OCCASIONAL REPORT SERIES: 1

Eradication of House Mice *Mus musculus* from Marion Island:

a review of feasibility, constraints and risks

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Recommended citation: Parkes J 2016. Eradication of House Mice *Mus musculus* from Marion Island: a review of feasibility, constraints and risks. In: Wanless RM (Ed) *BirdLife South Africa Occasional Report Series No. 1*. BirdLife South Africa, Johannesburg, South Africa. 27 pp

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Design: Bryony van Wyk

This publication was peer reviewed by two independent scientists. BirdLife South Africa thanks Keith Springer (*keith.springer@gmail.com*) and James Russell (*j.russell@auckland.ac.nz*) for conducting independent peer review of the draft of this manuscript

Cover Photo: Courting Light-mantled Albatrosses on a cliff ledge at Marion Island by Ross Wanless and Andrea Angel
Frontispiece: A house mouse atop an Atlantic Petrel *Pterodroma incerta* chick at Gough Island, where widespread attacks by house mice on seabird chicks was first confirmed byAndrea Angel and Ross Wanless

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John Parkes

Kurahaupo Consulting, New Zealand

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Summary

BACKGROUND

House Mice *Mus musculus* have been present on South Africa's sub-Antarctic Marion Island (29 000 ha) for over 200 years. They are part of an interacting syndrome of threats – warming and drying climate, invasive weeds, exotic invertebrates and the echo of past impacts from feral cats – that are having adverse impacts on the native biota and ecosystems. The eradication of mice was recommended, if possible (Angel & Cooper 2011).

BirdLife South Africa, in partnership with the South African National Antarctic Programme (SANAP) and supported by John Cooper, commissioned Kurahaupo Consulting to assess whether eradication of the mice is feasible, and to review the constraints and risks to be resolved or mitigated before making such an attempt. The author visited Marion Island between 14 April and 8 May 2015.

OBJECTIVES

To assess the feasibility that mice might be eradicated from Marion Island by describing:

- The techniques used against mice on other islands from which eradication has been attempted.
- Whether the obligate rules for success can be met for Marion Island using standard methods from successful precedents.
- The constraints, risks and costs specific to Marion Island that would need to be resolved or managed before a decision to proceed to operational planning could be taken.

MAIN FINDINGS

- Eradication of mice from Marion Island is definitely possible with a high chance of success.
- House Mice have been eradicated from 62 islands around the world with eight attempts awaiting a confirmed outcome. This is about twice the number reported in 2007 when the Gough Island feasibility plan was conducted. These include several islands south of 45ºS such as Macquarie Island (12 875 ha), Coal Island (1189 ha), Enderby Island (710 ha) and Ile Chateau (220 ha) which have been completed and success confirmed, and parts of South Georgia Island (at least 4932 ha with mice) for which success has yet to be confirmed. French attempts to eradicate mice on several islands in the Golphe du Morbihan (with Australia Island at 2100 ha being the largest) in the Kerguelen Archipelago appear to have failed, at least with respect to their mice.
- Attempts to eradicate mice from sub-Antarctic islands where mice are the only invasive mammal present are planned for Antipodes Island (2097 ha) in 2016, Gough Island (6500 ha) in 2019, and Steeple Jason Island (710 ha) at some unspecified time – with success being confirmed two or three years later. These will, if successful, give further confidence to South African decision-makers that an attempt on Marion Island is likely to succeed.
- Evidence from Marion Island is that invertebrate biomass has collapsed by about 90% since the 1970s while mouse densities have not – in fact their peak seasonal densities at the end of summer have increased. This, coupled with the evidence of prey switching from moths to weevils among the invertebrates and of increasing predation on birds is cause for concern. Invertebrate biomass is likely to continue to decline and bird predation to increase. Unless species that have become secondary prey (e.g. moths) have behavioural or physical refugia, they may be driven to actual or functional extinction by the mice.
- Aerial baiting from a helicopter fitted with a GPS linked to a bait-distribution bucket ensures all parts of the island are baited. Commercial cereal-based pellet baits (either from New Zealand or the USA) containing 20 or 25 ppm of the second generation anticoagulant toxin brodifacoum have been used in almost all successful rodent eradication attempts. The standard practice is to sow overlapping swathes of bait to achieve a bait density of at least 8 kg/ha, and to repeat the baiting after about 10 days with about 4 kg/ha. Depending on the helicopter model, bait bucket capacity, sowing rates, flying conditions, transit times from the base, pilot experience and topography, up to 480 ha can be baited per flying hour.
- Most attempts are made when the mice are not breeding on the assumption that non-breeding is caused by lower natural food availability per capita, i.e. when mice are hungriest. The absence of juvenile mice may also be an advantage if mice in this age class are less likely to encounter baits because of any behavioural characters, e.g. by remaining as semi-independent young in the den sites as bait disappears from the surface. On Marion Island this non-breeding period is from late May to early August, when mouse densities are also declining. However, there is little seasonal variation in invertebrate biomass on Marion Island, and the mice have more food in their stomachs in winter than other times of year. This may be simply an indication of their need to invest extra energy in thermoregulation (with no surplus for reproduction) and not necessarily that they are less hungry.
- Non-target deaths from birds eating baits or eating poisoned mice are inevitable. Lesser Sheathbills *Chionis minor* and Kelp Gulls *Larus dominicanus* are permanent residents on the island. They are at risk from primary poisoning as they will eat the baits, from secondary poisoning as they will eat poisoned mice, and possible tertiary poisoning if they eat potentially contaminated birds or invertebrates that have consumed toxin. A way to mitigate some mortality would be to establish temporary captive populations on the island, i.e. capture birds and hold them in a safe place for the risk period (yet to be determined).
- Sub-Antarctic Skuas *Stercorarius antarcticus* are also likely to eat bait or scavenge poisoned mice. Most skuas are absent from the island in winter and so the population is at lower risk assuming a winter eradication campaign. Giant petrels *Macronectes* spp. face low risks from either primary or secondary poisoning (based on the evidence from other islands) and their numbers also decrease on Marion Island during winter.

RECOMMENDATIONS

Operational recommendations

- The evidence of a collapse in invertebrate biomass and prey switching by mice among them and towards birds increases the urgency of action. Therefore, South African authorities should continue the planning process to eradicate mice from the island even before final decisions to proceed are made. Preliminary decisions on operational planning and funding should be made before the outcomes of other mouse eradication projects are confirmed and a final decision whether to proceed is made.
- Given the constraints on flying time caused by bad weather and the desirability of completing each baiting as quickly as possible, larger helicopters (four would be ideal) each capable of sowing up to 480 ha per flying-hour should be used. The logistics of getting these helicopters (and bait and staff) to Marion Island should be explored.
- The best month to bait is not clear. Late May – June is the best period based on biological parameters, but poor weather and short days are likely to constrict flying time and increase the total time, and thus the risks, unless many helicopters are deployed. Around March is the best period to bait based on weather and day length, but the biological parameters are sub-optimal at this time. The outcomes of late-summer baiting against mice on the island of South Georgia, further consultation with operational experts, and the trials suggested below will clarify this choice.
- A stratified baiting strategy should be considered. Highest bait densities with double bait sowings about 10 days apart should be used at lower altitudes (below about 550 m) but a single baiting with lower bait sowing rates might be sufficient in the the polar desert at high altitudes. The Pestoff 20M® mouse bait appears to be the most palatable bait, but both Pestoff 20R® or Final® rodent baits have been used with success elsewhere.
- Although use of the toxin diphacinone might avoid some of the non-target problems with birds, its track record against rodents with aerial baiting is poor. Therefore, the standard brodifacoum baits are recommended. There is some evidence that a slightly higher toxic loading (25 ppm rather than 20 ppm) might be efficacious for mice, but of course this may increase non-target risks.
- Methods to capture Kelp Gulls should be tested, and a plan to keep gulls and Lesser Sheathbills in captivity should be prepared.
- A contingency plan to react to invasion by rodents (mice if the eradication succeeds, and rats in any event from potential shipwrecks and relief visits) needs to be formalised.

Research and information recommendations

- The unpublished report by Angel & Cooper (2011) on the impacts of mice on Marion Island's biodiversity needs to be updated and published to include the new evidence of mouse predation on both surface-nesting and burrow-nesting birds. This would reinforce the justification for an attempt to eradicate the mice.
- The baseline status of invertebrate and plant biomass and composition and of predation rates on seabirds should be assessed prior to the eradication attempt to allow the benefits and consequences of removing the mice to be measured.
- If a May/June operation is rejected, a non-toxic bait acceptance trial around March 2016 should be conducted to see if 100% of tagged or radio-telemetered mice eat baits at this time of year.
- The hypothesis that young mice in maternal care might not be at risk from baiting needs to be tested with a toxic baiting trial. This trial can be done with suitable replication either during the proposed bait acceptance trial on Marion island, or at a more convenient location such as New Zealand.
- A toxic bait trial on Marion Island would also allow an estimate to be made of the proportion (or number) of radio-tagged or transponder-tagged mice that die in their burrows to assess risk to birds from the assumed proportion that died on the surface.
- An experiment to assess the time captive birds would need to be held before release should be conducted. Both the field life of baits and the decay rate of dead mice as palatable food for birds should be measured.
- A test flight of a helicopter over a King Penguin *Aptenodytes patagonicus* breeding colony (and other seabirds) could be conducted in 2016 to check the altitude in a baiting operation to avoid unacceptable disturbance. Data on helicopter disturbance of king penguins has been collected from Macquarie and South Georgia islands (see section 6.3.2) and suggest this trial is not essential.
- The distribution of mice by habitat/topography in the inland polar desert should be surveyed to determine the most efficient baiting strategy in this area – bait density, double or single baiting, or second baiting only in mouse-occupied habitat.
- All of the issues around putting mice in lava tubes and on cliffs at risk have been addressed in trials on Gough Island and in operational outcomes on Macquarie and perhaps South Georgia islands. There is no need to repeat this work on Marion Island as lava tubes and cliffs are not refugia for mice if the standard baiting procedures are followed.

Eradication of House Mice *Mus musculus* from Marion Island: a review of feasibility, constraints and risks

INTRODUCTION

House Mice *Mus musculus* have been present on the South African Marion Island (29 000 ha) in the sub-Antarctic Indian Ocean for nearly 200 years (Berry *et al.* 1978). The mice are part of a syndrome of factors having adverse impacts on native invertebrates, plants and possibly seabirds, as well as on aspects of ecosystem functioning (e.g. Phiri *et al.* 2009, Angel & Cooper 2011). However, the consequences of removing mice is possibly more subtle than on other sub-Antarctic islands and may not result in a simple or rapid reversal towards a pristine state (e.g. van Aarde *et al.* 2004). The current management plan for the island aims to eradicate alien plants and animals as far as possible (Chown *et al.* 2010).

In March 2015, BirdLife South Africa commissioned Kurahaupo Consulting to scope the feasibility that the mice might be eradicated from Marion Island and to review the constraints and risks to be resolved or managed before any decision to proceed with an eradication attempt could be made. Feasibility studies are the second step, after proponents have made a case that there is a problem, in a typical pest management project planning and action cycle (Appendix 1). The audience for a feasibility study is primarily those who have to decide whether to proceed with the project and those who have to fund it, and once these decisions are made leads to a project management structure, an operational plan, action and finally review or audit of the whole project (Appendix 1). The author visited Marion Island between 14 April and 8 May 2015.

OBJECTIVES

To assess the feasibility that mice might be eradicated from Marion Island by describing:

- The techniques used against mice on other islands from which eradication has been attempted.
- Whether the obligate rules for success can be met for Marion Island using standard methods from successful precedents.
- The constraints, risks and costs specific to Marion Island that would need to be resolved or managed before a decision to proceed to operational planning could be taken.

BACKGROUND

Marion Island, at 29 000 ha the larger of the two Prince Edward Islands, lies some 2300 km south-east of Cape Town at 46° 54´S, 37° 45´E in the southern Indian Ocean. It is an active volcano rising to 1230 m asl. The higher altitudes above about 550 m cover about 10 900 ha of polar desert habitat with sparse vegetation dominated by mosses and lichens. Lower altitude habitats include mires dominated by graminoids and mosses, slope habitats dominated by the fern *Blechnum penna-marina*, and fellfield habitats dominated by the cushion plant *Azorella selago.* Coastal areas used by penguins and seals are dominated by the tussock grass Poa cookii and several herbs such as *Cotula (Leptinella) plumosa.*

The flora consists of 15 native and 21 exotic angiosperms, seven pteridophytes and many liverworts, mosses and lichens (Gremmen & Smith 2008). Marion Island has a cool temperate climate with seasonal variation of only a few degrees between the coldest and warmest months. However, the climate is warming and drying with an increasing annual mean air temperature from 5.4ºC in the 1950s up to 6.4ºC in the 1990s and annual precipitation has dropped from around 300 cm in the 1960s to just over 200 cm in the 1990s (le Roux & McGeoch 2008).

