doi: 10.1111/j.1442-8903.2011.00583.x

# Eradication of the House Mouse (*Mus musculus*) from Montague Island, New South Wales, Australia

**By Frances Cory, Andrea Wilson, David Priddel, Nicholas Carlile and Nick Klomp**

***Francis Cory** undertook this research as part of her Bachelor of Science Honours degree at Charles Sturt University (Present address: Industry & Investment NSW (PO Box 18, Narrandera NSW 2700, Australia; Tel: +61 02 6958 8209; Email: frances.cory@industry.nsw.gov.au)). **Andrea Wilson** is a Senior Lecturer in Environmental Science at Charles Sturt University (Locked Bag 588, Wagga Wagga, NSW 2678, Australia; Tel: 02 69332552; Fax: 02 69332737; Email: awilson@csu.edu.au). **David Priddel** is a Principal Research Scientist with the NSW Department of Environment, Climate Change and Water (PO Box 1967, Hurstville, NSW 2220, Australia; Tel: 02 95856504; Fax: 02 95856606; Email: david.priddel@environment.nsw.gov.au). **Nicholas Carlile** is a Senior Project Officer with the NSW Department of Environment, Climate Change and Water (PO Box 1967, Hurstville, NSW 2220, Australia; Tel: 02 95856554; Fax: 02 95856606; Email: nicholas.carlile@environment.nsw.gov.au). **Nick Klomp** is Dean of the Faculty of Science at Charles Sturt University (Locked Bag 588, Wagga Wagga, NSW 2678, Australia; Email: nklomp@csu.edu.au).*

**Summary** **Of all the introduced mammalian pests, rodents are the most common invaders of islands and have triggered numerous extinctions around the globe. They have a short gestation period and large litter size, giving them the ability to colonise new areas rapidly. The same biological traits make them difficult to eradicate. Although the biodiversity benefits of removing exotic rodents from islands are increasingly being recognised, there are few published analyses of eradication attempts that critically evaluate eradication tools. This study examined the response of House Mouse (*Mus musculus*) populations to an eradication operation on Montague Island, Australia. While the specific impacts of mice have not been studied on this particular island, elsewhere they have been shown to have negative impacts on a range of species including plants, invertebrates, lizards and seabirds. On Montague Island, mouse abundance across different habitats was examined using mark–recapture data collected before and after the deployment of brodifacoum baits. Data obtained before baiting showed significantly lower numbers of mice in sites dominated by exotic grass compared with those dominated by native vegetation. Mouse numbers overall were declining during winter and the population was not breeding, making this an optimal time to undertake the eradication. Trapping immediately after the initial bait drop failed to capture any survivors, and no individuals have been detected during the 3 years since the deployment of baits. This study demonstrated that both small and large baits (0.6 and 2 g pellets) were effective in eradicating the House Mouse from Montague Island. While present, mice were probably slowing the re-establishment of native vegetation by grazing seedlings and consuming seeds. With this pest now gone, the process of natural regeneration is expected to accelerate. The eradication of the House Mouse from Montague is likely to have other positive effects on the island's biodiversity. The operation itself contributed to enhancing local capacity to eradicate exotic rodents from larger or more complex islands.**

**Key words:** *brodifacoum, eradication, invasive species, island restoration, pest control.*

## Introduction

There has been a dramatic increase in the transport of biota across the globe since the spread of humans into almost every environment on Earth. Of all the introduced pests, rodents are the most common invaders of islands and have triggered numerous extinctions around the globe (Groombridge 1992). The impacts of rats (*Rattus* spp.) on island ecosystems are well known (Towns *et al.* 2006; Howald *et al.* 2007). In contrast, the impacts of the House Mouse (*Mus musculus*), although sometimes severe, are poorly understood and often overshadowed by the impacts of rats (Angel *et al.* 2009). The House Mouse feeds on seeds, invertebrates and lizards and occasionally on seabird chicks (Jones *et al.* 2003; Wanless *et al.* 2007). On Gough Island, mouse predation on the larvae of two endemic moths, *Dimorphinoctua goughensis* and *Peridroma goughi*, had a significant impact on populations of these species (Jones *et al.* 2003). Following eradication of the House Mouse on Mana Island, New Zealand, numbers of McGregor's Skink (*Oligosoma macgregori*) increased in each successive year (Newman 1994). Dietary studies of the House Mouse on Marion Island suggest that mice can change plant community structure through seed harvesting, alter decomposer biomass by selective predation on invertebrates and subsequently cause the impairment of nutrient mineralisation (Jackson & van Aarde 2003).

The House Mouse has a short gestation period with large litters (Pye 1993; Alpin *et al.* 2003), enabling it to colonise an area rapidly. Individuals are also able to attain sexual maturity at very early ages owing to rapid growth, and females can conceive only days after giving birth (Alpin *et al.* 2003). The same biological traits make the House Mouse a difficult pest to eradicate. However, the biodiversity benefits of removing these and other invasive mammals from island ecosystems are increasingly being recognised (Howald *et al.* 2007), and eradications are now being attempted on progressively larger and more complex islands, including some with human populations (Clout & Russell 2006).

Despite there being extensive research on invasive species, there are few published analyses of eradication attempts that quantify, publicise or critically evaluate eradication tools (Howald *et al.* 2007). For example, Donlan *et al.* (2003) point out that a survey of papers on exotic species published in *Conservation Biology* from

 

1991 to 2002 showed that 86% dealt with impacts or population biology, 8% discussed management strategies but only 6% evaluated control or eradication initiatives.

New Zealand researchers were among the first to develop efficient methods for eradicating rodents from islands (Thomas & Taylor 2002). With the advent of effective second-generation anticoagulant rodenticides, it has proven possible to eradicate rats from even large islands, the largest to date being Campbell Island at 11 300 ha (Hadler & Buckle 1992; Amori & Clout 2003; Howald *et al.* 2007). The largest island from which the House Mouse has been successfully eradicated is Enderby Island (710 ha) in the subantarctic region of New Zealand (Torr 2002).

