of rodents and mustelids. Interaction is minimised to walking through the tunnel and the tunnels are perceived as the better alternative to snap traps (Gillies & Williams 2013). However, ship rats (*Rattus rattus*) showed hesitation in stepping on the ink pads in a pen trial, a behavioural response that can potentially affect monitoring rats in low population density (Cooper et al. 2018). The standard protocol advises a distance of 50 m between tunnels and using multiple lines (Gillies & Williams 2013); however, at small sites the number of tracking tunnels would be low or the distance between the tunnels would be too small. Various studies have shown that ship rats have an average travel distance of more than 100 m (Dowding & Murphy 1994; Hooker & Innes 1995; Harper & Rutherford 2016).

Motion-activated trail cameras are alternative detection devices which can optimize detectability in low population density or of species or individuals with reluctance to interact with detection devices (Mace et al. 1994; Karanth & Nichols 1998; Larrucea et al. 2007; Zimmermann et al. 2013). The majority of studies which have used camera traps targeted large mammals (Burton et al. 2015). The detection of small, fast moving animals can be technically challenging and is influenced by the sensor and flash type used (Glen et al. 2013). However, camera traps have been successfully used to detect presence, measure activity, and document behaviour of small rodents (Rendall et al. 2014; Mills et al. 2016; Gronwald et al. 2019). Camera traps have even been more successful in detecting small mammals than traditional live or kill trapping (De Bondi et al. 2010; Glen et al. 2014; Welbourne et al. 2015). The ongoing technological improvement of trail cameras, including sensors, trigger speed, and resolution, increases their suitability for surveys of small species.

Obtaining an estimate for the number of target animals in the study area is important for both scientific studies as well as conservation projects. Motion-activated game trail cameras extend the tool set for monitoring animal abundance. Population density estimates using established capture-recapture models can be used when individuals can be identified on a picture. Camera data were used to estimate the population density of tiger (*Panthera tigris*) in India, a secretive species which only occurs in low population densities (Karanth & Nichols 1998). However, many species cannot be identified to the individual on a photo. Therefore, many studies state an index of relative abundance (Rovero & Marshall 2009; Güthlin et al. 2014). An index of abundance is easier and cheaper to obtain than performing a capture-recapture study for robust population density estimates (O'Brien 2011). However, cameras have high initial costs to purchase and the unautomated analysis of videos is labour intensive (Anton et al. 2018a). The development of

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software which uses artificial intelligence to identify the target species in a photo can significantly reduce data processing time (Falzon et al. 2020).

Here we evaluate two different methods for obtaining an index of abundance from camera footage for invasive rats based on 1) the number of videos showing rats per time unit, and 2) the number of rats in videos per time unit. Rat population density at the study site was unknown. The comparison of the two methods sets out to determine if the obtained indices of rat relative abundance differ and if the difference changes when rat numbers are reduced due to ongoing kill trapping. We then also evaluate the reliability of a digital strike counter for characterising killed individuals at Goodnature A24 CO_2 powered self-resetting rat and stoat traps (Goodnature Ltd., Wellington, NZ, subsequently referred to as A24s) where carcasses do not necessarily remain at the trap and therefore cannot be counted. Finally, we compare indices of abundance from digital strike counters and camera traps to assess if camera traps are a suitable tool for monitoring rat abundance and trends in it.

Methods

Study site

Goat Island (Te Hāwere-a-Maki; 36°15′54.8″S, 174°47′51.1″E) is a small island of approximately 9.3 ha. It lies in the Cape Rodney-Okakari Point Marine Reserve in Leigh on the east coast 70 km north of Auckland (Fig. 1). The island has small breeding colonies of seabirds: grey-faced petrels (*Pterodroma gouldi*) and little penguins (*Eudyptula minor*). Ship rats are the only invasive mammal permanently present on the island. During low tide rocks are exposed along the coastline and reduce the distance between the mainland and the island to less than 100 m. This enables ship rats to swim across and imposes a risk of an incursion. Maintaining Goat Island rat-free has proven difficult and ship rats remain abundant (Pichlmueller & Russell 2018).

