CSIRO PUBLISHING

Wildlife Research, 2010, **37**, 524–530 www.publish.csiro.au/journals/wr

Risk assessment of birds foraging terrestrially at Marion and Gough Islands to primary and secondary poisoning by rodenticides

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Abstract

Context. Aerial application of poison bait pellets is an established and widely used method for removing invasive rodents and restoring insular ecological processes. However, the non-target effects of saturation poisoning require very careful consideration and precautionary risk-avoidance strategies.

Aims. We assessed the risk of primary and secondary poisoning by rodenticides to terrestrially foraging lesser sheathbills (*Chionis minor marionensis*), Gough moorhens (*Gallinula comeri*) and Gough buntings (*Rowettia goughensis*) at Marion and Gough Islands.

Methods. Birds taken into temporary captivity were offered non-toxic bait pellets dyed different colours and the carcasses of house mice (*Mus musculus*). In addition, dead mice were offered to these three species in the field, as well as to sub-Antarctic skuas (*Catharacta antarctica*) at both islands. Response to captivity was assessed by daily weighings.

Key results. Individual birds either gained or lost mass overall during their 4–7 days in captivity. Whereas all captive birds pecked at the pellets, minimal amounts were consumed. However, Gough moorhens offered pellets in the field did consume them. Sheathbills (in captivity and in the field) and moorhens (in the field) consumed mouse carcasses, whereas buntings in captivity ate little from them. Sub-Antarctic skuas offered mouse carcasses in the field at both islands readily consumed them. At Gough Island some, but not all, skuas consumed bait in the field.

Conclusions. Although the levels of assessed risk to primary and secondary poisoning differed among the three main species studied, it is recommended that populations for subsequent reintroduction be taken into temporary captivity before and during a poison-bait exercise as a precautionary measure. It is not deemed necessary to take sub-Antarctic skuas into captivity because they will be largely absent during a poisoning exercise in winter (the most likely period).

Implications. Captive studies to assess susceptibility to primary and secondary poisoning are useful for determining positive risk; however, cage effects can cause false negatives by altering behaviours, and should be conducted with complimentary field trials. Where endemic species show any degree of risk (e.g. are vulnerable to the poison, regardless of how it might be ingested), precaution dictates that the risk be mitigated.

Introduction

Of the world's ecosystems, islands are among the most vulnerable to biological invasions (Williamson 1996). Fortunately, because of their isolated and geographically limited nature, islands are more amenable to eradication of invasive species than are most mainland ecosystems. Eradication of invasive alien mammals from islands is widely considered the preferred management strategy once an alien species has become established (Veitch and Clout 2002; Zavaleta 2002; Towns *et al*. 2006; Howald *et al*. 2007; Lavoie *et al*. 2007). Poison-baiting is a very powerful technique for mammal eradications, and is the only successful method in use for eradicating rodents, which are the most widespread island invaders (Howald *et al*. 2007; Angel *et al*. 2009). However, there are no commercially available mammal-specific poisons for use in such eradications. Thus, a significant concern for all eradications that employ rodenticides is the potentially negative consequences for native biota (Eason *et al*. 2002; Fisher 2005; Lavoie *et al*. 2007; Wanless and Wilson 2007).

Invasive house mice (*Mus musculus*) are currently the only introduced mammals on the sub-Antarctic islands of Marion (Prince Edward Islands, southern Indian Ocean) and Gough (Tristan da Cunha group, South Atlantic) (Angel *et al*. 2009). Recent work has shown that mice on Gough Island have rat-like impacts and are responsible for demographically significant

 10.1071/WR10005 1035-3712/10/060524

breeding failures in the Tristan albatross (*Diomedea dabbenena*) and Atlantic petrel (*Pterodroma incerta*), with occasional records of attacks on chicks of the great shearwater (*Puffinus gravis*) and sooty albatross (*Phoebetria fusca*) (Wanless *et al*. 2007; Jones and Ryan 2010). In addition, mice are thought to be causing a decline in the population of the endemic Gough bunting (*Rowettia goughensis*) (Ryan and Cuthbert 2008). Fugler *et al*. (1987) suggested that blue petrel (*Halobaena caerulea*) chicks on Marion Island were attacked by mice. Recent observations at Marion strongly suggest that mice may also occasionally attack wandering albatross (*D. exulans*) and sooty albatross chicks, causing open wounds that lead to mortalities in some cases (Jones and Ryan 2010). An additional record exists of an incubating northern giant petrel (*Macronectes halli*) at Marion Island with a similar wound (J. Cooper, pers. obs.). The deleterious impacts of mice on Gough and Marion Islands' ecosystems and non-avian biota have also been shown to be severe (reviewed in Angel *et al*. 2009). Thus, there is a *prima facie* case for managing the impacts of house mouse on both islands, which may well include attempts to eradicate the mice (Chown and Cooper 1995; Angel and Cooper 2006; Parkes 2008).

