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RESEARCH

How low can you sow? House mouse eradication on Motuareronui/Adele Island

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Abstract: House mice (*Mus musculus*) are highly invasive mammals and can cause extensive ecosystem damage on islands where they are the sole mammalian pest species. Capability to eradicate mice has improved in recent years. Mouse eradication has been achieved on large islands where mice cohabit with other rodents and islands where mice are the sole mammalian pest. As the islands targeted for eradication become larger and more challenging, reduced toxic cereal bait application rates can reduce both complexity and cost, and ultimately make currently unachievable operations feasible. Auckland Island (45 891 ha) in New Zealand's subantarctic region is a desirable target for mouse eradication. However, logistics at this scale indicate that the required bait volume using New Zealand's currently agreed best practice (two applications, each 8 kg ha^{-1}) is not feasible using available resources. Small islands provide an opportunity to experiment with eradication methods with acceptable levels of risk. Here we test the eradication of mice from a small island in New Zealand using a low bait application rate. A single application of 3 kg ha^{-1} of rodent cereal baits containing brodifacoum was aerially applied on Motuareronui/Adele Island (87 ha) in New Zealand's Abel Tasman National Park, in winter 2017. Intensive monitoring immediately following bait application showed the mouse population rapidly succumbed to the baiting operation. Rodent dog checks 5 months after baiting increased confidence in the operations' success. A mouse was detected and caught 7 months later in a biosecurity trap network, but genetic analysis determined that this mouse was a recent incursion rather than the result of eradication failure. No further mice were caught, and the eradication was declared a success two summers after baiting. This study shows how undertaking, reporting on, and reviewing appropriate high-standard field trials can contribute to the evolution of best practice. This study adds to a growing body of evidence that low application baiting (relative to best practice) can be considered feasible for mouse eradications on islands where the benefits outweigh the risks, and points to further avenues of research to reduce risk and broaden the application of this method.

Key words: bait application, brodifacoum, invasive species, *Mus musculus*, rodent, temperate system

Introduction

Islands are biodiversity reservoirs with high levels of endemism that provide refuge for threatened species (Holmes et al. 2019). Island systems are vulnerable to invasive non-native species, which are one of the leading causes of extinctions on islands (Russell et al. 2017b; Holmes et al. 2019). The eradication of invasive pests is recognised as one of the most effective means of achieving conservation gains on islands (Jones et al. 2016; Holmes et al. 2019).

House mice (*Mus musculus*) are a common invasive species on islands, where they cause damage to ecosystems through predation of invertebrates, reptiles, birds and herbivory on vegetation (Howald et al. 2007; Angel et al. 2009; Broome et al. 2019). The eradication of mice is considered more challenging than other rodent species, due primarily to their small home-ranges when bait is broadcast (Broome et al. 2019). In New Zealand, eradication operations where mice are the primary target have increased in size and complexity since the 1990s (MacKay et al. 2007; Broome et al. 2019). Lessons from all projects have shown that aerial application of rodenticide is the most effective means of achieving the eradication of mice on anything but small islands (Holmes et al. 2015; Broome et al. 2019). Globally to date, the largest island cleared of mice where they were the sole invasive predator is 2012 ha Antipodes Island (Horn et al. 2019, 2022a), and the largest mouse eradication as part of a multi-species eradication is 12 785 ha Macquarie Island, along with ship rats (*Rattus rattus*) and rabbits (*Oryctolagus cuniculus*) (Springer 2016).

Recognition and acceptance that mouse eradication requires meticulous planning and operational precision has been met by establishing operational principles and best practice methodology that demand high technical, logistical and economic input (Broome et al. 2017, 2019). The singular method of broadcast baiting, and one-off nature of a rodent eradication attempt with binary outcomes (succeed or fail), means eradication design is generally approached conservatively by doing what is known to work. Therefore,

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mouse eradication operations to date tend to be over-engineered to ensure access for every individual target animal to a lethal dose of toxin (e.g. Horn et al. 2019; Martin & Richardson 2019). In New Zealand this cautious approach has resulted in a recommended aerial sowing rate of two applications of 8 kg ha^{-1} second generation anticoagulant rodenticide brodifacoum (Pestoff 20R™, Orillion, Whanganui, New Zealand), with bait preferably spread in winter when mice are less likely to be breeding and when food resources may be seasonally less abundant (Broome et al. 2017). However, every site is different and progression of eradication success over time has pushed boundaries of operational scale and/or complexity. For example, the eradication of mice on subantarctic Antipodes Island in 2016 used a baiting prescription of two applications: the first at 16 kg ha^{-1}, followed by 8 kg ha^{-1} (Horn et al. 2019). As the island sites being targeted become bigger and more expensive, the logistical challenges of transporting and applying large volumes of bait impact feasibility and the consequences of failure (ecological, reputational and expense) grow (Holmes et al. 2019; Horn et al. 2022b). With these challenges in mind, small islands offer the opportunity to test adaptations to methods with the ability to comprehensively monitor and learn about the risk of reduced application rates.

