The Lord Howe Island Rodent Eradication: Lessons Learnt from an Inhabited Island

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ABSTRACT: The 2019 rodent eradication on 1,455-ha Lord Howe Island was the second and largest attempted on a permanently inhabited island. With 350 residents, it presented numerous novel challenges, resulting in an operation best summarised in four words: Compromise, Commensal, Complexity, and Cost. A ground-based operation was conducted across the built-up portion of the island, some 300 ha, with aerial bait applied on forested higher ground (1,200 ha); brodifacoum was used exclusively for this attempted eradication. Initial community resistance and the presence of mice meant that almost 19,000 external bait stations were established within the Settlement, on a 10-m grid. The intensive grid was expected to result in numerous bait stations within rodents' home ranges. An additional 3,500 internal bait stations were put in all buildings and 9,500 hand-broadcast points overlapped the aerial and bait station boundaries. Over 60 field staff were employed locally, from Australia and overseas, to run the toxic baiting operation for 5.3 months. On-going resistance from a small community group resulted in two legal challenges early in the operational stage, including one in the Australian Supreme Court. Additional complications included initial active opposition to private land access; unaccepted personnel by the private land owners; resistance to livestock removal requiring novel bait station infrastructure; possible significant bait loss to invertebrates; and a small proportion of rats apparently avoiding bait stations. A fundamental aim of future operations on inhabited islands should be that they are community-led, which is likely to take several years to mature to the operational stage. Eradication practitioners should prepare for a significantly more complex operation with a concomitant increase in resourcing and planning.

KEY WORDS: Australia, bait stations, brodifacoum, commensal rodent, inhabited, island, mice, *Mus*, rats, *Rattus*, rodent, rodent eradication

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INTRODUCTION

Rodent eradication has proven to be an efficacious method for producing enduring conservation outcomes on islands worldwide and has resulted in the recovery of many previously at risk vertebrate, invertebrate and plant species (Harper and Bunbury 2015). Over 650 eradications of the three invasive rat species have been successful (Russell and Holmes 2015), with notable positive responses in native species populations, vegetation structure and diversity, and ecosystem function. The vast majority of rodent eradications have been conducted on uninhabited islands and only recently have inhabited islands been considered as suitable to attempt rodent removal. This is mainly because inhabited islands were considered too difficult due to the presence of humans and associated infrastructure, livestock, other domestic animals, and associated risk factors such as agriculture, which could provide alternative food for rodents.

As many inhabited islands are sites of high biodiversity values and significant conservation gains could be made from the removal of rodents, these islands are increasingly being proposed for eradication operations. The inherent complexity of these islands, principally due to human presence and activities, requires the combination of existing eradication techniques with social engagement programmes to achieve eradication success. As such, this incipient method will evolve new conventions for conducting eradications, based on prior practice. As the Lord Howe Island Rodent Eradication Project (REP) was only the second rodent eradication carried out on an inhabited island, as defined by Russell et al. (2018), the knowledge gained will provide a model for future operations. In this case, the ground-based portion of the REP is the focus of this paper, as it had the most direct and lengthy interaction with the local community during the eradication operation.

Site Description, Rodent Impact, and Control

Lord Howe Island (1,455 ha) is a remnant volcano in the north Tasman Sea, some 600 km east of Australia (31°S, 159°E; Figure 1). The northern portion of the island comprises low hills, whilst the southern end rises precipitously, with two summits up to 875 m high. The island is about 10 km long with a coastal mix of beaches and cliffs. The island was discovered in 1788 and settled in 1834, with many current residents tracing their ancestry to the original settlers. The settlement now covers some 15% of the island with about 350 permanent residents. Lord Howe Island is a World Heritage Area and largely forested, although there are small areas of settlement, pasture, and palm plantations. Tourism provides the major income source, with 400 tourists permitted on the island at any one time. Lord Howe Island (LHI) is part of New South Wales and administered by the LHI Board, which carries out local government functions on behalf of the residents, including management of the natural values. Property is not owned by residents, but leased from the LHI Board on a long-term basis.

Invasive rodents reached Lord Howe Island a little over 100 years ago, with mice (*Mus musculus*) arriving about the 1860s and black rats (*Rattus rattus*) from a shipwreck in 1918 (Hindwood 1940). The rat population irrupted to plague numbers within two years, necessitating the need for a bounty system to control them (Hindwood 1940). Rats probably caused the extinction of five endemic bird species, 13 invertebrate species, and two plant species (Wilkinson and Priddell 2011). Previous rodent control had focussed on reduction in mice and rat numbers to reduce damage to the kentia palm (*Howea forsteriana*) industry and to the residents' gardens, orchards, and homes. Warfarin had been used extensively since 1986. Reviews of the control programme had resulted in a pulse baiting regime, with recent rodent baiting comprising 4.5 tonnes of coumatetralyl and difenacoum through the settlement, per annum.

Rodent eradication on LHI was first suggested in 2001, and followed previous vertebrate pest eradications that had removed pigs, goats, and feral cats from the island. Significant effort in planning and consulting with the local community began in 2006 (Walsh et al. 2019). Funding of $9.5A million for the rodent eradication project was received in 2012 from the NSW and Federal government, some seven years before the recently completed operation began. The LHI REP, operating as part of the LHI Board, proposed a mix of aerial bait application in the forested parts of the island, with ground-based techniques for the settlement.

