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Research Article

Behaviour of invasive ship rats, *Rattus rattus*, around Goodnature A24 self-resetting traps

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Abstract

Invasive ship rats (*Rattus rattus*) are a major threat to the native species and ecosystems of islands. We used 10 self-resetting traps (A24 rat and stoat traps, Goodnature Ltd., Wellington, NZ), along with existing single kill DOC200 traps at two devices per hectare on a 9.3 hectare island in New Zealand to reduce rat numbers and ideally achieve eradication. Each self-resetting trap was monitored with motion-activated cameras to analyse rat behaviour and A24 kill numbers were documented using Goodnature digital strike counters. The traps were checked on 10 occasions from August 2016 to October 2017. The videos documented initial high rat activity on the island, which reduced over time following initial trapping success. An immediately obvious neophobic response towards the A24 traps was not observed. Rats interacted with the A24 traps within hours after initial deployment and 60% of the traps were triggered in the first night. After three nights, all traps were triggered at least once. While rats interacted with the traps at all times of the year the number of observed trap-triggers was relatively low. High number of interactions resulted in high kill numbers in late spring when population size was increasing and seasonal food abundance had not yet reached its peak. A second peak was observed in late autumn when rat abundance was presumably high. Recruitment of naïve individuals was a probable cause for high kill numbers during the breeding season. In winter, when rat abundance was presumably low, a few individuals were the likely cause for a high number of interactions while kill numbers were low. A knock-down (i.e. suppression from high to low abundance) of rats using both trap types was achieved in the first 100 days. However, kill numbers of A24s declined over time. After the initial suppression, the number of rats killed was insufficient to offset intrinsic population growth and reinvasion from the adjacent coast, thereby preventing eradication.

Key words: black rats, camera traps, density dependent, New Zealand, seasonality, suppression

Introduction

Invasive species are one of the main drivers for biodiversity loss on islands (Jones et al. 2008; Kurle et al. 2008; Reaser et al. 2007). Rats from the genus *Rattus* are among the world's 100 worst invasive alien species (Lowe et al. 2000). Ship rats (*Rattus rattus*), Norway rats (*R. norvegicus*), and Pacific rats (*R. exulans*) are present in New Zealand (Atkinson 1985). The damage done by invasive rats was recognized early and New Zealand has undertaken rat eradications on offshore islands for more than 50 years. However, some islands are a challenge for rat eradications due to their large size, human residents, or vulnerability to reinvasion from the mainland (Russell and Broome 2016). Eradication using traps only is rarely successful (DIISE 2020). An obvious limitation for the use of traps for eradications is island size and the labour required. The largest island in the list of successful eradications using only traps is Motuhoropapa, New Zealand (12.9 ha) (DIISE 2020).

World-wide, on only nine small islands have rodent eradications been successful with trapping as sole method (DIISE 2020). One approach to extend the tool box for rodent eradications is to improve present mechanical devices for rodent control, or develop entirely new ones. Often, the success or even the feasibility of predator control is influenced and limited by the availability of human and financial resources. Toxin-free devices like single-set traps demand a high amount of time for maintenance and, after an individual is killed, the area around the trap is left without any control until the trap is reset. Self-resetting traps can perpetuate more effective predator control. Mechanisms have been developed for existing traps, e.g. a battery powered motor attached to single-set traps to reset the bar (www.nzautotraps.com). Goodnature has chosen a different approach for a self-resetting trap (A24 rat and stoat trap, Goodnature Ltd., Wellington, NZ) that uses pressurised gas to operate a piston to kill the rat and then resets itself.

The success of rat control is defined by the expected outcome. Self-resetting A24s suppressed invasive rats on a large scale (> 140 ha), but rarely resulted in tracking tunnel detections at acceptably low levels (Gillies et al. 2014). In a trial of A24s over two and a half years in a 100 ha area on Aotea/Great Barrier Island, New Zealand, the traps also failed to fulfil conservation requirements (Gilbert 2018). On Oahu, Hawaii, A24s were more effective in controlling rats than single-kill traps but failed to meet requirements for the successful protection of the native tree *Cyanea superba* (Franklin 2013). Shiels et al. (2019) successfully used A24s to suppress rat relative abundance in Hawaii, but the A24s were used in combination with snap traps and the acceptable tracking tunnel index of 20% for the area was high compared to previous studies (Gilbert 2018; Gillies et al. 2014). While traps are usually used only to suppress numbers of invasive rats, an eradication using A24s was successful on a 6 ha cay in Puerto Rico (Zaluski and Soanes 2016). However, the rat eradication using A24s on nearshore 62 ha Native Island, New Zealand, was first reported successful (DOC 2015) but later described as a suppression operation (Carter et al. 2016, 2019). It remains unclear if the eradication failed or the island was reinvaded.