Brodifacoum is among the most potent of the second-generation anticoagulants that have been developed, and as a result, it is the most commonly used poison for eradicating rodents from islands (e.g. Imber *et al.* 2000; Taylor *et al.* 2000; Torr 2002; Jackson & van Aarde 2003). Although rodenticides have been used successfully for eradications on islands around the world, challenges arise when there are vulnerable native species present. Consequently, the associated ecological risks and non-target effects need to be fully considered (Myers *et al.* 2000; Amori & Clout 2003).

The primary purpose of this study was to assess how the House Mouse population on Montague Island, Australia, responded to an operation aimed at eradicating them. Until recently, almost a third of Montague Island was covered by a dense mat (approximately 1 m thick) of the introduced kikuyu grass (*Pennisetum clandestinum;* Weerheim *et al.* 2003). A long-term programme to eradicate this invasive species has reduced its extent considerably. Areas that have been cleared of kikuyu grass have been replanted with native seedlings. Mice, by grazing seedlings and consuming seeds, had the potential to slow the process of revegetation and hence, the need to remove them.

Worldwide, at least 332 successful rodent eradications have been undertaken (Howald *et al.* 2007), most involving the Black Rat (*Rattus rattus*), Brown Rat (*Rattus norvegicus*) or Pacific Rat (*Rattus exulans*). The House Mouse has been eradicated from at least 30 islands, but the failure rate (19%) exceeds that for similar programmes targeting rats (5–10% depending on the species; Howald *et al.* 2007). This difference in failure rate highlights the need for more research on House Mouse eradications. The causes of the high failure rate of such eradications are unclear but may be related to inadequate bait density. The House Mouse typically has smaller home ranges than rats, and therefore they have a lower probability of encountering a bait that is broadcast at a fixed density (Howald *et al.* 2007). A possible solution is to use smaller baits that, when broadcast at the same dose rate (kg per ha), provide a greater number of baits per unit area. Consequently, the secondary aim of this study was to test the relative efficacy of brodifacoum baits of two different sizes (0.6 and 2.0 g pellets) in eradicating mice.

## Study Site

Montague Island (36°15′S; 150°14′E) is located 9 km off the coast of New South Wales, Australia, approximately 350 km south of Sydney, near the township of Narooma (Fig. 1). It is 82 ha in size (1.5 km long and 0.8 km wide) and is partially divided into two sections, hereafter referred to as the North and South islands. Montague Island provides important breeding habitat for seabirds including the Wedge-tailed Shearwater (*Ardenna pacifica*), Short-tailed Shearwater (*Ardenna tenuirostris*), Sooty Shearwater (*Ardenna grisea*), Little Penguin (*Eudyptula minor*), Crested Tern (*Thalasseus bergii*) and Silver Gull (*Chroicocephalus novaehollandiae*). (All bird names in this paper conform to Christidis & Boles 2008.) Montague Island is also a haul-out point for Australian and New Zealand Fur Seals (*Arctocephalus pusillus* and *Arctocephalus forsteri*, respectively). The only other native mammals present are insectivorous microbats (Microchiroptera), which are highly unlikely to consume cereal baits and thus are not at risk from rodenticide. European Rabbit (*Oryctolagus cuniculus*) was present, but in low numbers following an outbreak of rabbit haemorrhagic disease.

There are a small number of buildings on the island, including a lighthouse and three separate residences originally built to accommodate the light keepers and their families. There are also a small number of associated outbuildings. Nowadays, the light is automated and light keepers no longer live on the Island. One of the residences is permanently occupied by maintenance workers and also accommodates visiting scientists; another caters for visiting groups of tourists or conservation volunteers; and the third is a museum.

Average annual rainfall is 889 mm, which is relatively dry compared with other coastal regions of Australia (Heyligers & Adams 2004). The hottest month is February with average minimum and maximum temperatures of 17.8 and 23.3°C, respectively. July, the coldest month, has average minimum and maximum temperatures of 9.9 and 15.5°C (Bureau of Meteorology 2007).

## Methods

We identified three major vegetation communities or habitats on Montague Island – Lomandra, Kikuyu and Revegetated. Much of the island was covered by native vegetation dominated by Spiny-headed Mat-rush (*Lomandra longifolia*), hereafter referred to as Lomandra. Other species present in this habitat included Common Bracken (*Pteridium esculentum*), Milk Vine (*Marsdenia rostrata*), Dusky Coral Pea (*Kennedia rubicunda*) and Common Reed (*Phragmites australis*). Introduced kikuyu grass was brought to the island in the early 1900s to stabilise soil that had been disturbed by construction of the lighthouse (DECC 2004). It spread rapidly, smothering and eventually killing native vegetation, in many places forming a virtual monoculture. In 2001, kikuyu grass covered approximately 30% of Montague Island (Weerheim *et al.* 2003). Since 2004, the National Parks and Wildlife Service has been engaged in a programme to remove kikuyu from the island. Areas of the grass are sprayed with herbicide and then burnt; reshooting grass is then sprayed again. Once an area is cleared of kikuyu, native seedlings are planted. At the time of the