Opportunities to test mouse eradication in a breeding population (Russell et al. 2019; Horn et al. 2022b) and with low sow rates (this paper; Oyston et al. 2022) were considered necessary next steps to commit to more ambitious projects. The eradication of invasive pigs (*Sus scrofa*), cats (*Felis catus*) and mice from subantarctic Auckland Island (45 891 ha) has been proposed (Horn et al. 2022b; Russell et al. 2022). The eradication of mice from Auckland Island in a single operation would be a 350% increase on the largest island cleared of mice to date; a huge leap in complexity and scale of operations. The magnitude of operations and environmental constraints of the site (Horn et al. 2022b) requires a departure from best practice. Specifically, a lower bait sowing rate (two applications of 4 kg ha^{-1} Pestoff 20R™ containing 20 ppm of the anticoagulant brodifacoum) and timing operations during summer has been proposed. The aim of this study was to inform operational planning for Auckland Island by testing a low bait application rate (single application of 3 kg ha^{-1}) on an established mouse population at reasonable geographic scale to achieve eradication of mice from Motuareronui/Adele Island.

Methods

Study site

The study took place on uninhabited Motuareronui/Adele Island (87 ha; 40.98°S; 173.06°E) in Abel Tasman National Park, New Zealand (Fig. 1). The island is a local reservoir of biodiversity, including threatened species such as South Island robin (*Petroica australis*) and South Island saddleback (*Philesturnus carunculatus*). Mice were first eradicated from

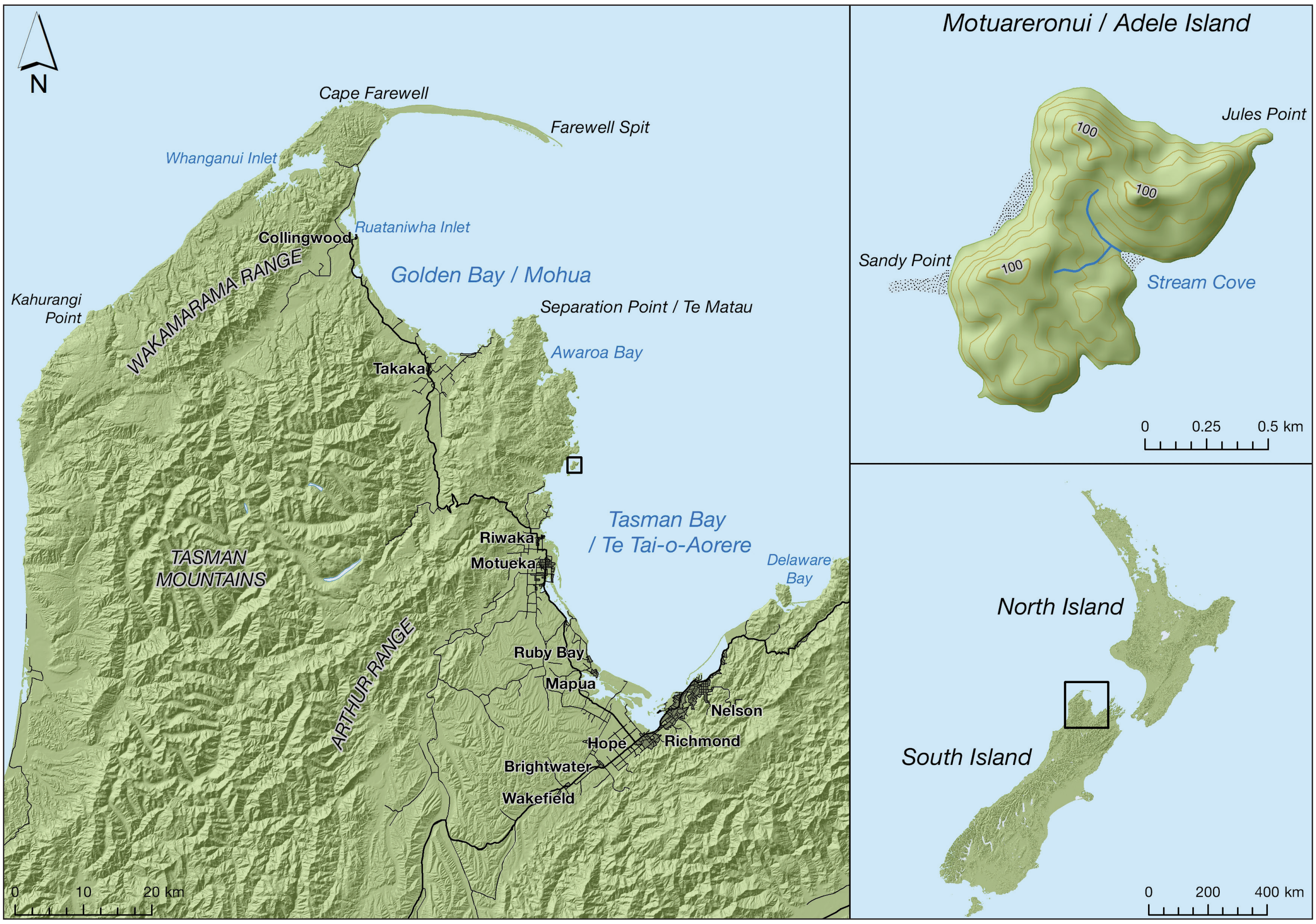

Figure 1. Location of Motuareronui/Adele Island, New Zealand.

