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A vertical bait station for black rats (*Rattus rattus*) that reduces bait take by a sympatric native rodent

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Abstract. Novel bait stations can be used as a targeted method of delivering bait by exploiting behavioural traits of the target species. On Muttonbird Island, New South Wales, the black rat (*Rattus rattus*) has been baited to aid the conservation of the island's wedge-tailed shearwater (*Ardenna pacifica*) colony, which may result in poisoning of the sympatric swamp rat (*Rattus lutreolus*). We aimed to design a bait station that *R. rattus* could reach, but that *R. lutreolus* could not. We found that 11 (92%) of 12 captive *R. rattus* reached the bait chambers by climbing a 50-cm vertical pipe, whereas only four (18%) of 22 *R. lutreolus* reached these bait stations. In a field trial on Muttonbird Island *R. rattus* entered the bait chamber on an average of 5.3 events per night of vertical bait station deployment, but *R. lutreolus* did not enter the stations. In a field trial on the mainland at a site with a high density of *R. lutreolus*, this species was detected in one vertical bait station five times, equating to an average of 0.017 events per night of vertical bait station deployment. We conclude that *R. rattus* readily climbs a 50-cm pipe to enter the bait station, whereas *R. lutreolus* rarely or never does on Muttonbird Island or at the mainland site.

Additional keywords: camera trap, island conservation, seabirds, swamp rat (*Rattus lutreolus*).

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Introduction

Many island ecosystems have been threatened by invasive rodents, particularly black rats (*Rattus rattus*), brown rats (*R. norvegicus*) and house mice (*Mus musculus*) (Atkinson 1985). Invasive rodents have been implicated in the decline and extinction of insular seabirds (Atkinson 1985; Towns *et al*. 2006; Jones *et al*. 2008; Banks and Hughes 2012) and mammals (Burbidge *et al*. 1997; Burbidge 1999; Burbidge and Manly 2002; Harris 2009; Banks and Hughes 2012). Predation by exotic rats on Australian Islands was recognised as a key threatening process under the *EPBC Act 1999* in 2006, and soon afterwards a Threat Abatement Plan was prepared by the Australian Government (DEWHA 2009). The eradication of exotic rodents from islands has led to the recovery of endemic fauna (e.g. Jouventin *et al*. 2003; Lorvelec and Pascal 2005). However, some islands are highly prone to reinvasion because they are near the mainland, or connected to it by human-made structures. In these cases, permanent eradication of invasive rodents is impossible and therefore sustained control may be needed.

Muttonbird Island, located 500 m off the north coast of New South Wales and connected to the mainland by a breakwall, is home to a large breeding colony of wedge-tailed shearwaters (*Ardenna pacifica*). Although the species is not threatened, nearly 30 species of seabirds that breed in Australia are threatened or near-threatened, often due to rodent predation (Garnett *et al*. 2011). Most breed on remote islands, but Muttonbird Island attracts over 100 000 visitors annually, providing a unique opportunity for educating the public about the threats experienced by seabirds. Volunteer bird-banders have been monitoring a subset of the *A. pacifica* population on the island for ~40 years, with their data suggesting a declining population on the island and poor breeding success in recent years (Narelle Swanson, pers. comm.).

The exotic *R. rattus* and the native swamp rat (*R. lutreolus*) coexist on the island (Egan 2008). Given the impact of *R. rattus* on seabirds elsewhere, predation of eggs and chicks by introduced rodents is listed as a potential threat to *A. pacifica* in the Muttonbird Island Plan of Management (NSW National Parks and Wildlife Service 2009). Furthermore, the island population of *R. lutreolus* differs genetically from that on the neighbouring mainland, suggesting that it is a long-term isolate on the island (CPCG 2010). Because *R. lutreolus* and *R. rattus* forage at ground level, and are of similar size, the resident *R. lutreolus* on Muttonbird Island are at risk of being poisoned during any attempt to control *R. rattus*.

