Preparations for the eradication of mice from Gough Island: results of bait acceptance trials above ground and around cave systems

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Abstract Gough Island, Tristan da Cunha, is a United Kingdom Overseas Territory, supports globally important seabird colonies, has many endemic plant, invertebrate and bird taxa, and is recognised as a World Heritage Site. A key threat to the biodiversity of Gough Island is predation by the introduced house mouse (*Mus musculus*), as a result of which two bird species are listed as Critically Endangered. Eradicating mice from Gough Island is thus an urgent conservation priority. However, the higher failure rate of mouse versus rat eradications, and smaller size of islands that have been successfully cleared of mice, means that trials on bait acceptance are required to convince funding agencies that an attempted eradication of mice from Gough is likely to succeed. In this study, trials of bait acceptance were undertaken above ground and around cave systems that are potential refuges for mice during an aerial application of bait. Four trials were undertaken during winter, with rhodamine-dyed, non-toxic bait spread by hand at 16 kg/ha over 2.56 ha centred above cave systems in Trials 1-3 and over 20.7 ha and two caves in Trial 4. Totals of 460, 202 and 95 mice were ear-tagged prior to bait spreading in Trials 1 - 3, respectively, to identify resident mice within the core of each study area. A total of 940 mice were subsequently caught with 100% bait acceptance by ear-tagged mice in all trials. All mice caught in caves were positive for rhodamine-dyed bait, indicating that cave systems are unlikely to be an obstacle for eradication. Our results indicate that mouse eradication could be successfully conducted on Gough Island and that planning for such an operation should proceed in order to remove the key conservation threat to the island's wildlife.

Keywords: House mouse, *Mus musculus*, Tristan albatross, *Diomedea dabbenena,* conservation

INTRODUCTION

House mice (*Mus musculus*) introduced to temperate/sub-Antarctic islands can have serious negative effects on seabirds and other species (Angel and Cooper 2006; Cuthbert and Hilton 2004; Jones *et al.* 2003; Ryan and Cuthbert 2008; Smith *et al.* 2002; Wanless *et al.* 2007). On Gough Island, these effects have resulted in the Tristan albatross (*Diomedea dabbenena*) and Gough bunting (*Rowettia goughensis*) being given a conservation status of Critically Endangered and Atlantic petrel (*Pterodroma incerta*) as Endangered (IUCN 2010). Mice also prey on the chicks of great shearwaters (*Puffinus gravis*) (Wanless *et al.* 2007) and sooty albatrosses (*Phoebetria fusca*) (RSPB unpublished data). Furthermore, many populations of burrowing petrels have decreased dramatically over the last few decades (Ryan 2010). Population modelling for the Tristan albatross and Atlantic petrel suggests that mice are driving these population declines (Cuthbert *et al.* 2003; Cuthbert 2004; Wanless *et al.* 2009).

Given their recorded and potential impacts (Smith *et al.* 2002; Jones *et al.* 2003; Ryan and Cuthbert 2008; Jones and Ryan 2010), strategies for eradicating mice from large islands are needed. At present, when mice are compared with rats on islands, the failure rate of mouse eradication attempts is higher (Howald *et al.* 2007; MacKay *et al.* 2007) and the maximum area from which mice have been successfully eradicated is smaller (710 ha Enderby Island v. 11,300 ha Campbell Island; McClelland and Tyree (2002), Torr (2002)). This means that the outcome of an eradication attempt on 6400 ha Gough Island is uncertain. The feasibility of eradicating mice from Gough Island was recently assessed by Parkes (2008), who concluded that an eradication was technically feasible, but that key questions remained to be answered prior to an operation being undertaken.

To provide confidence to operational managers and potential funders that an eradication operation is likely to succeed, trials have been used to determine the levels of bait acceptance by target species. Typically, these trials utilise non-toxic bait stained with a biomarker dye, with the baits spread at the likely density and time of year as the proposed operation. Such trials were undertaken for rats on Campbell Island (P. McClelland pers. comm.) and Lord Howe Island (I. Wilkinson pers. comm.) and recently at Gough Island (Wanless *et al.* 2008). Following near total bait acceptance in the first two trials, operations on Campbell went ahead and plans for Lord Howe Island are now close to being realised.