Camera traps are a valuable tool for documenting and analysing animal behaviour and activity patterns. Remotely triggered camera systems in wildlife monitoring have been used increasingly since the second half of the 20th century in different contexts in animal ecology, behaviour, and conservation (Kucera and Barrett 2011; Nichols et al. 2011). Recent studies have shown the potential of camera traps for monitoring small animals including rodents (Austin et al. 2017; Glen et al. 2013; Gronwald et al. 2019; Gronwald and Russell 2021; Mills et al. 2016; Yamada et al. 2016). Camera trapping for behavioural studies allows deeper investigation into how animals interact with devices prior to their final recovery as corpses. Understanding the behaviour around devices helps to identify the optimal deployment of these devices. Various contextual factors need to be considered when analysing behaviour of animals around devices in the wild including biogeography, seasonality, animal abundance, food abundance or competition. Important behaviours influencing interactions between animals and devices may include foraging strategies, intraspecific aggression or neophobia. Neophobia is the avoidance of a new object for an extended period of time. For example, animals may take some time after first encountering a device to interact with it. Wallace and Barnett (1990) reported avoidance behaviour of *R. rattus* lasting up to 12 days when being confronted with a new object. If a general cautious response towards a new device affects trapping success, then the installation of a new device will result in a temporally delayed interaction between rats and devices. Cameras can measure the extent of this delayed response in the wild and help interpreting trapping and monitoring results. Minimising the time and number of behavioural steps required to kill an animal ultimately maximises the efficiency of a control tool.

This study was conducted on a small island with ship rats as the only rat species present and sets out to determine i) if self-resetting Goodnature A24 rat traps along with single-kill traps can suppress rat numbers and ideally achieve eradication on a small island, ii) if the rats show cautiousness towards new deployed A24s, and iii) if season or population abundance affect the behaviour of rats around A24s. We used motion sensored camera traps to measure rat relative abundance and to monitor the behaviour of ship rats around A24s. Our study design allowed a non-invasive observation of the behaviour towards an unknown device within a familiar environment. Food abundance determined by season and intra-specific competition in the system might alter the behaviour of rats. The interaction rate between rats and traps might change disproportionately if novel behaviours emerge at low abundance after successful trapping. Analysing the behaviour of the rats around A24s will help to evaluate their suitability as a control tool.

Materials and methods

Study site

Te Hāwere-a-Maki, or Goat Island, is a small island (9.3 ha) north of Auckland at the east coast of North Island, New Zealand. The island is a nesting site for grey-faced petrels (*Pterodroma gouldi*), little penguins (*Eudyptula minor*), and variable oystercatchers (*Haematopus unicolor*). The island is used by numerous native and introduced bird species. Ship rats and stoats (*Mustela erminea*) can swim to Goat Island and pose a risk to the seabird colonies. The risk of incursions is particularly high during low tide when rocks are exposed and the distance to the adjacent mainland is reduced to less than 100 m. Ship rats have established a population on the island (MacKay and Russell 2005) while stoats are occasional visitors (Pichlmueller and Russell 2018; M. Gronwald *pers. obs.*). Eradication attempts using a combination of Victor traps and brodifacoum took place on the island in 1994 and 2005. In both cases rats were detected on the island two years later (MacKay and Russell 2005). From 2011 an intensive rat trapping campaign was conducted initially using only Victor snap-traps (Pichlmueller and Russell 2018). Pichlmueller and Russell (2018) suggest that, even though reinvasion occurred in 2012 and 2013, the main reason for not achieving eradication was that resident rats were not being removed fast enough and recolonisation further facilitated the reestablishment of the rat population. Control of invasive rats and stoats on Goat Island using eight DOC200 single-set kill traps baited with eggs started in June 2015 following the detection of a stoat incursion on the island (Pichlmueller and Russell 2018). The distance between traps was approximately 100 m and trap density one device per hectare. The traps were checked and rebaited approximately once a month from June 2015 to February 2016. After that, they were not serviced until the beginning of our study in July 2016.