Cameras and A24s

Ten A24s were placed across the island in July 2016 at an average distance of 75 m (range 45–89 m). Each trap was equipped with a digital strike counter. The strike counter senses the vibration of the triggering of the trap and briefly displays the number on a digital LED display and records the number of times the trap fires. The traps were baited with Goodnature Automatic Lure Pumps (ALP)-chocolate formula for rats. An ALP contains 55 g of non-toxic bait slowly dispensed continuously over 6 months. The traps were placed vertically on large tree trunks approximately 12 cm above the ground following the manufacturer's guidelines. During the 15-month field trial, from August 2016 to October 2017, the ALPs were replaced after 6 months in January and July 2017. Gas cartridges were replaced when the strike counter showed 20 or more. The traps were on average checked every 49 days (range 27–63 days).

Each A24 was monitored with a trail camera with PIR motion-activated sensor (Bushnell Trophy Cam HD 8MP; Bushnell, Cody, USA) to record rat activity around the devices. The cameras were attached to a tree, using adjustable mounts (Slate River EZ Aim Game Camera Mount), pointing to the trap at a 45°-angle from a height of 145 cm and a distance of c. 1.5 m. Slight variations were caused by the difficulty of the terrain, e.g. slopes, dense vegetation, and the availability of trees suitable for mounting. This set-up was chosen to limit the sensor field to approximately 1 m to each side of the trap to avoid the cameras being triggered by rats or movements which are too far from the trap, and to keep the camera at a height suitable for regular checks. The detection rate when using cameras with PIR sensors is related to the body mass of the detected animal (Lyra-Jorge et al. 2008). Small and fast or very slow-moving animals might not be detected (Glen et al. 2013). Therefore, the highest sensor sensitivity was used for all cameras. Cameras were set to record a 60-second video when triggered with a one second interval between videos.