From the outset, the Lord Howe Island Community participated in the development of the eradication plan for the REP. A detailed case study of the social engagement undertaken on Lord Howe Island prior to the operation is discussed in Walsh et al. (2019) and lessons learnt are summarised there. In summary, the REP was identified as being part of the LHI Board so was at odds with at least a section of the local community. There is a degree of mistrust and on-going resentment of LHI Board in particular, not mitigated by apparent poor historical interactions with the locals and the "…lack of trust of new people, new technologies, and the LHI Board in general, was perhaps the most difficult issue (for the REP) to address" (Walsh et al. 2019). Initial social opposition to the eradication was identified in a Cost Benefit Analysis (Parkes et al. 2004) and broadly fell into two camps: resistance to the proposed methods, and disagreement with the need for the operation. Ongoing consultation and public meetings occurred over the next eight years, alongside associated trials for risk to non-target species and an assessment of risk to public health, which found minimal risk with suitable mitigation in place. The release of funding for the project in 2012 suggested to a portion of the community that any further consultation was not required as the eradication project was a foregone conclusion. Despite there remaining a minority of local residents who continued to oppose the REP, the LHI Board made the final decision to proceed in September 2018, with the operational stage beginning in early in 2019. This paper describes the ground-baiting component of the project.

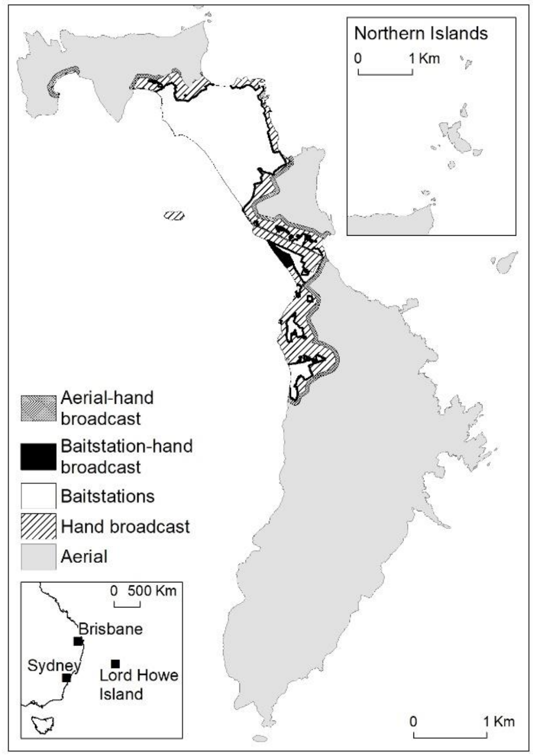

Figure 1. Map of Lord Howe Island showing its location and the areas of bait station, hand-broadcast, and aerial rodent bait applications.

METHODS

The original ground-operations plan called for brodifacoum-bait application through a combination of hand-broadcast and use of bait-stations throughout the Settlement. The application method used would reflect the land tenure of island leaseholders: as a general rule, opponents preferred bait-stations whereas supporters including LHIB approved of hand-broadcast of bait. There was concern this mix of techniques would create temporal and spatial gaps in the bait coverage meaning some rodents could conceivably not encounter baits. As hand-broadcast alone was not agreed to be acceptable on properties of opponents in particular, an operation solely based on the use of bait-stations within the built area of the Settlement was settled on. This received additional community support when it was announced. A 10 × 10-m grid was therefore deemed necessary to provide bait to mice of all ages and stages of the breeding cycle as well as numerous opportunities within the home range of rats to encounter bait in the 190-ha Settlement. This was a substantial undertaking.

The expectation was that the majority of rats would be dead within six weeks of the first brodifacoum-bait deployment in late May (i.e., about the first week of July) with likelihood of some mice remaining, if competing with access to bait stations with the last few rats. This was based on outcomes of rat eradications with bait stations elsewhere and known response of mice following rat removal (Brown et al. 1996, Witmer et al. 2007, Harper and Cabrera 2010, Bridgeman et al. 2018)

High risk sites, which were an alternative food source for rodents, were identified early in the planning phase and risk reduction strategies developed to deal with these sites. The principal risk sites were the island's Waste Management Facility (WMF), and any chicken coops or aviaries, compost bins, orchards, and/or gardens. Additional risks were likely from the few commercial kitchens, restaurants, and the bakery.

Pre-eradication Rodent Control

Prior to this operation, rodenticide baits were being used by LHI Board, dispensed to locals by LHI Board, or bought by locals from the local grocery stores. A mix of 1st generation and 2nd generation anticoagulants had been used for over 30 years, with little management or strategy. Most bait stations being used on the island were either Protecta LP (Bell Labs, New Providence, NJ) or bespoke PVC bait stations used by LHI Board field staff for localised rodent control.

GIS and IT Requirements

An electronic data capture infrastructure was trialled and developed for the operation by an IT technician with significant input from the Ground Operations Manager and GIS and software application providers. The system had three main requirements (De Schutter 2018):

1) High-accuracy GPS: ~1-2 m underneath canopy cover.
2) Mobile application: user-friendly, off-line data capture, synced back at the base.
3) Mobile device: user-friendly, water-proof, rugged, good battery life.