Aerial broadcast of bait pellets containing an anti-coagulant poison has been employed with notable success to eradicate rodents from many islands, and is considered an extremely powerful and cost-effective tool for permanently restoring rodent-infested islands (Towns and Broome 2003; Howald *et al*. 2007; Lavoie *et al*. 2007; MacKay *et al*. 2007). On Southern Ocean islands, a significant motivation for rodent eradications is to protect breeding seabirds from deleterious effects (e.g. Chown and Cooper 1995; Angel and Cooper 2006; Brown 2007; Parkes 2008). Most seabirds forage exclusively at sea and are thus not at risk of being poisoned. However, some birds on sub-Antarctic islands do forage on land and would thus be vulnerable to poisoning (e.g. Eason *et al*. 2002). Despite this, there is little published information reporting the susceptibility of such birds to poisoning from primary (direct ingestion of poison baits) or secondary (ingestion of poisoned animals) causes.

Where endemic island taxa are known or are suspected to be susceptible to poisoning, it is standard practice to take a founder population into captivity, which can be used for restocking the island in the event of incidental extermination of the species in the wild (e.g. Donlan and Wilcox 2007; Howald *et al*. 2007; Lavoie *et al*. 2007). Before this is done, however, it is useful to gain an understanding of the optimal conditions for keeping animals in captivity (e.g. in terms of diet, communal caging and minimum cage sizes), as well as of methods of capture.

We assess the risk of Gough moorhens (*Gallinula comeri*) (Gough Island), lesser sheathbills (*Chionis minor marionensis*) (Marion Island), sub-Antarctic skuas (*Catharacta antarctica*) (Marion and Gough Islands), kelp gulls (*Larus dominicanus*) (Marion Island) and Gough buntings (*Rowettia goughensis*) (Gough Island) to primary and secondary poisoning from rodenticides. We also investigate husbandry techniques for holding sheathbills, Gough moorhens and Gough buntings in captivity. No procellariiform seabirds and no terns (*Sterna* spp.) occurring on the two islands were investigated, because their behaviour when feeding terrestrially seems likely to place nearly all of them at a negligible risk (although giant petrels (*Macronectes* spp.) are considered to be at a high risk to secondary (but not primary) poisoning from rodenticides at Macquarie Island; Parks and Wildlife Service (2007, 2008); K. Springer *in litt.*).

Materials and methods

We kept six lesser sheathbills, six Gough moorhens and four Gough buntings in captivity within buildings during short visits to Marion (August 2006) and Gough (September 2006 and May–June 2007) meteorological stations. At capture (using hand-nets), all birds were weighed using spring balances (Pesola, Baar, Switzerland) to the nearest 5 g (sheathbills and moorhens) and 1 g (buntings). Birds were then placed in open-bottomed cages measuring $1 \times 1 \times 0.5$ m, made with plastic 'Hailguard' protective netting around treated pine frames. Clean cardboard was placed in the cages as liners and replaced as required. Each cage had an ample supply of fresh water provided in 2-L water-dispensers. All birds were given food *ad libitum* as soon as they were caged, and the food was removed from the cages at night (to minimise incentives for mice to create holes in the netting). Sheathbills were fed canned minced pilchards (*Sardinops sagax*) and a variety of canned cat food based on beef, chicken and fish. Buntings and moorhens were given a diversity of high-protein foods including canned tuna, canned corned beef, scrambled eggs (made from reconstituted egg powder), Pronutro® cereal powder (Bokomo, Bellville, South Africa) mixed with milk and a commercial dried insect food for cage birds. Sheathbills were classed as adults or juveniles according to published criteria (Burger 1980), moorhens as adults or juveniles on the basis of leg colour, and all buntings were juveniles or subadults (on the basis of Ryan 2007). All birds were released near to their points of capture at the end of the captive trials, which lasted $\leq$7 days (Table 1).