Self-resetting traps

In July 2016 the existing trapping grid was expanded by 10 Goodnature A24s, thereby increasing the overall trap density on the island to about two devices per hectare. The A24 is a self-resetting kill trap targeting rats and stoats. The rats fall underneath the trap after being killed leaving them open to scavenging by other rats, ruru (*Ninox novaeseelandiae*) or harriers (*Circus approximans*). The traps were equipped with Goodnature Digital Strike Counters and Automatic Lure Pumps – Chocolate Formula for rats. The strike counters sense the vibration of the triggering of the trap and show the illuminated number on a digital display. Automatic Lure Pumps (ALP) continuously deliver fresh lure for about six months (Carter et al. 2019). Installation and maintenance followed the manufacturer's guidelines. The traps were placed on large tree trunks approximately 12 cm above the ground. The traps were on average checked for strike counter numbers every 49 days (median = 53 days). During the 16 month field trial, from July 2016 to October 2017, the ALPs were replaced after six months in January and July 2017. Gas cartridges were replaced when the strike counter showed 20 or more. Dates in this manuscript represent dates of trap checks.

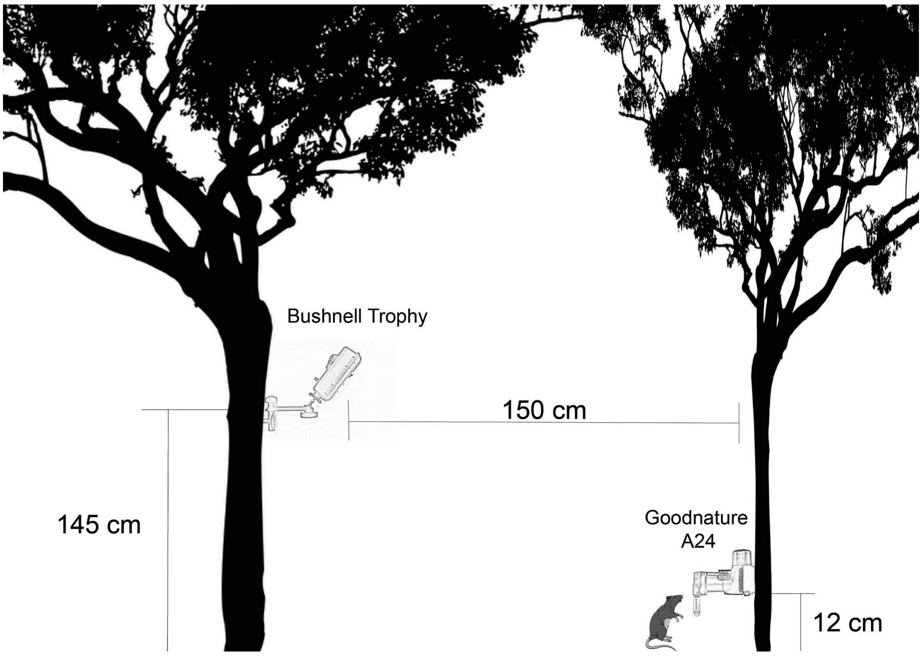

Figure 1. Schematic of equipment layout at each Goodnature A24

Video monitoring

Each of the A24s was monitored with a Bushnell Trophy Cam HD 8MP, a trail camera with passive infrared-based motion sensor. The cameras were pointing to the trap at a 45°-angle from a height of 145 cm and a distance around 1.5 m (Figure 1). The cameras were attached to a tree using adjustable mounts (Slate River EZ Aim Game Camera Mount). This set-up was chosen to limit the sensor field to approximately 1 m to each side of the trap. It avoided unwanted triggering of the cameras but kept the field of view large enough to analyse the behaviour. No cameras were placed at the DOC200 traps. All cameras were set to highest sensor sensitivity, lowest LED brightness, 1-minute video length and 5-secondinterval between videos. The cameras were equipped with 8GB SD cards fitting up to 240 videos.