Development and testing of the GIS system able to ensure the high accuracy placement of bait stations (every 10 m ±2 m) was carried out through 2018. The final selected system incorporated the Trimble R10 GPS as the high accuracy GPS for the set-up phase, *Fulcrum* as the mobile application, and AGM A8 ruggedised phones as mobile data collection devices. Data capture involved the use of a barcode scanner in the mobile device to identify barcoded bait stations alongside a data collection application. As Lord Howe Island does not have a mobile phone network for data transfer, records were stored on the mobile device and downloaded once returned to the base at the end of the day. Maps of bait distribution were available by the evening for the next day.

Besides the application developed for bait station placement and bait deployment and bait checking, additional applications developed in-house extended to include roof space baiting; rodent detection device deployment and recording; rodent sighting response; and for bait station recovery at the end of the operation. The application could be readily modified to adjust for changes in desired information capture. For example, for the search phase the application was readily amended that if there was rodent sign it included, what type of sign, and in the later stages of baiting if faeces were brown, green, or mixed (as an indication of if the rodent had already consumed bait).

Bait Stations and Access to Infrastructure

Bait stations needed to be deployed into 667 structures. This included a mix of domestic houses, accommodation providers (motel units and ancillary buildings), a small number of retail outlets, and numerous sheds and storage buildings in varying degrees of repair. There were very few multi-storied buildings with none over two stories. Although a small proportion of buildings (mainly sheds) were not identified until bait stations were being established, due to the dense canopy in many sites, all were recorded on mobile devices and baited simultaneously, and then incorporated into the database.

Many of the accommodation providers were initially wary about the eradication and the impact on their businesses, despite the most intense part of the operation largely occurring over the winter when most providers were closed. The operation required a mouse bait station in at least each unit, and there was considerable resistance to this, which required a significant amount of negotiation. As the tourist season started in September there was also a strong desire to have bait stations removed from units through this month. There was a significant amount of negotiation required to enable bait to still be present at accommodation after this.

In areas of thick forest or shrubland, lines had to be cut to allow access for bait station servicing and hand-broadcast of bait. This took a considerable amount of time, particularly in hand-broadcast areas as lines often needed to be closer than expected to effectively distribute bait (i.e., 10 m apart as opposed to 20 m apart in more open forest).

Toxic Bait

The principal bait for bait stations, hand broadcast, and aerial application was Pestoff 20R™ (2-g pellets; 0.02 g/kg brodifacoum: Orillion, NZ). Roban™ (0.05 g/kg difenacoum) blocks were planned to be added in internal and external bait stations later where bait station-shyness may have been a possible issue.

Bait Stations

External Bait Stations

The selected external bait station was the Globe™ (Globe Pest Solutions, Nyack, NY). In order to reduce water damage to bait, a bait tray was added inside the raised portion of the bait station, which required the use of hot-glue guns, as no other glue would adhere to the plastic. Bait trays were inverted plastic coffee-cup lids. Barcodes were affixed inside the bait station lid which ensured staff had to open the bait station to scan the barcode and therefore check the bait station status. This also improved quality control. These modifications took a considerable amount of time.

Bait stations were initially loaded with 80 g of bait (40 pellets), which was progressively reduced to 10 g by the sixth baiting round as rodent activity declined. Fewer bait pellets meant that bait take was easier to detect and reduced wastage.

Although most cattle were removed from the island for the operation, four cattle herds remained, necessitating 2,600 bait station covers over bait stations to allow their servicing while protecting the bait station from disturbance by cattle. These were triangular covers to deter cattle from standing on them, made out of 17-mm plywood pre-cut in Australia and constructed on island. These were a significant cost in time and resources, which could have been avoided with a stronger adherence to the proposed removal, and eventual replacement, of stock.

Internal Bait Stations

The selected internal bait station was the Protecta Evo™ (Bell Labs), with barcodes stuck on the inside lid. Bait stations were closed inside dwellings for safety reasons, whereas they were left open in roof spaces to provide a more secure bait dispenser and simplify bait loss counts. Open trays were also used in roof spaces. Bait trays and bait stations were placed around the roof access hatch. Restrictions were placed on bait placement by health and safety requirements and possible liability associated with staff possibly being electrocuted or putting their foot through the ceiling. Later in the operation some houses had bait hand-thrown into roof cavities if permitted by the leaseholder.

Internal bait stations were loaded with 12 g of bait pellets for the duration of the operation, but check frequency was to be reduced after two months as rodent activity declined.

Bait Station Servicing

About 60 field staff were employed for the ground-baiting portion of the Lord Howe REP. Tasking for bait station servicing was carried out by a Community Liaison team comprising staff with similar community experience or detailed knowledge of local politics and relationships. This team would determine which personnel could access particular properties as part of a larger sweep of bait replacement from north to south through the Settlement. Team tasking was determined at least 24 hrs prior to deployment, which was often based on team composition and their relationships with leaseholders. Detailed briefings were given to each individual supervisor each morning, along with a short overall briefing to all team members to ensure they were aware of any immediate issues relating to the project. Local team members often had more than one job, so information was passed to the staff about once a week, when almost all staff were present, in a briefing to outline where the project was progressing and provide additional pertinent and timely general information on the ground operation.