Response to captivity

We used changes in daily mass as a general determinant of the well-being of the captive birds (following Wanless *et al*. 2002). For one captive bunting, we used observations of the amount of food eaten and behavioural cues to monitor well-being, and did not handle the bird after placing it in the cage until it was weighed and released.

Susceptibility to primary poisoning

We tested palatability and colour preferences of caged birds with a standard, toxin-free bait of the type used in rodent eradications (12-mm 20-R Pest-off pellets, Animal Control Products, Wanganui, New Zealand). All captive birds were naïve to this as a potential food. Caged birds were presented with pellets of five colours in individual cafeteria (= choice) food trials to determine the attractiveness of bait as a food and any colour preferences or aversions. 'Plain', uncoloured beige pellets were used as well as pellets coloured with tasteless, water-soluble red, yellow, green and blue food dyes. We chose primary colours (red, blue and yellow) because these cover a wide visual spectrum, and green because it is sometimes added to Pest-off pellets in commercial operations (R. M. Wanless, pers. obs.). Trials were carried out in the morning before the birds were fed, and after they had been observed eating the previous day (i.e. had shown a level of

Table 1. Responses to captivity of bird species that forage terrestrially at Marion and Gough Islands
All masses are expressed in grams. Percentage change is the total change from capture to release

Species	Mass at capture	Mass at release	Change	Days in captivity	%Change	Mean daily change
Lesser sheathbill						
1	385	335	–50	4	–13.0	–12.50
2	390	370	–20	4	–5.1	–5.00
3	400	380	–20	4	–5.0	–5.00
4	415	370	–45	4	–10.8	–11.25
5	385	395	10	4	2.6	2.50
6	385	390	5	4	1.3	1.25
Mean	393.3	373.3	–20.0	4.0	–5.0	–5.0
Gough moorhen						
1	620	571	–49	4	–7.9	–1.98
2	390	409	19	5	4.9	0.97
3	447	427	–20	5	–4.5	–0.89
4	491	474	–17	5	–3.5	–0.69
5	588	561	–27	5	–4.6	–0.92
6	575	543	–32	5	–5.6	–1.11
Mean	518.5	497.5	–21.0	4.8	–3.5	–0.8
Gough bunting						
1	51	56.4	5.4	7	10.6	0.77
2	59.7	56.4	–3.3	6	–5.5	–0.55
3	62.4	61.3	–1.1	3	–1.8	–0.37
4	54.2	64.3	10.1	6	18.6	1.68
Mean	56.8	59.6	2.8	5.5	5.5	0.4

acclimatisation to captivity). Removing food overnight ensured that birds were hungry and therefore were strongly motivated to eat the next morning. Each trial was filmed on a MVX45i Digital Video Camcorder (Canon, Tokyo). Each experiment lasted 5 min (starting from the time the observer left the cage). The arrangement of pellets was randomised and recordings were reviewed frame-by-frame to determine the order of colour choice and the relative interest each bird displayed in the different colours. Interest was measured in seconds from when the bird first pecked at a pellet until it either chose another pellet or turned its head away from the pellet and engaged in another activity; each time a pellet was selected, it was scored as a single event.

Because the cereal-based pellets break down over time, especially in wet conditions, we investigated the possibility that soft, degraded pellets would be eaten by birds. Caged birds were presented with naturally coloured pellets that had been soaked in water overnight and had degenerated into a soft, mushy consistency.

On Gough Island, free-living moorhens and skuas were offered pellets variously coloured natural, red (dyed with rhodamine) and green (usual colour of poison bait) in both hard and mushy consistencies.

Susceptibility to secondary poisoning

We collected mice that had been killed in snap-traps during regular rodent-control activities at both meteorological stations. Each caged bird was presented with a dead mouse in place of a morning meal. During several visits to both islands from 2007 to 2009, we also opportunistically presented dead mice to free-living sheathbills (11 individuals), moorhens (9), sub-Antarctic skuas (10 at Marion, ~50 at Gough) and four kelp gulls at Marion by tossing single carcasses towards birds roosting or foraging solitarily on the ground.