On Gough Island, eradication attempts are complicated by large size, mountainous terrain and numerous caves, including lava tubes up to 20 m long (Parkes 2008). The caves are used as breeding sites by hundreds of broad-billed prions (*Pachyptila vittata*) (Cuthbert 2004) and may contain sufficient food to obviate the need for mice to forage outside. Mice could thus fail to encounter bait pellets (Parkes 2008; Wanless *et al.* 2008). If this were the case, some mice may only be killed if caves are targeted specifically – a logistically challenging endeavour given that only a fraction of the island's caves have been identified. Nonetheless, operation managers must be confident that aerially applied bait will be accessible to the mice in caves (Parkes 2008; Wanless *et al.* 2008). Before a full Operational Plan can be completed for a mouse eradication on Gough, the following steps remain: (1) define and test the optimal bait and baiting procedure, (2) determine whether all mice within caves systems will take aerially distributed bait, and (3) conduct bait acceptance trials that replicate eradication conditions in the field.

In this study, we present results of bait trials on Gough Island to determine the susceptibility of mice, including those in caves, to an aerial drop of bait. These trials build on the work of Wanless *et al.* (2008) who found that 3% of mice avoided bait in a trial conducted on Gough in 2006. Confounding effects of the study design may account for these results, but if some mice rejected the bait, the prospects for successful eradication are uncertain (Wanless *et al.* 2008). These authors also found that mice in a cave took surface bait. However, the small number of mice used (11), the small sample of caves (1), and the way bait application differed from aerial spread, limit the conclusions that can be made for the island as a whole.

We undertook further trials above ground and around three separate cave systems. We ear-tagged mice before bait was spread within the core of the first three trials (as on Lord Howe Island and recommended by Parkes (2008)

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and Wanless *et al.* (2008)) and conducted a further trial over a larger area (as on Campbell Island). Our study was thus able to remove the factors that confounded previous trials on Gough Island and provide empirical measures of potential for the success or failure for a mouse eradication attempt.

MATERIALS AND METHODS

Study area

Gough Island (40 °13'S, 9°32'W) is part of the United Kingdom Overseas Territory of Tristan da Cunha, and lies in the central-South Atlantic Ocean some 2600 km from South Africa and 380 km southeast of Tristan da Cunha (Fig. 1). The island is steep and mountainous rising to 910 m above sea level (asl). Annual precipitation is around 3100 mm and higher altitude areas are often shrouded in mist and cloud. Lowland areas are dominated by fern bush vegetation, characterised by relatively tall (up to 3–4 m), island cape myrtle (*Phylica arborea*) trees, dense ferns and sedges, whereas upland areas comprise low-lying wet heath habitat, peat bogs and bare rocks (Wace 1961).

Bait acceptance trials

Movement distances

This part of the study was based on the movements of mice on Gough Island in winter. Eight radio-tagged mice were observed at 160 locations, and 373 live trapped mice were recaptured 1584 times on four 8 x 8 m grids of 100 traps situated in lowland (n=2) and upland (n=2) areas. For mice previously captured in caves, the minimum distance moved was estimated as the distance from the cave-entrance to the trap on the trapping grid.