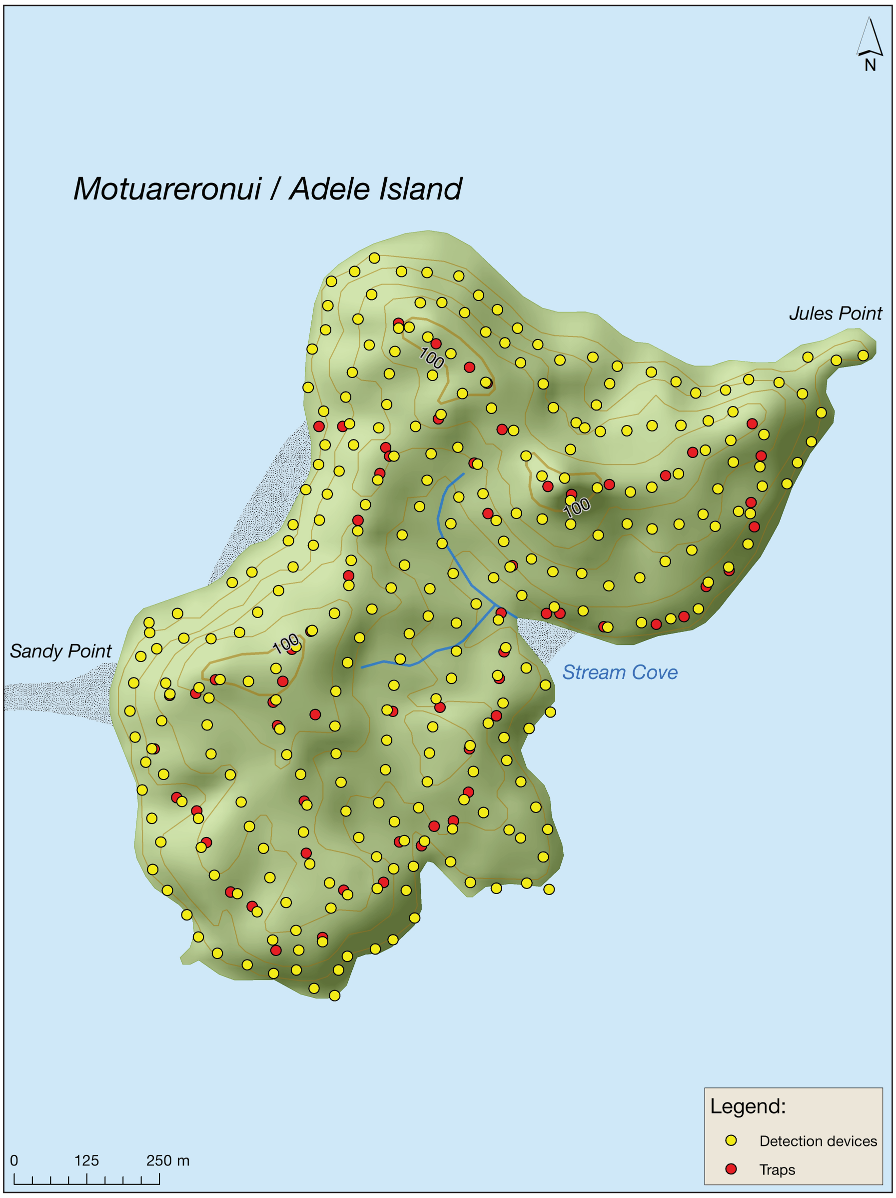

Figure 2. Motuareronui/Adele Island mouse detection network. Footprint tracking tunnels, wax chew tags and chew cards were placed at each marked site.