Mice were introduced probably by sealers in the early 1800s (Watkins & Cooper 1986). Feral cats *Felis catus* were introduced in 1949 in an attempt to control mice at the recently established meteorological station, from whence they spread as feral animals across much of the island and preyed on the native birds (van Aarde 1980). The cats were eradicated by 1992 (Bester *et al.* 2002) in the largest eradication attempt against cats to date (Parkes *et al.* 2014).

Mice may be seen as part of a suite of interacting factors (a syndrome) affecting the native biota and ecosystem on Marion Island. The arrival of cats and their destruction of the smaller burrow-nesting seabirds, which have not recovered to the extent expected (Ben Dilley pers. comm.), invasion of some places by weeds such as Procumbent Pearlwort *Sagina procumbens* and the grass *Agrostis stolonifera* (Gremmen & Smith 2008), a warming and drying climate (le Roux & McGeoch 2008), and 200 years of impact by the mice themselves have changed the state of Marion Island's ecosystems compared with the near-pristine condition of neighbouring Prince Edward Island (4500 ha). Removing the mice is predicted to have a net benefit to the native species (e.g. Rowe-Rowe *et al.* 1989, Huyser *et al.* 2000, Angel & Cooper 2011) and ecosystem functioning (Smith 1978). However, the benefits may take time to become apparent, and determining cause and effect of mouse removal alone may not be straight forward in all cases.

Invertebrate biomass has declined over the last 40 years (Table 1) yet mouse biomass in April-May increased between 1990 to 2002 (intrinsic rate of increase, r = 0.029 ± 0.018) although this was only significant in the mire habitat (Fig. 3 in Ferreira *et al.* 2006). This must be either because the mice are still efficient at preying on the capital of invertebrates by prey switching from moths to weevils as the primary prey (Chown & Smith 1993), or they are adding new food items such birds, or both. Introduced earthworms form the bulk of mouse diets on Gough Island (Jones *et al.* 2002) and Guillou Island (le Roux *et al.* 2002) and it is likely they will become the main invertebrate food on Marion Island when weevil biomass follows that of moths.

It seems that both prey switching among the invertebrates and the addition of new prey such as seabird chicks is underway on Marion Island. Prey switching has potentially severe consequences for the previous primary prey which has become secondary prey – the invertebrate keystone species on Marion Island, the flightless moth *Pringleophaga marioni* (Smith 1978). In the absence of physical or behavioural refugia such prey can be driven to extinction, assuming a Type II functional response (Sinclair *et al.* 2006). This (extinction caused by mice) has

PETER RYAN

Figure 1. *Wounds on the neck of a Grey-headed Albatross caused, it is suspected, by mice, Marion Island, 3 May 2015.*

BEN DILLEY

Figure 2. *The culprit, a mouse attacking the head and neck of a Grey-headed albatross chick, Marion Island, May 2015.*

occurred for beetles (*Loxomerus* spp., and *Tormissus guanicula*) on Antipodes Island (Marris 2000) and for the giant phasmid *Dryocoelus australis* on Lord Howe Island (Hutton *et al.* 2007).

To date, predation on seabird chicks on Marion Island has been infrequent (Jones & Ryan 2009), but may become significant – as on Gough Island (Wanless *et al.* 2009, Cuthbert *et al.* 2013, Davies *et al.* 2015), especially if growing shortages of invertebrate prey reinforce learned behaviour among sub-populations of mice (Wanless *et al.* 2005). This appears to be happening on Marion Island (Figs. 1, 2). In autumn and winter 2015 at least 102 (4.6% of the island's fledglings) of Grey-headed Albatross *Thalassarche chrysostoma*, 45 (4.3%) of Sooty Albatross *Phoebetria fusca* and 1 (4%) of Light-mantled Albatross *P. palpebrata* chicks observed were attacked by mice with an extrapolated mortality for the first two species of up to 10% of the island's 2015 fledgling populations. Most affected chicks died within a few days of being attacked (Dilley *et al.* 2015). Attacks by mice were also recorded in 2015 on three of 553 Wandering Albatross *Diomedea exulans* chicks, and in single chicks of the burrow-nesting Grey Petrel *Procellaria cinerea* and Great-winged Petrel *Pterodroma macroptera* in 2015 (Percy FitzPatrick Institute unpubl. data).

Year	Winter			Summer		
	Mire	Slope	Biotic	Mire	Slope	Biotic
1976-77	51.8 ± 68.0	49.3 ± 26.6	376.4 ± 202.6	83.4 ± 107.0	58.1 ± 50.1	305.2 ± 106.9
1996-97	6.1 ± 5.9	37.9 ± 26.7	167.9 ± 83.8	9.9 ± 5.2	60.7 ± 59.4	226.4 ± 168.7
2006-07	1.7 ± 3.2	16.4 ± 21.7	60.3 ± 43.7	2.3 ±2.1	7.1 ± 7.8	52.4 ± 23.4
% loss	97	67	84	97	88	83

Table 1. *Change in invertebrate biomass (kg/ha ± SD) in three habitats on Marion Island (1976-77 data from Burger 1978, 1996-97 data from Hänel 1999, 2006-07 data from McClelland 2013).*

The eradication of mice would of course stop the predation on birds and probably allow an increase in biomass of seeds, but the effect on invertebrate biomass is less clear. Following the eradication of mice, the composition and biomass of plants and animals might be expected to converge on that of mouse-free Prince Edward Island. A before-and-after (BACI) design could be used to monitor the consequences of removing the mice. However, it is a moot point whether Prince Edward Island could act as a non-treatment control to interpret any changes on Marion Island given the likely state-change in the ecosystem on Marion Island after decades of mice and cats, collapsed invertebrate abundance, and changes in seabird abundance. A study on Marion Island that excluded mice (or at least reduced them to low densities) over four years found no evidence that invertebrate abundance or biomass increased in the absence of mice (van Aarde *et al.* 2004) with between year changes being larger than any treatment effects. They also found no significant effect of the exclusion on vegetation composition. This might be expected in a bottom-up driven ecosystem where vegetation biomass and composition determines invertebrate biomass and composition which together determine mouse numbers – we might not expect any change in invertebrates over a short period until the plants recover. Of course it appears the whole system is being confounded by warming climates so despite declining food abundance the mice are at least maintaining their abundance – this cannot last unless the mice are finding new sources of food.

However, the experiment conducted by van Aarde *et al.* (2004) had low statistical power to detect changes and the exclosures were not entirely mouse-proof. It is possible that even low densities of mice within the exclosures could affect the biomass and recovery of the plants and animals. So their conclusions are, as the authors themselves suggest, tentative and require more work to assess.

Figure 3 shows the vegetation response in small exclosures I found in 2015 – presumably abandoned after some previous trials and *in situ* for an unknown time. It is a moot point whether this visible effect is due to the exclusion of mice or simply a cage-effect affecting the 'climate' within the wire.

JOHN PARKS (3)

Figure 3. *Vegetation response in three exclosures (top) the exclosure in situ, (middle) near Ship's Cove with flowering tussock grass Poa cookii and (below) near the old meteorological station with the forb Acaena magellanica.*

IS ERADICATION OF MICE ON MARION ISLAND FEASIBLE?

Eradication is the permanent removal of all individuals from a defined area, Marion Island in this case. It is an all or nothing management goal – one cannot almost eradicate a pest! There are two ways to judge whether eradication of a population is feasible – by considering the success of those who have attempted it against the same or similar species elsewhere, and by an analysis of the obligate rules required for all eradication projects (Parkes & Panetta 2009) and the particular constraints and risks associated with the proposed species on its island.

PRECEDENTS FOR MOUSE ERADICATIONS

By 2007, when the Gough Island mouse feasibility plan was written (Parkes 2008), mice were known to have been eradicated from 40 islands although sometimes repeated attempts were required. Failures (n = 27 attempts) had been reported for a further 19 islands (MacKay *et al.* 2007, Parkes 2008 and updated in Appendix 10.2). Since 2007 matters have improved and mice have been eradicated from 62 islands with an order of magnitude increase in the size of the largest islands. A further eight attempts have been completed but the outcomes are not yet known. Only one attempted eradication (Pomona Island in Lake Manapouri, New Zealand) out of the attempts since 2007 has failed to eradicate mice – apparently because of reinvasion (Shaw & Torr 2011), and so might have been an operational success but restoration failure. Of the rest attempted since 2007, 19 are known to have succeeded and the rest have outcomes that await confirmation or are unknown (Appendix 2). Six hundred and seven populations of rats (either Ship Rats *Rattus rattus*, Norway Rats *R. norvegicus* or Polynesian Rats *R. exulans* or combinations of these) have also been eradicated from islands using similar methods to those used against mice. Whereas some failures have been reported on tropical islands (Holmes *et al.* 2015) most recent attempts on temperate islands have succeeded in eradicating rats (DIISE database).

In this report I have focused on the outcomes on islands south of 45ºS for which we have some details on methods and where the outcomes against mice have been well reported – Coal, Enderby, Macquarie and Chateau islands which succeeded, and parts of South Georgia which is just completed and the outcomes are pending. I also report on islands in the French Southern Territories (Stoll, Moules, and Australia in the Kerguelen Archipelago, and St Paul) where the eradication attempts against mice failed.

1. Coal Island

Coal Island (1189 ha) is a forested island at 46º 07'S, 166º 37'E in Fiordland, southern New Zealand. Resident Red Deer *Cervus elaphus* and Stoats *Mustela erminea* were removed by hunting and trapping, respectively by 2007. The vegetation on Coal Island is a mixture of podocarp-beech and other hardwoods (Brown 2013). Southern beech *Nothofagus* spp. and podocarps periodically mast (mass synchronous seeding) that trigger irruptions of rodents, and in the absence of rats, mice can reach high densities during a mast event but collapse to only a few per hectare in intervening years (Ruscoe & Murphy 2005). No mast occurred in 2008 in similar forests 30 km away in south Fiordland (Canham *et al.* 2014) so mice were likely to have been at low densities on Coal Island at the time of the eradication attempt. Mice, being the only invasive mammal left, were successfully eradicated by aerial baiting with Pestoff 20R containing brodifacoum. Two Jet Ranger helicopters with GPS capability and eight people to load baits were deployed to drop two sowings of bait 13 days apart in July and August 2008. No mice have been found during ongoing trapping programmes (Anon. 2008).

2. Enderby Island

This 710-ha island in the Auckland Island group of New Zealand lies at 50º 29´S 166º 17'E and had mice, European Rabbits *Oryctolagus cuniculus* and feral cattle *Bos taurus*. Most cattle were removed by shooting in 1991, when it was observed that the rabbits' burrows were causing problems for Hooker's Sealion *Phocarctos hookeri* pups. A plan to eradicate the rabbits was drafted and the attempt made in 1993. Mice were something of a bycatch of the rabbit eradication although it was hoped that the rabbit operation would also remove the mice and so care was taken to ensure bait was placed in areas even when they did not harbour rabbits (Torr 2002).

One Eurocopter AS 350 B Squirrel helicopter without GPS capability was used to drop two sowings each of 5 kg/ha in February and 18 days later in March 1993. Areas of about 100 ha with high densities of rabbits received extra bait. A cereal bait, Wanganui No. 7, similar to Pestoff 20R, was used. It contained the standard 20 ppm of brodifacoum. The timing was determined by the lack of rabbit breeding rather than that for mice, which although not measured was probably occuring in February and March.

Most rabbits were killed although 22 animals survived with the last being killed by ground-based methods on 12 April 1993. All mice were killed by the baiting and none has been detected in subsequent years (Torr 2002).

3. Macquarie Island

Removal of introduced vertebrates on this 12 875-ha Australian island at 54º 36´S, 158º 52'E began with the successful eradication of Weka *Gallirallus australis* by 1989 and feral cats by 2000 (Copson & Whinam 2001). A major operation against the remaining mammals (Ship Rats, European Rabbits and House Mice) began with planning in 2004 (Springer 2011). A false start was made in 2010 when the helicopters were constrained by weather during the proposed baiting period and only 8% of the island was treated. However, this did demonstrate the level of non-target mortality with native birds. This led to the introduction of the rabbit biocontrol rabbit haemorrhagic disease virus in February 2011 which killed 80-90% of the rabbits and was intended to reduce the supply of poisoned rabbit carcasses once the toxic baits were applied and thus to reduce mortality in scavenging seabirds (see section 6.2.1 of this report). The main aerial baiting component of the operation was completed between May and July 2011. As expected some rabbits survived this baiting and were removed over the following five months by ground-based hunting methods.

Post-operational monitoring for surviving rats and mice used trained dogs (two handlers and three dogs) and searched the island from March 2013 to March 2014 with no animals being detected. Searches for rabbits had used up to 15 staff with 10 dogs between August 2011 and March 2014. The eradication of all three species was declared in April 2014 – limited localised searches with dogs were conducted in April 2015 around the research station with no sign of rats, mice or rabbits (Sue Robinson pers. comm.).