Results

Response to captivity

Individuals within each species showed individual responses to captivity, despite each group being treated almost identically. Two sheathbills and one moorhen showed consistent mass losses and were released weighing 8–13% less than their mass at capture (Table 1). Of the other 13 individuals, 11 fluctuated around their mass at capture and were released at ±5% of their capture mass. Two of the buntings were released weighing >10% of their mass at capture, and the bird that showed the greatest mass gain (bunting #4, Table 1) was the individual that was not handled during captivity.

All the sheathbills were aged as subadults, between 1 and 2 years old. They all readily ate the canned food provided, e.g. within 5 min of being placed in the cages they were all observed eating. All birds lost body mass between Days 2 and 3, when the lowest morning masses were recorded for all individuals. However, by Day 4, the mass of all birds had increased relative to the previous day and four birds weighed close to or more than at capture at the time of release.

Moorhens #2 and #4 were classed as juveniles and the others as adults. Only one bird (moorhen #1, Table 1) showed a consistent decrease in mass. We decided to release this individual before releasing the others because it appeared to have stopped eating and was clearly not responding well to captivity. Only one moorhen gained mass during captivity.

All Gough buntings had some period of mass gain relative to their mass at capture. Bunting #3, however, after initially gaining, started to lose mass. This bird was noticeably more agitated in the cage, even when observed remotely. It was released earlier than the others, weighing less than it did at capture.

Susceptibility to primary poisoning

All of the birds in each trial investigated the pellets at some point in the experiment; however, at the end of each trial, all had resumed other activities and ignored the pellets. None ate measurable quantities of pellets (Table 2). There was no discernable pattern of colour preference or aversion. All birds investigated the coloured pellets within 30 s of the researcher leaving the area. Only one sheathbill and one bunting made more concerted investigations of the pellets, pecking at four and five of the five proffered, respectively. The birds did not eat significant quantities of mushy pellets either. These results suggest that primary poisoning is of little consequence for these species. However, when moorhens in the field were presented with pellets, they showed much stronger interest than did the caged moorhens (Table 2). They pecked off and ate chips of pellets of all three colours, until, in some cases, they could swallow the remainder of the pellets whole. Red and mushy pellets were more consistently consumed. This suggests that being in cages affected the moorhens' behaviour.

Six Gough buntings observed in the field showed little or no interest in natural, green or red bait pellets, although two individuals pecked at the pellets once and twice, respectively, seemingly without consuming anything (H. Louw and P. Visser, pers. comm.; Table 2).

Free-living skuas in a communal roost at Gough Island showed no interest in hard or mushy pellets of any of the three colours tossed towards them. However, on the basis of their red-stained faeces, several territory-holding skuas (as well as moorhens) consumed red-dyed pellets that had been scattered in the field as part of a mouse-uptake trial on Gough Island in September 2009. A skua found dead in the trial area, but in otherwise healthy condition, had its stomach full of red bait on dissection.

Susceptibility to secondary poisoning

Results of the trials presenting mice to caged birds and in the field are given in Table 2. Of the 17 sheathbills that were presented with dead mice, 16 (94%), including all the caged birds, ate mice. Their reaction to the presentation was immediate and they clearly recognised mice carcasses as a food resource. Carcasses were vigorously pecked at and most were completely consumed within a short period. The one free-living sheathbill that did not take a mouse initially showed interest and a nearby sheathbill chased it from the carcass. In contrast to the sheathbills, only one of the six caged Gough moorhens ate a mouse, whereas all nine free-living moorhens that were presented with dead mice readily ate them or quickly carried them out of sight. All the caged buntings showed an interest in the dead mice, but none of them ate any significant quantity. When the mice were removed and regular food provided they all started feeding immediately. No free-living buntings were presented with mice. All free-living skuas ate offered mice, swallowing them whole, but the kelp gulls appeared too wary of our approach. Therefore, although they did not take the mice presented to them, the test was confounded and we could not properly assess their vulnerability.

Discussion

Husbandry

All three species (lesser sheathbill, Gough moorhen and Gough bunting) are relatively easy to capture with hand-nets, and keep in captivity. However, they should probably be caged solitarily (unless perhaps proven breeding pairs are captured at the same time) and visual contact between them should be minimised. A moorhen pair has bred successfully in captivity in the United Kingdom (Wilson and Swales 1958).