Video footage was used to estimate rat relative abundance (see Gronwald and Russell 2021) and observe rat behaviour around the self-resetting traps. Because rats could not be identified to individuals in the footage and we cannot distinguish changes in absolute abundance from detection, our video measure is only one of relative abundance, or here after "rat activity". Two consecutive videos may have been triggered by the same rat. In only 16 videos (0.2% of all videos) a rat was visible in two consecutive videos with maximum 15s between videos. Therefore, we defined each video as a separate event. Observed behaviour was categorised into No Interest, Interest, Interaction (touching the trap), and Trigger, following the methods of (Gronwald and Russell 2020b).

Season and abundance effects on behaviour

Rat activity was reported as the island-wide number of detections (videos showing a rat) per 100 camera days (Gronwald and Russell 2021). The effects of season and rat activity on rat behaviour were analysed using a generalised linear mixed model. Response variable was the number of videos counted per behaviour (Count). Fixed effects were season (spring, summer, autumn, winter), rat activity, and behaviour observed in the videos, which included No Interest, Interest, Interaction, and Trigger. The random effect in the model was the site which was represented by the trap number.

$$\text{Count} \sim \text{Season} * \text{Behaviour} + \text{Rat activity} * \text{Behaviour} + (1|\text{Trap})$$

The number of Trigger videos may differ from the number of individuals killed due to imperfect detection. Therefore, digital strike counts, which accurately reflect the number of rat kills (Gronwald and Russell 2021), were the preferred measure. The effects of time and rat activity on the number of kills were analysed using a generalised linear mixed model. Response variable was the number of kills (Kills). Fixed effects were the number of days after A24 trap deployment (Days) and rat activity. The random effect was site which was represented by the trap number.

$$\text{Kills} \sim \text{Days} + \text{Rat activity} + (1|\text{Trap})$$

The models were fitted using the R package lme4 (Bates et al. 2015). Data from August 2016 (the first session) was excluded from the generalised mixed models to exclude potential neophobic or neophilic behavioural responses in the rat population towards the A24s that could have biased the results. Therefore, the data used for this analysis of behaviour were from September 2016 (the second session), i.e. starting 53 days after the initial trap deployment once the devices would have become familiar to the rats in their environment. Video data from only nine cameras were analysed. A broken mount led to a different setup of one camera using a horizontal recording angle instead of the 45° used for the other cameras. This caused problems in the categorisation of the observed behaviour. Depending on the position of the rat in the video it was difficult to determine if the rat had touched the trap. This camera was subsequently excluded from any further analyses. All analyses were carried out in R Version 3.4.0 (R Core Team 2019).

Behavioural response to new devices

Video footage from nine cameras was used to document the time to the first encounter (either no interest or interest), interaction, and trigger at each trap after the initial installation on the island. One trap was excluded from the examination of the behavioural response because it was installed close to the base for the field staff and was disturbed throughout the day. However, data from all ten cameras could be used to determine the first night a rat was killed at each trap.