The baiting component of this project used 305 tonnes of Pestoff 20R cereal bait with 20 ppm brodifacoum spread over the entire island in two main bait drops with a third drop in areas predicted to harbour more rodents (rockstacks and penguin colonies). Four Eurocopter AS350 'Squirrel' helicopters were used with a combined load of 2.3 tonnes of bait every time they left the loading zones. Depending on flying conditions and distances from loading sites each helicopter could deliver about three loads per hour or 1725 kg of bait. Again depending on sowing rates and the extent of swath overlap this means that about 150 ha were treated per flying hour. The second baiting on Macquarie Island took up to five days to complete using all four helicopters (Keith Springer pers. comm.).

A budget of A$20 million was spent with about 60% of this total being spent on the aerial baiting component of the project. It is difficult to partition the added costs of aerial baiting from the need to target rabbits but the total of A$930/ha (about Rands 87 000/ha) would be an upper limit on costs.

4. Chateau

Ile Chateau (220 ha) at 49° 30'S, 69°55' E is one of the islands in the Golfe du Morbihan in the Kerguelen Archipelago. An attempt to eradicate ship rats and house mice was made in November/December 2002 when Pestoff 20R baits were sown in two baitings from a helicopter based on the *Marion Dufresne* supply ship. Four people stayed on the island for one month to conduct ground-based baiting as required. No rats or mice were detected during the week after the baiting and none was detected during surveillance in December 2003, December 2004 or May 2005 (Anon. 2006).

5. South Georgia

The island of South Georgia (375 000 ha) at 54° 20'S, 36° 47'W had Norway Rats, House Mice and Reindeer *Rangifer tarandus* as exotic mammals. The Government of South Georgia and the South Sandwich Islands (Reindeer) and the South Georgia Heritage Trust (rodents) launched plans to eradicate the mammals in 2010 (Anon. 2010). Rodents do not occupy the whole island and are seperated into nine discrete areas by glaciers. Mice (but not rats) occupied one peninsula.

Two (and later three) Bolkow 105 helicopters were used to treat nine zones of the island covering 108 423 ha in three operations in March 2011, 2013, and 2015. Final® (Bell Laboratories, Wisconson, USA) baits with brodifacoum at 25 ppm were sown at 5 kg/ha (3.5 + 1.5) in vegetated parts and a single 1.5 kg/ha in non-vegetated terrain. For the higher sowing rate (with no swath overlap) each helicopter could cover about 210 ha per flying-hour while for the lower rate about 480 ha per flying-hour was baited (Keith Springer pers. comm.).

Mice were certainly present in the rat-free Cape Rosa and Nuñez Peninsula area of 4932 ha, and possibly around some old whaling stations but their presence over the rest of the island is unclear; they may be absent or supressed to refugia and low densities by the rats (Black *et al.* undated). Trapping in March 2012 showed low mouse densities of between 2–9/ha in the

ROSS WANLESS

A male Wandering Albatross provisions its young chick at Marion Island. Albatrosses do not feed on land, therefore they are not at risk from primary or secondary poisoning.

Cape Rosa-Nuñez Peninsula area (Cuthbert *et al.* 2012). It was proposed to bait the known mouse range with a double baiting and at a higher sowing rate of 8 kg/ha in vegetated areas and 3 kg/ha in non-vegetated areas. The 2012 trapping project suggested lower rates would be sufficient (Cuthbert *et al.* 2012). The mouse areas were baited in April 2013 at planned rates of 5 kg/ha including overlaps in vegetated areas and 3 kg/ha in un-vegetated areas (Anon. 2012). When detection devices were checked in March 2014 and April 2015, no signs of mice were found (Anon. 2014).

6. Islands in the French Southern Territories

Saint Paul Island: Although north of 45°S, the rodent eradication project on this French island of 900 ha in the southern Indian Ocean at 38° 42'S, 77° 32'E was well reported (Micol & Jouventin 2002). Two aerial baitings of 10 and 5kg/ha of Pestoff 20R baits were planned but the supply ship had to leave early and only one drop was possible. Delays in getting the bait from New Zealand to the island meant some had gone mouldy and only 13.5 tonnes were available. The Lama helicopter did not have a GPS unit so the bait swaths were set at 100 m and marked by people with flags to guide the pilot. The engine on the bait bucket also malfunctioned during the January 1997 bait drop and some obvious gaps were filled by hand broadcasting the bait.

Despite these errors both Ship Rats and European Rabbits were eradicated (the latter after follow-up ground control) but not the House Mice (Micol & Jouventin 2002). The authors believed a second baiting may have killed all the mice, but poor bait quality, wide sowing swath widths and lack of GPS to identify gaps are as likely causes of the failure against mice.

Stoll Island: House Mice were the only invasive mammal on 60-ha Stoll Island (49° 45'S) in the Golphe du Morbihan, Kerguelen Archipelago. A single aerial drop of Pestoff 20R was made in 2003 but apparently failed to eradicate the mice (DIISE database). No detailed information is available.

Moules Island: Moules Island (400 ha) at 49°07'S, 69°56'E in the Golphe du Morbihan, Kerguelen Archipelago had Ship Rats and House Mice. A double bait drop in 2005 eradicated the rats but not the mice (DIISE database).

Australia Island: Ile Australia (2100 ha) at 49°28'S, 69°51'E in the Golphe du Morbihan, Kerguelen Archipelago was treated twice with 32 tonnes of bait in 2005 from the air. Ship Rats were eradicated but not the House Mice (DIISE database).

GENERAL POINTS FROM PRECEDENTS

The main lesson from these previous projects is that everything has to go right on the day. Meticulous planning, with over-engineering and redundancy planning with spare equipment, and patience with the weather (and a little luck if done in winter) are required. The basics must be followed (Broome *et al.* 2014) but the details of how they are applied can be, and are, flexible according to the circumstances. The standard methods are guidelines, not a recipe.

(a) Baiting during the breeding season may not be a problem. Successful eradications were conducted in February-March on Enderby Island, in December on Chateau Island and in April on the Cape Rosa – Nuñez Peninsula on South Georgia, but failed on three islands in the Golphe du Morbihan baited in December.
(b) Double baiting may not be necessary as a single baiting has worked against Norway Rats on Campbell Island (McClelland 2011), but failed against mice on Stoll Island.
(c) Recent projects have stratified the bait density used according to expected mouse densities.
(d) Apart from Stoll Island for which I have no detailed information, all of the exemplar islands had low densities of mice compared with Marion Island. Mice were the only rodent present on Stoll, Coal, Enderby and on the Cape Rosa – Nuñez Peninsula.
(e) Failures against mice over all attempts (Appendix 2) do not appear to have a common cause, but each appears to be a unique circumstance (MacKay *et al.* 2007, Holmes *et al.* 2015).

A CRITIQUE OF JACKSON & VAN AARDE (2003)

Jackson & van Aarde (2003) reviewed various mouse control techniques (see Appendix 3 of this report for updates on these methods) including three precedents where brodifacoum was used against mice but failed (according to Jackson & van Aarde 2003) to eradicate them. Based on these three case studies they were pessimistic about the chances of success on Marion Island. It is worth exploring their three cases in more detail to see if the pessimism is justified and supported by the evidence.

1. Mokoia Island

There had been two failed attempts to eradicate House Mice from Mokoia Island, a 133-ha island in Lake Rotorua in New Zealand, until success was achieved in 2001 (MacKay *et al.* 2007). Cleghorn & Griffiths (2002) discussed possible options for these early failures, including reinvasion, poor bait distribution and sub-lethal exposure. With respect to the last point, they conducted some choice and no-choice feeding trials on captive Mokoia mice to see whether the bait (Pestoff 20R with 20 ppm brodifacoum) and sub-lethal uptake when highly palatable alternatives were available were the cause of failure.

In no-choice cage trials all mice ate Pestoff 20R bait and died. However, when both the baits (not designed as a nutritional food for mice) and a commercial mouse food were presented, one mouse out of 10 in the trial did not eat the Pestoff 20R bait, which was presented as evidence to support Jackson & van Aarde's pessimism. Whether the presence of abundant (per capita) favoured natural food in the wild would mean some mice would likewise not eat the artifical bait is a moot point. It has been speculated that this might be a cause of eradication failure on season-less tropical islands where natural food abundance and mouse densities are thought to be more-or-less constant (Parkes & Fisher 2011, Keitt *et al.* 2015). However, on most temperate islands food abundance is assumed to be lowest in winter and the mice the hungriest – and thus winter is the recommended baiting period (Broome *et al.* 2014), and the *ad lib* provison of an artificial mouse food as in the Mokoia trial does not really replicate the situation.

Interestingly, the lack of strong seasonal variation in invertebrate biomass on Marion Island makes this consideration neutral (see Table 1) and we are trying to identify other factors (trends in mouse density, the balance between energy investment in breeding versus thermoregulation as ambient temperatures change) that suggest the best time of year to bait (see section 6.1).

2. Browns Island

Browns Island (58 ha) in the Hauraki Gulf in New Zealand had Norway Rats, European Rabbits and House Mice. The eradication attempt on 13 September 1995 used Wanganui No 7 baits with bromadiolone sown in a single baiting from a helicopter without GPS capability to ensure 100% coverage. One mouse was caught after 19 days and signs (from chewed baits) seen after 21 days, but no mice or rats have been seen since that time (Veitch 2002). The eradication therefore was a success (not a failure as implied by Jackson & van Aarde 2003) and the live mice detected three weeks after the baiting were simply a reflection of the high LD_{50} values for bromadiolone (Fisher 2005) taking time to kill the last mice – but see also section 5.1.2.

3. Australian wheat crops

Mice periodically reach plague numbers in the Australian rangelands and farmers reduce their numbers to mitigate damage to their crops usually by applying grains treated with the acute toxin zinc phosphide (Caughley *et al.*1998). Brown & Singleton (1998) tested brodifacoum (at 0.005%) as an alternative toxin for these sustained control (eradication is not the aim) operations.

A 99% kill with brodifacoum would be considered a significant success in these mainland control situations where reinvasion is almost instantaneous, as it would reduce damage to crops to a negligable amount. However, so does zinc phosphide and it is much cheaper. Nevertheless, Brown & Singleton (1998) showed the potential to achieve 100% kills as they radiocollared 19 mice and traced them after the baiting. Three mice were never located, four were found dead on the surface or at the entrance of burrows and 12 died in their burrows.

The pessimism in Jackson & van Aarde's paper around the ability of aerial brodifacoum baiting to eradicate Marion Island mice is not justified by the examples they use – it might be had they been able to consider the later French failures in the Golphe du Morbihan.

CAN THE OBLIGATE RULES FOR ANY ERADICATION BE MET?

All attempts to eradicate (permanently remove an entire population) must meet three obligate rules. Failure to achieve any one of these means that eradication is not possible, although other strategies may be attempted such as sustained control. Sustained control may aim for zero animals in priority places but with certain reinvasion and regular or continuous intervention with control. Of course even if these rules can be met, managers have to consider other factors (cost, social acceptance, non-target losses) before proceeding, but all these issues become irrelevant unless the basic rules are all met.

CAN ALL MICE BE PLACED AT RISK?

1. Aerial baiting – the only practical technique on a large island

The aim of the aerial baiting technique is to put 100% of the target population at risk in a single control event applied over a short time. The standard method is described in detail in a New Zealand Department of Conservation Standard Operating Procedure (Broome *et al.* 2014). In summary, helicopters fitted with specialised bait buckets (Fig. 4), linked with the aircraft's GPS, sow baits at fixed rates in overlapping swaths to deliver known densities of bait on the ground depending on flight height, speed and ground slopes. Generally two sowings are conducted a week or so apart with a lower bait density in the second sowing, and sometimes a third in 'hotspots' for the mice (Broome *et al.* 2014). Early projects treated only about 100 ha per flying hour with standard bait densities by a pilot experienced in the technique (Parkes 2008), but the recent two large attempts on Macquarie and South Georgia islands treated about 150 and 210 ha per flying-hour, respectively at the higher sowing rates suggested for Marion Island (see section 4.1). Lower sowing rates on South Georgia Island covered 480 ha per flying-hour while about 350 ha per flying hour were treated sowing 1.5 kg of bait/ha using AS 350 'Squirrel' helicopters in 1080 baiting operations in New Zealand (Graham Nugent, pers. comm.). These rates need to be extrapolated to Marion Island with caution as the type of helicopter and bait bucket, pilot skill, sowing rates, distances from bait depots, and daily weather variability all affect performance. Operational managers of previous rodent eradication projects stress the need to use pilots who are experienced in eradication projects, but note this is not always simple given they are often not available from the country leading the project.

Figure 4. *Typical helicopter and bait spreader bucket used in aerial rodent eradication projects.*

There are many other ways to control mice (as opposed to eradicate them) and these have been canvassed by Parkes (2008) for the Gough Island plan and by Jackson & van Aarde (2003) in a review of tactical options for Marion Island. These are updated and critiqued as methods to achieve eradication in Appendix 3.

