A Feasibility Study for the Eradication of House Mice from Gough Island

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Research Report

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Executive Summary

House mice *Mus musculus* were introduced to Gough Island some time in the 19th century, and are known to have adverse impacts on both terrestrial and marine birds and probably on invertebrates and plants. In April 2007, the Royal Society for the Protection of Birds commissioned Landcare Research to assess whether it would be feasible to eradicate mice from the 6,500 ha island, or if not, whether sustained control could mitigate the impacts of mice, or whether nothing should be done until technological advances in control techniques for mice might provide solutions. This report follows a visit to the island by the author between 13 September and 3 October 2007 and builds on an earlier draft report (Brown 2007) that considered rodent eradication from Tristan da Cunha.

Option 1: Eradication

The report aims to answer three questions that any decision-maker would want answered, or at least made transparent, if they were to invest the substantial funds required to attempt eradication of the mice. These questions are:

Is the attempt justified by the potential benefits?

Predation by mice on the chicks of the Critically Endangered Tristan albatross *Diomedea dabbenena* and the Endangered Atlantic petrel *Pterodroma incerta* is a significant component of the threat to these declining species. Predation by mice on the endemic Critically Endangered Gough bunting *Rowettia goughensis* may also be a cause of its limited numbers on Gough Island, compared with larger populations of other bunting species in the Tristan da Cunha group. Predation by mice on endemic invertebrates and seed-predation on endemic plants is substantial (mice eat about 3 tonnes of Gough Island biota per day) but the impact, both direct and indirect, and benefits of mouse eradication for native plants and invertebrates have not been measured.

Is eradication possible given the particular circumstances on Gough Island?

Eradication of mice from Gough Island is possible. However, there are several constraints that will have to be overcome (see below), and there are residual risks of failure even should these constraints be resolved and best practice used in any operations. These residual risks are consequences of the size of the island (being an order of magnitude larger than any previous successful eradication of mice), and the observation that irrespective of scale a higher proportion of eradications aimed at mice have failed than those aimed at *Rattus* species. These risks are addressed in more detail in the report.

What resources and actions are likely to be needed to overcome any risks and constraints identified and then to attempt the eradication?

- Aerial sowing with at least 100 tonnes (8 + 4.5 kg/ha in two sowings about a week apart is the standard protocol used in other successful rodent eradications) of brodifacoum baits during the winter (when mice are not breeding) using Differential Global Positioning System (DGPS) technology and at least three helicopters may put all mice at risk. Issues discussed are (1) the bait type to be used; (2) the potential of caves and lava-tubes and of buildings to act as refuges for mice; (3) the consequences of inclement weather and lack of mechanical loading facilities on the number and type of helicopters used and on

whether a single sowing is sufficient (as on Campbell Island) or whether the precautionary approach of a second application (some 7 to 10 days after the first and sown at right angles to the first) is justified (e.g. by the results of a preliminary non-toxic bait acceptance trial conducted in winter).

- Reinvasion risks are very low (the island is remote and rarely visited by ships) and can be managed to near zero. An on-island rodent contingency plan and the capability to implement it need to be developed – irrespective of whether the mouse eradication proceeds, to manage potential rat invasions.
- The whole endemic Vulnerable Gough moorhen *Gallinula comeri* population is likely to be at risk both directly by eating the baits and certainly from secondary poisoning by eating dead mice. Options to manage this risk are to hold birds in cages on Gough Island, or on Tristan da Cunha for the duration of the risk. The whole Gough bunting population is also at direct (but lesser) risk. The extent of the risk to buntings can be assessed in non-toxic trials and then a judgement made on the extent of mitigation required. Immature Southern (Tristan) skuas *Catharacta antarctica hamiltoni* that remain on the island during winter are at risk from secondary poisoning but this is probably acceptable at a population level and requires no mitigation. No other significant non-target species risks are identified.
- The cost of the operation (including management of non-target risks but excluding any preliminary trials) is likely to be about £1.5 million. This estimate is very crude and depends on guesses at some major costs, such as hiring a ship and the costs of helicopters, which will only become clear later in the planning process.

The improved understanding of the technical systems used in aerial application of bait (e.g. DGPS, sowing buckets, overlapping and multiple baiting to ensure no gaps in bait distribution, pilot skills) and perhaps the absence of rats *Rattus* spp. increase the likelihood of success on Gough Island – irrespective of its size and remote location.

Three constraints exist but all are manageable. First, protection of non-target species (particularly the two terrestrial birds) will need to be implemented. The only way to do this without compromising the eradication is by capturing and holding a proportion of each population in safety. Second, the weather on Gough Island is generally inclement for baiting from helicopters. A trade-off between added cost (of more helicopters) and increased risk (by having to repeat areas at the edges of baited zones when the weather curtails flying or heavy rain or snow ruins recently sown baits) has to be considered. If the weather severely restricts the ability to deliver an ideal double sowing of baits about 10 days apart, then a sub-optimal option is to deliver a single sowing event with increased bait density and decreased swath width. Third, mice living in lava-tubes, caves and in the buildings and infrastructure at the Meteorological Station may not be at risk from aerially-sown baits if some never venture out of the caves or buildings. The latter is easily resolved by hand-baiting in buildings, but the issue of lava tubes and caves may require further testing and additional responses if it proves of concern following further field trials.

There are substantial logistical problems that will need to be solved to attempt the eradication. If funding approval is forthcoming, the early appointment of a Project Manager responsible to a governance entity (e.g. the funding agencies, the Government of Tristan da

Cunha, and perhaps the South African Department of Environmental Affairs and Tourism) is recommended. This management role would be to solve these logistical issues and to manage a system of tenders for the technical delivery components of the work – leading to final approval to proceed from the governance group. An Operational Manager to deliver the on-ground part of the project would need to be appointed once final approvals were made and the responsibilities and accountabilities passed from the Project Manager to the Operational Manager as the project moves from planning to delivery.

Option 2: Sustained control

If critical areas could be identified, e.g. Tristan albatross nesting sites where predation was predictable, it would be possible to reduce local mouse densities at the key times of year by using sustained control techniques. The most effective method would be bait stations with a long-life bait reservoir using an acute toxin, such as zinc phosphide, interchanged periodically with a first-generation anticoagulant such as diphacinone. Both would reduce non-target and environmental persistence risks. These could be applied in a grid of stations at an appropriate scale to reduce *in situ* mouse populations and slow immigration into the core area to be protected. The details of how to intervene with such a system, and thus of the costs, would need to be determined by an adaptive management experiment.

It is unclear whether the achievable scale and intensity of sustained control, which would necessarily be very restricted, would protect sufficient of the widely dispersed Atlantic petrels or buntings to make a difference at a population level, or make much difference to wider ecosystem values affected by mice.

Option 3: Do nothing until technical advances are available

Mouse biocontrol options have been explored among the many viral, bacterial, and parasitic organisms that infect mice, but no effective candidate agent has so far been found that is capable of suppressing mouse populations to the extent required to act as a control on Gough Island.

Research on vectored immunocontraception using an engineered murine cytomegalovirus was conducted in Australia for a decade, but was abandoned in 2006 when the engineered virus was found to have poor transmission rates and thus low potential efficacy at a population level.

Various species-specific toxins are in early stages of investigation, but apart from avoiding non-target issues they offer no advantage, should one be developed for mice, over current toxins such as brodifacoum for eradication or of zinc phosphide or diphacinone for sustained control.

Contents

1 Introduction

House mice *Mus musculus* were introduced to 6,500 ha Gough Island (40ºS 10ºW) some time in the 19th century. They are known to have adverse impacts on native plants, invertebrates, and on both terrestrial and marine birds, in particular on the Critically Endangered Tristan albatross *Diomedea dabbenena* and the Endangered Atlantic petrel *Pterodroma incerta*, both of which have their last breeding strongholds on Gough Island (Cuthbert & Hilton 2004; Angel & Cooper 2006 and references therein).

In April 2007, the Royal Society for the Protection of Birds commissioned Landcare Research to assess whether it would be feasible to eradicate mice from the island, or if not whether any sustained control could mitigate the impacts of mice, or whether nothing should be done until technological advances in mouse control might provide solutions. This report follows a visit to the island by the author between 13 September and 3 October 2007.

2 Background

2.1 Purpose of the report

This report is not an Operational Plan to manage mice on Gough Island. Rather it aims to answer three questions that any decision-maker would want answered, or at least made transparent, if they were to invest the substantial funds required to attempt eradication of the mice – the preferred strategic option. These questions are:

- Is the attempt justified by the potential benefits?
- Is eradication possible given the particular circumstances on Gough Island?
- What resources and actions are likely to be needed (a) to overcome any risks and constraints identified and then (b) to attempt the eradication?

The first question is addressed in detail by Angel & Cooper (2006) and is merely summarised in this report.

Thus, the purpose of the main part of this report is to set out, as far as possible, the benefits, risks and constraints and decide whether the risks and constraints need to be further resolved before any eradication operation proceeds. This will enable the decision to proceed (or not) on Gough Island to be taken in full knowledge that the probability of successful eradication has been optimised – but not guaranteed. The report also expands some more generic issues to be useful for other decision-makers on other islands with mice.

Should eradication be assessed as feasible and funding allocated for Gough Island, the next steps in the process would include development of the capabilities to deliver the operation, an Operational Plan, the actual operation, and a post-operational phase to assess what was done and its consequences.

Should eradication not be assessed as feasible, or if funding is insufficient to attempt it, the option of sustained control is considered in terms of the technical feasibility of intervening at an effective scale, at the right place, at the right time of year and at sufficient intensity to protect critically endangered birds such as the Tristan albatross.

Should neither eradication nor sustained control be applied, the report summarises the advisability of waiting for some potential options that have been mooted for mouse control, such as biocontrol and immunocontraception, and on whether they are potentially capable of doing more than current techniques aimed at eradication or sustained control.

2.2 International context

This critical assessment of risks of failure is important internationally because there are several large-scale mouse eradications currently planned or under consideration (Table 1). While failure at one may cause delays for others while causes are assessed, failure because of inadequate planning processes may halt progress on others by discouraging funding agencies from taking the necessary risks, despite the large biodiversity gains. Hence, there is a responsibility to ensure that large-scale operations are planned and conducted to the highest standard.

Table 1. Proposed large-scale eradication attempts against mice

Island	Country	Area (ha)	Project status	Other species targeted
Macquarie	Australia	12,000	Feasibility Plan completed, funding approved, Operations Officer appointed, eradication to begin 2010	Ship rat, rabbits
Rangitoto/Motutapu	New Zealand	3,850	Funding approved Eradication to begin in 2009	Ship rat, stoat, rabbit, feral cat
Lord Howe	Australia	1,455	Feasibility Plans completed, Project Officer appointed	Ship rat
Tristan da Cunha	UK	9,000	Feasibility and initial Operational Plans completed	Ship rat
Floreana	Ecuador	17,000	Initial consideration	Ship rat
Santiago	Ecuador	58,000	Initial consideration	Ship rat
Guadalupe	Mexico	26,000	Initial consideration	Feral cat
Antipodes	New Zealand	2,025	Initial consideration	None

As well as these island eradication plans, there are large-scale sustained control operations against mice (other than as commensal pests) in Australia and to a lesser extent in New Zealand. Mice are controlled over large areas of agricultural land when they reach plague proportions in Australia. Aerial baiting with grain baits (e.g. Mouseoff®) using the acute toxin zinc phosphide is the preferred method (Caughley et al. 1998). Mice are targeted as by-catch in multi-species pest control for biodiversity protection in New Zealand. Aerial baiting using the acute toxin Compound 1080 is the preferred method against the main target pests (brushtail possums *Trichosurus vulpecula*, ship rats, and stoats *Mustela erminea*). However, such multi-species control efforts often do not effectively reduce mouse populations in New Zealand – recent data suggest mice can detect and avoid 1080 in bait (Fisher & Airey 2007).