Two published studies have demonstrated the ability of vertical bait stations to deliver bait to *R. rattus* but not to coexisting similar-sized native rodents: the Anacapa Island deer mice (*Peromyscus maniculatus anacapae*) (~25 g) on Anacapa Island, USA (Erickson *et al*. 1990), and the Santa Fe rice rat (*Oryzomys bauri*) (~65 g), the large Fernandina rice rat (*Nesoryzomys narboroughi*) (~78 g) and the Santiago Galapagos mouse (*N. swarthi*) (~98 g) in the Galapagos Islands (Phillips *et al*. 2007). Differences in the climbing ability between *R. rattus*, which is an agile and competent climber (Watts and Aslin 1981; Erickson *et al*. 1990; Morris 2002; Phillips *et al*. 2007), and the non-target species, which all climb less, have been used to design bait stations in these studies. *R. lutreolus* relies heavily on runways along the ground in dense ground cover (Fox and Monamy 2007), and so may not be well adapted for climbing. On the basis of this apparent lack of climbing ability, we postulated that vertical bait stations could exclude *R. lutreolus*. Therefore, the aim of this study was to test the hypothesis that *R. rattus* would climb to bait stations raised vertically to 50 cm in the field and laboratory, whereas *R. lutreolus* would be unable or unwilling to climb such bait stations.

Materials and methods

Site descriptions

Two study sites were used: the 8-ha Muttonbird Island (30°18′S, 153°09′E), located off Coffs Harbour, on the New South Wales mid-north coast, Australia; and a heathland site on the mainland near the Coffs Harbour Regional Airport (30°18′S, 153°07′E) (Fig. 1). Muttonbird Island is a nature reserve to protect the *A. pacifica* colony, which breeds from August to May (Swanson and Merritt 1974). The island is connected to the mainland by a 500-m-long breakwall that forms the northern wall of the Coffs Harbour International Marina. A paved walking track running east–west along the island provides pedestrian access to view the *A. pacifica* colony.

The vegetation of Muttonbird Island primarily consists of low-lying grasses, sedges and herbs, including *Commelina cyanea*, *Dianella caerulea*, *Kennedia rubicunda* and *Senecio lautus. Flagellaria indica* and *Cupaniopsis anacardioides* occur in patches on the island and the exotic *Lantana camara* is common on the northern edge. The Coffs Harbour Regional Airport (CHRA) site is heathland with *Xanthorrhoea* and *Banksia* species interspersed with stands of *Leptospermum polygalifolium*, bordered to the east by a narrow stand of *Melaleuca quinquinervia* swamp forest.

Study species

Egan (2008) estimated the density of *R. rattus* and *R. lutreolus* on the island to be 6.5 and 9 animals ha^{-1} respectively in 2008. There were also 53 *M. musculus* per ha, based on mark–recapture, although recent estimates suggest much higher populations of *M. musculus* and *R. lutreolus* (P. Meek, unpublished data). The western (landward) section of the island was baited to control *R. rattus* before each *A. pacifica* breeding season from 2007 to 2010 using a second-generation anticoagulant rodenticide presented in 20 conventional ground-based bait stations. Sporadic baiting also occurred along the breakwall.

Vertical bait stations

The vertical bait station we tested was modified from a design used in the Galapagos Islands by Phillips *et al*. (2007). Polyvinyl chloride (PVC) pipe (90 mm diameter) cut into 50-cm, 30-cm and 10-cm lengths attached to 90° bends and screw cap ends were used to construct each bait station (Fig. 2). A 5 × 5 cm square hole cut at the base of the upright pipe allowed rodents to enter the bait station, and reach the bait by climbing the vertical section. We securely mounted each bait station on two star pickets using

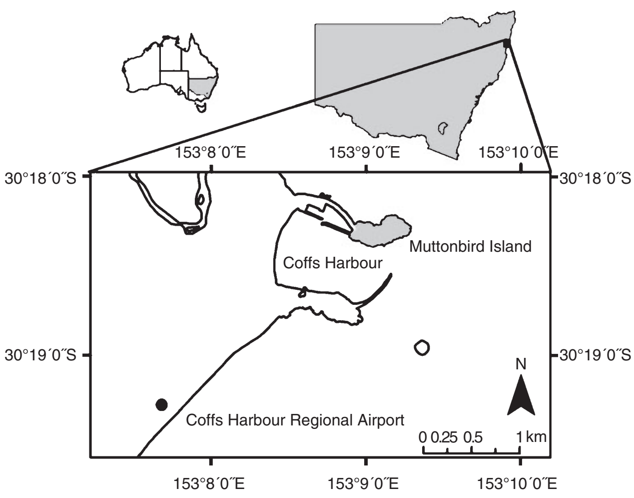

Fig. 1. Map of the study sites on the New South Wales mid-north coast.