Note: mice on Marion Island have home ranges as small as 200 m², i.e. a diameter of 63 m (Matthewson 1993) so any sowing gap larger than that would not expose all mice to bait.

2. Brodifacoum – the usual toxin

The second-generation anticoagulant brodifacoum is the preferred toxin because rodents may eat many baits before showing any symptoms thus avoiding problems of anorexia or bait avoidance (and resulting survival of some individuals) when more acute toxins are used (Fisher 2005). Of 546 rodent eradication attempts reported by Parkes *et al.* (2011), 73% used brodifacoum as the toxin and a further 8% used other second generation toxins such as bromadiolone. Aerial baiting with brodifacoum baits was used in 149 of these attempts (the rest being ground-based delivery) with a 92% success rate (Parkes et al. 2011).

Marion Island adult mice have a mean mass of 21 g (Berry *et al.* 1978). The LD_{50} of brodifacoum for mice has been variously calculated at between 0.4 and 0.52mg/kg (Fisher 2005 and references therein, Cuthbert *et al.* 2011) and whereas LD_{100} values are not known it is clear all mice would need to eat only part of a 2-g bait containing 20 ppm of brodifacoum to obtain an LD_{50} and most would probably die after eating just one bait pellet. This rough calculation was confirmed in some pen trials conducted on Gough Island mice - generally heavier than the average Marion Island mouse (Cuthbert *et al.* 2011). Basically, in choice tests 29 of 29 mice that ate one 2 g Pestoff 20R bait died after an average of 5.5 days. Of interest, the mice did not show any anorexia for about four days after eating a toxic bait (Cuthbert *et al.* 2011). A few mice (1% of the test animals) survived apparently lethal doses at first ingestion but all died after consuming more baits – suggesting some variability in individual susceptibility (or food preferences between bait and natural foods) and the need for excess baits in an operation to account for these resilient individuals.

3. Options for baits

Cuthbert *et al.* (2011a) tested the relative palatability of Pestoff 20R (the standard Animal Control Products rodent bait) against a new pellet formulated specifically for mice (Pestoff 20M) and Bell Laboratories Final® rodent bait. All three baits were highly palatable but the Pestoff 20M was best. Pen and field trials conducted in New Zealand also confirmed that a new mouse bait (presumably the same as Pestoff20M) was more palatable than the standard Pestoff 20R bait (Thomas 2008), and that Pestoff 20R was more palatable than three other commercial rodent baits – Talon 50WB, Racumin and Talon 20P (O'Connor & Booth 2001). It has been reported that the smaller (Bell Laboratories) baits used on South Georgia resulted in some problems with bait flow in the sowing buckets (Keith Springer pers. comm.), so the smaller Pestoff 20M bait might also suffer from this problem.

Cuthbert *et al.* (2011b) conducted a trial on Gough Island using ear-tagged mice (n = 757) which were then potentially exposed to rhodamine-dyed, non-toxic Pestoff 20R bait hand-broadcast over three sites up to 20.7 ha at a rate of 16 kg/ha. Results showed 100% of the tagged mice had eaten bait when trapped over three or four nights. Similarly, Elliott *et al.* (2015) hand-broadcast non-toxic Pestoff 20R baits dyed with pyranine over about 16 ha at a rate of 16 kg/ha. All 100 mice trapped up to 13 days after baiting were dyed with pyranine. Rexer-Huber *et al.* (2013) conducted a similar trial on Steeple Jason Island in the Falkland Islands. They dyed non-toxic Bell Laboratory baits with pyranine and spread them by hand at about 7.5 kg/ha over two trapping areas of 8 and 7 ha at where mice had been caught and tagged. Over four days, all 284 tagged mice that were re-caught had eaten baits.

In a cage trial (O'Connor & Booth 2001), 20 mice caught in the wild were exposed *ad lib.* to Pestoff 20R baits containing 21.5 ppm of brodifacoum. Mice ate on average 11.34 ± 0.6 g of bait over three days and died between six and 18 days (mean = 9.9 days) later. In this study the Pestoff 20R baits were more preferred than a commercial rodent food, c.f. Cleghorn & Griffiths (2002). See also section 6.2.4 for data on the time it takes for all mice to die after baiting.

Mice are also said not to cache baits and to nibble bait rather than eat whole baits at a sitting – in contrast to rats (O'Connor & Booth 2001), so keeping baits available in the field for longer is desirable when mice are the target. This behaviour might also explain the length of time it sometimes takes for the last mice to die after baiting.

4. Topography and physical refugia

Cliffs and caves or lava tubes as well as huts and buildings present complexities to (a) get sufficient bait onto them or (b) when the rodents may live permanently within a cave system. However, such features have not proved an issue on other sub-Antarctic islands such as Macquarie or Campbell and have been specifically investigated as risks that mice might not be exposed to bait in trials on Gough Island.

Lava tubes: Wanless *et al.* (2008) conducted a small trial on Gough Island where they placed dyed bait above ground near a lava tube used by prions *Pachyptila* spp. and mice, and then trapped mice (n = 11) within the tube. All trapped mice had ventured out of the tube and eaten bait so they concluded the tubes were not refugia from an aerial baiting.The bait acceptance trial conducted by Cuthbert *et al.* (2011a) also tested whether the lava caves might be refugia. The results showed all mice trapped within the caves had eaten bait laid on the surface.

The conclusion is that 'cave systems are unlikely to be an obstacle for eradication' on Gough Island (Cuthbert *et al.* 2011a) and by extrapolation any such features are unlikely to be a constraint on Marion Island. The possibility of locating **all** lava tubes and cracks in the lava and handbaiting them across the whole of Marion Island is exceedingly remote – so despite the results from Gough Island this remains a residual risk to the project, but I think a very small one.

Cliffs: Cuthbert *et al.* (2014) sowed non-toxic Bell Laboratory baits from a bucket slung under a Bell 212 helicopter along 500 m lengths of low (40 – 60 m) and high (200 m) sea cliffs, and a 500 × 200 m area of flat ground on Gough Island at a nominal sowing rate of 8 kg/ha. The density of baits on the cliffs was measured and compared with that on the flat area. The vegetated cliff areas retained sufficient baits (about 70% of the flat ground densities) to suggest adequate bait densities would be achieved if the standard extra sowings for the cliffs were applied (Table 2).

Huts and Marion Base: Mice are attracted to buildings by warmth, shelter and sometimes food. There are 12 buildings in the old unused station and 2 main + 2 small buildings at the new station, plus nine field huts around the island. Standard practice is to hand broadcast baits or set bait stations in, on and under buildings and within wall and ceiling spaces, and to rebait when these baits are eaten by mice. The old station and huts are relatively simple in design but the new station has ceiling spaces, wall spaces and other complexities that will have to be accessed.

Site	Area	Mean slope	Length of transects (m)	Mean bait density (pellets/ha)	% bait retention on cliffs relative to flat area
1	Flat	10º	640	2210	76
	Cliff	69º	546	1679	
2	Flat	6º	320	846	66
	Cliff	78º	304	562	

Table 2. *Bait densities on cliffs and flat areas in a trial on Gough Island (after Cuthbert* et al. *2014).*

5. Bait densities versus mouse densities

At a sowing rate of 1 kg/ha for standard 2-g baits there would be 500 baits/ha. Mouse densities at lower altitudes on Marion Island vary with habitat from about 150 mice/ha up to about 200-300 mice/ha in areas used by seabirds and seals in April-May (Ferriera *et al.* 2006). Therefore, assuming maximum mouse densities of over 100/ha in (see Fig. 2 in Ferreira *et al.* 2006) a baiting density of the standard 8 kg/ha for the initial drop would provide an average of 40 baits/mouse – more than enough if all mice are exposed and eat baits, and if not too many are eaten by birds. Marion Island mice live in multichambered (multimouse?) tunnel systems with distinct runways worn into the surface vegetation (Fig. 5). They appear to store some foods in their tunnels (Avenant & Smith 2003), so it is likely many baits will be taken underground and either eaten or stored.

Densities are probably much lower in the higher altitude 'polar desert' above 550 m and although Matthewson *et al.* (1994) thought 800 m asl was their altitudinal limit, Avenant (1999) noted mice had been trapped up to 1000 m asl and a dead mouse was found on the top of Bald Peak at 1162 m (John Cooper pers. comm.). In late April 2015, I set 40 snap-traps for one night and trapped three mice in the polar desert at an altitude of 793 m – one at the Katedraalkrans field hut and two along a talus slope under bluffs. Therefore, although mice may not live in bare scoria or other barrens they clearly do live (at least part of the year) in areas with very sparse vegetation, in the 'hypolithic communities containing mosses, liverworts and invertebrates within blocky substrates' as described by van Zinderen Bakker (1978). The polar desert cannot be ignored for baiting.

Figure 5. *Entrance to a mouse burrow and runway through* Blechnum penna-marina *caused by the traffic of mice.*

A decision has to be made about the bait densities to be sown and whether a double sowing is required in all areas. I make some suggestions here (Table 3) based on recent and planned projects, but wider consultation with practitioners and advice from referees of this report is recommended. For example, it is proposed to use 16 + 8 kg/ha in the two sowings on Antipodes Island (Horn & Zammit-Ross undated). A precautionary approach would be to use the same high bait density and two sowings across the whole island, but that is expensive and probably not necessary. The compromise is to select options that are still cautious.

Of interest is that bait consumption rates may be proportional to mouse density. Gough Island mice removed about 25% of baits per day when 15.7 kg/ha of non-toxic Pestoff 20R baits were sown, and 51% when 7.9 kg/ha was sown (Wanless *et al.* 2008) when mouse densities were probably over 100/ha (Cuthbert *et al.* unpublished data). A similar trial on South Georgia's Cape Rosa/Nuñez Peninsula, with mouse densities of only 2.1 mice/ha, showed daily removal rates of 0.9% when 8kg/ha of bait was sown and 2.1% when 4kg/ha was sown (Cuthbert *et al.* 2012). If these results are general, we would expect most baits, at the densities in Table 3, to be consumed at sites with high mouse densities over the first few days, suggesting that the recommended rates may be too low to allow surplus baits to put the last mice at risk.

Habitat/ zone	Area (ha)	Approx. density mice in (month)	Bait density (1st sowing) Kg/ha	Bait density (2nd sowing) Kg/ha	Tonnes bait required + 10% contingency
Coastal biotic zone (320 m or 4 bait swaths)	2240	191 (April)[1]	12	5	42
Mires and vegetated lava	5760	60 (May)[2]	8	4	77
Fellfield	10 400	?	5	3	91
Polar desert	10 600	?	3	1 (along talus areas)	38
Cliffs (extra), c. 520 ha	c. 65 km		4	4	5
Total					253

Table 3. *Suggested minimum bait densities and number of sowings in three main zones on Marion Island assuming a Februay/March baiting. 1After van Aarde* **et al.** *(2004), 2Avenant & Smith (2004)*

6. Potential genetic strains of mice to resistence to brodifacoum

Angel & Cooper (2011) raised the possibility that some genetic strains of mice (e.g. see Hardouin *et al.* 2010) might be less susceptible to anticoagulant toxins than others. MacKay *et al.* (2012) found no gross evidence of this for mice from six New Zealand populations so it is unlikely that any such resistence in Marion mice would impart that much resistence to the doses of brodifacoum they are expected to eat. The simplest way to test any effect would be to conduct some simple LD_{50} trials on Marion Island mice – as was done for Gough Island mice (Cuthbert *et al.* 2011b).

CAN THE TARGET POPULATION BE KILLED QUICKLY ENOUGH?

This rule is important in eradication projects that reduce the target population to zero by a series of culling events – such as might occur if we attempted to trap the mice to extinction. The advantage of the aerial-baiting technique applied in the non-breeding season is that the rule is automatically met in such one-hit baiting strategies when they are correctly deployed.

If the baiting was done during the breeding season, the second baiting becomes more important to expose any young mice that are not exposed to bait during the first sowing but are old enough to survive without maternal support.

CAN REINVASIONS BE PREVENTED?

The risk that mice will re-invade Marion Island, should eradication succeed, is very low, but not zero. Genetic studies of mice on sub-Antarctic islands suggest single primary establishments (van Vuuren & Chown 2007, Hardouin *et al.* 2010) or at least subsequent events failed to establish in the face of the resident mouse populations. There have been several shipwrecks on both Marion and Prince Edward Islands (Cooper 2008). The fact that the shipwrecks on or near Prince Edward did not result in the establishment of rodents shows that shipwreck is as risky to survival for a rodent as for a sailor – assuming of course that the ships were infested with rodents.