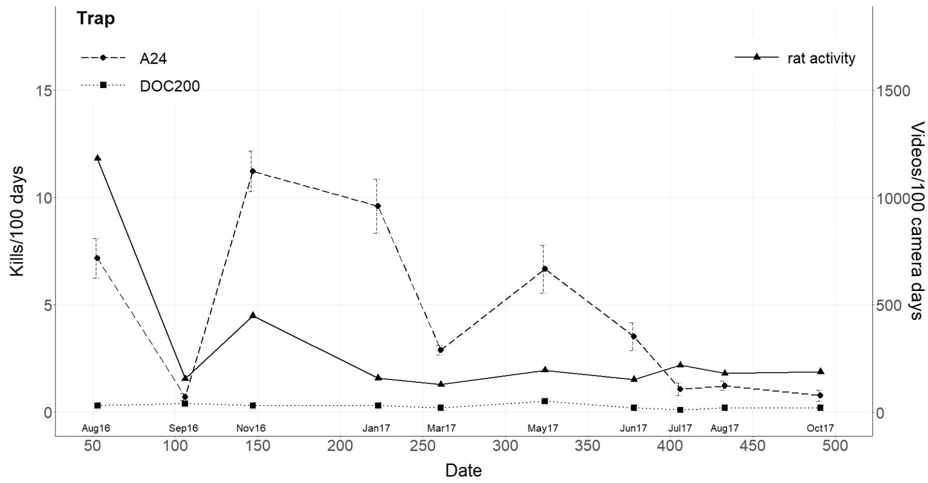

Figure 2. Kills per 100 days by eight DOC200 single-kill and ten Goodnature A24 self-resetting traps (left hand axis) and rat activity (videos per 100 camera days right hand axis) between July 2016 and October 2017 on Goat Island. DOC200s were installed one year before A24s but were not set for 6 months prior to our study. Dates represent trap and camera servicing dates. Numbers on the x-axis are number of days after camera/trap installation. Error bars represent standard error.

Table 1. Results of the General Linear Mixed Model analysing the effects of rat activity and time since trap deployment in the field (Days) on the number of kills by Goodnature A24 self-resetting traps on Goat Island from September 2016 to October 2017. Significance codes are "***" $p < 0.001$; "**" $p < 0.01$; "*" $p < 0.05$.

	Estimate	SE
Intercept	1.150**	0.231
Days	−0.002**	0.001
Rat activity	0.139***	0.025

Results

A total of 7155 videos from more than 119 hours of footage over 2161 camera days were analysed. Seventy-four percent (n = 5270) of the videos showed rats and could be included in the analysis of behaviour. The number of rat videos was the highest in August, the first month after installing the traps (1182/100 camera days). A second peak of activity appeared four months following deployment, in November 2016 (450/100 camera days); from then on, rat activity stayed consistently at a lower level (128–219 videos/100 camera days) (Figure 2). The A24s were able to remove more rats than the single-kill traps in the first three months of the study and at peak times in November 2016, January and May 2017 (Figure 2). The total number of rats killed throughout the study was 242 by A24s and 27 by DOC200s (Gronwald and Russell 2020a).

The kill rate of A24s decreased with increasing time of deployment in the field (Table 1, Figure 2) despite rat activity remaining relatively constant throughout 2017. More rats were killed when rat activity was high (Table 1, Figure 2). It should be noted that the DOC200s had been on the island for more than a year before the A24s were installed and thus trap efficacy could not be directly compared. Rats interacted with the A24s throughout the study but juveniles were not observed to be killed. An unexpected

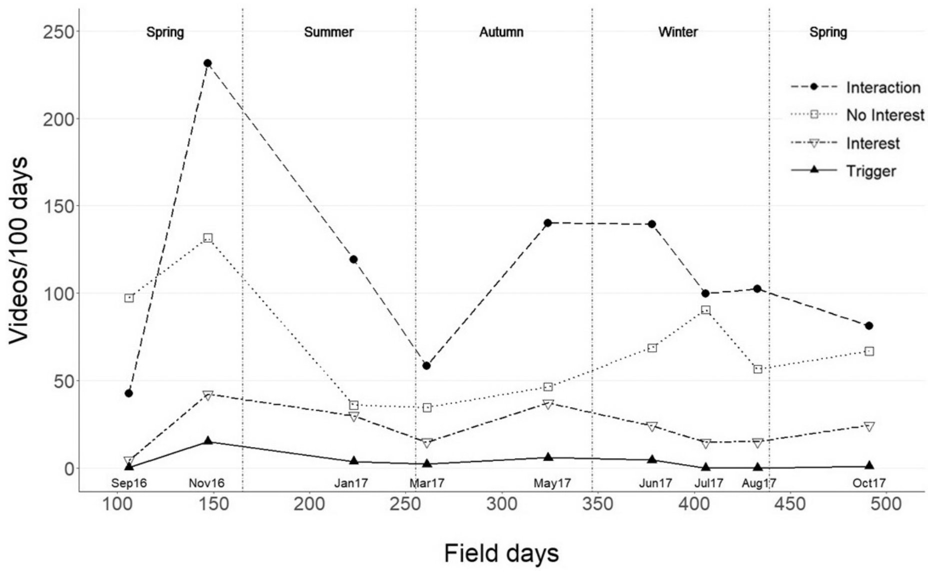

Figure 3. Number of videos per camera day plotted against time for the four behavioural categories observed by cameras around Goodnature A24 self-resetting traps on Goat Island from September 2016 to October 2017. Field days are the number of days after A24 deployment. Note the first 100 days of knock-down (i.e. suppression from high to low abundance) are excluded.