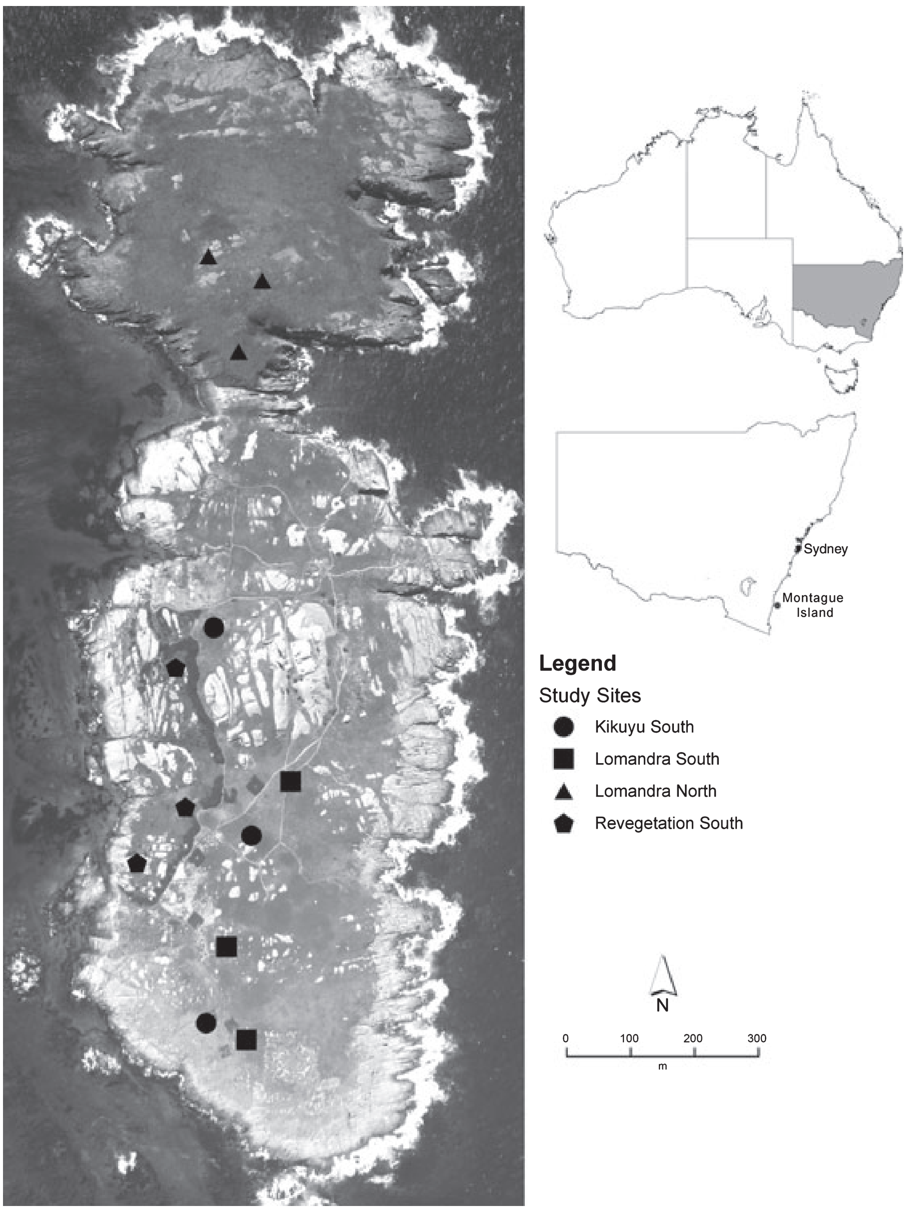


**Figure 1.** Location map of Montague Island off the south coast of New South Wales, Australia.

eradication operation, large parts of the South Island were covered by such plantings. This Revegetated community was the most diverse habitat, containing trees, shrubs and vines, including Coast Banksia (*Banksia integrifolia*), Coastal Wattle (*Acacia longifolia*) and Coastal Rosemary (*Westringia fruticosa*). (All plant names in this paper conform to PlantNET online.)

## Baiting procedure

Extruded cereal baits (Pestoff 20R; Animal Control Products, Wanganui, New Zealand) containing 20 parts per million (ppm) or 0.02 g per kg of brodifacoum were distributed on two separate occasions: 9 July and 16 July 2007. Bait was dispersed using a spreader bucket slung below a helicopter, which was guided by a satellite-based navigational system (i.e. global positioning system (GPS)). Aerial delivery of bait, guided by an appropriate GPS system, ensured that bait was delivered rapidly to all parts of Montague Island. When dropped from the air, some bait got caught in the vegetation, but most fell to the ground, and mice were observed climbing into tussocks and other low vegetation to feed on the bait. The area within a 30-m radius of all buildings was treated by broadcasting bait by hand. Baits were also placed within each building. Thus, the entire population of House Mouse on Montague Island was presented with bait.

The amount of bait used in an eradication operation is critical. If too little bait is used, then all individuals of the target species may not encounter the rodenticide or consume a lethal quantity, thus causing the eradication to fail. Too much bait increases costs and unnecessarily puts additional poison into the environment. For a baiting operation to be effective, bait should be available long enough for all targeted individuals to consume a lethal dose. For this operation, the amount was set higher than has been used elsewhere to successfully eradicate rodents (Broome 2009) because rabbits were also present on Montague Island, albeit in very low numbers. Rabbits, being relatively large, are capable of consuming large quantities of bait, thereby denying mice access to it. The operation also aimed to eradicate rabbits.

For both drops, 5-mm bait (approximately 0.6 g pellets) was used on the North Island and 10-mm bait (approximately 2 g pellets) on the South Island. When broadcast at the same dose rate (kilogram per hectare), the smaller bait had three to four times the number of pellets per unit area than did the larger bait. There was sufficient brodifacoum in one small pellet to kill a mouse.

## Trapping

Trapping was undertaken from the end of March through to September 2007 and was stratified by habitat because previous studies suggest that mouse density may vary between different habitats as well as temporally (Kaufman & Kaufman 1990). On the South Island, traps were set in the three major habitats – Lomandra, Kikuyu and Revegetated. On the North Island, Kikuyu and Revegetated habitats were poorly represented or absent, so trapping occurred only in the Lomandra habitat. Therefore, the four habitat categories sampled during this study were termed Lomandra South, Kikuyu South, Revegetated South and Lomandra North (Fig. 1). The extensive areas of exposed rock along the outer perimeter of the island were not sampled.