Enhanced quarantine procedures on regular shipping visiting the island would further reduce risks of reinvasion – note that the presence of mice on the Antarctic supply ship m.v. *S.A Agulhas* after one visit to Gough Island shows the potential on even a well-run vector is not zero (Cooper *et al.* 2013). Containers and cargo sent to Marion Island arrive at the two helipads or at the crane hoist at Gunner's Point. They are inspected for exotic biota when opened, but what would the environmental inspectors do if a mouse or rat jumped out and disappeared down the grating? A contingency plan (a buffer of traps and bait stations) would need prior preparation so it could be implemented immediately as required. Evidence suggests that immigrant ship rats stay in the arrival area for only three days before dispersing (Innes *et al.* 2008) so that sets the early response timeframe for this species.

However, I think the main risk would come from shipwreck with illegal, unreported and unregulated vessels poaching within sub-Antarctic waters being the highest risk. An early detection – rapid response (EDRR) to a catastrophe such as a ship grounding is required (e.g. NISC 2003). Basically, the staff on Marion Island need to know how to respond, with the correct equipment and materials readily available, to a potential rodent incursion if a ship grounds on the island. In summary, the early detection component requires that any ship aground is known about quickly, and is inspected for presence of rodents on board or ashore. If rodents are detected (or even as a precaution) a rapid-response phase is implemented (e.g. Ebbert *et al.* 2007). A general EDRR plan for Marion Island is worth developing even if the mouse eradication does not proceed.

MANAGING CONSTRAINTS AND RISKS

OPTIMAL TIME OF YEAR TO BAIT

It is generally assumed (Broome *et al.* 2014) that baiting will be most effective, i.e. 100% of mice will eat enough toxic bait to obtain a lethal dose, when they are most short of their natural food and so at their hungriest – although such seasonal differences in bait acceptance has not been tested. Rather, such periods are inferred from lack of breeding, declines in mouse population densities and declines in natural food availability. On temperate islands all this usually happens in winter. Mouse density *per se* is not necessarily a suitable signal for timing the bait drop, rather it is *per capita* food availability which may not coincide with minimum annual mouse densities.

Bait acceptance trials are often undertaken to confirm that the proposed bait type will be eaten by 100% of rodents exposed at the time of year when the main operation is intended, or to identify the best time of year to bait if this is unclear. These trials can be misleading and give false negatives if the trial area is too small in relation to the normal movements of individual mice, i.e. mice can immigrate from unbaited areas into the baited area after all or most marked bait is consumed by residents (e.g.Wanless *et al.* 2008). Section 5.1.3 discusses more certain methods to assess bait acceptability using tagged mice.

1. Breeding season

Apart from the notion that lack of breeding indicates food stress, it may also be a good idea not to bait when mice are breeding in case young mice still in the maternal nest are not exposed to bait yet are old enough to survive without their mother – an untested argument also raised in support of a second bait drop (Broome *et al.* 2014). A basic tenet of eradication planning for one-hit projects such as aerial baiting is to take a precautionary approach to such untested (or untestable) issues to minimise risks of failure. Thus, baiting outside the breeding season, excess baits in overlapping swaths, double baiting and spare equipment are considered necessary, especially when the added cost is small compared with the major costs of supply and logistics to even start the operation.

Breeding by Marion Island mice usually ceases in early May and begins again in late September (Fig. 6). However,

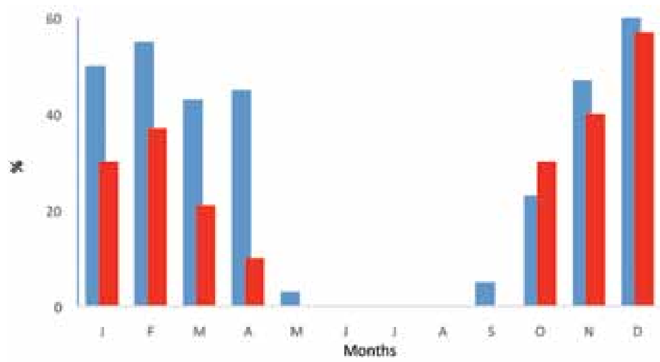

Figure 6. *Percent females pregnant in monthly samples of mice from Matthewson* et al. *(1994) (blue bars) and Avenant & Smith (2004) (red bars).*

as Avenant & Smith (2004) noted there is some between-year variation around the end and start of the breeding season.

Based on this character aerial baiting would be best between late May and early September (Table 4).

2. Seasonal declines in mouse density

Mouse densities in three habitats (vegetated black lava, mires and areas near penguin or seal colonies) showed similar monthly patterns across the years between 1979 and 2001 (Ferreira *et al.* 2006). Densities peaked in April-May at about 150, 220 and 300 mice/ha in the three habitats, respectively, and then declined to about 20, 30 and 50 mice/ha in November (Fig. 2 in Ferreira *et al.* 2006).

On this basis, baiting would be optimal in June when the population begins to decline and there are likely to be the least food *per capita* (Table 4).

3. Food seasonality

Per capita availability of invertebrates for mice varies seasonally. This is largely due to changes in mouse densities as there is little change in the biomass of the invertebrates between seasons (Gleeson 1091, Gleeson & van Rensburg 1982, McClelland 2013). For example, Matthewson *et al.* (1994) and Avenant & Smith (2004) measured mouse densities and macroinvertebrate biomass in two habitats in early summer and early winter and showed mouse densities were much higher in early winter than in early summer but that invertebrate biomass was higher in early summer (Table 5).

On this evidence the best time to bait would be early winter (Table 4).

Parameter	Optimal months
No breeding mice	Late May–early September
Declining mouse numbers	June
Food availability/*per capita*	May
Non-target birds	July
Precipitation	February–March and August–November
Least snow-days	January – April
Least days with gales	February – March

Table 4. *Parameters that influence the best time of year to attempt eradication of mice on Marion Island.*

Habitat		Early summer	Early winter
Biotic habitat	Mouse density (mice/ha)	43	242
	Macroinvertebrate biomass (kg/ha)	145	100
	Per capita food availability (kg/mouse)	3.4	0.4
Mire habitat	Mouse density (mice/ha)	9	51
	Macroinvertebrate biomass (kg/ha)	32	11
	Per capita food availability (kg/mouse)	3.6	0.2

Table 5. *Mouse densities, macroinvertebrate biomass (excluding slugs) and per capita food availability for mice in early summer and early winter in two habitats on Marion Island (after Table 5 in Avenant & Smith 2004).*

4. Weather

Of interest to this review the proportion of days without rain (and thus possibly the number of days suitable for helicopter baiting) has increased with only a mean of 49 days in the 1960s to 89 days in the 1990s (le Roux & McGeoch 2008). Snow can fall at all altitudes at any time of year but is more common in winter (Schulze 1971).

The weather is changeable all year and getting enough consecutive flying days to complete the whole island is highly unlikely, even with several helicopters. Previous projects have set operational rules to determine flying days (so that baiting is not wasted if the baits are washed out by heavy rain or covered in snow, or to rebait buffer zones in areas already baited when flying is curtailed by weather (e.g. Anon. 2012, Broome *et al.* 2014).

The best time to get a succession of days on which flying is possible (and day-length longer than in winter) is probably in late summer. For example, the average sunshine hours per day averaged around five between November and February but only around two in June-July between 1948 and 1965 (Schulze 1971) – it has probably increased as the climate has warmed.

February and March are on average marginally drier than June and July among the candidate months for baiting (Fig. 7). Days with snow and days with gales were fewest in late summer on average between 1959 and 1969 (Fig. 8). However, given the highly changeable weather patterns on the island and the changing climate it would be worth analysing the meteorological data to see if there are significant differences in the average length of successive spells of 'fine' weather between months or seasons, i.e. to see what periods provide best flying conditions and allow baits sown to persist for several days. Previous experience suggests wind speeds over 25 knots and lack of visibility due to cloud are the main restrictions on flying. Rain and snow *per se* are not fatal to sowing baits, although it is best to avoid such conditions for biological and cost reasons – too much rain washes away baits and the area requires rebaiting.

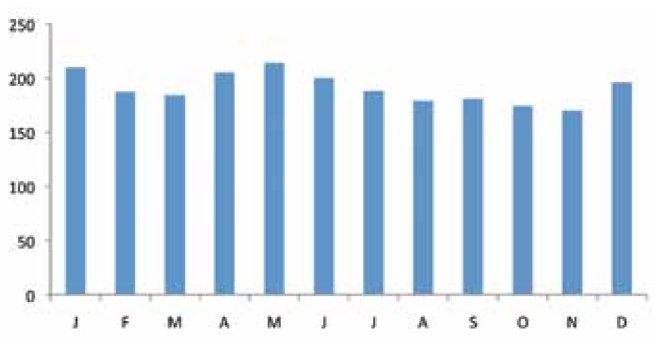

Figure 7. *Monthly average precipitation in mm (1960 to 2003) after Le Roux (2008).*

There is a tradeoff between baiting beginning in late May when mice stop breeding and peak numbers begin to decline as the *per capita* food is lowest, and baiting beginning in March when the weather is more suitable for flying and days are longer. If the operation can only deploy a few helicopters it might be better to start the baiting in March – having taken note of the outcomes from such timing in South Georgia where the planners had no choice but to avoid winter with deep snow a certainty. However, if four or more helicopters can be deployed (getting them to the island may be a constraint) it might be better to start in late May. I assume helicopters such as the Eurocopter AS350 Squirrel will be specified in a tender, and thus optimal coverage per flying hour achieved.

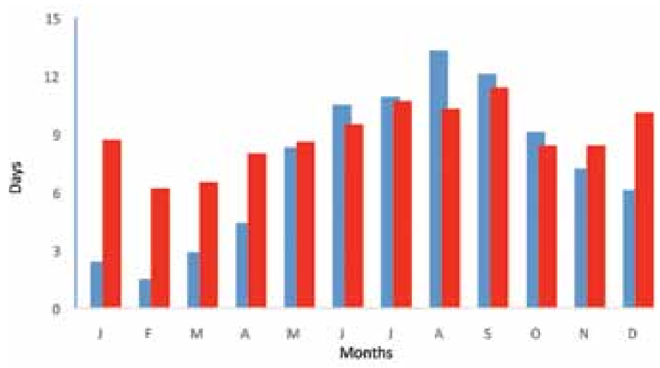

Figure 8. *Mean number of days with snow (blue bars) and gales over 55 km/h (red bars) at Transvaal Cove during the 1960s (after Schulze 1971).*

RISKS TO NON-TARGET SPECIES

The birds possibly at risk of primary (eating baits) or secondary (eating mice or other animals that have eaten baits) poisoning on Marion Island are Southern Giant Petrel *Macronectes giganteus*, Northern Giant Petrel *M. halli*, sub-Antarctic Skua, Kelp Gull and Lesser Sheathbill.

1. Evidence of risk to birds from other eradication projects using aerial baiting

Macquarie Island: The above species (other than sheathbills which are not present) were killed in the Macquarie Island project (Parks and Wildlife Service 2014). About 8% of the island was baited in 2010 after which dead birds were collected. Up to 90% of the rabbits were removed in February 2011 using the rabbit biocontrol rabbit haemorrhagic disease and then the whole island was baited from May 2011 and dead birds were again collected. If we assume equal search effort per unit area between the two searches and that the area treated in 2010 was representative of the whole island with respect to use by birds, the risk to non-target species appears to have declined by about 90% suggesting the birds were targetting rabbit carcasses and not dead rodents (Table 6). In fact the benefit of removing most rabbits before the baiting was even larger than shown in Table 6 because the search effort was not equal. The initial baiting in 2010 was at the remote end of the island and searching for carcasses was limited, whereas the 2011 baiting over the whole island allowed more intensive searches to be made - four people over three months, plus searches from a helicopter (Springer & Carmichael 2012).

Bird species	Deaths/km^2 with high rabbit densities in 2010	Deaths/km^2 with low rabbit densities in 2011
Kelp Gull	37.6	4.7
Northern Giant Petrel	29.9	3.0
Southern Giant Petrel	1.7	0.16
Giant petrel unknown species	0	0.2
Sub-Antarctic Skua	22.5	2.2

Table 6. *Birds found dead on Macquarie Island after a partial and a complete aerial baiting (after Table 2 in Parks and Wildlife 2014).*

Enderby Island: Aerial baiting in February/March 1993 using Wanganui No. 7 bait with brodifacoum on Enderby Island and Rose Island conducted in February/March eradicated rabbits and mice but killed about 40 sub-Antarctic Skuas (66% of the population). This was assumed to have been by primary poisoning, rather than secondary poisoning from dead rabbits or mice because of the presence of green dye in their faeces (Torr 2002). However, it is also possible that the skuas ate freshly killed rabbits' guts and obtained the dye from this secondary source (my interpretation). The skua population has subsequently recovered to pre-poisoning levels with 52 birds being counted in 2000/01 (Torr 2002).

Campbell Island: Aerial baiting, a single drop of 6 kg/ha of Pestoff 20R using three Bell JetRanger helicopters, in July 2001 on Campbell Island eradicated Norway rats. Casual searches for non-target victims were made after the baiting and found 10 dead gulls (Kelp Gulls *Larus d. dominicanus* and Red-billed gulls *L. novaehollandiae*, as well as some exotic species. No sub-Antarctic Skuas were present in July and no dead giant petrels were found (McClelland 2011).