The cage size used in the experiments (0.5 m^3) is probably sufficient for all the species, although bigger cages are expected to be better. The captive sheathbills readily consumed canned cat food and pilchards and dead mice and are expected to respond well in captivity to virtually any high-protein diet. Moorhens and buntings were offered canned tuna and corned beef; however, none appeared to like these foods.

The range of individual responses to captivity indicated in Table 1 suggests that some individuals are less amenable to being held in captivity than are others. This has important management implications, because a mortality factor should be included when calculating the desired size of a captive population. However, it is unlikely to be a coincidence that the bunting that received no handling during captivity responded best, showing the greatest percentage mass increase of all 16 captive birds. This suggests that minimal handling and interference with captive birds will

Table 2. Responses of bird species to presentation of 20-R Pest-off cereal bait and dead mice to determine susceptibility of each species to primary and secondary poisoning
'–' denotes where a food type was not proffered

Species tested		Bait eaten Red	Yellow	Green	Blue	Plain	Mice eaten
Lesser sheathbill	Cage	No	No	No	No	No	Yes
	Field	–	–	–	–	–	Yes
Gough moorhen	Cage	No	No	No	No	No	Yes
	Field	Yes	–	Yes	–	Yes	Yes
Gough bunting	Cage	No	–	No	–	No	No
	Field	No	No	No	No	No	–
Sub-Antarctic skua	Field	Yes	–	–	–	–	Yes

help maintain their condition and thus improve their survival rate. Regular handling appeared to have an impact on the moorhens' behaviour in other ways – such as their lack of interest in dead mice, a meal that no free-living Gough moorhen has ever been observed to ignore. This reinforces our prescription of minimal handling during captivity.

The fact that on the 4th day of captivity, most birds began to regain condition is a good indication that they became accustomed to captivity. On the morning of Day 3, one of the sheathbills escaped temporarily. Instead of fleeing, it headed for a neighbouring cage and briefly interacted with the caged bird before it was caught. The interaction appeared to be aggressive. This led us to suspect that their proximity and constant visual contact might have caused them to be in prolonged states of elevated alertness. Thereafter, we visually shielded the cages to prevent birds from seeing each other. On release, four birds moved off quickly in the direction of the foraging areas where they had been caught; however, two birds began to fight as soon as they saw each other. Although the aggressive interaction ended quickly and without apparent injury, this, together with the previous observation, suggests that sheathbills are not amenable to being caged together or even kept in close proximity. This might explain the decline in condition up to Day 4.

The likelihood of extirpation of a non-target bird population following a rodent-eradication exercise on an island is considered to be very low. There is one known case of the eradication of an avian population, and a few avian populations have been reduced significantly as a consequence of a rodent-poisoning operation (Eason *et al*. 2002; J. P. Parkes, pers. comm.). Thus, although we discuss risks to various species and present various management alternatives or likely scenarios, in the event of accidental eradication, we consider that eradication is unlikely.

Risk assessment

The lesser sheathbill is non-migratory and has relatively poor flying abilities, and so the Marion and Prince Edward islands' populations (19 km apart) may be isolated and, thus, genetically distinct from each other. There is currently no evidence of interchange of individuals between the two adjacent islands, on the basis of metal- and colour-banding and colour-dyeing activities over approximately three decades (Huyser *et al*. 2000; SAFRING records, Animal Demography Unit, Department of Zoology, University of Cape Town). The precautionary approach for this species is therefore to treat the Marion Island population as unique. Further, because the sheathbill population of the Prince Edward Islands has been accorded endemic subspecific status, a reintroduction from elsewhere within the species' range is also not recommended – except perhaps as a very last resort. This means that if accidental extermination of the Marion sheathbills remains a possibility, they should be protected from such an eventuality, given their clear risk to especially secondary poisoning.

The Gough moorhen appears to be at high risk of both primary and secondary poisoning. Although the caged birds showed little interest in the pellets, suggesting a low risk of primary poisoning, free-living Gough moorhens did eat bait pellets. In a separate study, Gough moorhens were responsible for eating 3 of 18 (non-toxic) pellets in a field trial designed to determine pellet-consumption rates by mice (Wanless *et al*. 2008). Thus, a poison-bait exercise should include a 15–20% loss of pellets in those habitats utilised by moorhens when estimating requisite baiting densities.