Tasking of baiting teams was exceedingly complex, and could be likened to three-dimensional chess, with 1st dimension: land tenure; 2nd dimension: timing; and 3rd dimension: social requirements. The Community Planning Team needed to determine appropriate teams for each lease and their access requirements, ensure each team had appropriate workloads and tie in with the overall baiting plan. Leases were given an ID code and loosely grouped so teams could work through a block of leases each day as part of the overall sweep of bait replacement from north to south. The Community Planning Team needed to call each leaseholder and gain prior access permission for the planned day and negotiate timing and team members allowed access. These conversations were being repeated every 8-12 days with each baiting round and became more refined each time. At first many phone calls were often difficult or tense and were often avoided by leaseholders. The approach of the Community Planning Team was to approach conversations with empathy and honesty. This resulted in solid relationships forming with most of the community and access was given with less difficulty. It was noted that over the course of the baiting rounds that many leaseholders became increasingly relaxed about access requirements as they became more familiar with teams and the work. Local staff were essential as team members and there were a few invaluable 'super-accessers' within teams who were able to access almost all properties.

Hand-broadcast of Bait

Areas of hand-broadcasted bait were overlapped with the areas of aerial bait application and bait station areas at an application rate of 12 kg/ha in the first application and 8 kg/ha in the second. It was carried out simultaneously with the two aerial applications to ensure temporal overlap. Therefore bait station servicing largely ceased during the hand-broadcast operation over 163.6 ha of mainly forest and pasture, largely in hill country. The island's aerodrome was also hand-broadcast in order ensure very accurate bait application to avoid the tarmac runway and timed to avoid commercial and private aircraft flights.

Management of Alternative Food for Rodents

Waste Management

The production and management of organic waste, a major alternative food source for rodents, was considered a significant risk for the project from an early stage. Organic waste was present in orchards and gardens as vegetables and fallen fruit, at the island's Waste Management Facility (WMF), and the few restaurants and grocery stores. A Waste Management team was formed and they provided lidded plastic pails for all householders and commercial operations and collected waste on a regular basis for disposal at the WMF. An industrial 'Hot-Rot' composter at the WMF processed the organic matter into compost within 24 hrs, which was then removed off the island during the operation.

Chickens

Chickens were an additional risk factor for the eradication as their food provided alternative forage for rodents. Most chickens were removed from the island. Some residents wanted to retain their chickens for a variety of reasons. Most were housed in a central, rat-proof, chicken coop specifically built, and managed, by the REP. A few chickens were retained by owners if the coops and feed dispensers were rodent proof. Chicken management took up an inordinate amount of time and could have been dispensed with if a stronger adherence to the proposed removal, and eventual replacement, of chickens had been followed.

Cattle and Livestock

There was a perceived risk to cattle and livestock that remained on the island of brodifacoum poisoning following the hand broadcast and aerial drop, particularly dairy cattle. Sales of milk from the cattle were stopped during the baiting and all of the milk produced was taken and destroyed on a daily basis. The cattle owner received compensation for this for the duration of the ground operation. This resulted in a significant time and financial cost to the project.

Non-target Species

Two species, the endemic Lord Howe woodhen (*Gallirallus sylvestris*) and native pied currawong (*Strepera graculina*) were regarded as particularly at risk from primary or secondary poisoning. A significant proportion of both species were taken into captivity prior to the operation and held until the post-operation risk of poisoning had dissipated. This was carried out by Taronga Zoo and was a substantial undertaking with an associated cost.

Monitoring and Response

A rodent detection grid was planned for establishment by early-mid July as very few rodents were expected to remain by then. The grid was a tool to guide the final efforts at removal of individual rodents that may remain and provide an initial indication of the outcome of the eradication ground operation (Samaniego-Herrera et al. 2013).

RESULTS

Bait Deployment

Bait stations were established on 190.4 ha throughout the Settlement (Figure 1) and 18,990 external and 3,475 internal bait stations were deployed. Twelve tonnes were applied using ground-based techniques between 22 May and 5 November at an average overall nominal application rate of 33 kg/ha. However, a significant portion of this bait was recovered from bait stations during the bait replacement rounds and disposed of through the waste management facility, so the actual application rate into the environment was much less than this. Most of the bait, some 8.9 tonnes, was deployed in the first six weeks over 3.5 baiting rounds and a hand-broadcast operation and was either consumed by rodents or invertebrates, or replaced. The application rate during this first six-week period averaged 10.7 kg/ha/round. The remaining 3.1 tonnes was used over the last four months from early July to early November over 15.5 baiting rounds and the final hand-broadcast operation at an average application rate of 0.9kg/ha/round over the final 17 weeks.

Bait station checks were considerably slowed by the need to clean most stations because of moisture, slug damage and slime, and other invertebrate [slaters (Isopoda) and spiders in particular]. Quality control was stressed to maintain bait station cleanliness so that a) any rodent sign was not missed, and b) that each station was totally clean after each servicing to ensure that if any rodent sign found on the next check was known to be fresh.

Overcoming Access Difficulties

A few remaining leaseholders refused access on properties and inside dwellings for REP field staff through into June. A variety of options to allow access were discussed with the leaseholders, including only allowing trusted acquaintances or relatives to apply bait, but were usually rebuffed. The final option was using the Biosecurity Act, which permitted access for biosecurity purposes as the REP was removing species posing a biosecurity risk. The Department of Primary Industries, which administered the Act, sent staff to talk directly to leaseholders about the significant legal consequences of refusing access, and in all cases, access was granted. Within the opposition group it appeared there was a degree of status attached to holding out against permitting access until the very last hurdle.