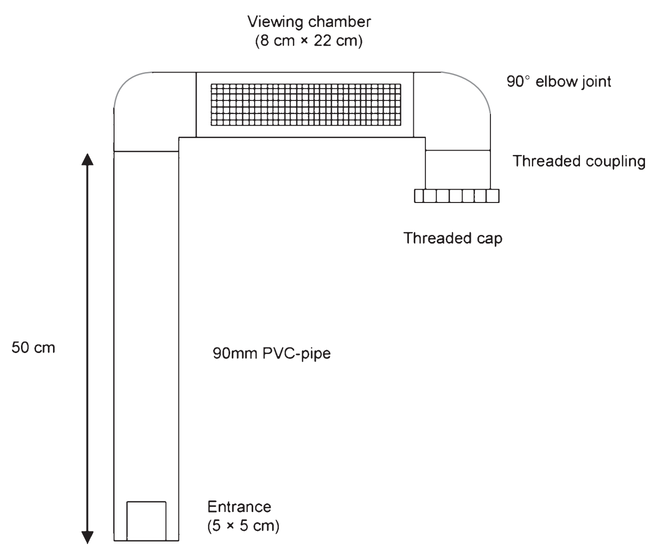

Fig. 2. The vertical bait station design tested in this study.

plastic cable ties in the field. The internal surface of the PVC pipe was not modified. The external surfaces of the PVC-pipe and fittings were spray-painted with green and brown to camouflage them in the field so as to reduce detection and tampering by the general public. The material cost about AU$9 per bait station in 2010. The bait chamber was a 30-cm horizontal section with a viewing chamber to photograph and identify animals entering it, using camera traps. A section (8 × 22 cm) was removed from the horizontal pipe and covered by a piece of 12.5-mm aviary mesh slightly larger than the viewing chamber (Fig. 2).

Captive trials

The climbing ability of the two rat species was tested by a series of captive trials conducted in an indoor laboratory at the University of New England Field Station, Arrawarra Headland, ~30 km north of Muttonbird Island. We trapped *R. lutreolus* for the trials on Muttonbird Island ($n = 10$) and at the CHRA site ($n = 12$). We trapped *R. rattus* on Muttonbird Island ($n = 9$) and at a residence near Coffs Harbour ($n = 3$). Rats were housed individually in cylindrical mesh enclosures (70 × 80 cm), each with one vertical bait station. Rats were provided with water *ad lib*, a cardboard box with shredded paper in it for a nest box and 6 g of commercial rat meal every day of the trial.

The trials allowed for staggered entry of rats into captivity on the basis of our success in trapping them, and started the day after each animal was captured and transported to the field station. Rats had access to each elevation of the bait station for 24 h unless otherwise stated. On the first day of the trial the bait station, with no food, was laid on its side and not elevated. On the second day the bait station was also laid on its side, but was baited with 5 g of peanut butter and rolled oat mixture. Supplementary food (6 g commercial rat meal) was also provided each day outside each bait station so the rats could access it without climbing. Then the bait stations were progressively raised vertically to 10 cm, 25 cm and finally to 50 cm by increasing the length of the upright section of PVC-pipe, to determine how high the rats would climb. Each rat was given a maximum of four nights to enter the elevated bait station, starting with a height of 10 cm. If the rat successfully entered, then the following day the station was elevated to the next height until the maximum height of 50 cm was reached. Failure to enter the station after four nights at any height resulted in the conclusion of the trial for that animal.