Saint Paul Island: The aerial baiting on Saint Paul Island resulted in no observed deaths among the few (10 to 12) sub-Antarctic Skuas present (Micol & Jouventin 2002).

Palmyra Island: This atoll consists of 24 low coral islets covering 232 ha and lies at 5ºN in the Pacific Ocean. Two aerial drops of a bait containing 25 ppm of brodifacoum were made in June 2011 when 80 and 75 kg of bait per hectare was sown to eradicate Ship Rats – the high sowing rates were to counter bait uptake by land crabs (Pitt *et al.* 2015). Extensive sampling for residues was made in freshwater, seawater, soil, fish and birds found dead after the operation and of some live invertebrates and reptiles collected. Brodifacoum was detected in soils (in fact pre-baiting soils had residues from past control of the rats around human habitations), but only in one of 10 freshwater samples and none of 36 seawater samples. Residues were found in all marine mullet found dead, and in most crabs. Most terrestrial and shore birds such as curlews, turnstones, plovers and tattlers found dead had residues consistent with brodifacoum poisoning being the cause of death, but marine birds such as noddys did not contain residues. Most living ants and cockroaches sampled had residues as did the geckos that presumably ate them (Pitt *et al.* 2015).

2. Evidence of risk to birds from field experiments

Antipodes Island trials: Non-toxic Pestoff 20R 10 mm baits with the bait marker pyranine and dead mice were used on Antipodes Island to assess the risk of future toxic baiting to northern giant petrels (Elliott *et al.* 2015). In July 2013, two piles of six dead mice were placed in a giant petrel colony (of about 20 birds) at the start of their breeding season, and 23 dead mice were placed along transects across and outside the colony. At each pile of mice, 30 – 40 non-toxic baits were also placed. The fate of the mice and baits were checked after a few days using motion-triggered camera traps. Results showed mice were responsible for moving the baits – all were gone after four days. The petrels removed none of the dead mice and ignored the baits – as did sub-Antarctic Skuas and

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Teams of scientists have studied the biology and demographics of albatrosses at Marion Island since the 1960s.

Kelp Gulls which 'showed little interest in dead mice' (Elliott *et al.* 2015).

Marion Island trials and observations: Six caged Lesser Sheathbills were offered non-toxic Pestoff 20R baits either plain or dyed with one of four colours and dead mice in a cafeteria experiment in August 2006. The birds investigated the pellets but none ate any of the pellets once they had become moist and lost some integrity (Wanless *et al.* 2010). This would suggest that primary poisoning will not be a problem for sheathbills. However, most Greater Sheathbills *Chionis albus* disappeared after the baiting on South Georgia and it has been suspected that primary poisoning was at least partly to blame (Keith Springer pers. comm.), and a similar result (no interest by caged birds) was found for Gough Island Moorhens *Gallinula comeri* yet free-ranging moorhens did eat part or all of baits presented (Wanless *et al.* 2010). No free-ranging sheathbills were exposed in this trial. Free-ranging sub-Antarctic skuas at a communal roost on Gough Island showed no interest in baits but evidence from other field trials showed they did consume baits (Wanless *et al.* 2010). In contrast the caged sheathbills on Marion Island all avidly ate dead mice – suggesting they recognised them as food and would be at significant risk from secondary poisoning. Later trials with free-living sheathbills and skuas on Marion island (and with moorhens and skuas on Gough Island) showed a near-complete uptake of mice offered to the birds (John Cooper pers. comm.). Dead mice were ignored when offered to incubating northern giant petrels on Marion Island and to incubating southern giant petrels on Gough Island (John Cooper pers. comm.). Ten regurgitated pellets from Marion Island Kelp Gulls were dissected in May 2015 and eight contained mouse hair (Bruce Dyer pers. comm.).

3. Seasonal presence of birds on Marion island

The two main Marion Island species at risk of primary or secondary poisoning, the lesser sheathbills and kelp gulls are permanent residents on the island. Terrestrial predators (skuas and giant petrels) are at risk from secondary poisoning but most individuals are absent from the island at some times of the year. All other species are not at risk from the poison but may be disturbed (especially when breeding) by the helicopters during the baiting, or subsequently if the machines are used, for example, to search for non-target casualties (Table 7).

4. Period of risk from baits and poisoned animals

The cereal baits that remain uneaten will disintegrate with rainfall. A trial on Antipodes Island in July 2013 showed Pestoff 20R baits were wet and slightly swollen but retained their shape and colour after 13 days – no data on rainfall were given (Elliott *et al.* 2015). A similar condition of Pestoff 20R baits was reported after 21 days and several heavy rainfall events in a trial on Little Barrier Island, northern New Zealand (Greene & Dilks 2004). Neither of these trials is adequate to predict what will happen to uneaten baits on Marion Island, but they do indicate that baits do not decay (and thus do not become harmless to mice or non-target animals) quickly. Pestoff 20R baits on Little Barrier Island, New Zealand, had 'nearly completely disintegrated' after 100 days (Fisher *et al.* 2010).

Mice that contain brodifacoum present a risk to predators and scavengers. The time to death of mice that consume a lethal dose of Pestoff 20R ranged from 0 to 16 days (mean = 5.5 ± 2.5 days) (Cuthbert *et al.* 2011). Therefore, we can assume some risk from temporarily living mice to predators for at least 16 days – probably longer given the results from O'Connor & Booth (2001). In the field, a few mice take a long time to die. On Maud Island (New Zealand), brodifacoum baits were laid in late July and early August and two mice with bait in their stomachs were trapped on 19 August and two with high (and supposedly lethal) levels of brodifacoum on 23 September. Bait was still available in September so it was not clear whether these animals were resilient to brodifacoum or simply late feeders. DNA evidence showed they were not immigrants (Elaine Murphy pers. comm.).

Mice that die on the surface also present a risk to scavengers, and whereas most are likely to die underground (66% in the trails in wheat fields in Australia (Brown & Singleton (1998), and over 95% on South Georgia (Keith Springer pers. comm.) this leaves plenty of potential risk to scavengers. On Marion Island in April-May, dead mice remained intact, if a little decrepit, after 20 days (J. Parkes unpubl. data). It might be possible to search for and remove mouse carcasses (around day five after the baiting when most mice will die) to mitigate some of the risk. This would be impractical over most of the island but might be possible at a few small priority sites, if they can be identified.

Therefore, risks from secondary poisoning to birds such as sheathbills and gulls are likely to persist for at least three weeks after baiting, and so any captive birds could not be released for at least this time. The risk period could be determined by field trials prior to any operation or could be assessed during the operation and captive birds only released once the risk had abated.

5. Baits falling in the sea, lakes and streams

Mice are at high densities around the coast and so baits will have to be distributed right to the high tide mark to be sure all are put at risk. Some baits will therefore fall into the sea. This has often caused concern among stakeholders and resulted in research to see if the contamination has any significant effects on marine life (e.g. Empson & Miskelly 1999, Howald *et al.* 2005, Primus *et al.* 2005). Similarly, baits will fall into waterways and lakes on Marion Island including the water catchment used in the meteorological station and at field huts for drinking and other domestic use.

Fisher *et al.* (2010) reviewed several projects where brodifacoum baits were sown and where some fell into the sea or streams. They showed that no brodifacoum was detected in 225 stream water samples in three projects from New Zealand, and no residues were found in shellfish sampled from the two island sites or from pilchards or dolphins found dead on beaches in the vicinity (Hauraki Gulf around Rangitoto/ Motutapu Islands where the baiting took place). However, of nine dead Little Penguins *Eudyptula minor* found, three had minute residues of brodifacoum in their livers. They had no symptoms of anticoagulant poisoning but were in poor physical condition and the authors concluded they had died of starvation. Where and how the penguins were exposed to brodifacoum is not clear, it may have been from domestic users of rat baits around the highly populated Hauraki Gulf – Little Penguins commonly breed under houses and holiday homes – rather than the eradication project itself, but it does show potential risks exist for this species.

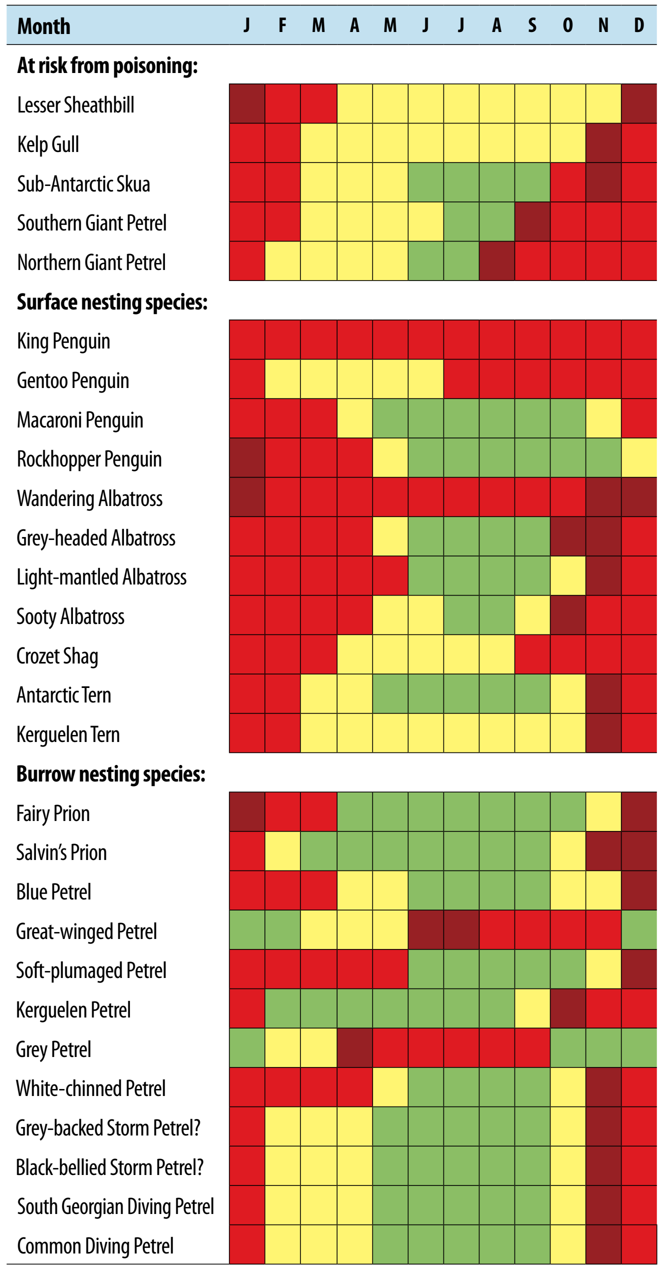

Table 7. Birds present and breeding on Marion Island.
incubating breeding present largely absent
? = breeding not proven.

Two cases of mass contamination of water by brodifacoum baits have been recorded. In 2001, 16 tonnes of Pestoff 20R baits were discharged into the sea in New Zealand when the transporting truck crashed. The contaminated area was localised to about 100 m² and brodifacoum was rapidly removed from water samples taken from the site. Residues in shellfish and crustacea species taken from the site took 31 months to decline to levels below the method detection limit (Primus *et al.* 2005). In 2010, about 700 kg of Pestoff 20R baits fell into a lake when being transported by helicopter. In the month following the accident no residues of brodifacoum were detected in water, sediment, benthic invertebrates, eels or birds (Fisher *et al.* 2011).

MITIGATING RISKS

1. Holding birds in captivity, reintroduction or natural recolonisation

The risks from primary and secondary poisoning to birds can be mitigated in one of three ways (or a combination of them). Sufficient individuals may be caught and held in safety until the risk passes, new birds may be translocated from Prince Edward Island, or the population might recover naturally from immigrants or residents returning to the island.

Wanless *et al.* (2010) held six Lesser Sheathbills in captivity on Marion Island for four days and showed most lost body mass and one was overly stressed and was released. They readily ate canned pet food and mice so it should be possible to hold them until risks from uneaten baits and poisoned mice are absent (at least 20 days). Alternatively (or in addition) birds might be captured on Prince Edward Island and transferred to Marion Island after the risks have gone. It appears the two islands have separate populations so this should only be considered in case of a failure with the captive option – and suggests natural recolonisation is not likely.

Kelp Gulls are of a sub-species shared between the Prince Edward Islands, Crozet Islands and the Kerguelen Archipelago and may well recolonise Marion Island naturally even if all the Marion Island residents were killed. However, it would be prudent to capture and hold some of the resident birds – a bit more difficult than for the sheathbills (which are easily caught with hand nets) but possibly the use of foot-tangling snares set at their roosting places or drop-traps over nests should work.