Three replicate trapping grids were established within each of the four habitat categories (i.e. a total of 12 grids). Grids were placed more than 100 m apart in an effort to obtain independent sampling on each grid. This distance was selected based on a study conducted by Moro and Morris (2000), which demonstrated that mice occupied home ranges of between 0.2 and 0.3 ha. Further to this, a study conducted by DeLong (1967) demonstrated that the average movement of mice was <11 m per day and <25 m over a lifetime.

Mice were captured using collapsible Elliott traps (approximately $33 \times 10 \times 10$ cm; Elliott Scientific Equipment, Upwey, Vic., Australia) with a spring-loaded door. Traps were placed approximately 10 m apart in grids of 25 (5 rows of 5 traps). All grids were located in areas where they were least likely to impact on the nesting habitat of shearwaters. Each trap was covered with a plastic bag to repel moisture and contained Hollofil® insulation for bedding as well as a food pellet made from peanut butter, rolled oats and honey. Captured mice were sexed and classified as either adult or juvenile based on body size (adults: body length >7.5 cm). Adult females were examined to see whether they were lactating. Each individual was tagged using miniature numbered ear tags and pliers (Hauptner brand distributed by Sieper and Co., Silverwater, NSW, Australia). The tags were inserted through the base of the ear just under the fold of cartilage to reduce tag loss as per Alpin *et al.* (2003). After processing, the mice were released close to the capture site. Recaptured mice were released after the ear tag number was recorded.

Each of the 12 grids was sampled for mice on six separate occasions between late March and September 2007 (Table 1). During each of these sampling occasions, trapping in each grid was conducted for three consecutive nights. Each trap was checked twice daily (morning and evening), and the data for each of the 3 days were combined. Where possible, all grids were activated simultaneously, but when this was impractical, the sampling of grids was staggered.

**Table 1.** Dates of House Mouse sampling undertaken before and after the deployment of brodifacoum baits on Montague Island. Toxic bats were laid on 9 and 16 July

| Sample occasion | Sample date |
|---|---|
| Before baiting 1 | 30 March–3 April 2007 |
| Before baiting 2 | 9–14 May 2007 |
| Before baiting 3 | 3–9 July 2007 |
| After baiting 1 | 14–18 July 2007 |
| After baiting 2 | 19–22 July 2007 |
| After baiting 3 | 17–21 September 2007 |

To investigate any change in mouse abundance owing to the application of baits, sampling of all 12 habitat grids was undertaken for three sessions before and three sessions after baiting, as indicated in Table 1. In addition, trapping (12 traps) was undertaken in and around the buildings once (for three nights) before the deployment of baits and once after. This was to address the concern that mice would persist in the buildings owing to the availability of alternative food resources.

### Long-term monitoring

One month after the second baiting, 75 tracking tunnels (Connovation, Auckland) were strategically distributed alongside tracks on the island. Tunnels were monitored for mouse activity (footprints) and visited approximately every 3 months for 24 months. At each visit, new ink boards and attractant (linseed oil) were fitted to each tunnel, because their effective life was limited to about 2 weeks. In addition, up to 100 Elliott traps (baited with peanut butter and oats), along with seven motion-activated cameras (Reconyx, Holmen, WI, USA), were deployed near any alleged sightings of mice. As a biosecurity measure, seven permanent bait stations loaded with wax blocks of rodenticide (Pestoff Rodent Blocks; Animal Control Products, Wanganui, New Zealand) containing brodifacoum (50 ppm) were set up on the island. These stations were monitored for activity, and the baits renewed, every 3 months.

### Data analysis

Trapping success was calculated using the adjusted trap success approach of Caughley (1977) also described by Alpin *et al.* (2003). It should be noted that results from this study only consider the trappable population. Any mice that were not old enough to be foraging above ground were unlikely to enter traps and so are not included in the analysis. Any individuals that died within traps were not included in the analyses (<2%). The minimum number of individuals known to be alive (MNA) was determined by totalling the number of individuals captured (disregarding any recaptures) in that sampling period. MNA was used as this has been found to be strongly correlated with the estimated population size of mice and a more accurate representation of mouse populations than other indices (e.g. tracking tunnel indices, one-night trap catch; Ruscoe *et al.* 2001). Independence of captures was assumed because the proportion of captures was low relative to the total number of traps (after Chambers *et al.* 1996).

Minimum number of individuals known to be alive was compared across different habitats and across different sampling occasions using general linear model (GLM) analysis in the software package SPSS version 14.0. All data were examined for normality using P-P plots and heteroscedasticity using the Levene's test in SPSS. Least significant difference *post hoc* tests were conducted to explore any significant differences between habitats or sampling occasions. The response of mice populations to baiting was investigated using the non-parametric Wilcoxon test in SPSS comparing the MNA of each grid in the sampling period immediately before and immediately after the baits were applied.

The total size of the mouse population on Montague Island before the eradication programme was estimated using the Jolly triple-catch method described by Blower *et al.* (1981). The total population estimate was calculated using capture data from the sampling occasion with the highest mouse abundance and recapture rates ('Before-1' sample). If recapture data from this sample were insufficient to estimate the population, data from the sample with the next highest abundance were used. The population estimation from each sampling grid was averaged to give a mean estimate per grid for each habitat type. It was assumed that the grid area extended 5 m beyond the peripheral traps, half the distance between adjacent traps as per Ruscoe *et al.* (2001). This gave a total grid area of 2500 $m^2$ and is referred to as the total effective trapping area. Digitised vegetation classification layers were imported into a Geographic Information System (ArcView ver. 3.2) to provide an estimate of the area of each habitat category on Montague Island. Once these areas were calculated, they were then multiplied by the estimated number of mice per square metre to give a population estimate for each habitat category and a total population estimate for the entire island.