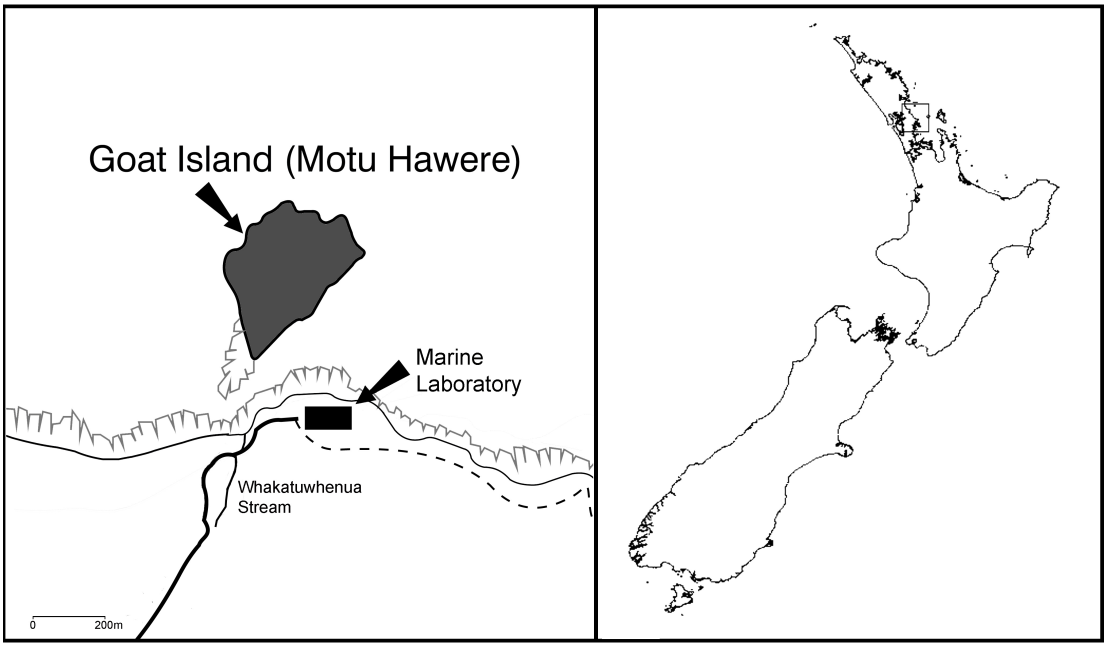

Figure 1. Goat Island and adjacent mainland sites. Leigh Marine Laboratory buildings indicated. Rectangle indicates the location of Goat Island in the North Island of New Zealand.

Measuring rat abundance

An index of abundance is commonly stated as captures per 100 corrected trap-nights (Nelson & Clark 1973). In this study the equation was simplified. Camera traps and A24s do not produce lost trap-nights because they retain the ability to detect individuals at all times. The trap-nights were extended to trap-days which cover 24 hours. Even though the main activity time of rats is during the night they can be and are active during the day (M. Gronwald pers. obs.). The resulting equation is:

$$\text{Index of abundance} = \frac{\text{Captures}}{\text{Trap-days}} \times 100 \qquad (1)$$

A24 index

Digital strike counters on the A24s register when the trap is triggered and the counts are assumed to equal the number of rats killed. These data can be used to calculate an index of abundance that is comparable to an index of abundance based on kill trap data with the advantage that the A24s do not have to be checked as frequently as single kill traps. The display of the digital strike counter blinks when the A24 is triggered. This makes a trigger count visible in the video. Only videos showing the moment when a rat triggers the A24 were analysed. Records were made if the rat was hit and/or if the strike counter was triggered to evaluate the reliability of the digital strike counts. Even though the ‘capture’ rate for predators are higher with cameras than kill traps (Glen et al. 2014), the strike counters have the potential to be a reliable and relatively cheap monitoring tool for Goodnature A24s.

Video index and rat index

Two different ways of counting can be used to determine an index of rat relative abundance from camera footage, either the number of rat videos (i.e. a video where one or more rat is present at any time) per 100 camera-days (video index) or the number of rats (i.e. the maximum number of rats observed at once in a video) per 100 camera-days (rat index). A video can show more than one rat. The maximum number of rats was documented for each video. If there was a rat at the beginning of a video leaving the field of view and a rat entering the video later in the same video it was counted as one animal unless they were obviously two different rats. Individuals within one video could be distinguished from each other when they were visible at the same time or when distinct characteristics were identifiable, e.g. adult/juvenile, tail/no tail. Determining the rat index is much more labour intensive than the video index. Therefore, an evaluation of the difference between the two indices will determine how much workload is needed for future video analyses.

Statistical analysis

The rat index and the video index were compared with a paired *t*-test to answer the question if the rat index differs significantly from the video index. A Pearson’s product-moment correlation test was run to analyse the relationship between the index of abundance from the video analysis and the A24 index based on the digital strike counts. All analyses were conducted in R (R Core Team 2019).

Results

A total of 7155 videos, more than 119 hours of footage, from 2161 camera days were analysed. Seventy-four percent of the videos recorded rats.

Comparison between rat index and video index

There were only minor differences in the index values between rat index and video index. The average number of rats per session that could be seen in a video with rats was 1.03 rats video^{-1} (range 1–1.18) (Table 1). The two indices did not differ significantly from each other ($t = 1.403$, $df = 9$, $p = 0.19$). Since usually only one rat was ever seen in a video, the video index is close enough to the rat index to be chosen as a measure of abundance without losing information but easier to obtain.