Motuareronui/Adele Island in 2007, following best practice (Golding 2010). Thereafter, an incursion network of 27 traps (DOC series, Department of Conservation, New Zealand) was established (Fig. 2) and biosecurity checks occurred every 1–2 months. Mice were again detected on the island in February 2015 and were the sole invasive predator detected on the island. Subsequent trapping and detections in May 2015 showed mice were breeding and had established across the island. The island is 800 m from mainland New Zealand and is a popular year-round visitor site. Incursion pathways include kayaks, leisure boats and debris rafts discharged from the mainland. The island is more or less pyramid-shaped with little flat ground, moderate to steep thin ridges, and numerous small bays and headlands. The highest point is 127 m a.s.l. The rock base is granite throughout, and the soil is thin, friable, and well-drained. The vegetation on the island has been heavily modified by past periods of burning and human occupation. Steep, dry, north-facing slopes are predominately kanuka (*Kunzea ericoides*) and black beech (*Fuscospora solandri*), with the occasional low gully of broadleaved species such as five finger (*Pseudopanax arboreus*) and māhoe (*Melicytus ramiflorus*). The more sheltered and gentle eastern faces are dominated by the broadleaf species of māhoe, five finger, kāmahi (*Weinmannia racemosa*), and broadleaf (*Griselinia littoralis*), with an understory of fern.

Mouse monitoring

A network of monitoring tracks spaced a maximum of 100 m apart was established on the island. A cluster of three detection devices were placed 1 m apart at ground level adjacent to the tracks at 50 m intervals (n = 287 each device type; Fig. 2): footprint tracking tunnels (FTTs; Black Trakka, Gotcha Traps, Rodney, New Zealand), peanut butter-flavoured wax chew tags (Connovation, Auckland, New Zealand) and chew cards (Connovation, Auckland, New Zealand). FTTs and chew cards were baited with peanut butter. The high density and distribution of detection devices was necessary to determine how quickly the mouse population declined following baiting, and to detect and follow the fate of survivors of the population decline. Pre-operational monitoring was conducted 10 to 17 July 2017, 5 weeks prior to the eradication operation. Detection devices were deployed for 7 continuous nights and checked 8 days after deployment.

Six weeks of intensive monitoring immediately followed the aerial bait application (28 August–9 October 2017). All detection devices were run simultaneously and were replaced every 1–2 weeks over the 6-week monitoring period (Table 2). Devices were almost always collected in the same order in which they were deployed, ensuring a consistent number of nights for almost all devices. FTTs, chew cards and tags were analysed by experienced personnel in the days following collection. Seven trail cameras were deployed for a month from the same day as baiting (21 August–21 September 2017). Trail cameras were mounted 1 m off the ground and set to record three photos and 10 seconds of video when triggered by movement. Three bait pellets were placed 2 m from each camera. Following the initial intensive post-baiting monitoring, the trap network was checked and rebaited, and FTTs were deployed for 7 nights every 3 months (ongoing incursion monitoring). Five months following mouse baiting, a rodent detection dog searched the island for 2 days.

Baiting methodology

The Motuareronui/Adele Island eradication/baiting trial was undertaken on 21 August 2017 (winter) and constituted a single aerial broadcast application of Pestoff 20R (10 mm diameter/2 g baits of 0.02 g kg^{-1} [20 ppm] brodifacoum toxic loading, dyed green and un-lured as per best practice; Broome et al. 2017).

A Bell 206L 3 LongRanger helicopter (Bell Helicopters, Mirabel, Canada) with an underslung bucket fitted with a cone (starting aperture approx. 40 mm) was used to distribute baits. In line with current best practice (Broome et al. 2017), the sowing bucket effective swath width was conservatively set to a distance where bait was shown (in calibration trials) to be consistently sown at the target sowing rate. The spacing of parallel flight lines guided by the global positioning system (GPS) was set at 50% of the effective swath width. Bait flow rates from the spreader bucket were adjusted during tests on baiting day to account for the wind speed and bait condition with a target flow rate of 1.5 kg ha^{-1} so that the overlapped swathes resulted in an application rate of 3 kg ha^{-1}. Additional bait was sown around the island's coastline (to the water's edge) using a directional bucket that only applied bait to the landward side of the coastal flight path.

Flight data (bait usage and area sown) was closely monitored by the pilot, operations manager and geospatial information systems (GIS) analyst throughout the operation. To accurately calculate the sowing rate, bait remaining in the bucket after each load was weighed.

Rapid eradication assessment

Following Kim et al. (2020), rapid eradication assessment (REA; www.rea.is) was retrospectively applied to outcome monitoring data. Detection data were collected, including the locations of static detection devices (FTT, chew cards

Table 1. Bait sowing rates for the eradication of mice from Motuareronui/Adele Island.

	Bait weight (kg)	Area baited (ha)	Average bait density per swath (kg ha^{-1})	Average total bait density (kg ha^{-1})
First run	39	22.32	1.75	3.49
Second run	111	75.96	1.46	2.92
Third run	125	89.01	1.40	2.81
Fourth run (boundary)	75	40.01	1.87	3.75

Table 2. Rapid eradication assessment model parameters used for Motuareronui/Adele Island. Data derived from Nathan et al. (2013), Kim et al. (2020) and Sagar et al. (2022).