## Results

### Summary of captures

The three trapping occasions prior to baiting resulted in a total of 541 captures, at an overall trapping success rate of 9.58%. The total number of individual mice captured was 331. No mice were captured in any trapping occasion after the initial baiting.

Overall the gender ratio of mice captured was not significantly different, with 56% male and 44% female ($t$-test; $P > 0.05$). Examination of the data for each sampling occasion showed that the Before-1 sample had a bias towards males (63%) over females (37%), but this pattern was not statistically significant ($t$-test, $P = 0.07$). No lactating females were observed and very few juveniles (<1% of captures) were caught during this study, indicating that the population was not breeding at this particular time.

### Comparison of mouse populations across habitats and sampling occasions

The analysis of mouse populations across different habitats and sampling occasions was undertaken only on data collected from the first three sampling occasions (Before-1, Before-2, Before-3) owing to the lack of captures after baiting. Results from the GLM analysis showed that there was a significant difference between the MNA across different habitats and also in the number of MNA captured over time (Table 2). *Post hoc* tests revealed that there were significantly lower numbers of individuals captured in the Kikuyu South habitat compared with other habitat categories (Fig. 2), but that Lomandra North, Lomandra South and Revegetated South habitats were not statistically different from each other. The number of mice captured declined temporally, with a statistically significant difference in mouse abundance between Before-1 and Before-3 sampling occasions. There was also a significant difference between the abundance of mice captured during the Before-2 and Before-3 sampling occasions, but no significance between the Before-1 and Before-2 samples. No statistically significant interaction between habitats and sampling occasions was evident (Table 2); however, Figure 2 shows that the pattern of decline in mouse abundance as winter approached was not consistent across all habitat categories. In particular, the MNA for Lomandra North increased between Before-1 and Before-2 sampling occasions, while all other habitats displayed a decrease in MNA.

During the Before-2 sampling occasion, 5.7% of mice trapped were recaptures (i.e. possessed ear tags) from the previous sample (Before-1). During the Before-3 sampling occasion, 9% of mice captured were from at least one of the previous sampling occasions (Before-1 or Before-2). One individual was recaptured after moving from the Kikuyu South habitat into the nearby buildings, a distance of approximately 100 m.

### Mark–Release–Recapture estimates of mouse population size

Population estimates for each habitat category show that the highest density of mice was found in the Revegetated and Lomandra South habitats (Table 3). The Kikuyu habitat, which covers a large proportion of Montague Island, contained the lowest density of mice of all the habitat categories.

### Comparison before and after baiting

A comparison of paired MNA data using the Wilcoxon test showed that there was a significant difference between the number of individuals captured before and after the brodifacoum baits were deployed (Fig. 3). The buildings were sampled on two occasions, the first (before baiting) resulted in the capture of 12 individuals and the second (after baiting) captured none.

### Long-term monitoring

Monitoring of the tracking tunnels and traps during the 24 months after baiting involved more than 5000 tracking-tunnel-days and 425 trap-nights. No mice were detected, and none have been seen in any of the buildings. During the same period, there was no evidence that rabbits were present on the island.

## Discussion

### Mouse abundance

Populations of House Mouse can fluctuate by orders of magnitude (Singleton *et al.* 2001). Judging from the level of infestation within the buildings, the population of mice on Montague Island varied substantially from season to season and from year to year (DP pers. obs.). In April 2007, the population was estimated to number over

**Table 2.** General linear model comparison of the minimum number of individuals known to be alive across habitats and sampling occasions

| Source | df | Mean square | $F$ | Sig. |
|---|---|---|---|---|
| Habitat | 3 | 135.880 | 5.810 | 0.004 |
| Sampling occasion | 2 | 116.028 | 4.961 | 0.016 |
| Habitat x sample occasion | 6 | 33.769 | 1.444 | 0.239 |
| Error | 24 | 23.389 | | |

 

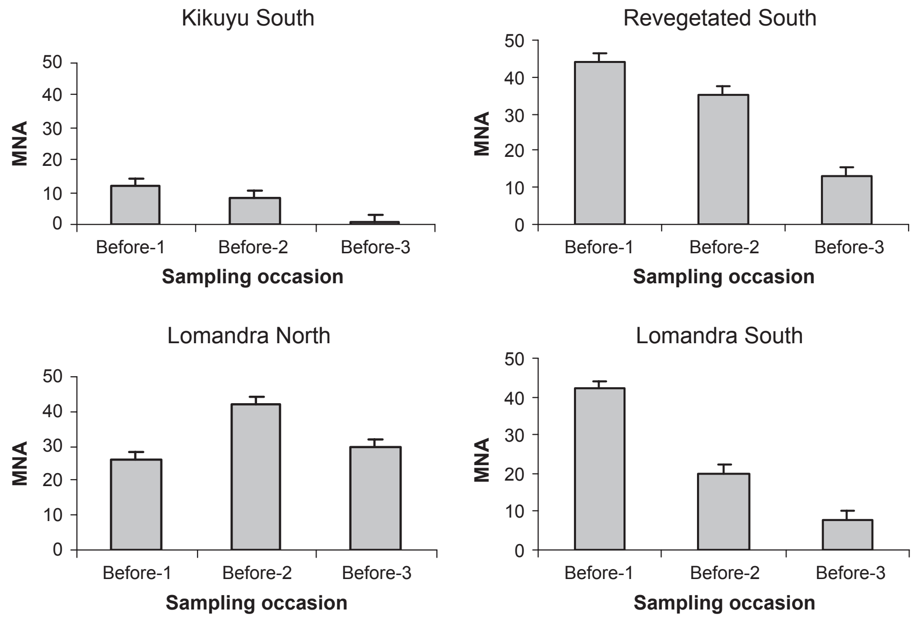


**Figure 2.** Minimum number of individuals known to be alive (MNA, ±SE) in each habitat across Before-1, Before-2 and Before-3 sampling occasions.