3 Impacts of Mice on Gough Island

Mice eat about 17% of their body weight each day to maintain themselves (Mutze et al. 1991). Thus, an average population of about 100 mice ha^{-1}, weighing on average 25 g each on Gough Island, eat about 3 tonnes of Gough Island biota per day! Not unexpectedly, this has an adverse impact on plants, invertebrates and birds (Angel & Cooper 2006). In summary, the main known direct impacts of mice are on Tristan albatross, Atlantic petrel and Gough bunting *Rowettia goughensis* and perhaps on some invertebrates. It is also likely that mice affect other seabird species, but these have not been assessed. Indirect impacts are unclear (potentially subtle) but likely.

Figure 1. Tristan albatross chick, September 2007 (photo M. Munting)

3.1 Impacts on birds

Mice have been recorded as predators of lizards on islands (Whitaker 1978), and were implicated in the decline of McGregor's skink *Cyclodina macgregori* on Mana Island in New Zealand (Newman 1994). However, evidence of predation on birds (or even their eggs) has been rare (Caughley et al. 1998; Ruscoe & Murphy 2005), so it came as some surprise when Cuthbert & Hilton (2004) recorded wounds on large Tristan albatross and Atlantic petrel chicks that they thought were being made by mice. This diagnosis was confirmed with video evidence that mice attacked healthy, large chicks of the above birds and of the great shearwater *Puffinus gravis* on Gough Island (Wanless et al. 2007). The attacks by mice either killed the birds or the debilitated animals were likely to be killed by Southern (Tristan) skuas *Catharacta antarctica hamiltoni* or Southern giant-petrels *Macronectes giganteus*.

Tristan albatross (Figure 1) is Critically Endangered because of its restricted breeding distribution (now confined to Gough Island), and because of bycatch of adults in long-line fisheries, and chick predation by mice. It has been estimated that their population is declining by 0.62% per annum, and that mice were responsible for 57% of chick mortalities in 2001 and 2004 (Cuthbert et al. 2004). Population models indicate that cessation of the long-line by-catch mortality would not be sufficient to arrest the decline and reduction in predation by mice would also be required (Cuthbert et al. 2004; Wanless 2007).

Atlantic petrels (Figure 2) are Endangered because almost the entire population nests on Gough Island, and although numerous, population models including observed reproductive rates indicate that the population is probably declining (Cuthbert 2004). Mice were again diagnosed as the cause of significant chick mortality (Cuthbert 2004; Angel & Cooper 2006).

Figure 2. Gough mouse feeding on an Atlantic petrel chick (photo R. Cuthbert)

Figure 3. Gough bunting (photo M. Munting)

The Gough bunting (Figure 3) is endemic to Gough Island, listed as Critically Endangered, and known to be preyed upon by mice. For example, of 15 nests in the highlands monitored in 2000/01, one had their eggs eaten by mice and three lost chicks apparently to mice (Cuthbert & Hilton 2004). Recent evidence suggests the population has declined and continues to do so, almost certainly as a result of predation by and competition from mice (Ryan & Cuthbert, in press).

Avian food forms the bulk of the diet of mice in September and October (Jones et al. 2003), but whether from scavenging on birds killed by skuas (which are back on the island and breeding by September) or by active predation is not clear.

3.2 Impacts on invertebrates

Mice alone can eliminate insular invertebrates (e.g. the endemic beetles *Loxomerus* spp. and *Tormissus guanicola* on Antipodes Island (Marris 2000) and the giant phasmid *Dryocoelus australis* on Lord Howe Island (Hutton et al. 2007)), as well as changing the composition of the fauna (Marris 2000).

On Gough Island, Jones et al. (2002) recorded invertebrates as forming the bulk of the diet in the lowlands, with introduced earthworms being the most common prey – as they were on Guillou Island in the Kerguelen Islands (Le Roux et al. 2002). This led Angel & Cooper (2006) to conclude that mice pose no significant threat to the lowland native invertebrate fauna. However, in the highlands, mice prey on moth caterpillars including those of two endemic moths *Dimorphinoctua goughensis* and *Peridroma goughi* (Jones et al. 2003) leading to their conclusion that these species might be at risk. In fact, it appears that the endemic moths are exceedingly rare in the lowlands (R Cuthbert, pers. comm.) so it is possible that mice have caused this difference – although habitat difference cannot be rule out. Angel & Cooper (2006) also concluded, by analogy with the role similar moths play in limiting peat formation on Marion Island, that any impact of mice on moths may have indirect ecosystem consequences.

3.3 Impacts on plants

Mice are efficient seed predators. For example, Ruscoe et al. (2005) have shown that mice at densities above 36 ha^{-1} in New Zealand beech *Nothofagus* spp. forests were capable of eating nearly all seeds produced in masting events, even with seed densities of up to 1200 m^{-2}. An average 20 g mouse can eat 1,042 beech seeds (3.3 mg each) per day.

On Gough Island, plant material was the most important item identified in the stomachs of mice during November 1999 through to March 2000, but apart from seeds and flowers of grasses and sedges (*Agrostis*, *Carex* and *Scirpus*) and the herb *Acaena sarmentosa*, most plant remains could not be identified (Jones et al. 2003). Wanless (2007) also reported generally low proportions of plant material in mouse diets in samples collected in September 2003. However, plant material, particularly the carbohydrates in seeds, are notoriously difficult to identify in mouse diets so the importance of seeds in driving the population dynamics of mice on Gough Island is, by implication from these diet studies, potentially grossly underestimated. The effects of seed predation on the recruitment and dynamics of the plants are likewise not known.

It has been suggested that mice may affect the regeneration of the dominant woody tree, *Phylica arborea*, on Gough Island (Breytenbach 1986; Ryan et al. 1989), but hard evidence for a mouse effect on the general condition of the vegetation on Gough Island is lacking.

Nevertheless, it is probable that mice are affecting the structure and perhaps eventually the composition of the flora. A comparison between mouse-free Prince Edward Island and neighbouring mouse-infested Marion Island, both subantarctic islands in the Southern Ocean, shows mice are slowing the spread of two native plants (*Uncinia compacta* and *Acaena magellanica*) that are taking advantage of climate warming (Chown & Smith 1993; Angel & Cooper 2006). On Marion Island the mice can damage the peat-forming cushion plant *Azorella selago* by burrowing into the mounds formed (Chown & Cooper 1995).

4 Relative Benefits of Eradication and Sustained Control

Put simply, eradicating mice from Gough Island will remove current and future impacts on biodiversity and may redress past impacts as the species and communities readjust to a predator-free environment. Sustained control may also achieve these goals at localised sites if mice are reduced to sufficiently low (but as yet undetermined) densities at the right places and right times of the year at the right frequency of years. Predation by mice on Tristan albatross chicks is triggered in some places but not others, independent of local mouse density (Wanless 2007), which gives cause for concern that the target mouse densities to ameliorate the problem might be very low, and thus difficult to sustain at appropriate scales (see section 7.1).

The cost–benefit ratios (actually benefit maximisation ratios for non-market values) can favour the short-term expense of eradication over the ongoing expense, ongoing negative environmental and non-target impacts, and institutional difficulty of maintaining sustained control (Choquenot & Parkes 2000). However, the comparison is case-specific and we do not have the information on what constitutes ‘effective’ sustained control for Gough Island biota, even assuming the input costs used in this report are accurate.

5 Feasibility of Eradication

There are several ways in which the feasibility of eradication can be assessed and, taken together, these can provide some measure of the chances of success and related risk of failure.

- First, previous attempts at eradicating mice can be reviewed, causes of failure (when known or suspected) assessed, and a judgement made about whether scaling up to an island the size of Gough is likely to succeed – does scale count?
- Second, previous attempts at eradicating other rodents at a similar scale to Gough Island can be reviewed and a judgement made about whether they can act as a template for mice on Gough Island – are mice more difficult to eradicate than other rodents?
- Third, the rules and constraints that have to be met or overcome as for any eradication attempt (e.g. Parkes 1990; Hone et al. in press) can be considered for the case of Gough Island, and a judgement made about whether to conduct further research to clarify critical uncertainties, or to proceed to an attempt at eradication.

5.1 Previous mouse eradication attempts

Established populations of mice have been eradicated from 30 islands around the world, with six islands up to 377 ha in size awaiting confirmation of success (MacKay et al. 2007; Russell et al. 2007). However, attempts have failed in 17 operations on 13 islands, although success was achieved on three of these islands at later attempts (Appendix 1). There have also been at least two recent failures to eradicate mice behind (supposedly) mouse-proof fences in New Zealand's 'mainland islands' – at Karori (252 ha) and Maungatautari (3,300 ha) reserves.

No general reasons for these failures are evident (MacKay et al. 2007). The causes of several of the failures are known or suggested, and should not be repeated on Gough Island if best practices are followed.

On Saint Paul Island (Kerguelen), the aerial baiting swaths were apparently sufficient to eradicate ship rats, but the failure of the bait spreader was thought to have allowed bait gaps in which mice were not exposed (Micol & Jouventin 2002).

On Varanus Island (Western Australia), the early attempts were made using 1080 baits – which it is now known that mice can detect and avoid (Fisher & Airey 2007).

On Buck Island (USA Virgin Islands) and Quail Island (New Zealand) mice appear to have survived because the bait stations were set too far apart (Witmer et al. 2007; M. Bowie pers. comm.).

On the New Zealand 'mainland islands' it is suspected that a new bait formulation (a smaller but harder version of the cereal baits) may have been less acceptable to mice, rather than failure of the fences (Robards & Saunders 1998; B Simmons, pers. comm.).

The largest island from which mice have been eradicated is 710 ha Enderby Island in the New Zealand subantarctic (50º 40'S) (Torr 2002). This island, and the 250 ha Ile du Chateau in the Kerguelen Islands from which mice may have also been eradicated, have cool-temperate, seasonal climates with similar habitats to those on Gough Island. It has been suggested that rodents might be more difficult to eradicate on tropical islands where there are no seasonal shortages of food, and by implication easier on temperate islands with winter food shortages – although this remains untested.

However, as Gough Island is an order of magnitude larger than Enderby Island the question arises: does increasing the scale increase the risk of failure, or is it just a matter of more effort and cost?

Three types of issues might increase failure risk as scale increases, some of which are manageable to a greater or lesser degree.

5.1.1 Murphy's Law – if it can go wrong it will

The chances of some operational failure that allows mice to survive logically increase with the scale of an operation. For example, it is possible that undetected gaps in bait coverage are more likely as the number of swathes required increases, or as the time to complete one coverage lengthens. The management solution to Murphy's Law is to 'over-engineer' the operation and ensure there are backup systems for all components. In the first example above, the risks of gaps (wide enough to include a mouse home range) in bait coverage are reduced (to zero) by using DGPS systems checked more-or-less as the flights are completed, by overlapping swathes, by double baiting steep sites or critical habitats, and by repeating the baiting on flight paths at right angles to the initial ones after a week or so.

5.1.2 Scale increases habitat complexity

It is possible that larger islands have more complex habitats than smaller islands, both in terms of physical complexity and biotic communities. Certainly on Gough Island the presence of lava-tubes adds another dimension to the requirement to put all mice at risk of exposure to bait; but the mix of tussock, fern/shrub, and alpine habitats and flat and steep terrain does not present any obvious risk that mice will not be exposed to bait.