behaviour observed was rats feeding underneath the traps on what was assumed to be lure that had dropped from the automatic lure pumps. The moment of a rat triggering the trap was visible in 70 videos but was never preceded by a rat feeding under the trap.

Season and activity effects on behaviour

The regression model showed seasonal differences in the behaviour of the rats around the self-resetting traps. The behaviours of Interest, Interaction, and Trigger followed a similar pattern, with the lowest counts all being in winter (Figure 3). The interaction rate was relatively high throughout the study while the number of trigger events stayed low. The number of videos showing No Interest, however, was lowest in summer and autumn before going up again in winter.

Interaction and No Interest were the most frequent behaviours observed at all levels of rat activity. The number of camera records increased linearly with rat activity for all behaviour types, although the number of Interactions was significantly higher than expected at higher rat activity (Table 2).

Behavioural response to new devices

Any cautiousness in the first monitoring session towards the newly-installed A24s was not observed. The rats visited the traps within hours after they had been installed. The cameras were all activated in the afternoon and the first interactions with a trap occurred just over an hour later around dusk. Times to the first interaction at each trap ranged from 63–199 min (median = 139 min, n = 9). It took no more than five visits at each trap until the first interaction occurred and in 50% of the first visits the rats

Table 2. Results of the Generalised Linear Mixed Model analysing the effects of rat activity and seasonality on rat behaviour around Goodnature A24 self-resetting traps on Goat Island from September 2016 to October 2017. Intercept is Spring and No Interest. Significance codes are '***' $p < 0.001$; '**' $p < 0.01$; '*' $p < 0.05$.

	Estimate	SE
Intercept	2.902***	0.110
Interest	−1.113***	0.151
Interaction	0.031	0.097
Trigger	−2.976***	0.343
Summer	−0.467***	0.113
Autumn	−0.440***	0.092
Winter	0.004	0.075
Rat activity	0.086***	0.013
Summer : Interest	0.880***	0.187
Summer : Interaction	0.690***	0.138
Summer : Trigger	0.765	0.396
Autumn : Interest	0.676***	0.163
Autumn : Interaction	0.602***	0.115
Autumn : Trigger	0.633	0.347
Winter : Interest	−0.501**	0.157
Winter : Interaction	−0.240*	0.098
Winter : Trigger	−0.934*	0.387
Rat activity : Interest	0.006	0.026
Rat activity : Interaction	0.073***	0.016
Rat activity : Trigger	0.030	0.063

immediately interacted with the traps. At 6 out of 10 traps we observed a rat getting killed in the first night. After three nights all ten A24 traps on the island had killed at least one rat.