Parameter	Likely	Min–max
Monitoring data		
Device spacing	0 (static and mobile devices supplied)	
Monitoring nights	42 (40–44)	
Iterations	2000	
Target	0.99	
Years since eradication	0.11 (40 days)	
Device parameters		
g_0 (tracking tunnels)	0.2	0.15–0.25
Biological parameters		
σ	10	5–15
Prior probability of success	0.8	0.7–0.9
Probability of reinvasion	0.01	0–0.02
Population growth rate (annual per capita)	7	5–10
Dispersal distance	50	
Incursion distance	200	

and chew tags) and rodent detection dog tracks. The model was run using island and species-specific parameters (Table 2). For comparative purposes, the model was first run with all three static detection devices, then FTT alone, then FTT and rodent detection dog tracks, and finally all three detection devices and rodent detection dog tracks.

Results

Mouse monitoring

Prior to baiting, all three device types (FTTs, chew cards, and wax tags) registered 100% detection, with the first detections observed after one night of deployment. FTT cards were all almost completely covered with mouse prints, the chew cards were chewed clean of peanut butter, and many wax tags were completely devoid of wax. Mice were occasionally seen during the day.

Following baiting, signs of mice lessened over the 6-week monitoring period (Table 3) across all detection device types. Tracking in FTTs decreased from 100% pre-eradication to 0% within 2 weeks of the bait application. Of the seven cameras, two recorded a single mouse eating bait the first night after aerial bait application. In addition, another camera captured footage of a mouse not interacting with the bait 12 nights following bait application. Five months post-baiting, a detection dog searched the island over 2 days and found no evidence of mice.

Mouse tracks were detected on a cluster of 11 FTTs during checks in late March 2018, 7 months after baiting. A single mouse was trapped in an area adjacent to the detections 3 weeks later. No further evidence of mice was subsequently detected.

Baiting

GIS analysis of baiting occurred in real time during baiting operations. Average flight speed was 88 km h^{-1} at an average elevation of 114.9 m above ground level. Effective swath width was 60 m. Application rate calculations ranged from 2.81 to 3.75 kg ha^{-1} (Fig. 3; Table 1), totalling 350 kg bait. Boundary application rates ranged from 5 to 34 kg ha^{-1} (Fig. 3). GIS analysis showed a possible small gap in bait coverage at the end of Jules Point (0.04 ha) that resulted from questions around the helicopter cornering and the swing of the bucket at the end of the line. On 11 September 2017, 2 kg of bait was hand sown at Jules Point, overlapping 70 m into the aerial spread area. Hand sowing was equivalent to 2.75 kg ha^{-1}. Weather on baiting day was sunny and calm, with maximum 5 knots easterly gusts. Six rain-free nights followed the operation.

Rapid eradication assessment

Together, the three static detection devices achieved 41.2% coverage of the island, compared to FTTs alone, which achieved 38.5% coverage (Table 4). Detection dog tracks with FTTs achieved 65.3% coverage, though coverage with dog tracks and all three detection devices was only slightly higher at 66.6% (Table 4). The probability of eradication success was high under all scenarios, though slightly lower when only FTTs were run (96.4% c.f. 100%; Table 4). The level of confidence in this result increased when three devices were used (61.3%), compared to FTT alone (39.6%; Table 4). Using a dog in conjunction with static devices had the largest impact on increasing confidence, regardless of whether one (82.0%) or three (84.5%) static devices were used (Table 4).

Discussion

Following an absence of mouse sign over the two breeding seasons (summers) after baiting, the eradication of mice from Motuareronui/Adele Island was declared a success. The completion of this work sets a new benchmark with respect to bait application for the eradication of mice from islands – a single application of less than 50% best practice bait volume per hectare.

There was a reasonable level of confidence of eradication success following the initial intensive post-baiting monitoring period because of the density, layout and variety of detection devices that were used (9.9 devices per hectare; approx. 48 250 detection device nights, equivalent to 554 detection device nights per hectare in first 6 weeks post-baiting). DOC best practice incursion surveillance states that one to two devices per hectare deployed a minimum of 5 nights is generally sufficient to detect mice, even at low density (DOC 2021). There are no prescriptive device density recommendations for post-eradication mice monitoring, except that detection devices should target representative habitat types and high risk areas (where confidence in bait spread was lower, habitat is complex or alternative resources are high) (Broome et al. 2017). Multiple static device types and detection dogs should be deployed. Where early detection is required, higher device density and multiple device types are recommended (Broome et al. 2017). In this study, the detection device density was very high compared to other mouse eradication result monitoring, which were considered strong enough to conclude the success of those projects. There were 1.85 static devices per hectare on Maud Island (318 ha; Oyston et al. 2022), while Antipodes Island (2025 ha) had 0.11 static devices per hectare (Horn et

Table 3. Mouse sign across three detection device types (n = 287 each detection device type each monitoring period) during 8 weeks immeditely post toxic baiting for mice on Motuareronui/Adele Island during 2017.