5.1.3 Scale increases mouse population size

It can be argued that any mouse exposed to the toxic bait has a very small chance of surviving (for whatever reason) and so the more mice, the greater the chance that some will survive. Thus, an operation killing 99.9% of mice on Gough Island would leave several hundred survivors and so fail as an eradication attempt. This risk is untested and, if true, could only be overcome if the reason for survival was known and manageable. For example, if the reason was some innate resistance to the toxin, then changing the toxin in the second (or subsequent) baiting application might work. However, if the reason was neophobic behaviours towards novel objects such as baits in a few mice, then the operation would be at risk as it is hard to see how this could be managed.

5.2 PREVIOUS ERADICATION ATTEMPTS FOR OTHER RODENTS – ARE MICE MORE DIFFICULT?

Rats have been eradicated from seven temperate islands larger than 500 ha since 1995, all but one by using aerial baiting with brodifacoum. There have been no failures against rats on islands this size (Appendix 2).

However, the failure rate of eradication attempts for mice of about 17 out of 47 attempts on 40 islands – three islands were later successfully treated and one island failed on three attempts (Appendix 1) is significantly higher (χ^2 = 36.0, P < 0.001) than that for the three species of rats (*Rattus norvegicus*, *R rattus* and *R exulans*) combined. Failure rates for these are 5%, 8% and 10%, of 109, 174, and 61 attempts, respectively (Howald et al. 2007).

5.3 Presence of ship rats

It has been suggested that the presence of ship rats makes it more difficult to eradicate sympatric mice (P. Fisher, pers. comm.). The demography and behaviour of mice in the presence of ship rats or other predators is different from those when no rats are present (Sweetapple & Nugent 2005; Witmer et al 2007) and it is possible that these changes interact in some way (see below) with the baiting strategy to protect some mice. This is not an issue on Gough Island, but understanding the mechanisms may be critical for the first six islands in Table 1, including Tristan da Cunha island.

5.3.1 Mouse behaviour to bait and toxin type

Mice are less prone to caching surplus food than rats and tend to nibble food intermittently rather than eat a find all at once (Crowcroft & Jeffers 1961; Fisher & Airey 2007). It is possible the current baits (all essentially developed for rat control) are larger than optimal for mice. The hypothesis is that mice have to visit larger baits and eat them *in situ* (rather than take them away), and the safety with which they can do so is compromised by the presence of predators, or by innate anti-predator behaviours. This may then interact with bait distribution and mouse home range size, and the number of feeding events required for different toxins to obtain a lethal dose (see section 6.3).

Two trials are being conducted in New Zealand to determine (a) the effect of bait size on bait 'portability' for mice, and (b) the minimum effective exposure of brodifacoum to kill 100% of mice exposed in a single feeding event (P Fisher, pers. comm.). Results should be available in 2009.

5.4 Meeting the obligate rules and managing constraints on Gough Island

There have been several attempts to formulate a set of parsimonious rules to judge whether eradication is feasible and justified, the latest being by J. Hone *pers. com*. These rules are:

(1) The average annual long-term rate of removal in source populations must be greater than the annual intrinsic rate of increase. This rule covers the older 'all at risk and rates of removal' criterion, and is applicable to situations where we have source–sink populations or where Allee effects (reduced rates of increase at very low densities) have been argued to negate the 'all at risk' condition (Liebhold & Bascompte 2003). It also implies the funds are available to achieve the rule.

(2) There is no immigration of individuals that can breed.

(3) There must be no net adverse effects. Eradication may not be desirable if the adverse affects on non-target species or contamination of the environment by the control methods available are predicted to be unacceptable and unresolvable, or if the consequences

of removal of the pest outweigh the benefits (Courchamp et al. 2003).

5.4.1 Putting all mice at risk

Meeting the first rule is achieved by ensuring all mice encounter and eat enough bait to ingest a lethal dose. The strategy of a single operation with one or more applications of bait over a short period ensures the generic 'rates' rule is met. All populations on the island are treated as sink populations, so the caveat relaxing the 'all at risk' rule in more complex populations is not applicable.

Ensuring all mice are at risk on Gough Island has both a temporal (what time of year is best) and spatial (are mice in some habitats or places likely to escape risk) component.

5.4.1.1 Time of year when most mice are at risk

There are several logical reasons why it is best to attempt the eradication when fewest mice are breeding. It is possible (although not proven) that some failures to eradicate rodents were because almost-independent young still in their maternal nest were not exposed to baits but could emerge later and survive without their parent (J Innes, Landcare Research, pers. comm.).

There are also reasons why it might be best to bait at times of year when mice are in poorest condition, when natural mortality is highest, and when densities are lowest. It is then that the mice might be hungriest and most likely to eat baits, and when any 'saturation' effects (too many mice in hot-spots for the bait densities sown) are absent.

(i) Breeding season

Mice in most temperate systems normally stop breeding in the winter, although some males remain fertile all year and a few females can become pregnant especially if food remains abundant (Ruscoe & Murphy 2005).

On Gough Island, the weight of evidence is that mice do not breed all year round, with two studies that autopsied mice showing no pregnant or lactating females between about May and August, the first pregnant females in September and the last lactating females in April. However, the Meteorological Station staff report the presence of 'young' mice in winter months, but of course, these animals are commensal and presumably are not limited by seasonal food availability (see below).

The evidence for seasonal breeding is summarised below:

- October 1990 (Rowe-Rowe & Crafford 1992): Sixty-nine adult female mice were snap-trapped and autopsied. Twenty percent were pregnant, 16% were lactating, and 7.2% were both pregnant and lactating. These results, and the presence of juveniles (at low altitude sites), showed that breeding must have begun in September. The absence of juveniles at higher altitudes suggested the breeding season began later at higher altitudes.
- September 1999 – July 2000 (Jones et al. 2003): One hundred and seventy females (all ages and all at lowland sites) were snap-trapped and autopsied. Pregnant and/or lactating females were found in all months between October 1999 and April 2000, with all in the last month being lactating only. No breeding females were recorded in September 1999 or between May and July 2000.
- November 2003 – September 2004 (Wanless 2007): About 110 female mice from lowland sites were snap-trapped

and autopsied. Pregnant and/or lactating females were found between November 2003 and February 2004 and again in September 2004. No breeding was recorded between March 2004 and August 2004.

- September 2007 (J Parkes & A Angel, unpubl. data): Mice were snap-trapped from two lowland sites, and 29% of 24 females were found to be pregnant or lactating, and one juvenile mouse was caught in late September.

(ii) Seasonal changes in the condition of mice on Gough Island

An index of body condition of Gough Island mice measured in 2006 declined in both sexes between April and May, reached minimum levels in August, and recovered again between August and November (Cuthbert et al. in prep).

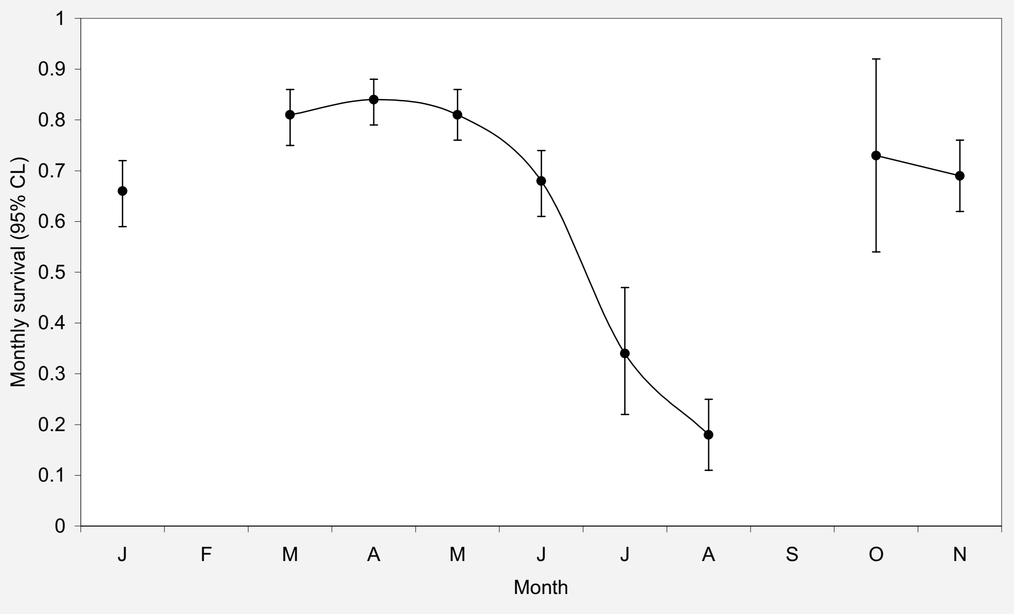
(iii) Time when there is least food for mice

One consideration might be to avoid baiting at times of year when there is an abundance of natural foods. The flowering plants on Gough do not flower and set seed until spring and summer. Atlantic petrel chicks (which are very abundant with about 1.8 million breeding pairs) become available as prey between late August and early January (Wanless 2007).

(iv) Seasonal changes in the survival of mice on Gough Island

The trends in body condition are broadly reflected in trends in monthly survival rates of the mice, with highest monthly mortality in July and August (Figure 2).

Figure 2. Monthly survival rates of Gough Island mice sampled at two lowland and two highland sites in 2005/06 (after Cuthbert et al. in prep.)



(v) Seasonal changes in density of mice on Gough Island

Mark-recapture studies in 2005/06 gave mouse density estimates of over 250 ha^{-1} in the lowlands between November and June, reducing to about 150 ha^{-1} in September and October. Densities in the highlands reached nearly 200 ha^{-1} at the end of the breeding season but took longer to reach this peak, presumably because breeding began later at higher altitudes (Wanless 2007; Cuthbert et al. in prep.).

Therefore, taking all 'mouse-seasonal' factors into account an operation sometime between May and August is indicated, with July or early August being the optimum period. Note: the timing of the operation (in February) that eradicated mice on Enderby Island was selected to be outside the breeding season of the primary target species (rabbits) rather than that of mice (Torr 2002).

Figure 4. Gough mice (photo M-H. Burle)

5.4.1.2 *Places where mice might avoid baits*

Mice may escape exposure to a bait if there are gaps in the sowing swathes, or if bait density is insufficient such that the smallest home ranges do not contain baits, or if some mice live entirely in habitats (seabird burrows, lava-tubes, sea caves, or in the roofs of buildings around the Meteorological Station) where no baits are sown.

(i) Home range size and daily movements

Four radio-tagged mice in the lowlands had home ranges of between 500 and 2,620 m^2 with a mean of 1,666 ± 880 m^2 (Cuthbert et al. in prep.). This gives home range diameters of between 25 and 58 m with a mean of 46 m. The mean distance between fixes was 17.6 m and this was similar to the distances between recaptures in the mark-recapture study (Cuthbert et al. in prep.). Thus, the bait coverage can leave no gaps wider than 25 m (incidentally, about the distances recommended for bait station grids for mice; Parkes et al. 2004). In fact, the overlapped sowing attempts to ensure no gaps are left.

The bait densities used in previous successful eradications, 8 kg ha^{-1} on the first sowing, plus 4.5 kg ha^{-1} on the second sowing, would provide ~6,250 baits per hectare or 0.625 baits m^{-2} (assuming 10 mm Pestoff® baits were used), or about 40 baits per mouse at their winter densities. This represents a significant degree of over-engineering, given that only one or two baits contain a lethal dose for a mouse (Fisher 2005). Note: LD_{100} values are not known, but a 20 g mouse would have to eat only about 30% of a 10-mm bait with 0.02% brodifacoum to obtain an LD_{50}, i.e. a 50% chance of death. Mice on Gough Island are larger than most other populations (Wanless 2007) but the above points remain valid.