Discussion

Understanding animal behaviour around control devices, particularly new-to-market devices, helps understand optimal ways to deploy these devices and determine the appropriate pest control contexts in which they should be deployed. While the self-resetting traps were useful for population suppression on Goat Island, eradication could not be achieved with one A24 per hectare in combination with DOC200s. Previous population estimates from exhaustive trapping of rats on Goat Island fluctuate between 28–33 individuals (Russell et al. 2009; Pichlmueller and Russell 2018). During our study the removal rate of rats on the island must not have been higher than the population growth rate, inclusive of recruitment within the population and immigration from the nearby mainland, both of which have plagued previous eradications (Pichlmueller and Russell 2018). Most kills by A24s happened during the breeding season in 2016 in the first third of the study and in May 2017 when food may have been scarce at the end of autumn. The substantial difference in rat activity and kill numbers between August and September 2016 shows the initial success in reducing rat numbers on the island. Kill numbers then continued to decline over time but never reached zero (i.e. eradication). These kills possibly comprised the ongoing removal of naïve individuals, such as recently recruited adults and immigrants, while a small number of cautious adults remained on the island. Such an effect has also been seen in stoat trapping operations on islands within swimming distance (McMurtrie et al. 2011). A long term trial of self-resetting traps on Aotea/Great Barrier Island showed a similar pattern of decline in A24 kills over time. A reduction in tracking tunnel indices in an area without previous rat control was achieved with A24s as the sole control tool with 3–5 traps/ha, but very low levels of rat abundance (< 20% tracking tunnel index) could not be maintained (Gilbert 2018). At Ark in the Park in the Waitakere Ranges near Auckland City, A24s were installed and reduced the tracking tunnel index after two months but also failed to maintain a very low level of rat abundance (Gilbert 2018). A recent trial of a bait delivery system for A24s on Native Island, which also has a high incursion risk, has shown a relatively high rat abundance (37% tracking tunnel index) when using A24 as a biosecurity tool at a density of three A24s/ha (Carter et al. 2019). A very high device density of 10 A24s/ha in combination with single-kill snap-traps (25 traps/ha) was able to maintain lower rat abundance than in an unmanaged area in Hawaii (Shiels et al. 2019). In addition to the relatively low device density, a potential issue for achieving eradication in our study was size selectivity, as small rats were not observed being killed by A24s and the DOC200s were not expected to kill juveniles with a trigger weight of approximately 96 g (Warburton 2016).

The observed number of trigger events was low compared to the interaction rate throughout the study. Our footage showed that rats did not avoid contact with the A24 itself but were hesitant in entering it. A key aspect in improving the capture rate of A24s may be the automatic lure pumps (Gilbert 2018; Ogden 2018). The number of rats showing no interest in the trap was high throughout the study. Generally, a food lure is less effective when food abundance is high and competition is low (Jackson et al. 2016). However, a lure which is more attractive than the food available in the habitat will likely increase interaction and capture rate. The exact composition of the Goodnature chocolate formula is unknown but it has a sweet chocolate-like smell. In a comparison of different food lures, milk chocolate and a hazelnut cocoa spread were more attractive to rats than peanut butter, which is a standard lure for rats worldwide (Jackson et al. 2016). However, the nutritional value of the lure also determines its attractiveness with fat being a preferred energy source for rats (Kasper et al. 2014). A comparative test of different lures in A24s is needed to evaluate the attractiveness of the Goodnature chocolate formula. The trap design may also influence the capture rate. Norway rats on Motukorea, New Zealand, were more likely to enter traps covered with clear plastic or wire netting than traps covered with solid iron (Weihong et al. 1999). A clear housing for A24s may have the potential to increase the number of rats entering and triggering the trap.

Season and activity effects on behaviour

Seasonal effects on the behaviour of ship rats around the self-resetting traps were evident. Interaction peaks appeared in spring and late autumn. The high interaction rate consequently led to high kill numbers in November 2016 and May 2017. Ship rats follow a seasonal breeding pattern and reproduction starts in spring and peaks in late summer with rat numbers being the highest in autumn (Wilmshurst et al. 2021). The high kill rate in late spring was likely due to increasing population size and recruitment of naïve individuals while food abundance had not reached its peak. The main factor controlling population density is food availability, which differs among seasons (Wilmshurst et al. 2021). Russell et al. (2009) found rat stomachs in autumn and winter on Goat Island to be almost empty, suggesting that food availability is very low in these seasons. Even though not measured in our study, we assumed that that seasonal food availability does not differ significantly between years. Therefore, the combination of increased rat abundance and decreased food availability likely led to a high number of observed interactions between rats and traps in autumn, which consequently resulted in high kill numbers in May 2017. On Goat Island, an expected higher interest in A24s as an additional food source in winter may have been offset by generally lower population density. The relatively high interaction rate in winter may have been caused by a few individuals repeatedly interacting with A24s. The lure, however, was then not attractive enough that these cautious surviving rats would enter the trap.