	Monitor 1 28 Aug–4 Sept	**Monitor 2** 4 Sept–11 Sept	**Monitor 3** 11 Sept–25 Sept	**Monitor 4** 25 Sept–9 Oct
Footprint tracking tunnels	1 tunnel, confident mouse track	None	None	None
Chew cards	3 cards, possible mouse chew	1 card, possible mouse chew	None	None
Wax chew tags	None	3 tags, confident mouse chew; 6 tags, possible mouse chews	None	4 tags, possible mouse chews

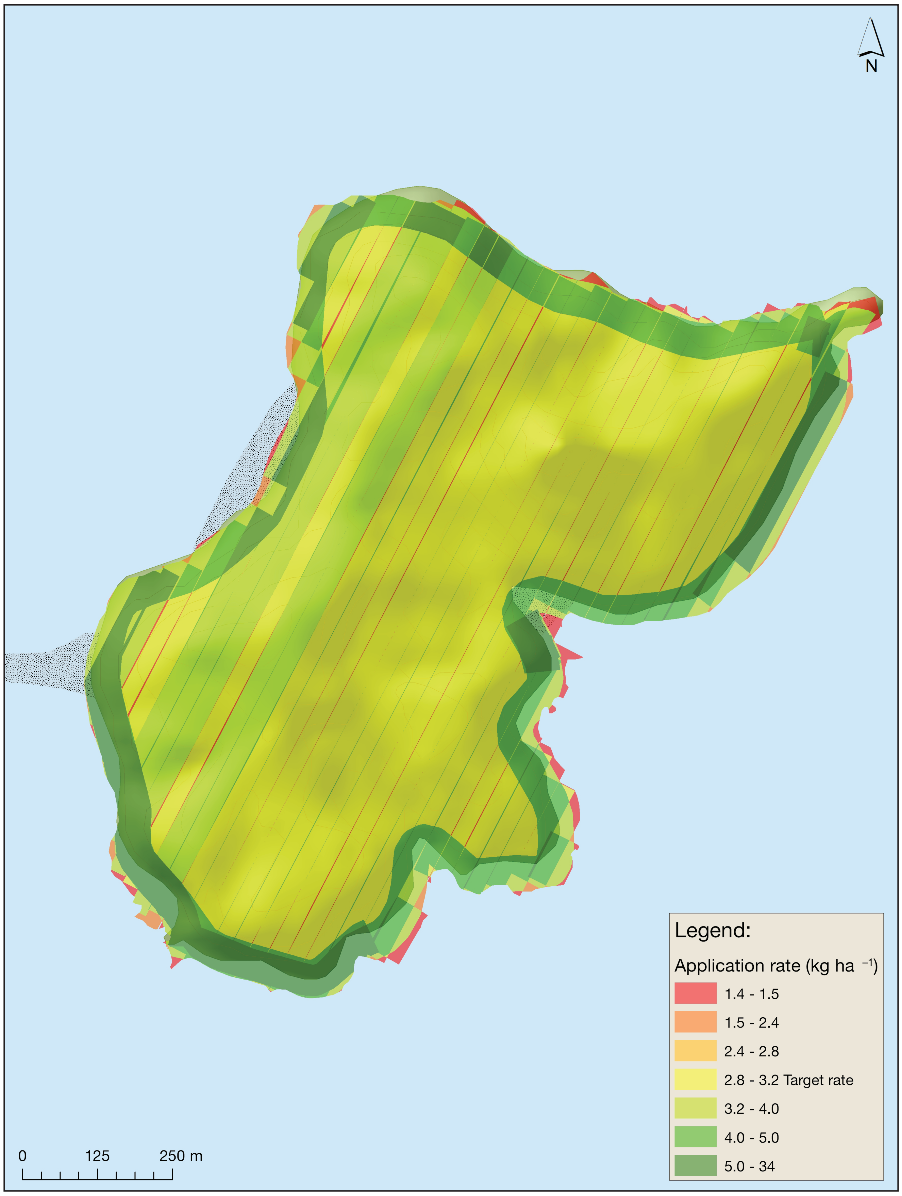

Figure 3. Effective Motuareronui/Adele Island bait application rates. Bait application rates are derived from GPS flight data using simple computer modelling and take account of the flying speed. Individual treatment areas depicted are indicative due to environmental effects such as wind and topographical variation.

Table 4. Rapid eradication assessment (Kim et al. 2020) model results for the island coverage of detection tools, median probability of eradication success and credible interval value (percentage of the posterior probability of eradication above the success target value, 99%) for Motuareronui/Adele Island mouse eradication. Static detection devices = footprint tracking tunnels, chew cards and chew tags.