Reliability of the digital strike counts

The moment of a rat triggering an A24 was visible and audible in 70 videos, in a further 24 videos the activation of the strike counter was missed due to delayed recording. In 60 videos the rat was obviously hit lethally. The strike counters recorded 92% of the kills correctly (i.e. were triggered when a rat was killed), slightly underestimating the actual number of kills confirmed by the video footage. In the remaining 10 videos where the rat was not obviously hit lethally, the strike counters still recorded the triggering 30% of the time, resulting in overestimated kill counts, although these cases were few. However, the overall counts correlated with the actual kill numbers well, as these two opposing errors of count tended to balance each other out. Ultimately, there was a slight underestimation from the strike counters with 97% of all kills being reflected in the strike counts (Table 2), i.e. 58 strikes for 60 kills. Taking the small margin into account, the strike counter numbers were an appropriate equivalent to the number of rats killed by the A24s.

Table 1. Number of rats and rat videos per 100 camera days from August 2016 to October 2017 on Goat Island.

Recording period	Rats	Rat videos
August 2016	1282	1182
September 2016	156	156
November 2016	465	450
January 2017	164	159
March 2017	131	129
May 2017	204	195
June 2017	153	152
July 2017	219	219
August 2017	183	181
October 2017	189	188

Table 2. Number of Goodnature digital strike counts on A24s. False negatives (top row) are observed kills which were not registered by the digital counters. False positives (bottom row) were observed strikes which did not kill the individual but were counted by the digital counter.

	Visible in video	Digital strike counts	Digital strike counts as a % of recorded strikes
Kill	60	55	91.67
No kill	10	3	30.00

Comparison of indices of abundance

The video index was the highest in the first month after trap deployment (Figure 2) and after three months it remained relatively constant for the rest of the study. The A24 index showed a similar pattern in the first three months but then fell to almost zero at the end of the study, 0.7 kills per 100 trapping days in October 2017. Unlike the A24 index, the number of rat videos stayed at a constant high level (Fig. 2). There was no significant evidence of a correlation between the two indices (r = 0.36, n = 9, p = 0.34) (Fig. 3).

Discussion

When measuring the abundance of rats on Goat Island the video index and the rat index differed only to a small margin. However, obtaining the rat index involved more work. The whole video had to be watched to count all possible rats and the identification of individuals costed extra time and would always contain an element of subjectivity. The time used for the analysis went beyond the actual footage time and increased the work nearly ten-fold. The difference between the indices could be larger when the population density is higher, i.e. many more than one rat seen per video. A comparison with other temperate ecosystems with similar densities as well as studies in tropical environments where densities can be many times higher than in New Zealand are needed to confirm the widespread suitability of a video index for rat abundance.

Regarding labour costs in research, as well as limited human resources in community projects, reducing the work time can be crucial. Categorising the videos into rat presence and absence was a quick and useful approach and did not lose essential information compared to distinguishing individuals in the videos. Besides time saving, video categorising can be undertaken by any person who is capable of identifying a rat. This enables the involvement of non-professionals in the analysis of huge data sets in academic research (Citizen Science) which is already in use, e.g. in monitoring biodiversity, abundance or pest detection (Chandler et al. 2017; Anton et al. 2018b et al.). Furthermore, automated identification technology in development (e.g. Thermal Imaging: https://cacophony.org.nz/) has the potential to even further increase the number of recordings that can be processed.

While a kill by a single kill trap can be confirmed by the presence of a carcass or parts of it, the only consistent evidence at an A24 is the strike counter number. The numbers