Baiting in Roof Spaces

Although most structures had roof spaces that were accessible through access hatches, during the course of roof baiting, staff noted a large minority of buildings with internal inaccessible roof spaces, and some roofs (e.g., skillion) that had narrow spaces between the ceiling and roofing. An inventory of inaccessible roof spaces was collated, which took a considerable amount of time and needed to be done by a 'roofing space specialist' in each team in order to obtain quality information. A specialist roofing contractor was contracted from Australia to carry out baiting due to issues with liability. This baiting procedure required a portion of the roofing to be detached, bait placed in the space, and the roofing re-attached.

Once again, there were issues with access to some buildings due to resistance from detractors and a significant amount of time was spent re-negotiating access. A two-page information flyer with information and Frequently Asked Questions was sent prior to approaching leaseholders and this eased the subsequent discussions. Approximately 180 inaccessible roof spaces were opened (~1/4 of all dwellings), with most roofs requiring multiple access points to provide adequate bait coverage.

Bait Hand-broadcast

Bait was hand-broadcast twice on 8-12 June and again on 1-5 July when the aerial application was taking place. Later in the ground operation an additional hand-broadcast application was carried out in pasture near sites with vestigial clusters of rat detections, in order to circumvent any remaining rats dispersing into rodent-cleared sites.

Bait Damage

Damage to bait by slugs and slaters was substantial and to the untrained eye could be confused with rat or mice damage. In internal stations, bait damage was often caused by cockroaches. Over two tonnes of slug bait was eventually used in external bait stations from late June to October to reduce slug damage. Staff needed additional training in separating out the difference between rodent take, invertebrates. This was the focus for a senior supervisor and physical examples and photographs were used to highlight differences in field sign, with informal quizzes as motivation.

Removal of Residual Rats

Although bait take had declined through June and over 140 dead rats had been found, several live rats were sighted over the weekend of 6-7 July and detected by dogs at the same location on July 8, some six weeks after bait application had begun. Additional sightings occurred through July and this, coupled with further detections by dogs and on the monitoring grid, spurred increasing numbers of searches using the local biosecurity dogs in the following months. Properties adjacent to sighting locations were also investigated and often detected additional live rats. These properties required numerous inspections until no rats had been found for at least three or more searches. Although rats were detected throughout the northern Settlement, rat distribution tended to be clumped, with several live or freshly dead rats found within 100 m or so of each other, with few detections in between. Intensive searching took place, with several additional dog teams brought to the island to assist, until the REP field component finished in mid-December.

Through July and August rats were detected on a little over half of dog searches, but the detection rate declined rapidly through September until the last rats were found in early October (Figure 2). By the end of October, 762 individual searches using dogs had been conducted across a multitude of properties. Rats tended to be located in sites providing security from predation and protection from the elements, such as palm windrows, woodpiles, limestone holes, and caves, in the base of banyans, and under buildings. Detection staff quickly learned to scrutinise these refuges when first accessing a property, which improved efficiency.

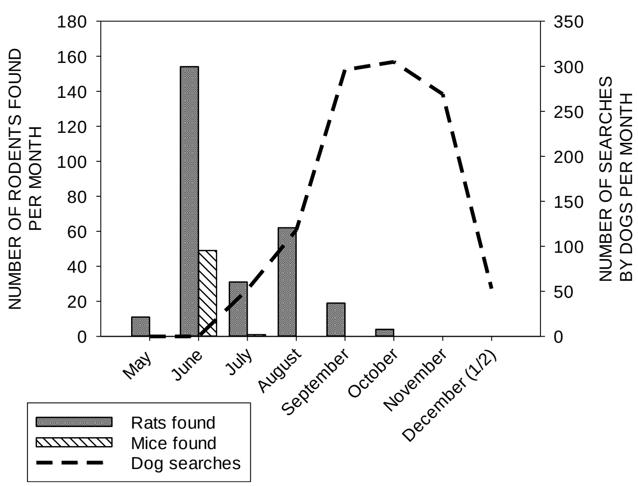

Figure 2. Numbers of dead rodents located each month of the LHI REP and the detection effort for residual rats by rodent dogs.

Waste Management

All orchards/gardens were checked for fallen or rodent-chewed fruit by baiting teams' staff during the course of the baiting rounds. Fallen fruit was collected and returned to the owner or sent to the WMF for composting. Where possible, orchard and garden owners were encouraged to collect their own fruit and vegetables daily, and any waste became part of the REP waste collection scheme. Some fruit and vegetables were particularly sought after by rodents (particularly avocados, sweet citrus, passionfruit, and banana) and these were often rat 'hot-spots' in the latter stages of the operation.

In order to monitor possible secondary poisoning, the baiting teams collected poisoned carcasses during the course of their baiting rounds. Almost all carcasses (rodents and non-targets) were collected from within the Settlement. Many carcasses were dissected and assessed for cause of death. Demographics and breeding data helped with final few months of baiting strategy and prioritising monitoring/dog checks. Samples were also collected from rodents for a DNA record. Carcases that were not needed for further analysis were disposed of in the WMF 'Hot Rot' composting system.

Monitoring

The rodent detection grid was established through early July 2019, and was in operation by July 15. However, by this stage it was already clear that a small remaining population of rats was present, so initially the detection grid then assisted with their detection and removal.