Not only do moorhens take dead mice, they also actively hunt and consume live mice (Wanless and Wilson 2007). Clearly, mice are recognised as a source of food by both moorhens and sheathbills, and the potential impact of the loss of this food source after eradication merits investigation. A recent genetic study has confirmed that the introduced moorhen present on the main island of Tristan da Cunha is identical to the Gough moorhen from which its population derives (Groenenberg *et al*. 2008). This means that birds from Tristan (where it is legally unprotected as a non-native; St Helena Government 2006) could be used to repopulate Gough if necessary, arguably obviating the need for a captive population during and immediately after the eradication exercise. However, the husbandry lessons learned in the present study remain relevant, because if translocating birds from Tristan to Gough becomes necessary, it is likely to require that birds be caged for periods of several days to a few weeks. The few vegetated offshore islets of Gough are not thought to support moorhens (P. G. Ryan, pers. obs. for Penguin Island) and so they do not represent a likely source for a reintroduction, whether passive or active (i.e. assisted), of this flightless species.

The endemic Gough bunting has no *ex situ* populations, and although there is at least one offshore vegetated islet (Penguin Island) thought to be mouse-free that supports several pairs of Gough buntings (Ryan and Cuthbert 2008) it (and the other islets) should still be treated with poison bait as a precautionary measure (Parkes 2008). In addition, the presumed small number of buntings residing on vegetated islets may form too small a population to restock reliably the main island, either naturally by colonisation or by capture and translocation. However, recent successful reintroductions of the endemic Campbell Island teal *Anas nesiotis* (actively) and the endemic Campbell Island snipe *Coenocorypha* sp. nov. (passively) to the main island from offshore islets have occurred at New Zealand's Campbell Island following the eradication of Norway rats (*Rattus norvegicus*) (McClelland and Gummer 2006; Miskelly and Fraser 2006; Shepherd 2007; with another example described by Ortiz-Catedral *et al*. 2009). In any event, an assisted reintroduction of the bunting from offshore islets would be technically difficult to undertake and so should be regarded as a last resort. Thus, any action that could threaten this species should be countered with appropriate mitigation measures. Fortunately, the prognosis for the bunting during a poison-bait operation appears positive, because none of the free-living or caged individuals showed significant interest in the bait pellets or in dead mice. Further, buntings have only rarely been seen to scavenge from avian carcasses (Ryan and Cuthbert 2008). These lines of evidence together suggest that buntings are at a relatively low risk to both primary and secondary poisoning, and thus complete extermination following a mouse-eradication exercise is unlikely. However, taking a precautionary approach, a captive population should still be secured over the period of the poisoning exercise (as recommended by Parkes 2008).

Trials conducted at Enderby Island, Auckland Islands and Macquarie Island elicited little or no interest from skuas to non-poison bait, suggesting that the risk of primary poisoning was low

(Torr 2002; Parks and Wildlife Service 2007, 2008; K. Springer, *in litt.).* However, following the summer eradication exercise on Enderby, 40 skuas (two-thirds of the population) died, assumed to be from primary poisoning on the basis of the presence of green dye from the bait in faeces (Torr 2002). A summer eradication exercise on Ile Australie, Kerguelen Islands, also resulted in the loss of skuas (T. Micol, *in litt*.). In contrast, an eradication exercise on St Paul Island, also in summer, was considered to have killed none of the 10–12 skuas present (Micol and Jouventin 2002). A mid-winter rodent eradication exercise at Campbell Island was not thought to have resulted in the death of any skuas, which were then largely absent from the island (McClelland and Tyree 2002; P. McClelland, *in litt*.).

The most likely timing for the application of a rodenticide will be in winter (e.g. McClelland and Tyree 2002; Parks and Wildlife Service 2007, 2008), when skuas have mostly deserted both Marion and Gough Islands (Ryan 2007; Wanless 2007; Ryan and Bester 2008). Thus, whereas the few skuas that do over-winter on the islands would be at risk of both primary and secondary poisoning, birds returning some months later in summer would be unlikely to be affected and population-level consequences would not be expected at either island.