The preliminary non-toxic baiting trials conducted by Wanless et al. (2008) in winter 2007 showed very rapid removal of baits sown at nearly 16 kg/ha. A precaution might be to increase the bait sowing density from the normal rates, either in both sowings or in the second sowing, in case this high rate reflects severe competition for baits and potential non-exposure of mice (e.g. subordinate animals).

(ii) Lava-tubes, caves and seabird burrows

It is possible that some mice live entirely in areas where baits dropped from the air cannot reach, such as in lava-tubes, caves or down burrows (Figure 5).

The lava tubes on Gough contain many crevices and short caves likely to be used by mice. Inspection of one site in September 2007 (Prion Cave near the Meteorological Station) failed to find invertebrates that could act as a food source for mice, although it did have nesting broad-billed prions *Pachyptila vittata* that could support mice during their breeding season from August to December.

Figure 5. Cave entrance (photo R. Cuthbert)

Wanless et al. (2008 conducted a small experiment at Prion Cave in June 2007. They placed non-toxic Pestoff® 20R baits containing the dye rhodamine B outside the cave and trapped mice inside the cave two days later. All mice (n = 11) caught in the cave had eaten baits – at least some evidence that cave-dwelling mice forage on the surface.

The possibility that mice living in lava-tubes and caves do not forage on the surface and would not therefore be exposed to aerially sown baits remains a risk to the eradication attempt despite the positive result from the small trial in Prion Cave. The trial could be replicated at more sites and if a problem were revealed then trials to determine whether such mice could be put at risk by placing baits in the lava-tubes would be required. If they could, then a complete survey of the lava-tubes on Gough Island would be required.

(iii) Cliffs and islets

The cliffs on Gough Island are similar to those found and managed in other aerial baiting eradications. Slope *per se* affects the density of bait delivered – if the helicopter flies horizontally, the bait density reduces by the cosine of the slope. For example, at 45º slope, the density is only 70% of the value on flat land, and at 75º the density is only 26%. This is overcome by the excess baiting density on mild slopes, but best practice is to sow double swaths on slopes over ~60º.

Some operations have used a deflector on the sowing bucket to direct baits towards steep sites (for example on Farallon de San Ignacio and San Pedro islands in Mexico; A Aguirre, Grupo de Ecologia y Conservacion de Islas, pers. comm.).

There are cliffs around the entire coastline of Gough Island (~ 42 km), and perhaps a further 10 km of internal cliffs – although this figure requires verification - that will need attention. This is equivalent to about an extra 1,500 ha of coverage.

There are at least 17 islets and rock stacks around Gough Island. Cooper and Ryan (1993) thought they were mouse-free but recommended they be checked. This is not necessary (for this eradication plan) as they should all be treated as though they have mice. The only possible caveat to this is that some of the islets that are mouse-free might be significant refuges for Gough buntings. If confirmed mouse-free, then avoiding baiting them might be a means of mitigating non-target impacts on buntings.

(iv) Dense vegetation

It is highly unlikely that any vegetation on Gough Island is so dense or tiered (for example the *Blechnum palmiforme* stands) that either some baits would not fall or be blown through, or that mice would not climb over it to reach food.

(v) Buildings

There is no reason why the Meteorological Station should not be covered by the aerial drop. However, extra baits would need to be laid inside the buildings (in roofs and wall spaces) and around the Skivvie Gat (where waste soft food is dumped). A precautionary approach should be taken, with baits maintained for some period after the main aerial sowing. A moratorium on dumping food at Skivvie Gat and of sewage and wastewater should be in place before any baiting.

5.4.1.3 Bait acceptance trial

In June 2007, Wanless et al. (2008 hand-broadcast non-toxic Pestoff® 20R baits containing rhodamine B dye over two areas, each of about 150 × 150 m, at rates of about 15.7 and 7.9 kg ha^{-1}. Mice were snap-trapped in core patches of 18 × 18 m in each area, and along transects extending through and up to 90 m beyond the baited zones. Each area was re-baited after 10 days. Mice were trapped 5 days after each baiting and again at 8 days after the last baiting. Mice that had eaten baits were identified from obvious signs of dye in their mouths and alimentary tract and by bands of fluorescent dye in their whiskers (Fisher 1999).

Of the 434 mice trapped, 421 had eaten baits and all baits in a marked sample area were eaten between two and four days of sowing

The design of this experiment must always give equivocal results – less than 100% acceptance may be caused either by some mice not accepting baits, or by mice moving into the sample area from outside the baiting area, while 100% acceptance is always a probabilistic statement as the next exposed mouse sampled might have proved negative. Mice clearly moved greater distances than expected in the trial, as of the 27 mice trapped outside the baited areas, 26 had eaten baits, so based on this and the time post-baiting when they were caught Wanless et al. (2008) concluded that the unmarked mice caught in the core areas were probably non-exposed immigrants.

If the risk of non-exposure or non-acceptance of baits is considered a significant concern, experiments giving less equivocal results are suggested in Appendix 3.

5.4.2 No immigration

Mice have reached Tristan da Cunha and Gough islands but not Inaccessible or Nightingale islands in the archipelago. It is not clear how many times mice might have arrived on Gough Island, but invasions are obviously rare events (otherwise mice would have established on Inaccessible and Nightingale), so the present population may well represent a single 19th century invasion event.

In New Zealand, none of the 14 islands

from which mice have been eradicated have been reinvaded, although on one (Mana Island) a mouse was intercepted on a visiting boat. Further, of 11 other islands where mice are known to have reached shore, they failed to establish on five and were killed before they could establish on six (Russell et al. 2007).

The lack of a wharf reduces the risk of invasion by rodents (Atkinson 1985) so apart from shipwreck, the route ashore on Gough Island would have to be with cargo currently flown ship to shore by helicopter, or lifted ashore with a crane – assuming rodents would not abandon ship and swim. A rat was reported on Gough Island in 1983 but, despite extensive trapping and searches for sign in 1984, no rat or sign of rats were found (Wace 1986). Given the low probability of detecting invading individuals (Russell et al. 2005), and the impossibility of searching everywhere, the failure to find or catch the rat (if indeed there was one) was not surprising, but in any event no population was established.

There are three sources and routes by which a new population might invade Gough Island: from Cape Town via the SA Agulhas or the two Tristan lobster fishing boats; from Tristan da Cunha via these vessels; or from passing ships or yachts. Three interception points are possible to reduce the risk of rodent invasion – at the source ports, on the ships, and on Gough Island.

5.4.2.1 *Interception at source ports*

Some quarantine measures (of variable quality) are in place in Cape Town to keep the places where the containers and cargo are packed before loading on the ships rodent-free. These measures are largely permanent bait stations serviced regularly (or not at all at one site) by commercial pest companies. The main packing facility at the SANAP building of the Department of Environmental Affairs and Tourism has a 'dirty to clean' flow system for incoming and outgoing cargo, and most cargo for Gough Island is packed here. The Ministry of Works packing facility was not of such a high standard – no flow from dirty to clean, and the rodent bait stations had not been serviced for some time. For personal baggage there is a reliance on its owner to inspect and ensure it is pest-free.

The SA Agulhas has rodent-guards on its mooring lines and maintains de-rat certification, but apparently the two fishing vessels do neither.

5.4.2.2 *Interception on ship*

Mice already inside containers or other enclosed cargo as they are loaded are probably invulnerable to any remedy on board vessels. However, all vessels unloading cargo on Gough Island should have a de-rat certificate and have a response capability to deal with any rodent sign found.

5.4.2.3 *Interception at Gough Island*

In 2007, 30 enclosed metal containers and two other loads of cargo (food, equipment, personal baggage) were flown ashore by helicopter. These were landed at five places, all in the open, and unpacked over the following four weeks. Should a rodent have been in one of these it is difficult to know whether it would have been detected and what would have been done in the event.

It appears impractical to unload containers in some secure facility – without a large change in the infrastructure and way cargo is delivered ashore – but it would be worth having an on-call contingency plan and capability now (for rats) and in the future if mice are eradicated (for all rodents) should a rodent emerge during unpacking.

If mice are eradicated, bait stations with long-life rodent baits (Morriss et al. 2006) should be set around the Meteorological Station a few days before the annual change-over and left in place for some months as a prophylactic way to reduce the chance that undetected rodent arrivals will establish. A station design to exclude the endemic Gough moorhens *Gallinula comeri* would be useful.

5.4.2.4 *Response to a shipwreck*

Shipwreck is a possibility and although there are no data on the frequency with which modern ships harbour rodents, this remains a possible source of invasion on Gough Island. Effective reaction to such an event depends on the time taken to respond. If reaction was prompt, the use of bait stations or broadcast baits might intercept a rodent invasion. If reaction time was slow, the potential for invasion increases until eventually no effective local-scale response is possible.

5.4.2.5 *Interception of arriving rodents: conclusion*

Proactive intervention to ensure rodents do not access cargo bound for Gough Island can be improved, and the three vessels that unload cargo on Gough Island should maintain de-rat certification. A combination of reactive management on Gough Island should any rodent be seen in cargo, and prophylactic action during unloading periods once mice are eradicated, should be conducted.

5.4.3 No net adverse effects

5.4.3.1 *Non-target animals*

All toxins that could be used are hazardous to all vertebrates that eat them. Toxins such as diphacinone are less toxic to birds (Erickson & Urban 2002), but require mice to eat more bait more often (Ashton et al. 1987) and so may increase the probability that mice will not be eradicated – and may not reduce the risk to the moorhens enough to take the chance of avoiding mitigation management. The use of brodifacoum is recommended as it provides a toxic dose at a single feeding event and has been the toxin most commonly used in recent successful rodent eradications.

Reducing exposure of non-target animals is the factor that has to be managed. Exposure can be primary where animals encounter baits and eat enough of them to obtain a lethal dose, or secondary where animals eat poisoned mice or invertebrates that have eaten baits.

(i) Seabirds

Angel & Cooper (2006) have summarised the seasonal presence of nesting seabirds (Table 2).

Skuas are mostly at sea during winter, but those that remain on the island may be at high risk of secondary poisoning. The birds at risk are largely 'surplus' juveniles whose loss, even at the rates shown in other operations, is not catastrophic for the population. The evidence from other eradication operations using aerially sown brodifacoum baits demonstrates this risk to skuas. On Enderby Island, about 30 of the 40 skuas present died during the February/March poisoning (Torr 2002), but on Campbell Island, no skuas were killed during the July operation (McClelland 2001).

(ii) Terrestrial birds

There are two terrestrial bird species present on Gough Island, the Gough moorhen and the Gough bunting. The former is listed as Vulnerable and the latter as Critically Endangered (Birdlife International 2008). Both are endemic to the island, although an introduced population of Gough moorhens also exists on Tristan da Cunha.

Figure 3. Gough moorhen scavenging a dead mouse (photo J. Parkes)

The moorhen is at very high risk, especially from secondary poisoning. Moorhens often scavenge mice caught in snap-traps, and the viscera of dead mice presented to moorhens around the Meteorological Station were avidly eaten (J Parkes, pers. obs.; Figure 3). Moorhens may also be at risk from primary poisoning. Similar gallinule species, such as the purple swamphen *Porphyrio porphyrio*, have suffered significant losses during aerial baiting with brodifacoum baits. For example, aerial application of Talon 20-7 brodifacoum baits on Motuihe Island (New Zealand) killed 49% of the purple swamphen population (Dowding et al. 1999).

The bunting is a generalist finch, eating mostly seeds and invertebrates. It also scavenges on food scraps at the Meteorological Station and occasionally on the carcasses of dead animals. Thus there is an *a priori* indication that it may be at risk of both primary and secondary poisoning.