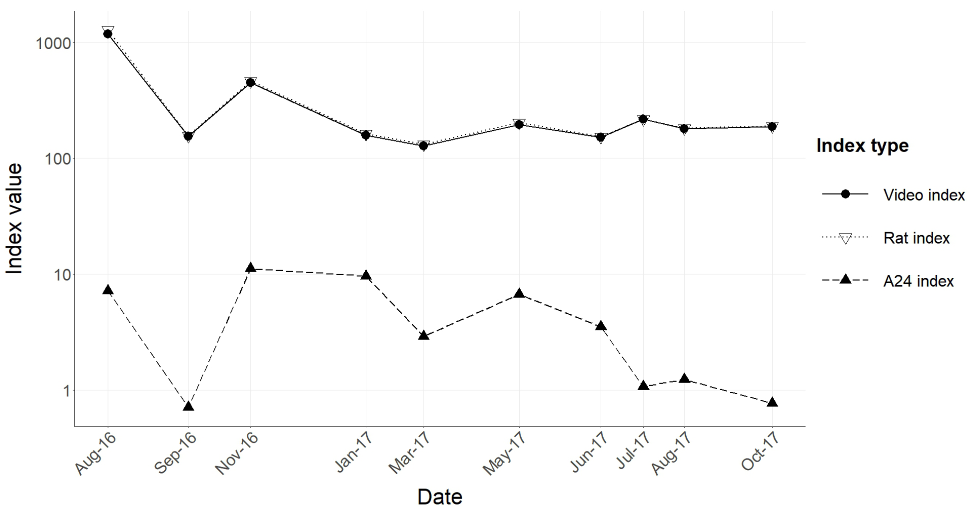

Figure 2. Indices of ship rat relative abundance on Goat Island plotted against time from August 2016 to October 2017. A24 index represents Goodnature digital strike counts per 100 trap days and video index represents number of rat videos per 100 camera days.

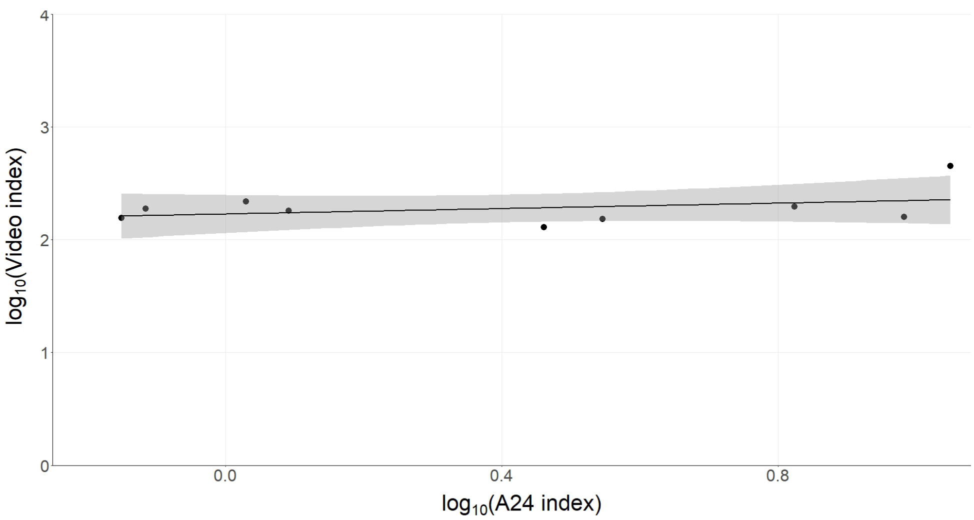

Figure 3. Correlation between A24 index based on digital strike counts and video index for Goodnature A24s monitored by cameras on Goat Island, Sep 2016–Oct 2017, both log10-transformed to remove high leverage effects of large values. Pearson's product-moment correlation: r = 0.36, n = 9, p = 0.34.

acquired from the digital strike counters were generally a suitable representation of the actual number of individuals killed. When a rat is killed by the self-resetting A24 its body drops to the ground. However, the rats can still move a few metres away from the trap and roll out of the field of view in spasms. In addition, rats, ruru (*Ninox novaseelandiae*), and kāhu (*Circus approximans*) are potential scavengers (M. Gronwald pers. obs.) and were present on or nearby Goat Island. The strike count numbers have shown to slightly underestimate but approximately match the real number of kills closely enough to be seen as a reliable source of information. Ogden (2018) has described an underestimation by the counters of 19% on Aotea/Great Barrier Island. However, the data were based on counting carcasses around the trap and data from a malfunctioning strike counter might also have been included. It should be noted that the strike counts can only be used to estimate relative abundance in areas with only one target species and when it is unlikely that non-target species can trigger the trap. A general advantage of the strike counters is that they provide information suggesting when the gas cartridge has to be replaced. In high population density of the target animals the traps might be triggered more than 24 times within 6 months, which is the maximum trigger number advised for the cartridges per manufacturer.