A June baiting would see most of the sub-Antarctic Skuas off the island and so not at immediate risk. However, skua mortality on Macquarie Island was observed when the birds had returned to the island in the spring, three months after the baiting, and continued for several months (Keith Springer pers. comm.) presumably as they scavenged dead rabbits or rodents. In contrast, a February/March baiting would put them at higher risk – actually this risk is a bit unpredictable given the outcomes on other islands. It is certain that even if most were killed they would soon repopulate Marion Island by natural immigration, so no actions are essential. The giant petrels may suffer some losses from eating poisoned mice, but as with the skuas the population is likely to recover.

3. Mitigating the effects of the helicopters on birds and seals

Helicopters or other aircraft may cause panic and stampedes in colonial species. This apparently occurred in a King Penguin colony on Macquarie Island when a Lockheed C-130 Hercules aircraft was flying nearby (Rounsevell & Binns 1991). However, disturbance is generally not so catastrophic (Southwell 2005) and rules about flying height have been developed to mitigate partially this problem (Cooper *et al.* 1994, Harris 2005) and need to be considered in any operational plan for Marion Island. For example, Nansikombi (2004) showed less disturbance to the birds on Dassen Island, South Africa when the helicopters flew above 300 m, and a 500-foot (*c.* 150 m) flying height was used for both the Macquarie and South Georgia projects without unacceptable disturbance to the penguins (Keith Springer pers. comm.).

3. Mitigating baits in water

Apart from not deliberately dropping baits in the sea and large lakes there is little that can be done to mitigate this effect. Some projects have restricted the bait swath to avoid the tide mark, but this project failed to eradicate the target rodent – although probably not because of this factor (Parkes & Fisher (2011). Other projects have attached a lateral deflector to the bait sowing bucket in an attempt to direct baits towards the land when flying along the tide mark (Samaniego-Herrera *et al.* 2009).

It is possible to avoid much bait falling into the larger lakes on Marion Island by careful flying. Key waterways and streams are more difficult to avoid but I think there is little environmental benefit of doing this. However, it may be that the perceptions of the meteorological station staff around contamination of their water supply will need to be considered. On Macquarie Island, the water supply was disconnected before aerial baiting and then baits were removed from the stream margins before the water was reconnected (Keith Springer pers. comm.).

ARE THERE LIKELY TO BE ADVERSE EFFECTS IF THE MICE ARE ERADICATED?

The conservation benefits of eradicating the mice are likely to far outweigh the costs, but it is possible that exotic plants whose seeds are now eaten by mice will become more invasive (although the opposite is true if mice are dispersing seeds), and exotic invertebrates preyed upon by the mice might increase at the expense of native prey. Of course the only way to test these predictions at a practical scale is to eradicate the mice and, short of reintroducing them if adverse effects are evident, accept either the outcome or manage those that are manageable.

VALIDATING SUCCESS OR REACTING TO FAILURE

The probability of success or failure can be judged immediately after an aerial baiting only if a detection system can be deployed over the whole island (Samaniego *et al.* 2013), but this is impossible for an island the size of Marion. Of course if a mouse is detected some time after the baiting then failure is the likely outcome and even if the mouse is killed it is probable that other undetected survivors exist, so failure is absolute and the only reaction is to start again – if the funders are willing. The usual way to judge success is to wait for several years (usually two) to allow any survivors to reproduce and repopulate the island, and if no mice are found during searches in likely places, success is then declared (Broome *et al.* 2014). It would be worth taking some tissue samples from the mice in case mice are discovered on the island in the future – are they relict survivors or new invaders?

INDICATIVE COSTS AND CONTRACTING SUGGESTIONS

INDICATIVE BUDGET

I cannot develop a complete or even accurate budget for a potential Marion Island mouse project. I began to do so, but the results might be quite misleading. The main costs would be bait (at about R35 000 per tonne delivered to Cape Town), manufacture of suitable bait pods to transport the baits to the island, helicopters and bait buckets, the costs of getting up to four helicopters to the island with their support staff, the costs of ground staff to support loading baits, maintaining captive birds, and many others.

CONTRACTING OPTIONS

Aerial baiting for eradication projects requires highly skilled operators. One way to ensure decisions around acceptance of tenders to conduct this part of the project is to require bidders to submit bids in two sealed components. The first is essentially the *curriculum vitae* of the bidder to show they have the necessary skills and experience to do the work (a critical requirement as they cannot 'learn on the job'). The terms of reference for the advertised contract need to be carefully written to attract potential bidders and discourage those who cannot meet the specifications. The second component is price, and must only opened once a short list of bidders is assembled. This process was followed for the major UNDP-funded feral goat *Capra aegagrus hircus* eradication project in the Galapagos Islands (Parkes & Aguirre-Muñoz 2006). Two types of contracting arrangements are then possible in pest eradication projects – performance-based contracts or simple fee-for-service contracts.

Performance-based contracts for eradication projects pay some final part of a fixed sum only if eradication is achieved. This drives efficiency as the sooner the task is completed the more profit accrues to the contractor. This system was followed for the eradication of feral pigs *Sus scrofa* on Santa Cruz Island in California. It benefited the funder, the Nature Conservancy, as it ensured a quick outcome which avoided costly ongoing litigation and benefited the contractor as it optimised their profit (Morrison *et al.* 2007). Judging whether the contractor's claims of success are true and they should be paid requires independent assessment (Ramsey *et al.* 2009) but allows the funder to quantify their risks of stopping the project and falsely declaring success or investing in more surveillance (Ramsey *et al.* 2011). This type of contracting has not been used in the one-hit eradication projects typified by aerial baiting because contractors might be reluctant to buy into the risks of failure, and of course confirmation of success takes several years on a large island.

Fee-for-service contracts are more usual and can simply undertake a set of tasks for a fixed fee, such as for most aerial eradications, or the fee can be increased as the project proceeds. Under this system the risks are borne by the funder.

Some eradication project managers and contractors have considered taking out insurance against the costs of failure, but to my knowledge none have proceeded with this, presumably because of the expense.

ACKNOWLEDGEMENTS

I thank John Cooper and Ross Wanless for their hospitality and support in Cape Town. I thank the staff of the Marion 71 and 72 Overwintering Teams and the South African Department of Environmental Affairs for logistic support. I also thank Peter Ryan for comments on an early draft of the report, and Ben Dilley, Bruce Dyer, Niek Gremmen, and Stefan Schoombie and many Marionites for helpful discussions while on Marion Island. Elaine Murphy, Sue Robinson, James Russell and Keith Springer provided data on other projects aimed at mice, while John Cooper and Ross Wanless provided comments and editorial assistance with the draft, and Keith Springer and James Russell provided input as referees of the report.

Mouse-free Prince Edward Island has no base or permanent structures, and visits to the island are highly restricted and subject to stringent biosecurity measures.

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APPENDICES

APPENDIX 1. THE PLACE OF A FEASIBILITY STUDY IN A PEST MANAGEMENT PROJECT

The role of a feasibility study is to set out the strategic and tactical options to manage a pest and describe the issues and problems that might determine which strategy (eradication, sustained control or do nothing) a decision-maker would have to resolve before committing to further action (Table 8).

This report is therefore not a detailed justification for the proposed eradication of Marion Island mice; that is provided by proponents (Angel & Cooper 2011) and in the management policy for the Prince Edward Islands (Chown et al. 2010). However, some reconsideration of the evidence provided to justify an eradication attempt is given in the background to this feasibility report because of new evidence and new interpretations of evidence of impacts that affect my view on the urgency of action, and partly to help predict whether there might be any negative consequences if the mice are eradicated. This feasibility report also recommends some research needs, but has not designed the experiments or monitoring required.

The report is also not an operational plan, although it does suggest some options relevant to operational matters such as contracting systems. A detailed operational plan can only be developed after the research issues are resolved, a decision to fund the eradication is made, a governance and management structure set in place and contracts tendered.

Project phase	Key question addressed	Who asks?	Who answers?	Who decides to proceed?	Main set of widerstakeholders
Project selection and justification	Is there a problem worth fixing?	Beneficiaries	Proponents, advocates	Beneficiaries, proponents	Anyone affected by the pest or the management proposed
Feasibility	What are the strategic options to fix the problem?	Proponents and potential funders	Independent analysts	Funders	Potential project governance team, stakeholders who can say no
Project design	How is the project to be governed, and managed?	Governance team	Project team leader	Funders and proponents	Potential operational team
Operational plan	How will the project be delivered?	Project team	Operational manager	Governance team via the project leader	Stakeholders that may be affected by the management
Implement the project					
Assessment	Was the problem fixed?	Beneficiaries, governance team	Depends on the complexity of the questions	Beneficiaries, funders	All stakeholders
Sustain the project - or stop and declare success, failure, or need for review					

Table 8. *A typical project management process or cycle (modified from Pacific Invasives Initiative project cycle (www.issg.org/cii/pii/).*

APPENDIX 2. ISLANDS ON WHICH ERADICATION OF HOUSE MICE HAS BEEN ATTEMPTED

Island	Area (ha)	Country	Latitude	Year	Other pests eradicated (at the same time or in past)*	Refs	Notes
Mice eradicated as only rodent present at the time of the attempt							
Coal	1189	New Zealand	46° 07´S	2008	Stoat, Red Deer	1	July - Aug, 2 aerial bait drops of 8 + 8 kg/ha, Pestoff 20R, brodifacoum
Enderby	710	New Zealand	50° 29´S	1993	European Rabbit,feral cattle	2	Feb, 2 aerial bait drops, Wanganui No. 7, 5-10kg/ha, brodifacoum
Blumine	377	New Zealand	41° 10´S	2005	Domestic Pig, Stoat, Red Deer	3	Aerial, Pestoff 20R, brodifacoum
Bugio	350	Portugal	32° 29´N	2008	European Rabbit, feral goat	4	Hand broadcast from helicopter, brodifacoum.
Selvagem Grande	270	Portugal	30° 09´N	2003	European Rabbit	5	Aug – Mar, bait stations at 12.5 m, Talon and Klerat wax blocks, brodifacoum
Mana	217	New Zealand	41° 05´S	1989	Rat found and removed in 2011	6	Various ground methods, then aerial, Talon 20P in Sept
Mou Waho	140	New Zealand	44° 33´S	1996	Stoat	7	May, Aerial, Talon 20P at 10 kg/ha. Op costs NZ$12,238
Ilheu de Cal	140	Portugal	33° 00´N	2013	European Rabbit	4	Hand broadcast on 12.5 x 12.5 m grid, cereal pellets and wax blocks
Rotoroa	90	New Zealand	36° 49´S	2011	Norway Rat in 2005	8	Jul-Sept-Oct, 2011. Aerial Pestoff small baits in 3 bait drops (15 + 15 + 9kg/ha)
Adele	88	New Zealand	40° 58´S	2007	Stoat	9	Mice and rat reinvaded 2015. Jul-Aug, aerial in 2 baitings at 8 + 4kg/ha. Pestoff 20R, brodifacoum
Quail	88	New Zealand	43° 37'S	2009	Ship Rat, European Rabbit, European Hedgehog, Stoat	10	Pestoff 20R 2 sowings on 26 July and 6 Aug. At risk of reinvasion
Montague	82	Australia	36° 15´S	2007	European Rabbit, goat	11	Jul, Aerial Pestoff 20R in 2 baitings at 12 + 6 kg/ha with 5mm and 10mm Pestoff 20R with brodifacoum
Varanus	80	Australia	20° 39´S	1997		12	Wheat with pindone and wax blocks with brodifacoum on 20 x 20m grid over months succeeded
Rona	60	New Zealand	45° 29´S	2007	Stoat	13	Jul-Aug, aerial with 2 bait drops of 8 + 4 kg/ha of Pestoff 20R 10 days apart. One mouse trapped March 2010 but no more
Chao	44	Portugal	32° 34´N	1996		4	Hand broadcast on 12.5 x 12.5 m grid, cereal pellets and wax blocks
Gombrani	36	Mauritius	19° 46´S	1995		14	Hand broadcast, brodifacoum
Cat	33	Mauritius	19° 46´S	1995		14	Hand broadcast, brodifacoum
Motuketekete	29	New Zealand	36° 28´S	2014		14	Outcome pending
Bridled	22	Australia	20° 38´S	1997		12	Wheat with pindone and wax blocks with brodifacoum on 20 x 20m grid over months succeeded
Cocos	21	Mauritius	19° 43´S	1995	Musk Shrew	15	Nov, Pestoff 20R bait stations at 10 x 10m. 10 kg/ha.
Moturekareka	19	New Zealand	36° 28´S	2014		14	Outcome pending
Allports	16	New Zealand	41° 14´S	1989	Common Brushtail Possum	16	July, 81 bait stations, Storm, flocoumafen
Patiti (Banded)	13	New Zealand	38° 16´S	2013	Ship Rat, Norway Rat	14	Rats eradicated 2004
Tonga	9	New Zealand	40° 53´S	2007		9	Jul-Aug, aerial in 2 baitings at 8 + 4kg/ha. Pestoff 20R, brodifacoum
Plaza Norte	9	Ecuador	00° 34´S	2011		14	Aerial, brodifacoum
Sables	9	Mauritius	19° 42´S	1995		15	Nov, Pestoff 20R bait stations at 10 x 10m. 10 kg/ha
Allen Cay	8	Bahamas	23° 43´N	2012	s	17	May, hand broadcast, brodifacoum
Three Bays	5	Australia	26° 33´S	2012		14	No data
Te Haupa (Saddle)	5	New Zealand	36° 30´S	2008	Norway Rat	18	Rats eradicated by 1975. Mice by trapping and bait stations (Pestoff wax blocks) and Pestoff 20R on cliffs
Tropicbird	4	Mauritius		1995		19	Hand broadcast, brodifacoum
Flat	4	Mauritius		1995		15	Hand broadcast, brodifacoum
Fisherman	4	New Zealand	40° 59´	2007		9	Jul-Aug, aerial in 2 baitings at 8 + 4kg/ha. Pestoff 20R, brodifacoum
Catherine	3	Mauritius	19° 44´S	1995			Hand broadcast, brodifacoum
Pajaros	3	Mexico	22° 21´N	2011		14	Hand broadcast, brodifacoum. Outcome pending