Table 2. Presence and breeding activity of seabirds nesting on Gough Island and an assessment of the risk (= exposure × hazard) of non-target poisoning for each species

Species	Threat status[1]	Breeding season	Primary poisoning risk[2]	Secondary poisoning risk[3]
Northern rockhopper penguin *Eudyptes moseleyi*	Endangered	Oct–Feb	Very low	None
Tristan albatross *Diomedea dabbenena*	Critically Endangered	Jan–Nov	Very low	None
Atlantic yellow-nosed albatross *Thalassarche chlororhynchos*	Endangered	Sep–Apr	Very low	None
Sooty albatross *Phoebetria fusca*	Endangered	Oct–May	Very low	None
Southern giant-petrel *Macronectes giganteus*	Near-threatened	Sep–Mar	Low	None
Broad-billed prion *Pachyptila vittata*		Aug–Dec	None	None

Species	Threat status[1]	Breeding season	Primary poisoning risk[2]	Secondary poisoning risk[3]
Kerguelen petrel *Lugensa brevirostris*		Oct–Feb	None	None
Soft-plumaged petrel *Pterodroma mollis*		Nov–Apr	None	None
Atlantic petrel *Pterodroma incerta*	Endangered	Jun–Dec	None	None
Great-winged petrel *Pterodroma macroptera*		Jun–Dec	None	None
Grey petrel *Procellaria cinerea*	Near-threatened	May–Nov	None	None
Great shearwater *Puffinus gravis*		Nov–Apr	None	None
Little shearwater *Puffinus assimilis*		Sep–Feb	None	None
Grey-backed storm-petrel *Garrodia nereis*		Oct–Mar	None	None
White-faced storm-petrel *Pelagodroma marina*		Oct–Mar	None	None
White-bellied storm-petrel *Fregetta grallaria*		Jan–Jul	None	None
Common diving-petrel *Pelecanoides urinatrix*		Oct–Feb	None	None
Southern skua *Catharacta antarctica*		Sep–Dec	Low	High for a few birds
Antarctic tern *Sterna vittata*		Nov–Jan	None	None
Brown noddy *Anous stolidus*		Dec–Mar	None	None

1: Threat status is the 2008 Red List status (BirdLife International 2008).
2: Primary poisoning is the risk of mortality from direct consumption of poison baits.
3: Secondary poisoning is the risk of mortality from consumption of poisoned mice or other animals.

(iii) Marine mammals

Juvenile and female subantarctic fur seals *Arctocephalus tropicalis* and southern elephant-seals *Mirounga leonina* will be present on Gough Island during any winter operation and will be exposed to bait. No mortality has been reported from other pinnipeds exposed to bait on other islands.

(iv) Invertebrates

Invertebrates appear unlikely to be killed by eating brodifacoum baits, partly because they lack the same blood-clotting mechanisms on which the toxin acts in vertebrates (Morgan et al. 1996; Eason & Wickstrom 2001). However, Booth et al. (2003) showed that massive doses of brodifacoum were toxic to a test species of earthworm, and it is known that invertebrates can contain toxin residues and act as sources of secondary poisoning for vertebrates that eat them. The half-life appears to vary with taxa from a few days to a few months (Booth et al. 2003).

Analysis of 14 invertebrate taxa after aerial sowing of Talon 20P brodifacoum bait (on Red Mercury Island) and with bait stations containing Talon 50WNB wax blocks (on Coppermine Island) in New Zealand found low residues only in slugs (Morgan & Wright 1996), and Spurr (1996) could detect no change in abundance of 16 taxa of invertebrates exposed to these toxins in trials in New Zealand.

Thus, invertebrates on Gough Island are unlikely to be directly affected by aerial baiting, although the introduced earthworms present a very low risk to birds that may eat them following an eradication attempt; *cf*. the high risk to the same birds, moorhens and maybe buntings, of secondary poisoning from eating mice.

5.4.3.2 *Adverse consequences of no mice*

Mice may limit the abundance, or even the future establishment, of some exotic invertebrates. For example, introduced lumbricid earthworms form a significant part of the diet of Gough Island mice (Jones et al. 2002), and the eradication of mice might allow these to increase – with unknown consequences. An increase in seabird abundance after rodent eradication may itself have unforeseen consequences that are not simply a return to some pristine state (Fukami et al. 2006).

However, it is difficult to see how any of these speculated consequences would outweigh the expected benefits of eradication. Short-term responses might be identified by excluding mice from small areas – but the consequences of these changes (if any) for longer-term ecosystem changes would be difficult to interpret.

5.4.3.3 *Environmental fate of brodifacoum*

Brodifacoum is relatively insoluble in water and is most unlikely to be found in water even when the baits drop directly into it. However, it binds to soil particles when the baits break down and is only slowly degraded by microorganisms – with a half-life of between 12 and 25 weeks depending on conditions (Eason & Wickstrom 2001).

Small quantities of brodifacoum may be found in drinking water on Gough Island if soil particles to which it is bound leach into the water. Thus as a precaution (largely to allay staff concerns) potable water used at the Meteorological Station could be stored prior to the operation and used for a period afterwards.

Baits will have to be sown right to the edge of the sea and it is inevitable that some will fall in the water. The effects of brodifacoum on marine life have been investigated in three cases – Kapiti Island (Empson & Miskelly 1999) and Anacapa Island (Howald et al. 2005) during aerial rodent eradication operations, and at Kaikoura in New Zealand where about 18 tonnes of brodifacoum bait were deposited in the sea when a truck carrying them crashed (Primus et al. 2005). No detectable effects were found on marine life around Kapiti or Anacapa islands, and even in the extreme case at Kaikoura the toxin remained in the water and sediments for only a few days but in shellfish for up to 31 months (Primus et al. 2005).

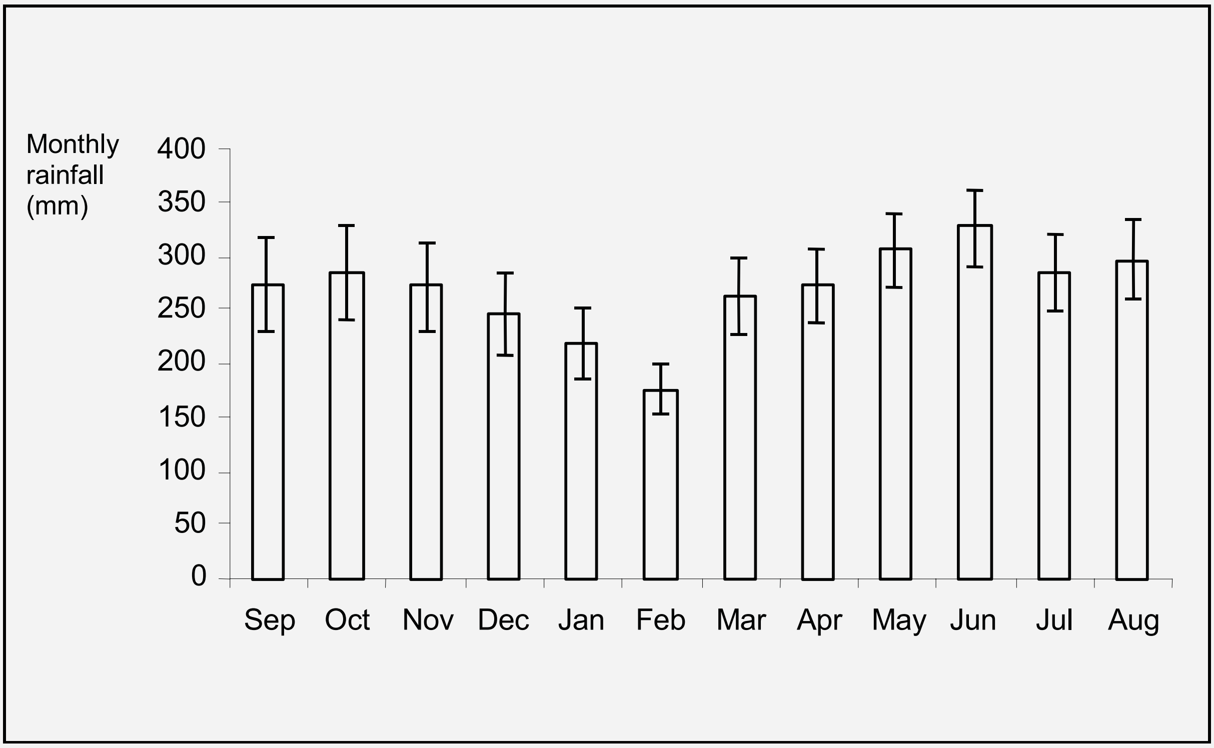
5.5 CLIMATIC CONSTRAINTS

Finding sufficient days over short periods on which helicopters can fly and cover the whole island in an initial and then a secondary baiting is a major constraint on the operation. Gough Island's weather is wet and windy, and the higher altitude areas are often shrouded in mist.

Annual precipitation averages 3,116 mm and is fairly evenly spread through and between years. Summer is consistently drier than the rest of the year (Figure 4).

The same constraints faced the Campbell Island Norway rat eradication project. They used three Bell Jet Ranger helicopters plus a larger machine to transport bait. Baiting began on 2 July and finished on 22 July, with 11 days on which some flying was possible (range 2–8 hours). The managers set up some simple rules to back-track and re-bait the leading edges of areas when weather prevented flying for various periods, for example, re-baiting three swath widths when up to 6 days lost due to bad weather. There are two issues these rules cover. First, baits disintegrate after about 200 mm of rain (see section 6.4), and second, temporal gaps in the baiting front may allow mice from the unbaited areas to move back into a previously baited area after the resident mice have eaten all the bait, and so survive.

Figure 4. Average monthly average monthly rainfall (with 95% CI) at the Meteorological Station 1980–2005