Video data and kill numbers on Goat Island have given different information about rat abundance. The correlation between rodent relative abundance indices from different devices are influenced by population density and behaviour (Blackwell et al. 2002; Nathan et al. 2013). Relative abundance estimates from camera traps strongly correlated with indices obtained from traditional methods for a range of large herbivores (Rovero & Marshall 2009; Palmer et al. 2018). On Aotea/Great Barrier Island true density estimates for invasive rats from live trapping data also strongly correlated with an index of relative abundance from camera traps (M. Gronwald, unpubl. data). The population density on Goat Island was expected to decline over time during this study due to the sustained trapping effort. With rat trapping ongoing at the coastline of the adjacent mainland the rate of incursions was assumed to be low. Even before the trapping along the mainland coast was started, incursions to Goat Island were not the driving factor in population growth (Pichlmueller & Russell 2018). The A24s failed to detect remaining individuals on Goat Island towards the end of this study. The camera traps revealed that the rat removal rate was too low to sufficiently reduce rat activity. Long term trials have shown a reduced kill rate for A24s when initially successful trapping reduced abundance to low levels (Carter et al. 2016; Gilbert 2018; Carter et al. 2019). Therefore, camera traps were a valuable tool to gain information about rat abundance on Goat Island.

Motion-activated cameras, as a non–invasive detection tool, circumvent the need for device interactions. At the moment the most common method in New Zealand is the use of tracking tunnels with ink cards which require interaction between the individual and the tunnel. The animal has to enter the tunnel and can show reluctance in the first night (Cooper et al. 2018). Cameras don't intervene with the natural behaviour of the rats. The distance between detector and individual can be several metres, while animals may sense cameras through audible and visual cues (Meek et al. 2014), it does not necessarily influence the detection rate (Taggart et al. 2019; Henrich et al. 2020). Ball et al. (2005) have described the probability of detection as the product of the probability of encountering a device and the probability of interacting with the device. When using cameras, the probability of interaction can be removed from this equation. However, technological imperfections cause error. Camera specifications, e.g. different types of sensors or trigger speed, influence the detectability in a negative way (Glen et al. 2013). Standardising the field of view, sample size and trapping distance in a best practice protocol for the use of cameras in monitoring the abundance of invasive mammals is needed to enable the comparison of results across study sites and ecosystems. In a conservation context a reduced probability of detection due to the lack of interaction with devices is problematic. Not detecting individuals during ongoing control as well as missing invaders in a predator-free ecosystem can lead to wrong decision making in the management of the area, e.g. reducing control effort or not responding to incursions In addition, simplifying the camera monitoring methodology allows the involvement of groups without a specific knowledge background, e.g. community groups, schools, etc.

We showed that for an index of abundance based on video data the number of rat videos can be used instead of the number of individuals visible in the videos without significant loss of information. The video index is preferred to the rat index because it is easier and cheaper to obtain. Although videos were used here the results are expected to hold true for photos as well. Digital strike counters were proven to be a reliable source of information for the number of individuals killed by A24s in our study, where ship rats were the only target species and interactions of non-target species with the traps were unlikely. However, the cameras were better than A24s in detecting rats once abundance was reduced after sustained trapping. The camera traps were a suitable tool for monitoring invasive rats at different abundances on Goat Island.

Authorship Statement

MG designed and performed research, undertook statistical analyses, and wrote the manuscript; JCR designed and supervised the research and assisted with data collection

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