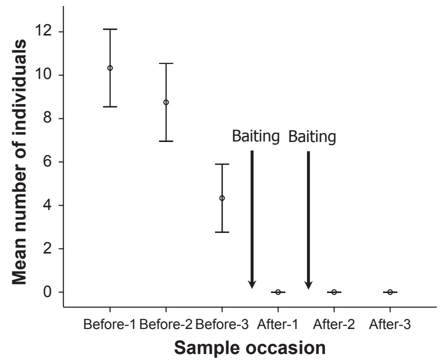


**Figure 3.** Mean (±SE) minimum number of individuals known to be alive (MNA) across all sampling occasions.

**Table 3.** Estimation of pre-baiting mouse populations in each habitat sampled

| | Mice per TETA* | Density ($ha^{-1}$) | Habitat size (ha) | Estimated number of mice |
|---|---|---|---|---|
| Lomandra North | 16.8 | 67 | 14.45 | 971 |
| Lomandra South | 30.2 | 120 | 15.68 | 1895 |
| Revegetated South | 31.5 | 130 | 3.98 | 502 |
| Kikuyu South | 12.0† | 48 | 15.87 | 761 |
| Buildings | 29.3‡ | 83 | 0.35 | 29 |
| Total | | | 50.33 | 4158 |

Population estimates calculated from 'Before-1' sample data (i.e. highest mouse abundance and recapture rates). *TETA, total effective trapping area (2500 $m^2$); †insufficient recapture data from Before-1 sample were available to estimate the population; therefore, data from Before-2 sample were used; ‡non-standard trapping grid used for buildings.

4000 individuals but declined as winter approached. Abundance varied across habitats with higher numbers present in Lomandra and Revegetated habitats. Highest average density (approximately 0.013 mice/$m^2$) was recorded from the Revegetated habitat, but this is lower than maximum mouse densities recorded on some other islands, such as Gough Island (0.022 mice/$m^2$; Rowe-Rowe & Crafford 1992).

Kikuyu South habitat had significantly lower numbers of mice than the other habitats, and this difference could be influenced by the availability of food. Kikuyu grass spreads predominantly through vigorous vegetative reproduction and sets seeds only infrequently (Baker 1974; Richardson *et al.* 2006). Few other plant species were present in this habitat, so fruits and seeds would be relatively scarce.

## The eradication of mice from Montague Island

The programme to eradicate mice from Montague Island utilised a high application rate of bait. The total application rate of 18 kg per hectare was far in excess of what was actually needed to kill the mouse population. The $LD_{50}$ of brodifacoum for mice is 0.35 mg/kg (Hone & Mulligan 1982), so each individual mouse needed to consume only 80% of a single 5-mm bait or 20% of a 10-mm bait to get a potentially lethal dose of poison. Although it is common practice to over-bait in an eradication operation (Cromarty *et al.* 2002), considerable quantities of bait remained after the last mouse were detected, so it may have been possible to use a lesser amount of bait without jeopardising the outcome.

Trapping conducted after the baits had been deployed failed to catch a single mouse. Monitoring of the tracking tunnels during the following 3 years also failed to detect any mice, and none have been seen in any of the buildings. Montague Island was declared free of mice (and rabbits) in July 2009.

Eradication was successful on both the North Island, where 5-mm bait was used, and on the South Island, where 10-mm bait was used. This demonstrates that mice can be eradicated using either size bait provided adequate coverage is achieved. The study also found that, despite the availability of potential food resources within the buildings on Montague Island, mice did not persist in these buildings after baiting for any longer than they did outside. This finding suggests that, providing food is stored appropriately and bait can be distributed inside buildings as well as across the entire island, it should be feasible to eradicate mice from inhabited islands. To date, most rodent eradications have been conducted on uninhabited islands (Howald *et al.* 2007). The few inhabited islands from which rodents have been eradicated have all had relatively few people on them. Examples include: the inner islands of the Seychelles (Merton *et al.* 2002); Anacapa Island in California (Howald *et al.* 2010); Rangitoto Island (R. Griffiths pers. comm.) and Urupukapuka Island (A. Walker pers.

comm.) in New Zealand; and Laucala Island (D. Merton pers. comm.) and Ringgold Islands (S. Cranwell pers. comm.) in Fiji.

The eradication programme on Montague Island was timed to target the mouse population when it was at its lowest and not breeding and when natural food sources were at their minimum. Populations are at their most vulnerable during these times, and authors such as Torr (2002) identify this as the most effective time to undertake eradication. Although the estimates of mice abundance obtained during this study do not encompass the full year, the data confirm that, as anticipated, baiting was conducted following a period of population decline. This study also confirmed that eradication was undertaken at a time when the population was not breeding. The absence of breeding alleviates the problem of having dependent young in burrows that do not consume bait, but survive the loss of their mother to emerge sometime later. The second bait drop is undertaken as a precaution and is intended to target any such newly emergent young.

The success of the mouse eradication programme using brodifacoum on Montague Island is consistent with results from some similar programmes conducted in other parts of the world. For example, in New Zealand brodifacoum has been used successfully to eradicate rats and mice from Browns Island and Motuihe Island (Veitch 2002a,b), and mice from Enderby and Rose islands (Torr 2002). However, while there are numerous cases in which brodifacoum has been successful in the eradication of rats from islands (Garcia *et al.* 2002; Morris 2002; Howald *et al.* 2007), there are fewer examples of mice being eradicated, and many of the attempts to do so have failed (Howald *et al.* 2007). Unfortunately, few of these failed eradication attempts have been critically evaluated, and none has quantitatively monitored the pest population before and after the eradication attempt.