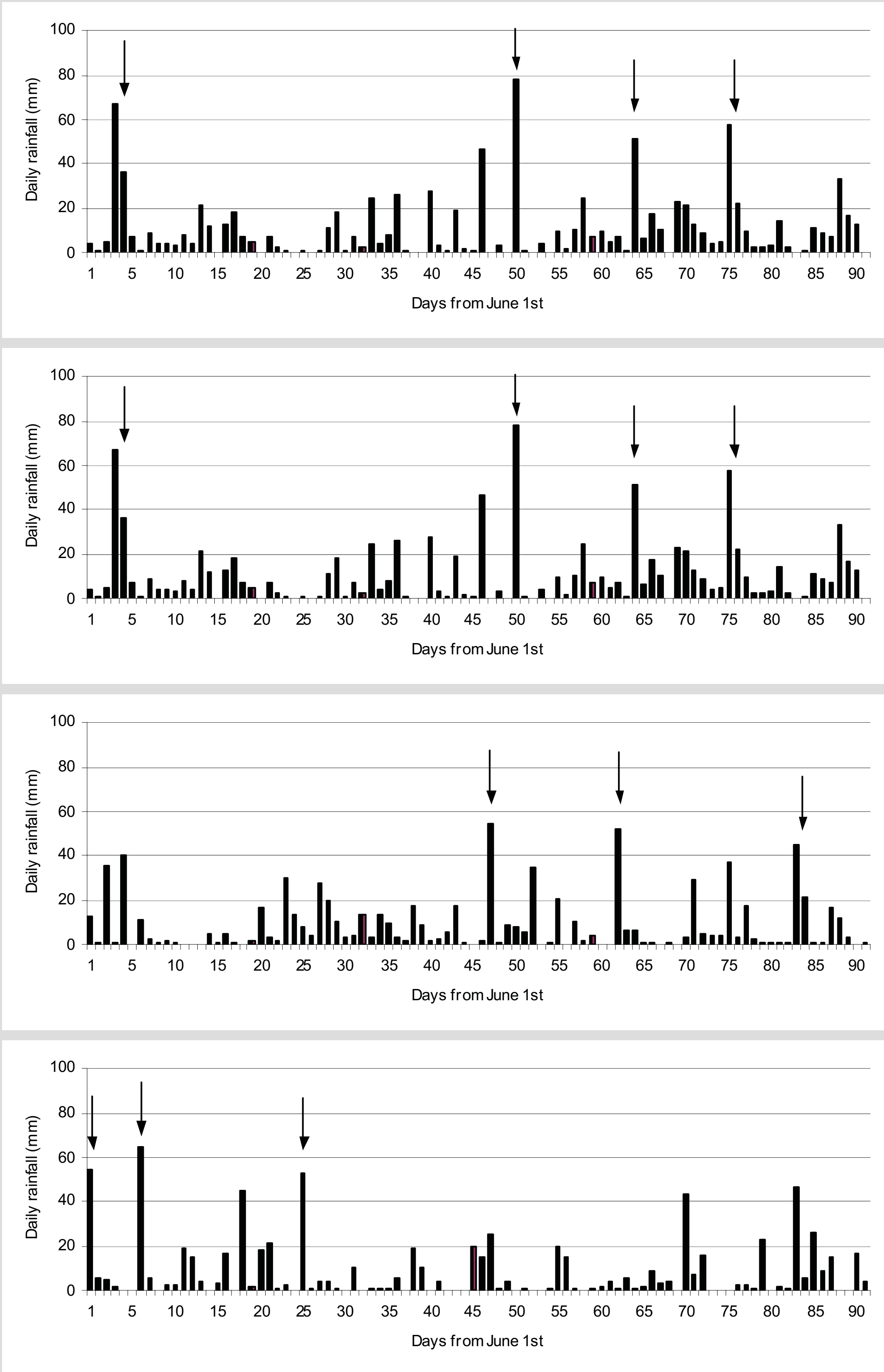
The daily precipitation between 1 June and 30 August recorded at Gough Island Meteorological Station for four years picked at random shows precipitation was recorded on an average of 27 days per month (Figure 5). Precipitation events >25 mm occurred on average on 4.0, 3.4 and 4.0 days for June, July and August, respectively.

Precipitation in highland areas of Gough Island is likely to be around 50% greater than in lowland areas where the weather station is situated (Wace 1961). The maximum single daily rainfall event (in 1980–2004) occurred on 17 June 1997 when 107.1 mm of rain was recorded.

Figure 5 suggests that bait persistence will not be an issue, especially as the non-toxic acceptance trials conducted in June 2007 (see section 5.4.1.3) suggest that most of the bait was eaten by mice on the first night.

What Figure 5 does not tell us is whether a helicopter could fly on the days with or without rain. That will have to be determined by the contracted pilots in consultation with the operations manager.

Figure 5. Daily rainfall between June and August in four years. Vertical arrows indicate either single rainfall events >50 mm, or cumulative events >50 mm for consecutive days where >10mm of rain fell



6 Technical options for eradication

6.1 WHY AERIAL APPLICATION?

It would be utterly impractical to use bait station methods on Gough Island to achieve eradication – even assuming the 100,000 bait stations required could be positioned and serviced.

Previous aerial baiting covered ~100 ha per flying hour for one overlapped coverage (e.g. for Campbell Island; (McClelland 2001) and for four small islands totalling 749 ha in the Seychelles (Merton et al. 2002)). Therefore, an initial coverage of Gough Island would require about 65 flying-hours, plus about 15 flying-hours to double bait the cliffs, plus about five flying-hours to bait the stacks. A second coverage (if that was applied) with lower bait densities and less swath overlap would require less time – say 130 flying-hours in total for both baitings.

The decision on what types of helicopters to use will be driven by (a) the number of helicopters deemed necessary to obtain island-wide coverage within a set period; (b) the need for hand-loading of the bait, thus smaller loads, smaller sowing buckets and smaller aircraft; (c) the ability to operate in marginal flying conditions; (d) the logistic constraints of shipping the aircraft to the island; and (e) the ability to hangar the machines on-ship or on-land.

Failures in sowing bucket technology have been the cause of at least one failure to eradicate rodents. Several sowing buckets are commercially available in New Zealand and the USA. Grupo de Ecologia y Conservacion de Islas (Mexico) recently informally reviewed three sowing buckets (two from New Zealand and one from the USA) and purchased one from HeliOtago Ltd, New Zealand, for use on their rodent eradications in Mexico. They were satisfied with their purchase (A Aguirre, GECI, pers. comm.).

Differential Global Positioning Systems are obviously a key tool to ensure bait coverage and swath overlaps. A trained specialist in operating DGPS systems and downloading each day's flight paths must be part of the team.

6.2 WHAT TIME OF YEAR?

So far this report has considered the time of year when mice are most at risk, when non-target species are least at risk, and when the climate gives the most opportunity for flying. Combining all of these is a trade-off, essentially between the optimal time to kill all the mice with least non-target impacts (to seabirds at least), which is winter, and the extra costs of operating at that time of year – short days and fewer good flying days.

Essentially, optimising the chance of killing all mice (in winter) must take precedence over the best weather for flying helicopters (in summer). The extra costs and constraints (shorter days and potential needs to re-bait overlapped areas if flying is curtailed for several days) should be managed with extra helicopters rather than by extending the baiting period.

6.3 WHICH TOXIN?

The toxin of choice in most recent aerial eradications against rodents has been the second-generation anticoagulant, brodifacoum. However, other options, such as the first generation anticoagulant diphacinone, are being considered, particularly in the USA, presumably because it presents a lower non-target risk (see section 5.4.3.1).

Fisher (2005) has reviewed the susceptibility of mice to a range of anticoagulant poisons and calculated the amount of standard bait a mouse weighing ~20 g would have to eat and as a percentage of its body weight (Table 3).

Table 3. Amount of bait containing standard concentrations of anticoagulant toxins that a 20 g mouse would have to eat in order to obtain an LD_{50}, and the bait weight as a proportion of its body weight (after Fisher 2005).

Poison	Concentration in usual baits (ppm)	LD_{50} ($mg\ kg^{-1}$)	Amount of bait (g) to give an acute LD_{50} dose	Lethal dose per unit body weight (LD_{50} bait dose, (g) / LD_{50} (g))
First generation				
Coumatetralyl	500	>1000	33–50	2
Warfarin	250	374	25–37	1.5
Diphacinone	50	30 or 1.4 $mg\ kg^{-1}\ day^{-1}$	10–15 0.4–0.87	0.6 0.6
Second generation				
Bromadiolone	50	1.75	0.58–0.87	0
Flocoumafen	50	0.8	0.27–0.40	0.035
Brodifacoum pellets	20	0.52	0.43–0.65	0.016
Brodifacoum wax blocks	50	0.52	0.17–0.26	0.026
Difenacoum	50	0.8	0.27–0.40	0.0104
Difethialone	25	1.29	0.86–1.28	0.016

The ideal bait/toxin should deliver a lethal dose to a mouse from a single feeding episode or bait. However, LD_{100} doses of anticoagulant toxins for mice are not known, but it is assumed by extrapolation that one or two brodifacoum baits would be sufficient (P Fisher, pers. comm.). Given that mice may eat small amounts intermittently, this is one reason why it is critical to attempt the operation at a season when the mouse population is food-stressed. Despite the non-target and persistence advantages of diphacinone, it has lower toxicity to mice than brodifacoum and the requirement for multiple feeding episodes is a problem, given the uncertainties of bait longevity under the unpredictable and wet Gough Island conditions. Brodifacoum is the recommended toxin.

6.4 WHICH BAIT?

Several commercial pellet bait formulations suitable for aerial application, all with brodifacoum at 20 ppm, are available (Table 4).

O'Connor & Booth (2001) compared the palatability to mice (n=20 mice in each trial) of two cereal pellet baits, original Pestoff® 20R and Talon® 20P (as well as a wax-block bait and a paste bait, not suitable for aerial distribution), with a commercial mouse food pellet. The Pestoff® bait was most palatable and killed 100% of the test mice, compared with a mortality of only 50% of those eating Talon® 20P baits.

Table 4. Advantages and disadvantages of commercially available brodifacoum rodent baits

Bait name and manufacturer	Weight (g)	Size (mm)	Advantages	Disadvantages
Pestoff® 20R (original) Animal Control Products	2 or 2.5	10 or 12	Used with success, no viable seeds in wholemeal cereal base	Process does not kill contaminating invertebrates; disintegrates after 200 mm of rainfall
Pestoff® 20R (new) Animal Control Products	0.3, 2, 7 or 12	5.5, 10, 16, or 20	Process kills contaminating invertebrates	Baits are harder and may not be accepted by 100% of mice
Talon® 20P ICI	3		Intact after 500 mm rainfall	Not accepted by all mice
Talon® 7-20 ICI	2			Contains Bitrex (see Veitch 2002a)
Final® pellets Bell Labs.	2		Used with success in USA and Mexico	Not often used against mice to date

Original Pestoff® 20R cereal baits disintegrate after 200 mm of rainfall (Booth et al. 1999). This is both an advantage as it ensures excess baits do not persist too long, and a disadvantage in wet climates as it means baits may not persist long enough (see section 5.5).

The bait most often used in recent rodent eradications, original Pestoff® 20R, is pelletised in a way that does not kill some invertebrates that contaminate the wholemeal cereal flour. This may not be a problem if (a) the addition of brodifacoum kills the invertebrates or (b) the species concerned cannot persist in the wild on the target island. The moth *Ephestia sp.* (Phycitinae) has been found in some batches of non-toxic Pestoff® 20R baits (J Parkes, pers. obs.). This is a commensal insect species, and is unlikely to survive in the wild (L Clunie, Landcare Research, pers. comm.). Food supplies on Gough Island are occasionally contaminated with Coleoptera (eight species have been recorded), but no Lepidoptera have been seen (Gaston et al. 2003). The baits can be sterilised but this would add to the cost.

The new Pestoff® 20R baits are extruded in a different process that kills invertebrates but results in a harder bait that may be less acceptable to mice. Trials to soften the bait matrix are being conducted in New Zealand (B. Simmons, pers. comm.)

6.5 SINGLE OR DOUBLE SOWING?

Most recent rodent eradications (Table 5) have used a double sowing of baits with swathes on the second sowing at right angles to the first. This is done partly to ensure no gaps in coverage occur, and partly to account for any animals that are not exposed, because of some behavioural trait, to the initial baiting – for example as almost-independent young still in nests or as subordinate animals excluded from bait. There is no evidence that these two factors are genuine concerns, but the practice is followed where possible as a precaution.

Depending on the number of helicopters available, and how long the initial coverage takes, it would be possible to begin the second sowing application on Gough Island before completing the first one. That is, assuming about 10 days between sowings but more than 10 days to complete the first coverage (due perhaps to gaps in flying time caused by weather), it would be sensible to begin the second sowing in say lower altitude zones begun first if flying was restricted at higher altitudes by weather.