Besides the detection grid other detections of remaining undetected rats within the Settlement were coming from four additional sources: 1) dog searches, 2) rodent sign on natural food, 3) sightings, and 4) bait station activity.

Rodent detections on the grid quickly peaked to 42 per baiting round in early August and declined to the no detections from 26 September onwards. The monitoring effort continued unabated through October to December with 2.5 checks of the entire grid in the last month alone, or some 5,681 detection devices checked.

In addition to the sustained checks of the monitoring grid, the period from early October until 13 December involved intensive monitoring of the Settlement and the immediate boundary with the aerially treated area with additional dog teams brought in from Australia. Despite this substantial effort, no further live or recently dead rats were located after 9 October 2019 (Figure 2).

Rat Breeding Activity

Rat breeding activity continued through winter on Lord Howe Island. Of 62 adult female rats found through the June-August period, 13 (21%) were pregnant or lactating. The last rat to be found on 9 October was also a pregnant female. Although no juvenile rats were detected in July and only four in August, by early spring (September-October) juveniles comprised more than half (59.4%, n = 19) of the residual detected population (n = 32). The adult rats recovered from the field had a male sex bias (1.35♂:1♀).

DISCUSSION

The ground-based portion of the Lord Howe Island REP was the most complex rodent eradication of its type attempted thus far, with the most bait stations ever deployed and it easily exceeded the next largest bait station eradication attempt on an inhabited island (Scilly Islands, 142 ha; Table 1). Although the Wake Island eradication was similarly complex (Brown et al. 2013), in that it combined aerial, hand-broadcast, and bait station techniques across 602 ha of Wake and Wilkes Islands, with approximately 100 defence employees present, all techniques were on a smaller scale. For example, only ~1,500 bait stations were deployed across 33.1 ha and bait was hand-broadcast across 45.7 ha of flat land (Griffiths et al. 2014).

Table 1. Ground-based rodent eradication operations comparing area, species, time elapsed, and baiting intensity.

Island	Area (ha)	Target Rodent Species	Total Time Elapsed from 1st Baiting	Time Elapsed to Last Bait Take	Bait Station Grid (m, # stations)	Reference
Scilly (UK)	142	Norway rats	4 months	23 days	40 × 50 m (1,000 stns)	Bell et al. 2019a
Breaksea (NZ)	170	Norway rats	3 weeks	21 days	100 × 100 m (170 stns)	Taylor and Thomas 1989
Shiant (UK)	173	Ship rats	5 months	25 days	50 × 50 m (1,200 stns)	Main et al. 2019
Dog (Anguilla)	207	Norway rats	7 weeks	26 days	30 × 30 m (1,700 stns)	Bell et al. 2019b
Lundy (UK)	430	Norway rats & ship rats	5 months & 3 months	~6 months	50 × 50 m (2,100 stns)	Appleton et al. 2006; Lock 2006
Canna (UK)	1,126	Norway rats	4 months	64 days (2 months)	50 × 50 m (4,400 stns)	Bell et al. 2011
Langara (Canada)	3,100	Norway rats	2 years	26 days & 3 monthly checks	100 × 100 m (3,100 stns)	Taylor et al. 2000
Cocos (Mauritius)	21	Mice	21 days	10 days (?)	10 × 10 m (210 stns)	Bell 2002
Mana (NZ)	217	Mice	5 months	~2.5 months	25 × 25 m (5,000 stns)	Newman 1994
Selvagem Grande (Portugal)	270	Mice & rabbits	8 months	6 months	12.5 × 12.5m (17,000 stns)	Olivera et al. 2010
Lord Howe Island (Aus.)	191	Mice & ship rats	5.5 months	132 days (4.4 months)	10 × 10m (external) (19,500 stns)	–

The complexity of the ground-baiting operation on Lord Howe Island stemmed from several factors. There was a significant amount of resistance to the eradication operation, which meant in order to access property, compromises to ‘usual’ minimum standards of an eradication operation on an uninhabited island were made, (e.g., only bait stations were used in the Settlement, instead of hand-broadcast or aerially application of bait). This intense baiting grid, designed for mice, meant the required resources for baiting were substantial and a large workforce was required. Tasking was also complicated by the need to secure access for each lease in each baiting round, which also often required leaseholder approval of the staff members that would carry out bait servicing.

As such the electronic data collection infrastructure, based on mobile devices, was invaluable and provided accurate information and mapping with a system that was quick and easy for field staff to use. The ground operation got maximum value from the system through the employment of dedicated, high calibre IT experts with experience in eradication and pest control who understood what was required for the field work. Although it was costly to establish a similar system it would be essential for any future operations of this complexity, particularly for effective and timely data management. Moreover, the ability to develop and modify applications on the mobile devices as required was of immense value. As the required type of information changed, so did each applicable application. For example, if there was rodent sign, the type of sign was recorded initially (faeces, urine, chews), but in the later stages of baiting if faeces were brown, green, or mixed this could be recorded as an indication of if the rodent had already consumed bait.