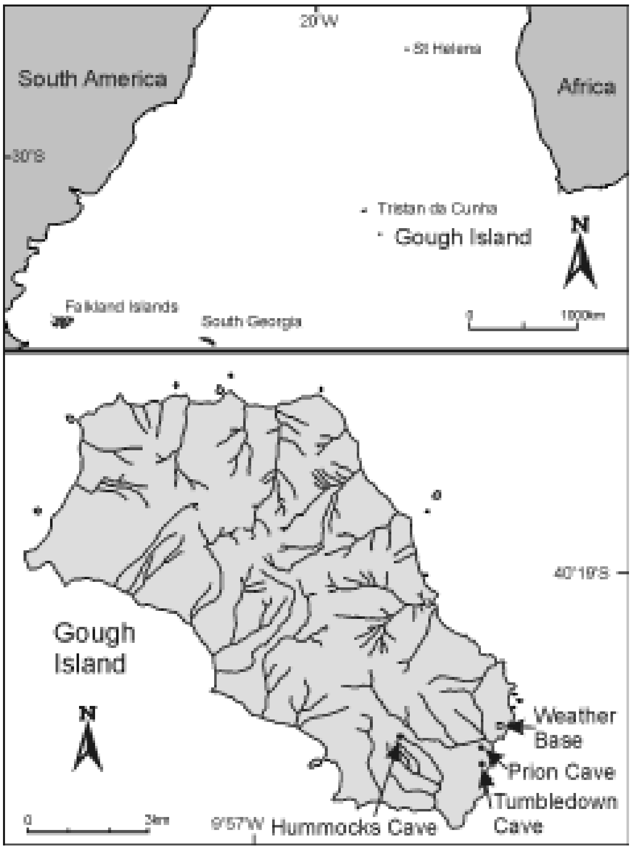

Fig. 1 Gough Island is part of the United Kingdom Overseas Territory of Tristan da Cunha, in the central-South Atlantic Ocean. Trials were undertaken around Prion Cave, Tumbledown Cave and Hummocks Cave.

Susceptibility to baits

Four bait acceptance trials were undertaken, with three in lowland areas (Trials 1, 2 and 4; C. 50 m asl) and one in the uplands (Trial 3; 530 m asl). Trials 1-3 were conducted in winter: mid June (Trial 1), early July (2) and late July (3). Trial 4 was at the onset of spring in late September.

Trials 1-3 were around Prion Cave, Tumbledown Cave and Hummocks Cave respectively (Fig. 1). Mice were caught within caves and on a 72 x 72 m trapping grid outside caves with the cave entrance at its centre. One hundred single catch live-traps were set outside and 3-12 multi-catch live-traps were set within caves for four consecutive nights. All mice captured were fitted with individually numbered ear-tags (Vet Tech Solutions, UK). Bait was then spread over a 2.56 ha area (160 x 160 m), with the cave and trapping grid at its centre and a minimum distance from the outer edge of the baiting to the core trapping-grid (buffer zone) of 44 m.

Mice were not ear-tagged in the core area of Trial 4 as the baited buffer zone was a minimum of 180 m beyond the trap grid and thus well beyond the maximum distance moved by mice entering the grid from outside. The baited area of Trial 4 measured 20.7 ha (ca 397 x 598 m) and overlapped the caves of Trials 1 and 2.

Non-toxic cereal bait pellets (PESTOFF20R, Animal Control Products, New Zealand) with the same formulation as toxic bait were used for the trials. Rhodamine dye was applied to bait on Gough Island, following protocols recommended by the manufacturer. The palatability of baits to rodents is not affected by rhodamine concentrations in the range used to mark bait (Fisher 1999), so the results of these trials should be directly comparable to a toxic bait operation.

In all trials, baits were spread by fieldworkers walking line-abreast along linear transects and spreading bait by hand over a 4-5 m swathe on either side to simulate aerial spread. Bait density was 16 kg/ha over 2.56 ha for Trials 1-3 and 16.9 kg/ha over 20.7 ha for Trial 4. No bait was spread in the caves.

Beginning one day after the baits were spread, mice were kill-trapped for three consecutive nights in Trials 1-3 and four consecutive nights in Trial 4. Two hundred snap traps and 100 live traps were set within the core area (72 x 72 m) of each trial, with 2 snap traps and 1 live trap set at each grid-point. In addition, 3-12 multi-catch live traps and additional snap traps were set in the cave systems.

All mice were checked with an ultraviolet light for the presence of rhodamine at the mouth and anus and within their intestinal tract (Jacob *et al.* 2002). When results were unclear, 6-12 whiskers were collected from each animal, washed in ethanol, and stored for examination under