Kelp gulls have been shown to take non-toxic bait in trials and/or to die from assumed primary poisoning in eradication exercises at several New Zealand islands (Campbell, Kapiti and Putauhinu) and at Kerguelen Island and are thus considered be at a high risk at Macquarie Island (Chapuis *et al*. 2001; Parks and Wildlife Service 2007, 2008; P. McClelland, T. Micoll and K. Springer, *in litt*.). The population at Marion Island (which is both small and resident, and thus present through the winter months) is therefore also at risk of poisoning. Kelp gulls do not occur (other than as vagrants) at Gough Island.

Conclusions and recommendations

Lesser sheathbills are generalist, omnivorous birds, with a broad diet that includes seaweed, penguin excrement, avian and mammalian carrion, eggs, terrestrial invertebrates and even pieces of plastic material (Burger 1981; R. M. Wanless, pers. obs.). They are also naturally inquisitive. Despite these traits, they did not appear to associate the pellets, either in hard or softened form, with food. They therefore appear to be at a negligible risk of primary poisoning. However, they readily ate dead mice and are thus at a high risk of secondary poisoning. We thus recommend that a founder population of sufficiently representative genetic stock be taken into captivity before any eradication exercise commences.

Gough Buntings made no concerted attempts to eat either pellets or dead mice. Thus, they appear to be at minimal risk of either primary or secondary poisoning. Nonetheless, given their endemic status, we recommend that if eradication of mice is attempted, buntings be first taken into captivity as a precautionary measure. Equally, given the endemic status of the Gough moorhen, and its readiness in the wild to consume mouse carcasses, it also recommended that a captive population be kept over the period of a poison-bait exercise.

It is not considered necessary to take sub-Antarctic skuas into temporary captivity at either island, primarily because of the majority of their populations being absent during winter (when poison bait is most likely to be applied; Parks and Wildlife Service 2007, 2008), and also because of the likelihood of an affected population recovering quickly, by breeding and/or immigration from genetically similar stocks within the island groups, as happened following an eradication exercise on Enderby Island (Torr 2002). However, we were unable to assess the risk facing kelp gulls; however, we note that individuals have been killed in other operations, so consideration should be given to reducing the risks of poisoning them at Marion Island.

Following the recommendation of Parkes (2008), an investigation into the husbandry needs of both Gough moorhens and buntings has been carried out on the island over 2009–10 (R. J. Cuthbert, *in litt*.; www.ukotcf.org/otep, verified 27 September 2010). Before an eradication operation is planned at Marion Island, it is recommended a similar investigation should be undertaken for the lesser sheathbill. The minimum number of captive individuals of lesser sheathbills, Gough moorhens and Gough buntings to be captured should be ascertained to ensure a representative, heterogeneous stock in the event of their complete eradication following an attempt to eradicate mice at either island.

Acknowledgements

Logistical support was provided by the then South African Department of Environmental Affairs and Tourism (DEAT) through the South African National Antarctic Programme. We thank the United Kingdom Overseas Territories Environment Programme for financial support via the Tristan da Cunha Government on Gough Island and DEAT for financial support on Marion Island. We thank Animal Control Products for donating non-toxic bait. Research on Gough Island was conducted with the permission of the Administrator and Island Council of Tristan da Cunha and with the approval of the Tristan Biodiversity Advisory Group, and on Marion Island with the permission of the Prince Edward Islands Management Committee. Neither island's research-vetting system required a specific animal-ethics clearance procedure. Brian Bowie, Jonathan Kotze, Petrus Kritzinger, Henk Louw and Paul Visser are thanked for assistance and observations on Gough Island and Jen Lee for assistance on Marion Island. We thank Pete McClelland, Thierry Micol and Keith Springer for making unpublished information on eradication exercises available to us.

References

Angel, A., and Cooper, J. (2006). 'A Review of the Impacts of Introduced Rodents on the Islands of Tristan da Cunha and Gough.' (Royal Society for the Protection of Birds: Sandy, UK.)

Angel, A., Wanless, R. M., and Cooper, J. (2009). Review of impacts of the introduced house mouse on islands in the Southern Ocean: are mice equivalent to rats? *Biological Invasions* **11**, 1743–1754. doi:10.1007/s10530-008-9401-4

Brown, D. (2007). 'A Feasibility Study for the Eradication of Rodents from Tristan da Cunha.' (Royal Society for the Protection of Birds: Sandy, UK.)