	Footprint tracking tunnels only	**Three static devices**	**Footprint tracking tunnels + rodent detection dog**	**Three static devices + rodent detection dog**
Coverage	38.5%	41.2%	65.3%	66.6%
Posterior probability of eradication success (2.5% and 97.5% quantiles)	96.4% (75.9–100%)	100% (76.8–100%)	100% (78.9–100%)	100% (78.0–100%)
Credible interval value (%)	39.6%	61.3%	82.0%	84.5%

al. 2022a). A higher density of devices was achievable on Motuareronui/Adele Island because it is smaller than Maud or Antipodes Islands and had an established track network that facilitated monitoring activities.

A key difference between the Maud and Antipodes Islands operations and the current study is the period between baiting and result monitoring: for Maud and Antipodes Islands, two breeding seasons passed before the main monitoring was conducted and the projects declared a success. In this study, monitoring immediately followed baiting using static devices only. The REA model showed that confidence in the result was high following the static device monitoring in the period immediately following baiting, with three devices increasing the confidence over FTT alone. The rodent detection dog check 5 months after baiting increased the confidence in eradication more strongly than having multiple static devices. Further, there was limited advantage to running clusters of three different static detection devices compared to only one when a detection dog was utilised. Given the increased input (deployment, rebaiting and interpreting sign) required for three devices versus one, and diminishing returns on confidence, these results suggest that one static device (although not necessarily always the same type of device) with high coverage in addition to a detection dog is sufficient to confirm eradication success for small islands in a short time frame. REA (Russell et al. 2017a; Kim et al. 2020) is a useful tool that can optimise the spacing of detection devices on smaller islands during planning so that the required level of confidence in eradication can be reached. This method could be especially useful for small islands with manageable terrain that employ early monitoring, as early detection of survivors could allow mop-up, meaning the difference between eradication success or failure (e.g. Olivera et al. 2010).

Trials have shown that FTTs have higher detection sensitivity than chew options (Sweetapple & Nugent 2011; Nathan et al. 2013). Additionally, footprints can be identified with a high level of confidence, but bite marks can be difficult to distinguish or attribute (e.g. Olivera et al. 2010). Tree wētā (*Hemideina crassidens*) present on the island are also attracted to peanut butter and have bite marks that present similarly to mice and likely caused identification issues (C. Golding unpubl. data). There was no evidence to suggest wētā affected the outcome of the current study by consuming baits, interfering with bait coverage or consuming the peanut butter lure in detection devices (J. Livingstone; unpubl. data). Future low-sow operations should consider non-target bait or device interactions that could impact an operation's success or ability to monitor outcomes. Mitigations may alleviate or reduce risk from non-target species interference (e.g. Holmes et al. 2015 and references therein). It was difficult to assess when mice started and stopped consuming baits, since footage of mice consuming baits on camera was limited. However, comparing tracking results of the first post-operational monitoring event to the pre-operational monitoring showed mouse activity dropped substantially to almost zero during the first 7 nights, and was 0% thereafter. One mouse was observed on the cameras 12 nights after baiting, but this is not unusual. For example, live mice were seen on Antipodes Island 20 days after baiting, but no evidence of mice was found during intensive monitoring two breeding seasons after baiting, and the eradication was declared a success (Horn et al. 2019). Generally, mice die 5 days after the first bait application, but there is the extreme example of a mouse surviving on Maud Island for 60 days after the first bait application (Broome et al. 2019). The mouse observed on camera 12 days after baiting was not detected on FTTs. This shows that even when FTTs are deployed at high density they cannot detect every surviving mouse in a short timeframe. This finding is supported by the lower confidence in FTT alone in the REA, compared to when multiple devices and detection dogs are also used. Further exploration of factors that influence how mice populations succumb to baiting during eradications is warranted and could inform ideal timing for intensive result monitoring.

The detection of a mouse on multiple FTTs 7 months following bait application was cause for concern. Other projects have failed to remove mice for unknown reasons, though small home ranges and breeding populations have been implicated (MacKay et al. 2007). It is feasible the mouse population on Motuareronui/Adele Island was still breeding at the time of baiting. In winter mouse breeding generally slows, but may not cease in temperate systems (Wilson & Lee 2010; Sagar et al. 2022). The mouse sign detected in March 2018 indicated either the eradication had failed, and detection devices had likewise failed to detect survivors until this point, or an incursion had occurred. Subsequent genetic analyses provided clarity; the trapped mouse most likely originated from the wider Marlborough region and was very unlikely to be a descendent of the 2015–2017 Motuareronui/Adele Island population (Pichlmueller et al. 2020). It is considered likely the mouse was inadvertently transported to the island by one of many visiting vessels. The 2015–2017 population was found to have established from the nearby mainland Abel Tasman area (Pichlmueller et al. 2020). It is speculated that the 2015–2017 incursion may have been facilitated by mice rafting on flood debris (C. Golding pers. comm.), though there is increasing evidence to suggest mice can swim long distances (>600 m; Broome et al. 2019). The 2018 incursion highlights biosecurity risks for regularly visited islands, such as Motuareronui/Adele Island, and promotes investment in education and regular incursion monitoring for high-value sites. Moreover, this event shows the value in collecting voucher specimens for genetic analysis from sites where incursion risks are high. This was particularly important for our research objectives, which relied on knowing whether the eradication attempt succeeded or failed. Establishing whether the target population is breeding during an eradication attempt could be valuable if a breeding population may contribute to possible eradication failure.