The bait stations were monitored with a Reconyx PC90 RapidFire camera trap (Reconyx Inc., Holmen, WI, USA) by cutting holes in the perspex lid of the holding cages corresponding to the infrared sensor and lens and placing the camera horizontally face-down above each cage. The cameras were set to capture five photographs at 1-s intervals after being triggered, followed by a 30-s stand-by period. Therefore two methods were used to confirm successful entry into the bait station in the captive trials: (1) the consumption of bait from the station (by comparing initial and final bait weights), and (2) the examination of camera trap photographs for images of the rodent in the bait chamber.

Rodent enclosures and bait stations were spot-cleaned daily by removing soiled bedding and faecal material from the cages, and thoroughly cleaned with a dilute solution of dishwashing detergent and hot water, rinsed in fresh water and air-dried before housing a new rat. After the trial the sex, reproductive condition, mass and length of the pes, manus, head, body (snout to vent) and tail of each rat were recorded before release (*R. lutreolus*) or euthanasia (*R. rattus*).

Muttonbird Island field trial

Two vertical bait stations (VBS1 and VBS2) were set up on the eastern side of Muttonbird Island 10 m apart. This part of the island was chosen because of its low density of *A. pacifica* burrows. Two different brands of camera trap were used during the Muttonbird Island field trial: the Reconyx PC90 RapidFire and the PixController DigitalEye (PixController Inc., Export, PA, USA). Both cameras used passive infrared sensors to detect animal movement, but the Reconyx has an infrared flash whereas the PixController has a xenon flash. One of each camera type was deployed on a tripod at each bait station, which was baited with peanut butter and rolled oat mixture for three nights (i.e. 6 camera-nights). A small portion of peanut butter and rolled oat mixture was scattered around the base of the bait station in every field trial as a form of prefeeding, as employed by Phillips *et al*. (2007) in the Galapagos Islands. However, we found this technique to be largely ineffective because we deployed the bait stations during the day and ants consumed most of the scattered bait before dark. Therefore photos of rats actually feeding on this scattered bait were rare. In order to reduce the risk of theft, cameras were deployed at 1800 hours and collected at 0700 hours daily. At VBS1 the PixController and Reconyx cameras were set to take a single photograph with a 10- and 15-s stand-by period respectively; at VBS2 both cameras were set to take a single photograph with a 30-s stand-by period.

The Muttonbird Island field trial was conducted in November when the *A. pacifica* were digging burrows and mating, which limited our ability to move off the pedestrian path to deploy cameras and check bait stations, due to the risk of causing burrow collapse. In addition, the island was visited frequently by the public, so there was a risk to camera security. This meant that cameras were deployed only at night, which may have underestimated visitation by *R. lutreolus* individuals, which are partially diurnal (Braithwaite 1977; Watts and Aslin 1981; Meek *et al*. 2012). We therefore conducted another trial at the CHRA, which has a large population of *R. lutreolus* and two previous instances of *R. rattus* occurring on the northern edge of the site. Few people visit this site, so we were able to deploy the cameras continuously throughout the trial.

Coffs Harbour Regional Airport field trial

Ten bait stations were mounted on star pickets at intervals of 20 m along two transects. The vegetation surrounding each bait station and its camera was cleared with hand tools. A 30 × 40 cm section of black non-slip mat was placed at the entrance to the bait station to provide a contrasting background to assist animal identification in the photographs taken by the cameras. The bait stations were baited with peanut butter and rolled oat mixture encapsulated within a tea strainer and securely fastened inside the bait station to ensure the bait was present throughout the trial.

The first and second trials were conducted in March and November/December of the same year, respectively, and the bait stations were removed from the field between trials. Due to camera availability, two different models of Reconyx camera with the same functionality were used for the two field trials: a PC90 RapidFire for the first trial (38 camera-nights) and a HC600 HyperFire (Reconyx Inc., Holmen, WI, USA) for the second trial (250 camera-nights). In the first trial cameras were mounted on tripods 145 cm from the bait stations, which we hoped would detect rodent movement at both the entrance and viewing chamber of the stations. However, on one occasion in the second trial, we found *R. lutreolus* scats in the bait chamber, with no corresponding photograph taken by the camera. We presumed that this was due to the placement of the camera, so after setting the camera at various distances from the station we found that the optimal distance for exclusively detecting animals in the viewing chamber was 50 cm, and so we moved the cameras to this distance for the second half of the second trial. After this time any *R. lutreolus* near the entrance of the station would have been missed, which was acceptable because we knew that *R. lutreolus* were present at the site, and our aim was to determine whether they were able to climb into the bait chamber.