Island	Area (ha)	Country	Latitude	Year	Other pests eradicated (at the same time or in past)*	Refs	Notes
Motutapu	2	New Zealand	41° 14´S	1989		16	Aug, Bait stations with Storm flocoumafen
Papakohatu (Crusoe)	1	New Zealand		1997		20	Bait stations, trapping, brodifacoum
Beacon	1	Australia	28° 28´S	1997		12	Bait stations, pindone and brodifacoum
Mice eradicated as part of rat or rabbit eradication							
South Georgia	103 000	UK	54° 23´S	2015	Norway Rat, Reindeer	21	Outcome pending
Macquarie	12 785	Australia	54° 36´S	2013	Ship Rat, European Rabbit, feral cat	22	May-Jul, 2-3 bait drops, Pestoff 20R, brodifacoum
Rangitoto/Mo-tutapu	3830	New Zealand	36° 47´S	2009	Ship, Norway & Polynesian Rats, European Rabbit, Stoat, Common Brushtail Possum, European Hedge-hog, Brush-tailed Rock Wallaby, feral cat	23	Jun, Jul, Aug, 3 aerial bait drops. Pestoff 20R at 22.1, 9.5, and 6.6kg/ha with brodifacoum. All eradicated
Dragonera	362	Spain	39° 35´N	2011	Ship Rat, European Rabbit	24	Jan - Feb, 2 aerial bait drops (no GPS), 14 kg/ha, brodifacoum.
Maud	309	New Zealand		2014	Ship Rat, Stoat	25	Aerial Pestoff 20R. Outcome pending
Flat	253	Mauritius	19° 53´S	1998	Ship Rat, feral cat	15	Sept-Oct, Pestoff 20R bait stations at 25 x 25m, brodifacoum
Chateau	220	France	49° 30´S	2002	Ship Rat	26	Aerial baiting
Fregate	219	Seychelles	04° 35´S	2000	Norway Rat, feral cat	27	3 aerial bait drops in 2000, 8 and 12 June, 7 July. 13.8 + 9.3 + 11.9 kg/ha
Indian	217	New Zealand	45° 46'S	2010	Ship Rat	28	2 aerial baitings
Motuihi	195	New Zealand	36° 48´S	1997	Norway Rat, European Rabbit, feral cat	29	July-Aug, 2 bait drops of Talon 7-20 brodifacoum
Denis	143	Seychelles	03° 48´S	2002	Ship Rat, feral cat	14	Repeated with bait stations and succeeded for rats and mice
Mokoia	133	New Zealand	38° 04´S	2001	Norway Rat	31	Mouse eradication failed in 1989 and 1996, succeeded 2001, Aerial brodifacoum plus bait stations
Fajou	120	France	16° 21´N	2001	Ship Rat, Small Indian Mongoose	32	Rat failed, mongoose eradicated. Bromadiolone trail + trapping. Outcome for mice unclear
Kayangel	112	Palau	08° 05´N	2011	Ship Rat, Polynesian Rat	33	Rat eradication failed (DIISE). Not clear if mice were ever present
Pickersgill	103	New Zealand	41° 09´S	2005	Ship Rat	3	Aerial, Pestoff 20R, brodifacoum
Browns	58	New Zealand	36° 44´	1999	Norway Rat, European Rabbit	34	Sept, 1 bait drop, Wanganui No. 7 with bromadiolone
Rasa	57	Mexico	28° 49´N	1995	Ship Rat	35	Bait stations 25 x 25m grid wax blocks with brodifa-coum
Flatey	54	Iceland	66° 10´N	1971	Norway Rat	14	Unknown
Motutapere	45	New Zealand	36° 46´S	1994	Ship Rat	3	Rat failed
Ohinau	43	New Zealand	36° 43´S	2005	Polynesian Rat	3	
Crab	42	Mauritius		1995	Ship Rat	14	Hand broadcast, brodifacoum
Cocos	37	USA	13° 14´N	2009	Polynesian Rat	36	Mice outcome pending
Surprise	24	France	18° 29´S	2005	Ship Rat	37	Wax blocks on 5 x 5 m grid repeated, bromadiolone
Rimariki	22	New Zealand	35° 25´	1989	Norway Rat	38	Rat still present?
Plaza Sur	21	Ecuador		2012	Freal goat	39	Mice pending
Muertos	15	Mexico	22° 25´N	2011	Ship Rat	40	Hand broadcast, brodifacoum. Outcome pending. ? rats present
White (Sandy) Cay	15	Bahamas	23° 24´N	1998	Ship Rat, Racoon	14	
Piana	14	Italy		2010	Ship Rat	41	Hand broadcast , brodifacoum
Proratora	5	Italy		2010	Ship Rat – reinvaded	41	Hand broadcast , brodifacoum
Guineafowl	3	Mauritius		1995	Ship Rat	14	Hand broadcast, brodifacoum
Whenuakura	3	New Zealand	37° 13´S	1983	Norway Rat	42	Bromadiolone
Cavalli	2	Italy		2010	Ship Rat – reinvaded	41	Hand broadcast , brodifacoum
Moturemu	5	New Zealand	36° 25´S	1992	Norway Rat	3	Rat failed
Taere'ere	4	France	15° 00´S	2004	Polynesian Rat	43	No data

Island	Area (ha)	Country	Latitude	Year	Other pests eradicated (at the same time or in past)*	Refs	Notes
Mice only rodent attempted but failed:							
Mokoia	133	New Zealand	38° 04´S	1996		44	Aerial baiting with Wanganui No. 7, at 10 kg/ha
Varanus	80	Australia	20° 39´S	1993		12	1080 in wheat
Stoll	60	France	49° 45´S	2003		14	1 bait drop
Mice eradication failed as part of rat or rabbit eradication:							
Australia	2100	France	49° 28´S	2005	Ship Rat	43	2 bait drops 80 m swaths of 32 tonnes. Rats eradicated, mice outcome unclear
Deserta Grande	1000	Portugal	32° 32°N	1996	European Rabbit	45	Wanganui No 7. 20 tonnes in bait piles on 25 x 25m grid and hand or helicopter broadcast
St Paul	900	France	38° 42´S	1997	Ship Rat, European Rabbit	46	Jan, aerial with 1 bait drop of 13.5 tonnes plus 0.3 tonnes hand broadcast in gaps. Pestoff 20R, Rats and rabbits eradicated
Moules	400	France	49° 07´S	2005	Ship Rat	43	2 bait drop, rats eradicated, mice outcome unclear
Curieuse	286	Seychelles	04° 16´S	1996	Feral cat, Ship Rat (failed)	27	2 bait drops 12.9 + 10.1 kg/ha, 5 – 13 July.
Pomona	262	New Zealand	45° 30´S	2007	Ship Rat, Possum Stoat, Red Deer	13	Jul-Aug, aerial with 2 bait drops of 8 + 4 kg/ha of Pestoff 20R. 80 mice trapped since 2010. Reinvaded?
Bird	210	Seychelles	03° 42´S	1996	Ship Rat, European Rabbit	7	Bait stations, brodifacoum
D'Arros	150	Seychelles	05° 25´S	2003	Norway Rat, feral cat	47	
Denis	143	Seychelles	03° 48´S	2000	Feral cat	27	Failed aerial baiting for both ship rat and mice
Mokoia	133	New Zealand	38° 04´S	1989	Norway Rat	44	Bait stations
Tromelin	97	France	15°53´S	2005	Norway Rat	48	Pestoff 20R broadcast (10 kg/ha) and rodent blocks in bait stations
Rotoroa	90	New Zealand	36° 49´S	1992		8	Norway Rat and mice failed
Rotoroa	90	New Zealand	36° 49´S	2005	Norway Rat	8	Norway Rats eradicated using 50 x 50 m bait stations
Quail	88	New Zealand	43° 37´S	2002	Ship Rat, European Rabbit, European Hedgehog, Stoat	10	Bait stations 40 x 40 m
Buck	80	USA	17° 47´N	2000	Ship Rat	49	Rats targeted with bait stations with diphacinone – too wide for mice which appeared after rats eradicated
Limestone	38	New Zealand	35° 47´S	1996	Norway Rat	50	Aerial brodifacoum
Limestone	38	New Zealand	35° 47´S	1997		50	Aerial brodifacoum
Limestone	38	New Zealand	35° 47´S	1998		51	Aerial brodifacoum
Limestone	38	New Zealand	35° 47´S	1999		3	Bait stations. Mice again present in 2015, unclear whether survivors or invaders
Venecia	13	Ecuador	00° 32´S	1980	Ship Rat, feral cat	14	Rat failed, cat eradicated
Hokianga	8	New Zealand	38° 01´S	2006	Ship Rat	3	Pindone in bait stations
Haulashore	6	New Zealand	41° 16´S	1991	Ship Rat	52	Brodifacoum in bait stations
Hauturu (Clark)	3	New Zealand	37° 12´S	1994	Norway Rat	3	Bait stations and hand broadcast brodifacoum

*Full names of mammals mentioned in the appendix but not in the text.

Brush-tailed Rock Wallaby *Petrogale penicillata*
Common Brushtail Possum *Trichosurus vulpecula*
European Hedgehog *Erinaceus europaeus*
Musk Shrew *Suncus murinus*
Racoon *Procyon lotor*
Small Indian Mongoose *Herpestes auropunctatus*

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APPENDIX 3. SUMMARY OF ALTERNATIVE MOUSE CONTROL TECHNIQUES

Alternative toxins

An alternative anticoagulant, diphacinone, has been used in some projects partly because it reduces risks to birds since it does not accumulate in the tissues of rodents and is much less toxic to birds that eat baits or poisoned rodents (Erickson & Urban 2002). Its disadvantage over brodifacoum is that a rodent has to eat baits every day for many days to obtain a lethal dose (Fisher 2005). Diphacinone baits have been successfully deployed in bait stations against rats, especially in the Falkland Islands (Poncet et al. 2011), but have failed in five out of six cases when the baits are applied aerially (Parkes et al. 2011). The only attempt against mice using diphacinone (in bait stations targetting rats) killed the rats but not the mice (Witmer et al. 2007).

Acute toxins such as sodium monofluoroacetate (compound 1080) or zinc phosphide are used in sustained control of rodents in New Zealand and Australia and can result in a high percentage kill – but rarely if ever 100% (e.g. Nugent et al. 2011). Acute toxins cause mice that nibble a bait without immediately receiving a lethal dose to feel ill and become anorexic and stop feeding, and worse associate the symptoms with the bait and refuse to eat more of it. They are of no use in eradication projects that attempt to kill all the target animals in one control event.

ROSS WANLESS

A house mouse at Gough Island investigates a marked bait pellet in a field trial.

Ground-based control

Ground-based methods, such as using toxic baits in bait stations have been used with success against rats (e.g. Thomas & Taylor 2002) but up to 2007 over half attempts against mice failed when bait stations were used (Parkes et al. 2011). In any event the logistics of deploying and maintaining the baits in grid set at no more than 25 × 25 m over Marion Island is utterly impractical. Trapping has never been used, by itself, to eradicate mice and is also impractical on an island the size of Marion.

Immuno-contraception

The Australians attempted to use a genetically engineered mouse virus, a cytomegalovirus, that express proteins that act as immunological blocks to target fertility (Tyndale-Biscoe 1994). Pen trials showed the virus did render a high proportion of female mice sterile, but the engineered virus would not easily transmit to other mice in the field and the research was curtailed.

Biocontrol

There are plenty of pathogens affecting mice, but none cause sufficient mortality to act as a biocontrol let alone a tool to eradicate mice.

BirdLife South Africa is a registered non-profit, non-governmental organisation (NGO) that works to conserve wild birds, their habitats and wider biodiversity in South Africa, through research, monitoring, lobbying, conservation and awareness-raising actions. It was formed in 1996 when the South African Ornithological Society became a country partner of BirdLife International.

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