There are examples of other successful low sow or single application eradications, though this project is the lowest single successful application known for the eradication of mice. Campbell Island (11 331 ha) was cleared of Norway rats (*Rattus norvegicus*) and possibly mice (presence on island could not be confirmed) with a single brodifacoum application of 6 kg ha^{-1} in winter 2001 (McClelland 2011) while rabbits and mice were eradicated from Enderby Island (695 ha) in winter using one whole-island brodifacoum application of >5 kg ha^{-1} and a second application that targeted high risk areas (Torr 2002). Two recent examples are the most comparable. A non-toxic bait uptake trial on Falla Peninsula (1000 ha), Auckland Island, where mice were the sole target, showed that a single bait application of 4 kg ha^{-1} in summer was consumed by >99% of mice, and it is believed a second application would ensure all mice would be put at risk (Russell et al. 2019). Mice were the sole target on nearby Maud Island (318 ha), where they were successfully eradicated with two bait applications of 4 kg ha^{-1} in winter (Oyston et al. 2022).

In recent low sow trials (Maud Island, Oyston et al. 2022;

Auckland Island, Russell et al. 2019; this study), the bucket mechanism has been identified as a risk. Baits are more likely to bridge and block the aperture disk when flow rates are low, because the aperture in the disc is considerably smaller (for example Russell et al. 2019; Oyston et al. 2022; this study). There is less redundancy in low sow-rate operations compared to those with higher bait applications. Innovative bucket design to more accurately regulate and monitor bait delivery from the hopper to the spinner mechanism (from where bait is thrown in an 360° arc) could alleviate these risks. However, incentive to invest in improving current designs are low and engagement with industry is required (buckets are generally provided by helicopter companies completing baiting operations). New designs would need to be proven and reliable ahead of high-risk or complex operations, such as Auckland Island.

The binary outcomes of eradication (succeed or fail) mean tolerance for risk is lower and projects should aim to balance operational constraints with risk, informed through field trials. Recent low sow operations (Russell et al. 2019; Oyston et al. 2022), together with this project's success, show that larger or more complex projects, such as Auckland Island, can depart from best practice with a reasonable expectation of success. The success of these field trials on multiple islands that are diverse in climate (cool-temperate Auckland Island vs. warm-temperate Maud and Motuareronui/Adele Islands), topography, vegetation, resource availability and operational scale (1000 ha Auckland Island; 318 ha Maud Island and 87 ha Motuareronui/Adele Island) is particularly encouraging.

There are a minimum of 15 islands >5 ha around New Zealand where mice are the sole rodent species (Murphy & Nathan 2021). Many of these islands could be considered logistically challenging due to remoteness or difficult access (e.g. Auckland Island, Pitt Island, Fiordland islands). Others may have social licence considerations due to habitation or proximity to high population areas (e.g. Pitt Island, Quail Island). Low sow operations could help overcome both challenges. Achieving operational success on these islands is integral to attaining New Zealand's Predator Free 2050 (PF2050) interim goal that all uninhabited islands are free of mammalian pests by 2025 (DOC 2020), and will support social acceptance of wider PF2050 goals. In support of PF2050 goals, and global conservation needs, future research could investigate the feasibility of low sow operations under different climatic and environmental conditions, for other taxa (e.g. *Rattus* spp.) or where multiple taxa are present.

This study was designed to test the proposed departure from best practice proposed for Auckland Island, not to advocate a change in best practice. The need for a different approach to application rates was driven by the logistical constraints of using best practice rates. In essence, Auckland Island would have to balance the risk of failure due to reduced rates with the risk of failure due to an inability to bait the island at best practice rates. On smaller islands, such a trade-off is not necessary, so it becomes a risk 'not worth taking'. To reduce risk when departing from best practice, it is imperative to undertake, report on, and review appropriate high-standard field trials, with each trial building on prior knowledge and building confidence for application of lessons at increasing scale. In time, such evidence can lead to the evolution of best practice. Eradication best practice is a fluid concept that needs to remain 'current' with the latest available information, but for rodent eradication, conservative in the adoption of changes to what we know works when the consequences of risks can be catastrophic failure (Broome et al. 2017). This study highlights the importance of small island sites for researching improvements to eradication efficiency. Through an adaptive and innovative approach, we will be able to take on more ambitious conservation goals.

Author contributions

JL, SRH and KGB designed the study; JL undertook fieldwork; JL and RLS analysed the data; and RLS wrote the paper with input from JL, SRH and KGB.

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