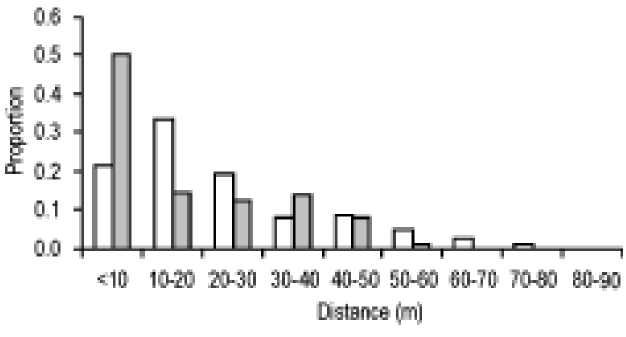

Fig. 2 Frequency distribution of distances moved by mice during the three nights of live-trapping and single night of kill-trapping for trials 1, 2 and 3, for mice captured above ground (unfilled bars) and mice initially caught within caves and subsequently captured above ground (shaded bars).

a microscope and/or hand-lens. Vouchers for positive samples of whiskers were obtained from 20 mice scored positive from their stomach contents. Negative samples were obtained from 20 mice before the baits were spread. Information on sex and reproductive status was collected from all kill-trapped mice.

Potential mouse food resources within caves

If mice in caves were to avoid poison bait outside they needed an alternative source of food. This was most likely to be associated with breeding broad-billed prions within the caves. Monthly checks were conducted at several caves (including those used in Trials 1-4) during the year to record whether birds were breeding and if there was any evidence of predation by mice. Caves were also searched for the presence of invertebrates and other potential food resources.

RESULTS AND DISCUSSION

Movement distances

Over 95% of recorded overnight movements were <40-50 m, with <1% of movements >80 m (R. Cuthbert unpublished data). Mice on the trapping grid most frequently moved 10-20 m (Fig. 2). When mice originally caught within caves are compared with those originally caught above ground, the mice in caves moved shorter distances (Fig. 2). However, this ignores the 10-20 m mice must move within the caves to reach the entrance. Even though 50% of the mice originally from caves were caught < 10 m from the cave entrance and >90% were within 30-40 m of the cave, all mice left the caves when bait was available outside.

Bait trials

Before the baits were spread, 460, 202 and 95 mice were ear-tagged in Trials 1, 2 and 3, respectively. After the baits were spread, 811 mice were captured, with numbers decreasing in sequence from Trials 1 to 3 (Table 1). These declines probably reflected decreasing mouse densities during winter and lower densities of mice in highland areas (Trial 3).

The percentage of mice recaptured also decreased within each trial, with 85%, 41% and 16% over nights 1, 2, and 3 (respectively) in Trial 1 and 83%, 50% and 14% in Trial 2. In Trial 3, few mice were captured on the second and third nights (Table 1), probably as a result of kill-trapping the resident (tagged) mice. In this trial increasing proportions of (non-tagged) mice from the outer zone were captured on nights 2 and 3.

Of the 811 mice examined in Trials 1-3, 810 (99.9%) were positive for rhodamine dye. One untagged mouse caught on night one of Trail 1 tested negative. Of the 368 ear-tagged mice that were re-trapped, all were positive for rhodamine. The dye was clearly visible within the intestines or mouth and anus of all but two mice. Whiskers examined from these two indicated rhodamine on one mouse but no evidence of rhodamine on the second.

Of the mice caught during Trials 1-3, 422 mice were female and 389 male (not significantly different from an equal sex ratio, χ^2=1.26). No females were pregnant and neither sex showed signs of reproductive activity, which reflects the winter trapping period (Jones *et al.* 2003).

Despite increased trapping after the spread of bait for Trial 4, only 116 mice were captured although all of them were positive for rhodamine (Table 2). The small number of mice trapped likely reflected the effects of season and size of the trapping grid. In early spring, mice numbers are at their lowest, and the much larger area baited provided little incentive for peripheral mice to move into the trapping grid.

In the caves, 122 mice were captured during Trial 1 over four nights of live trapping before baits were spread, but only six mice were captured in caves after baits were spread. Similarly, 44 mice were captured during Trial 2 in the cave before baits were spread, but only six were captured in the cave after bait distribution. For Trial 3, six mice were live-trapped in caves before baiting with two re-caught after baits were spread. These results suggest that with abundant food outside caves, most mice previously captured from inside the caves moved out to forage. Furthermore, although both caves in Trials 1 and 2 were within the larger area baited in Trial 4, no mice were caught in the caves despite four nights of trapping. This also suggested that when food was abundant outside, mice moved out of the caves.