Data analysis

Photographs of animals visiting the bait stations were catalogued according to date, time and activity. An event was defined as the detection of an animal until the activity of the animal changed. Key morphological features between the two rat species, such as tail length relative to body length, and ear size and morphology (Watts and Aslin 1981), allowed us to identify rats to species level in most photographs from the field trials. Each event was classified as a 'probable' or 'definite' detection of a species, depending on our confidence in identifying each animal to species level.

We used Fisher's Exact Test to test for differences in the proportion of rats of each species that entered the bait station at each height. Analysis of variance (ANOVA) and unpaired *t*-tests were used to test for a difference in body mass between the *R. lutreolus* and *R. rattus* tested in the captive trials, and to determine any relationship between body mass and maximum height climbed. Minitab for Windows 15.1 was used for statistical analysis.

Results

Captive trials

All *R. rattus* and *R. lutreolus* entered the unelevated bait stations and those elevated to 10 cm (Fig. 3). *R. rattus* and *R. lutreolus* varied in their ability to climb to 25 cm (Table 1), but the difference was not significant (Fisher's Exact Test, $P = 0.069$). A greater proportion of *R. rattus* (92%) than *R. lutreolus* (18%) climbed to 50 cm (Fisher's Exact Test, $P < 0.001$). Although more *R. lutreolus* from CHRA than from Muttonbird Island climbed to 25 cm, this was marginally non-significant (Fisher's Exact Test, $P = 0.0557$).

The mean mass (±s.e.) of the rats used in the captive trials was 127.8 ± 18.7 g for *R. rattus* ($n = 12$), 121.0 ± 8.7 g for Muttonbird Island *R. lutreolus* ($n = 10$) and 102.7 ± 7.7 g for CHRA *R. lutreolus* ($n = 12$), which were not significantly different ($P = 0.373$). The mean mass of the *R. rattus* did not differ from that of the *R. lutreolus* from the two populations combined ($P = 0.409$). There was no relationship between body mass of *R. lutreolus* and maximum height climbed (ANOVA, $F = 0.030$, d.f. = 21, $P = 0.864$). The one *R. lutreolus* from Muttonbird Island and three *R. lutreolus* from CHRA that climbed to 50 cm were all males. One *R. lutreolus* was found dead the morning after the third night of the trial at 50 cm, but as it had failed to climb to 50 cm the two previous nights the data were included in the analysis.