Removal of Residual Rats

Of considerable concern was the apparent avoidance of bait stations by a small percentage of rats within the settlement. It was widely assumed that rodents would respond to bait stations as they had during eradications on uninhabited islands of a similar size to the Settlement (~200 ha), with rats rapidly removing bait and being extirpated or rare within about six to eight weeks. This was patently not the case in the northern Settlement and there was strong evidence that some rats were avoiding bait stations. Evidence that rats were avoiding bait stations was based on remaining rats consuming Pestoff™ 20R bait when presented in the field, with dead rats, having eaten bait, found after bait was distributed in the open from July onwards. Bait consumption was based on necropsy showing green staining of the alimentary canal from bait dye and/or indications of anticoagulant poisoning. Furthermore, in the Southern Settlement where most houses had bait hand-broadcast to within 20 m of the houses there was only a single detection of a live rat during the mop-up phase, so rats were ingesting bait when it was available on the ground. Based on the total number of captured or killed rats from 8 July when the first live rat sighting was reported (281 animals), an estimate of the rats avoiding bait stations was ~16% of the original population, based on a likely population density of 8-10 rats/ha in the northern Settlement (~200 ha × 9 rats/ha = ~1,800 rats).

It is proposed that bait station avoidance on the island developed from poor baiting procedures over the past 30-plus years. Rodent control on LHI prior to the operation suggested that anticoagulant rodenticide deployment had been technically poor at best and cavalier at worst and in many cases were not following the written instructions (G.

Harper, pers. observ.). If commensal rats had been exposed to sub-lethal doses of 1st generation anticoagulant over several generations then it is possible that at least some rats associated bait stations, *rather than bait*, with illness and subsequently avoided them. As rats also learn food avoidance from their mother and conspecifics (Galef 1982), it raises the possibility they also learn to avoid specific sites or infrastructure that have been associated in sub-lethal poisoning of their mother or conspecifics. It should be noted that no apparent bait or bait stations avoidance was observed in mice.

In any case, the effect on the operation of live rats being present for much longer than expected cannot be overstated. The situation resulted in a longer project duration, requiring intense team effort and additional assistance with rodent detection by several dog teams, and it was this work that removed the last known rats.

Far and away the most important improvement for future rodent eradication operations on inhabited islands would be to avoid probable bait station avoidance by commensal rats. There are only two practical methods for overcoming this situation, being either: 1) Cease all bait station use on a target island for at least 18 months, but preferably longer, prior to the start of a planned eradication. This ban would include any person that may use bait stations, be it by locals, local area authorities, government agencies and any other pest control entity. To ensure this ban is enforced, there should be a concurrent ban on the importation of any type of anticoagulant rodenticide, be it 1st or 2nd generation, which will need to be in force well before the bait station ban to avoid stockpiling. To replace rodenticide use, alternative rat control methods will need to be available, with assistance provided (advice, financial, resources, staffing); and/or 2) only apply rodenticide externally using hand-broadcast or aerial methods, with internal baits only presented in open trays.

Rats were present for about 136 days (4.5 months) after the first baiting commenced in late May. The average time for the last bait take by rats during five rat eradications using bait stations on comparable sized islands elsewhere was 56 days (~2 months) (Table 1). The last dead mouse was found on 6 July or 45 days (1.5 months) after baiting commenced. No further mice (alive or freshly dead) were found despite a significant search effort using dogs, and there was little evidence of mice detections on the monitoring grid after this date. The average time for the last bait take by mice during three rat eradications using bait stations on comparable sized islands elsewhere was 87 days (~3 months).

Rodent Detection

Although certified rat-detection dogs were to be used in post-eradication monitoring to confirm eradication success (LHIB 2019), dogs had not been planned to be part of the ground-baiting process, as it was assumed a bait station operation would eradicate all the rodents within the target area. The unforeseen requirement for detection dogs to remove the last rats added extra effort and cost that had not been accounted for. In addition, rat searches consumed a considerable amount of time and effort by the Ground Operations Manager, and other selected staff trained to assist the dog teams with organising search tasking, identifying rat sign, and leading rat detection responses. One of the benefits of using dogs is that they were invariably well received by locals and were granted access to all areas almost without exception.

Analysis of rat detection dog searches revealed they were not infallible and a few rats were found in areas that had just been searched. Similarly, the rat monitoring grid did not detect all rodent presence and either detection method probably worked at about 80-90% effectiveness. The conclusion is that although the two detection methods complimented each other well neither should be relied on as the sole mode for verification of rat presence.

Future planning should account for these apparent limitations. The aim should be to 'over-check' and 'over-monitor' areas, especially if suspect. Natural sign was also often very important indication of rat presence, with natural food often being preferred to monitoring tools and on a few occasions the *only* indication of rat presence.

Staffing

The experienced and high calibre supervisory staff contributed greatly to improve management of the ground-baiting operation, as they fully understood the 'eradication ethos' from the beginning and were able to inculcate field staff so a high quality work standard was achieved. Moreover their experience led to several modifications of field operations which improved management and efficiency. Regular meetings of the Ground Operations Manager and supervisors outside of work hours provided an additional informal setting for operational pre-briefings, critical discussion and amendment of the work programme, over and above the usual morning staff meetings.

In addition, the Ground Operations Manager, Operations Manager, Technical Advisor, and IT technicians all worked in the same office in a collegial atmosphere. This meant there was good situational awareness of the operation within the team and an ability to immediately discuss any issue. This team worked well with the Community Planning Team and assisted each other to progress the project. Daily briefings assisted with the transfer of information between the two principal teams. This said, it should be noted that the efficiency of project staff would have benefited from a dedicated operations facility.