Table 5. Recent aerial control operations against island rodents. All the rodent baits contained brodifacoum, and the cat bait used on Raoul Island contained sodium fluoroacetate (Compound 1080)

Island	Area (ha)	Target species	Helicopter type	Kg ha^{-1} 1st sowing	Kg ha^{-1} 2nd sowing	Days between sowings	Bait	Reference
Stanley	100	Kiore, Rabbit	AS-350 Squirrel (no GPS)	17.5 (aerial)	1 (ground)	0-4	ICI Talon 20P Talon 50WB	Towns et al. (1993)
Red Mercury	225	Kiore	AS-350 Squirrel (no GPS)	15.6 (aerial)	0.62 (ground)	0	ICI Talon 20P Talon 50 WB	Towns et al. (1994)
Cuvier	194	Kiore	AS-350 Squirrel (no GPS)	12.9 (aerial)	0.06 (ground)	0-42	ICI Talon 20P Talon 50 WB	Towns et al. (1995)
Kapiti	1,965	Norway rat, Kiore	Not known	9.2	5.1	25	Talon 7-20	Empson & Miskelly (1999)
Tuhua	1,280	Norway rat, Kiore, Cat	1 Bell UH1 Iroquois	8	4	14	Pestoff 20R	Anon. (2001)
Campbell	11,331	Norway rat	3 Bell Jet rangers	6		Single baiting	Pestoff 20R	McClelland & Tyree (2002)
Raoul	2,940	Norway rat, Kiore, Cat	2 Bell UH1 Iroquois	8	4	5	Pestoff 20R 1080 cat bait	Anon. (2003)
Anacapa	280	Ship rat	1 Bell Jet Ranger	15			Bell Labs. Final pellets	Howald et al. (2005)
Farallon de San Ignacio	17	Ship rat	1 Bell Jet Ranger	24.4	0	Single baiting	Bell Labs. Final CI25	Samaniego-Herrera et al. (2008)
San Pedro Martir	267	Ship rat	1 Bell Jet Ranger	8.8	8.8	9	Bell labs. Final CI25	Samaniego-Herrera et al. (2008)

6.6 INFRASTRUCTURE AND MANAGEMENT REQUIREMENTS FOR ERADICATION

An eradication project would require appropriate governance, planning and delivery management systems (Table 6). I suggest separating the roles of Project Manager (the quartermaster) from that of the Operational Manager, although the jobs will need to overlap in time and responsibilities as the planning process advances.

Table 6. Suggested management structure for Gough mouse eradication programme

Management group	Roles	Constituents
Resource application	Seek funding source for approval in principle	Royal Society for Protection of Birds?
Governance	1. Legal entity for holding and disbursing funds 2. Oversight of project policies	1. Tristan da Cunha Government 2. Funding agency 3. SA DEAT
Project manager	1. Arrange logistics and subcontracts for shipping, helicopters, bait, infrastructure 2. Arrange legal consents	Contractor to governance group
Operational manager	1. Deliver eradication 2. Manage subcontractors	Contractor to either the project manager or governance group

7 Feasibility of Option 2: Sustained Control

7.1 Understanding when, where, how much to intervene and what to protect

Sustained control is a more complicated strategy than eradication because it requires knowledge about the relationships between mouse abundance, prey condition, and how our intervention in time and space affects the former to protect the latter. These relationships are not usually simple or linear (Choquenot & Parkes 2000), and are likely to vary for the different species being impacted by mice.

Sustained control, by definition, has to be maintained in perpetuity (or until better alternative strategies are implemented) and, as we shall see, the methods to do this preclude treating the whole of Gough Island as a unit – in fact a few hundred hectares at most seems practical.

First, we could select a 'representative' part of the island and control mice over it. This would be an interesting but essentially an academic exercise because it is the whole island and its populations of native biota that are the primary resources to be protected rather than a relict part of it.

Second, we could control mice over an area sufficiently large to make a difference to some native species under threat from predation. Ideally, such an area should protect the suite of species under threat but in fact several controlled areas, some in the highlands and some in the lowlands, might be required in order to protect all affected species.

If this argument is correct, then which population of affected native species could be protected by sustained control? If we consider the birds, controlling mice in say 500 ha of Atlantic petrel breeding area or prime Gough bunting lowland habitat might make a difference to the sustainability of the whole population if sufficient additional recruitment was the result – this would have to be tested. Tristan albatross only nest in higher-altitude parts of the island and mouse predation is patchy and potentially predictable within these sites (Wanless 2007). It is more likely that targeted sustained control might reduce predation on albatross chicks with a population-level benefit. It might even eliminate it as there appears to be some unknown trigger mechanism that induces mice to eat chicks at some places but not others despite similar mouse densities. This too would have to be tested.

The issues are best resolved using a management experiment, which would need to resolve the following questions:

- Where to apply the control around sites where predation is a regular event?
- When to apply the control; (presumably between June and August when most mouse predation has been observed to occur, Wanless 2007)?
- How much effort to expend and thus what target residual mouse density is required to stop or ameliorate the predation?
- Over how large an area can mice practically be controlled, and therefore how many albatross nests can be protected, and hence given an expected predation level in the absence of mouse control, what power to detect a treatment effect can be expected?

- How many treatment replicates are required?
- How many non-treatment areas should be included, and should these be sites where predation has historically been lower or parts of sites with high expected predation rates; or are data from previous years' monitoring sufficient to act as an experimental control?

Most Tristan albatrosses nest in about 10 more-or-less discrete areas on Gough Island. Most lay eggs in January, which hatch in March and the chicks fledge in November. Wanless (2007) assumed that natural mortality rates of eggs and chicks would be similar between areas and years, and about the same for similar albatross species elsewhere (at between 25% and 40%). He thus assumed that the observed higher mortality rates in some areas (77% at the most populated site at West Point) was due to the known but unmeasured effects of predation by mice.

The discrete breeding areas cover about 1,000 ha, so it would be very expensive to control mice each year over all areas, and especially in the largest nesting site at West Point, which is the most remote part of the island from the Meteorological Station. It would require about 25,000 bait stations assuming these are on a 25 × 25-m grid. The advantage of bait stations is that they can be set once and operate for a long time to kill both resident and immigrant mice. Ground-distributed baits may be cheaper to lay (even if by hand rather than from the air), but because they will decay more rapidly than those in stations, the treatment would have to be repeated several times during the period when birds were at risk. I note that all of this detail would need to be tested to reach optimal control designs.

Even protecting the main breeding sites where predation has historically been high (Albatross Plain, Green Hill, Spire Crag, Triple Peak and West Point) would require a very large effort and not many fewer bait stations than protecting all sites.

An experimental compromise (rather than an operational solution) to test whether sustained control of mice had a measurable effect in reducing chick mortality might be to control mice over parts of say Green Hill (say to contain half of the nests) and compare the resulting rates of predation with that in nests in the uncontrolled parts. The individual nest then becomes the replicate rather than the discrete breeding areas.

7.2 TECHNICAL OPTIONS FOR SUSTAINED CONTROL

Bait stations (that exclude birds) with long-life anticoagulants baits, alternated with an acute toxin such as zinc phosphide to reduce environmental accumulation of toxins, might be used to control mice. The efficacy of such a strategy would have to be tested. Trapping or periodic aerial baiting would appear to be too expensive to sustain.

Trials to develop long-life baits for rodent control (particularly for use as a precaution against invasions) have been conducted in New Zealand (Morriss et al. 2006). Baits with a wax component were most suitable, and four commercially available were tested against mice. Pestoff® Rodent Blocks, Talon® wax blocks with brodifacoum, and Rentokil Ridrat® and Contrac® All Weather Blox with bromadiolone were all palatable but only Pestoff killed 100% of exposed mice. The proportion of mice eating Pestoff and Contrac was measured over 12 months as the baits weathered. Both baits remained toxic, palatable, and killed up to 100% of mice exposed to 12-month-old baits – despite invasion of the baits by mould (Morriss et al. 2006).

7.3 INFRASTRUCTURE AND MANAGEMENT REQUIREMENTS FOR SUSTAINED CONTROL

If the long-life baits effectively suppressed mouse populations in the areas baited, then the only infrastructure needs would be the deployment of bait stations and replenishment of the baits as mice consumed them. The scale of the former (see section 7.1) and the frequency of the latter remain unknown.

8 Option 3: Do Nothing until Technical Advances are Available

8.1 BIOCONTROL

Mouse biocontrol options have been explored among the many viral, bacterial, and parasitic organisms that infect mice (Singleton et al. 1995; Moro et al. 2003), but no effective candidate agent has been found that is capable of suppressing mouse populations to the extent required to act as a control on Gough Island. The potential effectiveness of biocontrol for Gough Island mice is currently being reviewed (RJ Cuthbert pers. comm.).

8.2 VECTORED IMMUNOCONTRACEPTION

Australian researchers were investigating the use of a genetically engineered mouse cytomegalovirus that would sterilise mice that contracted the virus (Seamark 2001). The idea of such immunocontraception is to genetically modify a natural vector with antigens involved in the host animals' reproductive system so that a host exposed to the vector (naturally or in a bait) raises antibodies to the foreign vector that also affect its own ability to reproduce (Tyndale-Biscoe 1994). The research was stopped in 2006 (along with that on fox and rabbit immunocontraception) because the engineered virus was found to have insufficient transmission rates to affect mouse population reproductive rates (T Peacock, Invasive Animals CRC, Canberra, pers. comm.).

8.3 SPECIES-SPECIFIC TOXINS

Landcare Research in New Zealand is currently developing new toxins that are aimed to be specific for rats and not affect other species. The first, a development of a rodenticide registered in Italy, is specific to *Rattus* spp. (B Hopkins, Landcare Research, pers. comm.). The ingredients are not very palatable to rats and would have to be encapsulated to ensure 100% acceptance. Research is also underway to identify the mechanism behind this specificity and to determine if chemical analogues of the toxin can be made to specifically target other pest species or genera. Useable products against say *Mus* spp. are many years away.

9 Preliminary Cost Estimates

9.1 Eradication

My preliminary guess at the cost of an eradication is £1.5 million (Table 7), but so many major costs are essentially unknown that the final costs could be twice this or half if shipping was provided at no cost.

Table 7. Estimated first-pass costs of eradicating mice from Gough Island

Item	Estimated costs (GBP)	Notes
Bait (100 tonnes)	£120,000	Assume Pestoff 20R
Bait transport etc.	£80,000	From New Zealand
Helicopters (130 flying-hours)	£119,000?	Assume two sowings
Helicopters (down time, fuel, bait buckets, DGPS, engineer, etc.)	£300,000?	Depends on how the subcontract is written (seems cheap to me)
Island infrastructure (bait storage, hangars, accommodation)	£50,000?	
Ship hire	£500,000?	An absolute guess taken from Brown's (2007) guess
Project manager (18 months' salary + costs)	£75,000	
Operations manager (1 years' salary + costs)	£55,000	
Operational staff (10 × 3 months)	£100,000	
Non-target management	£100,000	Assume need to capture and relocate moorhen and buntings to Tristan
Miscellaneous equipment	£25,000	Computers, etc.
TOTAL	**£1,524,000**	

9.2 Sustained control

The main costs would be for bait-stations, bait and labour to deploy and service the stations, and the totals would vary depending on the scale of areas to be treated (see section 7.1).

I would guess at a set-up cost of ~£85 ha^{-1} and an annual cost of about £170 ha^{-1} yr^{-1} to maintain the stations – assuming three visits per year by a team of say four people.

10 Legal Issues

Brodifacoum pellets baits are registered for aerial application in New Zealand, the USA and Mexico, and an initial opinion from the previous Tristan da Cunha Administrator (Mr M. Hentley) is that so long as it is not specifically illegal in the United Kingdom and was for a purpose justified under Tristan da Cunha's policies (for example the Biodiversity Action Plan or the Gough Island Management Plan), then the Tristan da Cunha Government could approve its use on Gough Island.

The Tristan da Cunha Conservation Ordinance 1976 prohibits 'the spreading of …pesticides except within a building or tent or for agricultural or horticultural purposes ...'. However, the Administrator of Tristan da Cunha may permit any named person to do any of the things forbidden in the Ordinance.