Rat activity appeared to influence the behaviour of the rats on Goat Island. The rats were more likely to interact with the traps when rat activity was high. A higher rat activity was assumed to lead to more interactions with the A24s which presented a food source in an environment with relatively low food productivity. Population density is often positively correlated to competition (Adler and Levins 1994). Increasing intraspecific competition due to growing rat numbers may have been the driving factor for the higher observed activity and interaction rate with the A24s in November 2016, the end of austral spring. However, in July 2017 increased rat activity did not result in increased numbers of kills. The reason for the low kill numbers could have been that the rats were able to access the lure without entering the trap. The automatic lure pumps released the lure steadily over time. Excess lure dropped underneath the trap and video footage showed that the rats were feeding on it. Preventing the lure from dripping down the trap could be a key improvement to the design of automatic lure pumps for A24s, since it can also cause mechanical issues with the trigger mechanism leading to trap failures (Gilbert 2018).

Behavioural response to new devices

The rats on Goat Island did not show any reluctance in interacting with the Goodnature A24s and trapping success was immediately high at the beginning of the study. At all trap locations first encounters occurred around dusk when rats became active and it took only few visits before rat-trap interactions were observed. The first kills occurred in the first night at most traps. The rat population on Goat Island was not naïve towards kill trapping. Predator control with DOC200s had been conducted for more than a year prior to the installation of Goodnature A24s. The time between deployment of A24s and the rats showing interest in and interacting with the traps was short enough to exclude neophobia. In addition, after three nights kills had been observed at each of the ten A24s. On Aotea, A24s have also been most effective in the first week after deployment (Ogden 2018). In contrast, the highest capture rate for DOC200s during our study, which was in May 2017 (two years after first activating DOC200s), was only five rats in eight traps.

Previous research suggested that new objects in the environment cause avoidance behaviour in rats that lasted up to 12 days (Barnett 1988; Wallace and Barnett 1990). The context in which rats encounter unknown objects influences their behaviour. Ship rats showed a neophobic response when they encountered new objects in their familiar environment (Cowan 1976) but new food in a familiar container did not induce a neophobic response (Inglis et al. 1996). However, it can be assumed that rats in these studies were either stressed or habituated to disturbance and artificial environments since they were either bred for laboratory experiments or caught in the wild and laboratorized (Boice 1971). Therefore, one must be cautious to make inferences to the behaviour of wild rats in their natural habitat. While the presentation of a new object can influence rat behaviour in the laboratory it does not mean that it will affect the behaviour of free-living rats (Martin and Bateson 1993). In an observation of two A24 traps on Aotea/Great Barrier Island rats were also killed in the first night (Ogden 2018). Most of the rats in our study possibly avoided the newly-installed A24s while a small proportion of the population did not. The bold behaviour of a few individuals interacting with the traps might have concealed any cautious response by most other rats. However, by the time the bold rats are removed the remaining individuals are probably habituated to the presence of the new devices. As additional context, Goat Island is small and does not have a very diverse and productive forest (Russell et al. 2009). Therefore, the population is probably strongly regulated by food availability and hunger may have been a driving factor for prompt interactions with the traps.

Our study showed that environmental seasonality and rat activity influenced the behaviour of ship rats around self-resetting traps on Goat Island and no neophobic response towards the new devices was found. After initial knock-down rats killed subsequently may have been naïve invaders and young adults while a certain number of cautious island residents avoided the traps. On Frégate Island, Seychelles, mainly juvenile Norway rats were killed in a trapping operation while adults avoided the traps (Thorsen et al. 2000). Studies of home range and behaviour of individuals that survive control efforts are needed to identify if trap avoidance or lack of device encounters are the reason for their survival (Garvey et al. 2020). Given the seasonality in rat activity on Goat Island, intensifying rat control in autumn when interaction rates between rats and traps are high may increase A24 trapping success. The self-resetting Goodnature A24 traps were useful in reducing rat numbers and required relatively low maintenance effort. However, at one per hectare the self-resetting traps were not able to offset population growth and achieve eradication on the island, which requires additional investments in the system, e.g. a more attractive lure, higher device density, or a combination of tools including toxins. Video monitoring a combination of different control devices could identify if the low A24 kill rate following knock-down is unique to the A24s or simply an outcome of low abundance due to ongoing control.

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Ethics and Permits:

The authors understand that with submission of this article the authors have complied with the institutional and/or national policies governing the humane and ethical treatment of the experimental subjects, and that they are willing to share the original data and materials if so requested. This study was conducted under animal ethics permit R1677 from the University of Auckland.

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