During Trials 1-3, 148 mice marked inside caves were recaptured outside, and 14 mice were recaptured inside the caves following bait distribution. All of these mice tested positive for rhodamine.

Table 1 Numbers of house mice trapped on Gough Island over the three consecutive nights of trapping and for the total period of Trials 1-3.Numbers of ear-tagged individuals retrapped above ground from within cave systems are shown in parentheses.

Trial	Night 1			Night 2			Night 3			Total		
	New	Retrap	Total	New	Retrap	Total	New	Retrap	Total	New	Retrap	Total
1	20	118 (3)	138 (3)	79	56 (1)	135 (1)	168	32 (2)	200 (2)	270	203 (6)	473 (6)
2	14	68 (6)	82 (6)	16	16 (0)	32 (0)	147	24 (0)	171 (0)	176	109 (6)	285 (6)
3	9	37 (0)	46 (0)	1	6 (2)	7 (2)	0	0 (0)	0 (0)	10	43 (2)	53 (2)

Table 2 Summary statistics of trapping effort after bait spreading for house mice over the four cave trials and results for presence or absence of rhodamine dye after bait spreading for both ear-tagged and non-tagged mice.

Trial	Nights trapped	Traps set	Mice killed		Tagged		Non-tagged	
			Grid	Cave	Positive	Negative	Positive	Negative
1	3	900	479	6	209	0	269	1
2	3	900	291	6	114	0	177	0
3	2	600	55	2	45	0	10	0
4	4	1200	116	0	-	-	116	0
Total	12	3600	941	14	368	0	572	1

During Trials 1-3, baits were still visible on the ground two days after they were spread and in Trial 4 (in early spring) baits were visible for >10 days. This suggests that baiting densities used in the trial areas were sufficient to provide bait for all mice present.

Potential food resources within caves

Monthly visits indicated that broad-billed prions entered the caves in September, incubated eggs during November-December, reared chicks from December to March, and had departed by April/May. There were few remains of chicks or eggs within caves in winter and no invertebrates were found. In November, some eggs had holes that were nibbled by mice, and in January, February and March, seven prion chicks were found with sign that mice had fed on them. It was not clear whether these were examples of predation or scavenging.

CONCLUSION

Bait trials on Gough were designed to closely mimic the suggested design for an eradication (Parkes 2008) in terms of time of year, bait density and bait formulation. There was 100% bait acceptance in three trials and 99.8% in the fourth, with one mouse negative for bait out of 479 examined. This mouse, which was not captured and ear-tagged in the study grid prior to the spread of bait, may have subsequently moved into the study area. Supporting this inference, all ear-tagged mice resident to the study areas were positive for rhodamine-dyed bait. Moreover, all mice caught within the cave systems before the bait application later tested positive for rhodamine dye, regardless of whether they were re-caught above or below ground. Visits to multiple caves on Gough confirmed conclusions by Wanless *et al.* (2008) that during winter, the absence of breeding birds and other food resources would provide little food for mice.

Our results differ from a previous bait acceptance trial on Gough Island (Wanless *et al.* 2008), where 3% of mice were negative for bait. Combined with relatively high failure rates for mouse eradications, this result has led conservation decision makers in the UK to express concern about the likelihood of success of an eradication operation on Gough. However, with the use of ear-tagged mice, trials over a larger area, and trapping the mice immediately after baits were spread, our study provides greater confidence of a successful result.

Furthermore, given that all four trials on Gough found 100% bait acceptance by resident tagged mice and by non-tagged mice within the larger trial, planning for an operation on Gough Island should now proceed. The final steps in feasibility analyses will now involve evaluating the risk of primary and secondary poisoning to non-target species and captive husbandry trials of potentially vulnerable land birds. Whether there are additional obstacles to eradicating mice from Gough depends on the husbandry trials and the results of attempts to eradicate mice from Coal Island in Fiordland and Rangitoto/Motutapu islands in New Zealand, and Macquarie Island in Australia's sub-Antarctic. If these indicate no fundamental obstacle to removing mice from large islands, the eradication of mice should proceed on Gough Island, a key conservation threat to this World Heritage Site would be removed, and the recovery of Gough's threatened wildlife would become possible.

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