While present on Montague Island, mice were thought to be slowing the re-establishment of native vegetation by grazing seedlings and consuming seeds. With this pest now gone, the process of natural regeneration is expected to accelerate. Quarantine measures are already in place to prevent rodents reinvading, including the requirement that all boats visiting the island are permanently fitted with bait stations containing rodenticide.

Although the specific impacts of the House Mouse on Montague Island are largely unknown, in other island ecosystems mice have had negative impacts on both plant and animal species and on ecosystem functioning and structure (e.g. Miller & Miller 1995; Le Roux *et al.* 2002; Smith *et al.* 2002; White 2002; Jackson & van Aarde 2003; Jones *et al.* 2003). There is evidence of mice preying on lizards (Newman 1994; Miller & Miller 1995) and seabird chicks (Jones *et al.* 2003), both of which are present on Montague Island. Based on experiences elsewhere, the eradication of mice from Montague Island is likely to have broad biodiversity benefits. The operation on Montague also helped to develop local capacity to eradicate exotic rodents from larger or more complex islands, such as those with threatened endemic species, human populations, livestock or well-developed tourist industries.

## Implications for Managers

Exotic rodents can have devastating impacts on islands; they can negatively affect both plant and animal species and can impair ecosystem functioning. Fortunately, it is now possible to eradicate both rats and mice from islands. The House Mouse can be eradicated using either 0.6 or 2.0 g pellets of brodifacoum bait, provided there is adequate coverage of the entire island. In Australia, winter is the optimal time to conduct such eradications.

## Acknowledgements

Funding for this project was provided by the NSW Department of Environment and Climate Change. All trapping of mice was conducted under CSU Animal Care and Ethics Committee approval number 07/048. Ian Wilkinson provided comments on an earlier draft of the manuscript. We thank the DECC staff and CSU volunteers who participated in this conservation program.

## References

Alpin K., Brown P., Jacob J., Krebs C. and Singleton G. (2003) *Field Methods for Rodent Studies in Asia and the Indo-Pacific*. BPA Print Group, Melbourne.

Amori C. and Clout M. (2003) *Rodents on Islands: A Conservation Challenge*. Australian Centre for International Agricultural Research, Canberra.

Angel A., Wanless R. and Cooper J. (2009) Review of impacts of the introduced house mouse on islands in the Southern Ocean: are mice equivalent to rats? *Biological Invasions* **11**, 1743–1754.

Baker H. (1974) The evolution of weeds. *Annual Review of Ecology and Systematics* **5**, 1–24.

Blower G. J., Cook L. M. and Bishop J. A. (1981) *Estimating the Size of Animal Populations*. Allen & Unwin, London.

Broome K. (2009) Beyond Kapiti – a decade of invasive rodent eradications from New Zealand islands. *Biodiversity* **10**, 14–24.

Bureau of Meteorology. (2007) Bureau of meteorology weather data (online). Available from URL: http://www.bom.gov.au.

Caughley G. C. (1977) *Analysis of Vertebrate Populations*. Wiley and Sons, New York.

Chambers L. K., Singleton G. R. and van Wensveen M. (1996) Spatial heterogeneity in wild populations of house mice (*Mus domesticus*) on the Darling Downs, South eastern Queensland. *Wildlife Research* **23**, 23–37.

Christidis L. and Boles W. E. (2008) *Systematics and Taxonomy of Australian Birds*. CSIRO Publishing, Collingwood.

Clout M. N. and Russell J. C. (2006) The eradication of mammals from New Zealand Islands. In: *Assessment and Control of Biological Invasion risks* (eds F. Koike, M. N. Clout, M. Kawamichi, M. De Poorter and K. Iwatsuki), pp. 127–141, IUCN, Gland, Switzerland.

Cromarty P., Broome K., Cox A., Empson R., Hutchinson W. and McFadden I. (2002) Eradication planning for invasive alien animal species on islands – the approach developed by the New Zealand Department of Conservation. In: *Turning the Tide: The Eradication of Invasive Species* (ed. C. R. Veitch), pp. 85–91, IUCN, Gland, Switzerland.

DECC (2004) Montague Island nature reserve – Seabird Habitat restoration project. Available from URL: http://www.environment.nsw.gov.au/parkmanagement/MontagueIslandShrp.htm

DeLong K. T. (1967) Population ecology of feral house mice. *Ecology* **48**, 611–634.

Donlan C. J., Tershy B. R., Campbell K. and Cruz F. (2003) Research for requiems: the need for more collaborative action in eradication of invasive species. *Conservation Biology* **17**, 1850–1851.

Garcia M., Diez C. and Alverez A. (2002) The eradication of *Rattus rattus* from Monito Island, West Indies. In: *Turning the Tide: The Eradication of Invasive Species* (ed. C. R. Veitch), pp. 116–119, IUCN, Gland, Switzerland.

Groombridge B. (1992) *Global Biodiversity: Status of the Earth's Living Resources: A Report*. World Conservation Monitoring Centre, British Museum (Natural History) and World Conservation Union. Chapman & Hall, London.

Hadler M. and Buckle A. (1992) Forty five years of anticoagulant rodenticide – past, present and future trends. In: *Proceedings of 15th Vertebrate Pest Conference* (eds J. E. Borrecco and R. E. Marsh), pp. 149–155, University of California, Davis.

Heyligers P. and Adams L. (2004) Flora and vegetation of Montague Island – past and present. *Cunninghamia* **8**, 285–305.

Hone J. and Mulligan H. (1982) *Vertebrate Pesticides*. Department of Agriculture, New South Wales, Science Bulletin 89.

Howald G., Donlan C. J., Galvan J. P. *et al*. (2007) Invasive rodent eradication on islands. *Conservation Biology* **21**, 1258–1268.

Howald G., Donlan C. J., Faulkner K. R. *et al*. (2010) Eradication of black rats *Rattus rattus* from Anacapa Island. *Oryx* **44**, 30–40.