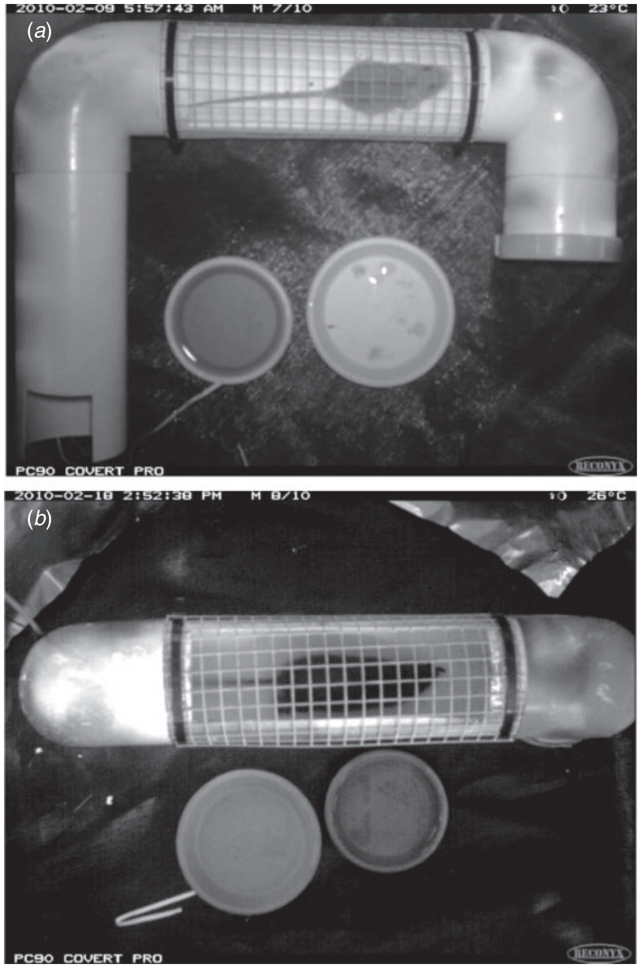

Fig. 3. Camera trap images taken from above used to quantify rodent visitation to bait stations during the captive trial. (*a*) A *R. rattus* in the horizontal bait station; (*b*) a *R. lutreolus* in the 10-cm vertical bait station.

Table 1. The number of *Rattus lutreolus* from both study populations (Muttonbird Island and Coffs Harbour Regional Airport) and *R. rattus* from Muttonbird Island and residential locations that climbed the vertical sections of PVC-pipe to 10 cm, 25 cm and 50 cm heights to enter the vertical bait stations in the captive trial

MBI, Muttonbird Island; CHRA, Coffs Harbour Regional Airport

Species	*n*	Height of vertical section of pipe		
		10 cm	25 cm	50 cm
R. lutreolus (CHRA)	12	12[A]	11[A]	3
R. lutreolus (MBI)	10	10	5	1
R. rattus	12	12	12	11

[A]Includes result from animal that died on the third night of 50-m elevation.

Muttonbird Island field trial

The animals photographed in and around the bait station were identified to species in 223 cases. Of these, 210 (94%) were *R. rattus*, with four *R. lutreolus* (2%), seven Pacific black ducks (*Anas superciliosus*) (3%) and two *A. pacifica* (1%). No *M. musculus* were photographed at the stations.

R. rattus were photographed in the viewing chamber in 32 (15%) events, indicating that they had climbed the 50-cm vertical section of the bait station (Fig. 4). This equates to an average of 5.3 successful entries per bait station per night of deployment. Because rats were not marked we do not know how many individual *R. rattus* actually climbed the vertical bait station. Two *R. rattus* were present in 50 (24%) of the camera trap images with one or both in the bait station, or around the base of the station. *R. rattus* were climbing externally on the bait station or on the star pickets in 28 (13%) events, on the black mat near at the entrance to the bait station in 94 (45%) events and in the area surrounding the black mat in 56 (27%) events. All four *R. lutreolus* events were of individual animals near the entrance to the bait station, with no successful entries detected.

Coffs Harbour Regional Airport field trial

R. lutreolus accounted for a total of 56 definite and three probable detections in the trials at the CHRA. They were most commonly photographed on the mat (36 events) or in the vegetation surrounding the vertical bait station (13 events). *R. lutreolus* were also observed placing their forepaws on the external surface of the upright PVC-pipe (three events) and feeding on bait scattered at the entrance to the bait station (one event). One *R. lutreolus* was photographed in the viewing chamber in five events at the same bait station in the second field trial, which equates to 0.017 successful entries per bait station per night of deployment. The size of the rat was consistent across photographs, but rats were not marked so we cannot confirm whether it was the same animal or not. A single *R. rattus* was photographed climbing externally on the bait station but no other rodents were detected. Other species present at the vertical bait stations included two detections of swamp wallabies (*Wallabia bicolor*), one detection of a pheasant coucal (*Centropus phasianinus*) and 13 detections of Australian ravens (*Corvus coronoides*).

Fig. 4. Camera trap image of one *R. rattus* in the viewing chamber and another climbing externally on the station in the field trial on Muttonbird Island.