A quartermaster and assistant managed the on-island team transport, bait provision and storage, gear provision and storage, and advised the Ground Operations Manager on required procurement requirements. This would be an essential position in any other operation of similar complexity, as it removed a significant workload from the Ground Operations Manager.

Waste Management

The Waste Management Facility was significant risk site for the project and REP staff assisted to clean up the site and reduce refuges and food sources for rodents. The Facility Manager also worked with the REP by improving the waste management processes, particularly with the 'Hot-Rot' industrial composting machine.

Most leaseholders cooperated with the removal of compostable waste using the lidded plastic 10-litre pails collected by the Waste Manager and team. A significant amount of alternative food for rodents was removed by this method and passed through the 'Hot-Rot' composter. There was always some fruit fall and although much was picked up by leaseholders, a large amount was still recovered by baiting teams during each baiting round and either left with leaseholders or passed on to the Waste Manager.

Bait Station Covers

The bait station covers required a substantial amount of work to construct and deploy. In the face of resistance to cattle removal the LHI REP had little choice to proceed with this methodology. Once established the covers proved to be effective at keeping bait stations secure, although there were a few isolated incidents of covers being flipped by bulls in particular.

Norfolk Pine Seed Mast

During the rat detection and response phase of the eradication from July onwards, many Norfolk pine (*Araucaria heterophylla*) seed caches were found in rat refuges. Often caches were adjacent to Norfolk pines, but several were 80-100 m distant, which suggested these relatively large seeds were valuable food items. Discussion with the LHI museum director highlighted the fact that Norfolk pines mast-seed every 3-5 years, and the pines were presently seeding heavily for the first time in a while. Other Araucaria species mast-seed, with invasive rats being significant seed predators (Shepard and Ditgen 2013). The mast-seed event may have been a partial explanation for the presence of live rats well after bait station operation started, as they had access to a copious supply of apparently high value food items, although it did not resolve why rats were detected at sites a kilometre or so from any Norfolk pines. In any case, this was an unknown risk to the operation and should be included in any future rodent eradication planning for islands with *Araucaria* present.

Banyans

It did not appear to affect the overall outcome because although they did not appear to provide significant arboreal habitat for rats or mice, rodents did use refuges at their base in the form of numerous small gaps and holes. During the rat detection and response phase of the eradication from July onwards bait take continued in areas of banyans and many of the last known rodent detections and bodies were associated with banyan trunks. Although arboreal baiting is not recommended in future eradications banyans should be targeted for specific ground-baiting for rodent removal.

Opposition to the Project

The unique relationship of the LHI Board with leaseholders did not assist with the operational implementation as the LHIB was essentially a landlord. Because of this situation and previous poor interactions with the LHIB, many islanders mistrusted the LHIB and this was often the basis for the opposition to the LHI REP, rather the rodent eradication operation *per se*. The state of the relationship was a considerable handicap to the project, particularly at the early stages of implementation.

Staunch opponents deliberately set out to make the operation difficult. Opponents hindered the operation in an apparent effort to frustrate staff, derail the eradication and paint its execution in a poor light in the eyes of the LHI residents. However, damage to the baiting infrastructure was less than anticipated. There were only a small number of cases such as someone planting bait during the aerial operation in an opponent's yard, opening bait stations, shifting bait stations or running them over. Two, ultimately unsuccessful, legal challenges were made to the operation, one of which reached the Supreme Court. This created uncertainty within the team about the likely completion of the operation, diverted middle and senior management from core roles, and created delays in the work programme. Careful scrutiny of the wording of any permits, in addition to with working with permitting bodies that are unfamiliar with eradication techniques, would likely have reduced the likelihood of legal challenges.

The recently completed Lord Howe Island Rodent Eradication Project was a difficult operation due to a variety of factors. A poorly executed social engagement programme over many years, coupled with historically rancorous relationships between a sector of the community and the implementing body, meant there was a degree of perpetual resistance to the project. This may have been circumvented if the project had developed as a groundswell from within the local community, rather than imposed on it. In addition, many novel components of the ground operation not previously encountered in rodent eradication operations on uninhabited islands contributed to significantly more operational complexity, over and above the additional intricacies involved with working with a community. These included the need to bait numerous residents' properties, inside their buildings and roof spaces, along with public amenities such as the school and playing fields. The intensity of the baiting operation, due to the need to target mice, increased the staff size considerably, together with the associated provisioning, logistics, and data management requirements. Moreover, the unexpected need to search for and remove commensal rats apparently avoiding bait stations likely extended the operation duration, with consequent flow-on effects on resourcing. This is a valuable lesson for future eradication operations on inhabited islands.

CONCLUSION

The Lord Howe Rodent Eradication Project showed that future operations on inhabited islands will be different to uninhabited islands for four main reasons: 1) Compromise: existing eradication protocols are likely to be compromised in order to enable access to properties; 2) Commensal: rodents will have been subject to control operations for many years and will have developed novel avoidance behaviours; 3) Complexity: the operation will be significantly more complex, leading to increased expenditure; and 4) Cost: eradication operations will be significantly more costly than uninhabited islands. In future eradication practitioners should strive to ensure an eradication project is community-led and to not underestimate the complexities involved. Very careful planning, preparation and leadership is essential, with the understanding that it will require significantly more time and resources than an uninhabited island.

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