The cooperation of the South African Department of Environmental Affairs and Tourism for the use of their facilities on Gough Island would be required.

Insurance issues would depend on how the contracts are formed.

11 Preliminary Recommendations

The high annual cost and uncertain benefits of sustained control suggest that the eradication option should be favoured.

Improved understanding of the technical systems (DGPS, sowing buckets, multiple baiting to ensure no gaps in bait distribution, pilot skills) increase the likelihood of eradication success on Gough Island – irrespective of its size and remote location. There are no unique habitats that alter this judgement. Rodents have been eradicated from islands with 'three dimensional' problems such as caves and large talus or boulder fields. However, the presence of lava-tubes on Gough Island may be an issue that should be further addressed in field trials on the island.

Two major constraints exist, but both are manageable. First, the issue of protecting non-target species (particularly the two landbird species) will need to be managed. The only way to do this without compromising the eradication is by capturing and holding a proportion of each population in safety. Second, the weather on Gough Island is generally inclement for baiting from helicopters. A trade-off between added cost (of more helicopters) and increased risk (by having to repeat areas at the edges of baited zones when the weather curtails flying) has to be considered. There are substantial logistical problems that will need to be solved to attempt the eradication.

While current evidence strongly suggests that brodifacoum should be the toxin, it is not yet clear which bait would be best to deliver the toxin. Most recent eradications have deployed Animal Control Products Pestoff® 20R bait, using the older versions with 10 mm or 12 mm pellets. However, recent operations in the USA and Mexico have succeeded against rats using the Bell Laboratory Final pellet baits. I know of no experiments that have compared the palatability and acceptance of all of these baits to mice – although I understand such trials (on palatability at least) may be underway in Hawai'i (W Pitt, USDA, Hawai'i, pers. comm.). A recent comparison between the older Pestoff 20R baits and the latest version of the Animal Control products bait showed that the new 'softened' version was significantly more palatable to mice (Thomas 2008). Palatability per se might of course not be the reason for less than 100% acceptance by mice so research is also being undertaken in New Zealand to try to identify why mice are apparently more difficult to eradicate than rats. Studies being conducted include tests of bait size and hardness on palatability (= amount of bait eaten) and acceptability (= proportion of mice that eat baits), and of the influence of ship rat presence on bait acceptance by mice (P Fisher, pers. comm.).

A non-toxic trial to compare the relative acceptance by mice (and rats) of the candidate baits might be conducted on Gough. A similar design to that used in the small trial conducted by Wanless et al. (2008) on Gough Island would give relative values, but a better trial might be to duplicate the options noted in Appendix 3 for all candidate baits.

Even if all these constraints and issues are addressed and the eradication operation uses current best practice, there remain residual risks of failure. About a third of previous attempts to eradicate mice have failed – sometimes because best practice has not been used, but often the reasons are not known. Further research to reduce remaining areas of uncertainty, particularly in relation to the Gough island terrain and optimal baits for mice, followed by a well planned, best practice operation, will have the greatest chance of successfully removing mice from Gough Island.

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Appendix 1 Successful and failed eradication attempts against mice on islands

(updated and modified from Howald et al. 2007).

Island	Country	Area (ha)	Year	Rats present[1]	Method[2]	Reference
SUCCESSFUL FOR MICE						
Enderby	New Zealand	710	1995	No	1, a, i	Torr (2002)
Blumine	New Zealand	377	2005	No	1, a, i	MacKay et al. (2007)
Curieuse	Seychelles	286	1996	*R rattus*	1, a, i	Merton et al. (2002)
Flat	Mauritius	253	1998	No	3, a, i	Bell (2002)
Fregate	Seychelles	219	2000	*R norvegicus*	1, a, i	Merton et al. (2002)
Mana	New Zealand	217	1990	No	¼, a/c, ii/iii	Hook & Todd (1992)
Selvagem Grande	Madeira (Portugal)	200	2003	No	2/4, a, i	R Trout (pers. comm.)
Motuihe	New Zealand	179	1997	*R norvegicus*[1]	1, a, ii	Veitch (2002a)
Denis	Seychelles	143	2003	*R rattus*[1]	2, a, i/v	Climo (2003)
Mou Waho	New Zealand	140	1995	No	1, a, i	Clout & Russell (2006)
Mokoia	New Zealand	133	2003	*R norvegicus*[1]	1, a, i	MacKay et al. (2007)
Pickersgill	New Zealand	103	2005	*R rattus*[1]	1, a, i	MacKay et al. (2007)
Varanus	Australia	80	1997	No	4, a/f, v/vii	Burbidge & Morris (2002)
Rasa	Mexico	60	1994	*R rattus*[1]	4/5, a, ?	Howald et al. (2007)
Browns	New Zealand	58	1995	*R norvegicus*[1]	1, b, i	Veitch (2002b)
Flatey	Iceland	50	1971	*R norvegicus*[1]	?, e, ?	Howald et al. (2007)
Motutapere	New Zealand	45	1994	*R rattus*[1]	¼, a, ?	MacKay et al. (2007)
Ohinau	New Zealand	43	2006	*R exulans*[1]	1, a	MacKay et al. (2007)
Surprise	New Caledonia	24	2005	*R rattus*[1]	2, b, ?	MacKay et al. (2007)
Rimariki	New Zealand	22	1991	*R norvegicus*?	4, b, ?	MacKay et al. (2007)
Bridled	Australia	22	1997	No	4, a, v	Burbidge & Morris (2002)
Allports	New Zealand	16	1989	No	4/5, a, ?	Brown (1993)
White Cay	Bahamas	15	1998	*R rattus*[1]	4, a, ?	
Cocos	Mauritius	15	1995	No	3, a, i	Bell (2002)
Sables	Mauritius	8	1995	No	3, a, i	Bell (2002)
Moturemu	New Zealand	5	1992	*R norvegicus*[1]	3, a	MacKay et al. (2007)
Whenuakura	New Zealand	2	1984	*R norvegicus*[1]	4, b, ?	Newman (1985)
Motutapu	New Zealand	2	1989	No	4, c, iv	MacKay et al. (2007)
Beacon	Australia	1	1997	No	4, a, v	Burbidge & Morris (2002)
Papakohatu	New Zealand	1	1996	No	3, a, i	MacKay et al. (2007)

Island	Country	Area (ha)	Year	Rats present[1]	Method[2]	Reference
FAILED FOR MICE:						
St Paul	France	800	1996	*R rattus*	1/2, a, i	Micol & Jouventin (2002)
Fajou	Guadeloupe	120	2001	No	2/5, b,	Lorvelec & Pascal (2005); M Pascal (pers. comm.)
Tromelin	France	100	2005	No	2/4, a, ?	MacKay et al. (2007)
Denis	Seychelles	143		*R rattus*	1, a, i	Merton et al. (2002)
Mokoia	New Zealand	133	1996	*R norvegicus*[1]	1, a	MacKay et al. (2007)
Bird	Seychelles	101		*R rattus*	2/4, a, i/v	Merton et al. (2002)
Quail	New Zealand	88		*R rattus*[1]	3, a	M. Bowie (pers. comm.)
Varanus	Australia	80	1993	No	4, g, vii	Burbidge & Morris (2002)
Buck	US Virgin Is	71		*R rattus*[1]	3, d	Witmer et al. (2007)
Matakohe	New Zealand	37	1997	*R norvegicus*[1]	1, a	MacKay et al. (2007)
Matakohe	New Zealand	37	1998	No	1, a	MacKay et al. (2007)
Matakohe	New Zealand	37	2001	No	3, a	MacKay et al. (2007)
Patiti	New Zealand	13	2004	R rattus	3, a	MacKay et al. (2007)
Te Haupa	New Zealand	6	1993	No	3, c	MacKay et al. (2007)
Hauturu	New Zealand	10	1993	*R norvegicus*[1]	2/4, a, ?	MacKay et al. (2007)
Haulashore	New Zealand	6	1991	*R norvegicus*[1]	4, a, ?	MacKay et al. (2007)
RESULTS PENDING						
Ile du Chateau	Kerguelen, France	250	2002	No	1, a, ?	Howald et al. (2007)
Adele	New Zealand	87	2007	No	1,a, i	MacKay et al. (2007)
Fisherman	New Zealand	4	2007	No	1, a, i	MacKay et al. (2007)
Pomona	New Zealand	262	2007	No	1, a, i	MacKay et al. (2007)
Rona	New Zealand	60	2007	No	1, a, i	MacKay et al. (2007)
Tonga	New Zealand	8	2007	No	1, a, i	MacKay et al. (2007)

Key to Methods:

1. Aerial	a. Brodifacoum	i. Cereal pellets(Pestoff20R®)
2. Handbroadcast	b. Bromadiolone	ii. Cereal pellets (Talon20P®)
3. Open stations	c. Flocoumafen	iii Cereal pellets (Talon 7-20 2g + Bitrex®)
4. Bait stations	d. Diphacinone	iv Storm®
5. Traps	e. Warfarin	v Wax blocks (Talon50WB®)
	f. Pindone	vi Pestoff blocks®
	g. 1080	vii. Whole grain

Appendix 2 Temperate and subantarctic islands >500 ha from which rats have been eradicated

Island	Country	Area (ha)	Year	Species	Method[1]
Campbell	New Zealand	11,300	2002	*R norvegicus*	1, a, i
Langara	Canada	3,105	1995	*R norvegicus*	3, a
Hauturu	New Zealand	3,083	2004	*R exulans*	1, a, i
Codfish	New Zealand	1,396	1998	*R exulans*	1, a, i
Kapiti	New Zealand	1,965	1996	*R exulans; R norvegicus*	1, a, i
Tuhua	New Zealand	1,277	2000	*R exulans; R norvegicus*	1, a, i
St Paul	France	800	1996	*R rattus*	1/2, a, i

Key to Methods:

1. Aerial	a. Brodifacoum	i. Cereal pellets (Pestoff20R®)
2. Handbroadcast	b. Bromadiolone	ii. Cereal pellets (Talon20P®)
3. Open stations	c. Flocoumafen	iii Cereal pellets (Talon 7-20 2g + Bitrex®)
4. Bait stations	d. Diphacinone	iv Storm®
5. Traps	e. Warfarin	v Wax blocks (Talon50WB®)
	f. Pindone	vi Pestoff blocks®
	g. 1080	vii. Whole grain

Appendix 3 Bait acceptance trials

The preliminary trial conducted by Wanless et al. in June 2007 showed that 3% of mice putatively exposed to bait apparently did not eat it. However, in retrospect the design of the trial and the apparent wide-ranging behaviour of the mice meant that it was unclear whether these mice had been exposed to bait or had immigrated into the sampling area after resident mice had eaten the baits.

Three options to overcome these uncertainties are possible under either a single baiting or double baiting protocol.

First, the trial could be repeated using a helicopter to distribute bait over a much wider area so that immigration into a sampled core area would be very unlikely. For example, non-toxic acceptance trials on Campbell Island covered 600 ha.

Second, the trial could be repeated using mice caught and ear-tagged in the baiting area immediately prior to the baiting, and recaptured after the baiting.

Third, if a double baiting protocol is used (to mimic a double baiting operation) two bait markers could be used (rhodamine in the first baiting and pyridine in the second) and mark-recapture methods used to estimate acceptance.

All trials assume there are no false negatives to the dye, i.e. all mice eating baits are marked.

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The Tristan Natural Resource Department is responsible for biodiversity conservation on Tristan da Cunha. It works in partnership with organisations from around the world, to reduce the rate of biodiversity loss on the Tristan Island group.

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