Imber M., Harrison M. and Harrison J. (2000) Interactions between petrels, rats and rabbits on Whale Island, and effects of rat and rabbit eradication. *New Zealand Journal of Ecology* **24**, 153–160.

Jackson T. and van Aarde R. (2003) Advances in vertebrate pest control: implications for the control of feral house mice on Marion Island. *South African Journal of Science* **99**, 130–136.

Jones A., Chown S. and Gaston K. (2003) Introduced house mice as a conservation concern on Gough Island. *Biodiversity and Conservation* **12**, 2107–2119.

Kaufman D. W. and Kaufman G. A. (1990) House mice (*Mus musculus*) in natural and disturbed habitats in Kansas. *Journal of Mammalogy* **71**, 428–432.

Le Roux V., Chapuis J., Frenot Y. and Vernon P. (2002) Diet of the house mouse (*Mus musculus*) on Guillou Island, Kerguelen archipelago, Subantarctic. *Polar Biology* **25**, 49–57.

Merton D., Climo G., Laboudallon V., Robert S. and Mander C. (2002) Alien mammal eradication and quarantine on inhabited islands in the Seychelles. In: *Turning the Tide: The Eradication of Invasive Species* (ed. C. R. Veitch), pp. 182–198, IUCN, Gland, Switzerland.

Miller C. and Miller T. (1995) Population dynamics and diet of rodents on Rangitoto Island, New Zealand, including the effects of a 1080 poison operation. *New Zealand Journal of Ecology* **19**, 19–27.

Moro D. and Morris K. (2000) Population structure and dynamics of sympatric house mice, *Mus domesticus*, and Lakeland Downs short-tailed mice, *Leggadina lakedownensis*, on Thevenard Island, Western Australia. *Wildlife Research* **27**, 257–268.

Morris K. (2002) The eradication of the black rat (*Rattus rattus*) on Barrow and adjacent islands off the northwest coast of Western Australia. In: *Turning the Tide: The Eradication of Invasive Species* (ed. C. R. Veitch), pp. 219–225, IUCN, Gland, Switzerland.

Myers J., Simberloff D., Kuris A. and Carey J. (2000) Eradication revisited: dealing with exotic species. *Tree* **15**, 316–320.

Newman D. (1994) Effects of a mouse, *Mus musculus*, eradication programme and habitat change on lizard populations of Mana Island, New Zealand, with special reference to McGregor's skink, *Cyclodina macgregori*. *New Zealand Journal of Zoology* **21**, 443–456.

Pye T. (1993) Reproductive biology of the feral house mouse (*Mus musculus*) on subantarctic Macquarie Island. *Wildlife Research* **20**, 745–757.

Richardson F., Richardson R. and Sheperd R. (2006) *Weeds of the South East: An Identification Guide for Australia*. Everbest, China.

Rowe-Rowe D. T. and Crafford J. E. (1992) Density, body size, and reproduction of feral house mice on Gough Island. *South African Journal of Zoology* **27**, 1–5.

Ruscoe W., Goldsmith R. and Choquenot D. (2001) A comparison of population estimates and abundance indices for house mice inhabiting beech forests in New Zealand. *Wildlife Research* **28**, 173–178.

Singleton G., Krebs C. J., Davis S., Chambers L. and Brown P. (2001) Reproductive changes in fluctuating house mouse populations in south-eastern Australia. *Proceedings. Biological sciences/The Royal Society* **268**, 1741–1748.

Smith V., Avenant N. and Chown S. (2002) The diet and impact of house mice on a sub-antarctic island. *Polar Biology* **25**, 703–715.

Taylor R., Kaiser G. and Dever M. (2000) Eradication of Norway rats for recovery of seabird habitat on Langara Island, British Columbia. *Restoration Ecology* **8**, 151–160.

Thomas B. and Taylor R. (2002) A history of ground-based rodent eradication techniques developed in New Zealand, 1959–1993. In: *Turning the Tide: The Eradication of Invasive Species* (ed. C. R. Veitch), pp. 301–310, IUCN, Gland, Switzerland.

Torr N. (2002) Eradication of rabbits and mice from subantarctic Enderby and Rose Islands. In: *Turning the Tide: The Eradication of Invasive Species* (ed. C. R. Veitch), pp. 319–328, IUCN, Gland, Switzerland.

Towns D. R., Atkinson I. A. E. and Daugherty C. H. (2006) Have the harmful effects of introduced rats on islands been exaggerated? *Biological Invasions* **8**, 863–891.

Veitch C. (2002a) Eradication of Norway rats (*Rattus norvegicus*) and house mouse (*Mus musculus*) from Browns Island (Motukorea) Hauraki Gulf, New Zealand. In: *Turning the Tide: The Eradication of Invasive Species* (ed. C. R. Veitch), pp. 350–352, IUCN, Gland, Switzerland.

Veitch C. (2002b) Eradication of Norway rats (*Rattus norvegicus*) and house mouse (*Mus musculus*) from Motuihe Island, New Zealand. In: *Turning the Tide: The Eradication of Invasive Species* (ed. C. R. Veitch), pp. 353–356, IUCN, Gland, Switzerland.

Wanless R. M., Angel A., Cuthbert R. J., Hilton G. M. and Ryan P. G. (2007) Can predation by invasive mice drive seabird extinctions? *Biology Letters* **3**, 241–244.

Weerheim M., Klomp N., Brunsting A. and Kondeur J. (2003) Population size, breeding habitat and nest-site distribution of Little Penguins (*Eudyptula minor*) on Montague Island, New South Wales. *Wildlife Research* **30**, 151–157.

White T. C. R. (2002) Outbreaks of house mice in Australia: limitation by a key resource. *Australian Journal of Agricultural Research* **53**, 505–509.