Discussion

This experiment evaluated whether the introduced *R. rattus* and the native *R. lutreolus* were physically able to climb and enter a vertical bait station. In the captive trial, most of the *R. rattus* (11 of 12; 92%) climbed the vertical bait station to a height of 50 cm, which supports our hypothesis that *R. rattus* are good climbers. The apparently good climbing ability of black rats was mirrored in the field trial on Muttonbird Island where *R. rattus* were observed in the bait chamber in 32 occasions over 6 camera-trap-nights. Our result is similar to the 28 (93%) of 30 *R. rattus* that reached 45 cm in the study by Erickson *et al*. (1990). Unlike in our trial, Erickson *et al*. (1990) used toxic bait in the bait chamber, and so visitation was inferred from death of the rat. Erickson *et al*. (1990) suggested that *R. rattus* climb a vertical pipe by adopting a 'spread-eagled' stance and exerting pressure onto the insides of the pipe. If this is so, then larger rats may be better equipped for climbing. Our results may support this suggestion as the only *R. rattus* that failed to climb to 50 cm was a small animal. It is, however, unlikely that absolute size is the only determinant of climbing ability because the *R. lutreolus* used in the trial were no lighter, on average, than the *R. rattus*.

In contrast to the results from the *R. rattus* trials, few *R. lutreolus* from Muttonbird Island (1 of 10; 10%) and the CHRA site (3 of 12; 25%) climbed to 50 cm in the captive trial. This does not support our hypothesis that *R. lutreolus* are unable to climb. It is likely that *R. lutreolus* were more motivated to climb in the captive trials than the field trials because they had little other food and were restricted in where they could move. This is similar to the findings of Weerakoon and Banks (2011) who showed that black rats were more willing to eat peanut butter and oats mixture with higher doses of Rhodamine B when they had to work to access other foods. A *R. lutreolus* was photographed in one of the 10 vertical bait stations at CHRA five times. It is possible that all photographs were of the same *R. lutreolus* repeatedly entering the station, though the animals were not marked so we cannot confirm this. So a small percentage of *R. lutreolus* are physically able, and willing, to climb to 50 cm; however, we suggest that this would be a much lower value than would enter conventional ground-based bait stations. Although the proportion that climbed to 50 cm did not differ significantly between mainland and Muttonbird Island swamp rats, mainland rats may be better climbers. Hence, whereas bait stations at 50 cm above the ground should lead to minimal mortality of swamp rats on Muttonbird Island, further trials should be conducted on mainland sites before using 50-cm bait stations there, as more swamp rats may be killed.

Camera traps were effective in identifying mammalian visitors to the bait stations. By placing a wire mesh window near the bait chamber we could photograph and identify most rats that reached the bait chamber and hence infer the likelihood of each species being poisoned if we had used toxic bait. We initially had a problem with the horizontal banding pattern of the Reconyx camera's detection zone, which we addressed by moving the camera closer to the bait station. It is important that the users of camera traps determine precisely the nature of the array of the passive infrared sensor (detection zone) of their cameras. For example, in our study it was crucial that animals in the relatively narrow viewing chamber were detected, or visits by rats may be missed. We used the removal of bait as a second measure for detecting visitors to the bait station in the captive trials and are confident that we did not miss any visits by the rats.

A baiting program using just vertical bait stations may be limited if not all *R. rattus* enter them. Erickson *et al*. (1990) suggested that this problem was not unique to vertical bait stations, as some rats may also fail to visit conventional bait stations. A study of bait station preferences of *R. rattus* in New Zealand found that 75%, 87% and 100% of wild-caught captive *R. rattus* entered a wooden box, yellow plastic pipe and wooden tunnel bait stations respectively (Spurr *et al*. 2007). The similarity in the proportions of *R. rattus* that entered conventional bait stations in Spurr *et al*. (2007) and vertical bait stations in this study suggests that few *R. rattus* would avoid using vertical bait stations. Other factors that may affect the likelihood of rodents entering bait stations include their density and social behaviour, attractiveness of the bait, availability of natural foods, weather conditions and the number of bait stations (Erickson *et al*. 1990). While we are confident that the use of vertical bait stations would reduce the incidence of swamp rats consuming toxic bait, future research should focus on any population-level reduction in *R. rattus* numbers that could be achieved by deploying vertical bait stations during rodent control campaigns.

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