Burger, A. E. (1980). Sexual size dimorphism and aging characters in the lesser sheathbill at Marion Island. *The Ostrich* **51**, 39–43.

Burger, A. E. (1981). Food and foraging behaviour of lesser sheathbills at Marion Island. *Ardea* **69**, 167–180.

Chapuis, J.-L., Le Roux, V., Asseline, J., Lefèvre, L., and Kerleau, F. (2001). Eradication of the rabbit (*Oryctolagus cuniculus*) by poisoning on three islands of the subantarctic Kerguelen Archipelago. *Wildlife Research* **28**, 323–331. doi:10.1071/WR00042

Chown, S. L., and Cooper, J. (1995). The impact of feral house mice at sub-Antarctic Marion Island and the desirability of eradication: report on a workshop held at the University of Pretoria, 16–17 February 1995. Directorate Antarctica & Islands, Department of Environmental Affairs & Tourism, Pretoria, South Africa.

Donlan, C. J., and Wilcox, C. (2007). Complexities of costing eradications. *Animal Conservation* **10**, 154. doi:10.1111/j.1469-1795.2007.00101.x

Eason, C. T., Murphy, E. C., Wright, G. R. G., and Spurr, E. B. (2002). Assessment of risks of brodifacoum to non-target birds and mammals in New Zealand. *Ecotoxicology (London, England)* **11**, 35–48. doi:10.1023/A:1013793029831

Fisher, P. (2005). Review of house mouse (*Mus musculus*) susceptibility to anticoagulant poisons. Department of Conservation Science Internal Series 198, pp. 1–18. Wellington, New Zealand.

Fugler, S. R., Hunter, S., Newton, I. P., and Steele, W. K. (1987). Breeding biology of blue petrels *Halobaena caerulea* at the Prince Edwards Islands. *Emu* **87**, 103–110.

Groenenberg, D. S. J., Beintema, A. J., Dekker, R. W. R. J., and Gittenberger, E. (2008). Ancient DNA elucidates the controversy about the flightless island hens (*Gallinula* sp.) of Tristan da Cunha. *PLoS ONE* **3**, e1835. doi:10.1371/journal.pone.0001835

Howald, G., Donlan, C. J., Galvan, J. P., Russell, J. C., Parkes, J., Samaniego, A., Wang, Y., Veitch, D., Genovesi, P., Pascal, M., Saunders, A., and Tershy, B. (2007). Invasive rodent eradication on islands. *Conservation Biology* **21**, 1258–1268. doi:10.1111/j.1523-1739.2007.00755.x

Huyser, O., Ryan, P. G., and Cooper, J. (2000). Changes in population size, habitat use and breeding biology of lesser sheathbills (*Chionis minor*) at Marion Island: impacts of cats, mice and climate change? *Biological Conservation* **92**, 299–310. doi:10.1016/S0006-3207(99)00096-8

Jones, M. G. W., and Ryan, P. G. (2010). Evidence of mouse attacks on albatross chicks on sub-Antarctic Marion Island. *Antarctic Science* **22**, 39–42. doi:10.1017/S0954102009990459

Lavoie, C., Donlan, C. J., Campbell, K., Cruz, F., and Carrion, G. (2007). Geographic tools for eradication programs of insular non-native mammals. *Biological Invasions* **9**, 139–148. doi:10.1007/s10530-006-9011-y

MacKay, J. W. B., Russell, J. C., and Murphy, E. C. (2007). Eradicating mice from islands: successes, failures and the way forward. 'In Managing Vertebrate Invasive Species: Proceedings of a International Symposium'. (Eds K. A. Fagerstone and G. W. Witmer.) pp. 294–304. (United States Department of Agriculture: Fort Collins, CO.)

McClelland, P., and Gummer, H. (2006). Reintroduction of the Critically Endangered Campbell Island teal *Anas nesiotis* to Campbell Island, New Zealand. *Conservation Evidence* **3**, 61–63.

McClelland, P., and Tyree, P. (2002). Eradication. The clearance of Campbell. *New Zealand Geographer* **58**, 86–94.

Micol, T., and Jouventin, P. (2002). Eradication of rats and rabbits from Saint-Paul Island, French Southern Territories. In 'Turning the Tide: the Eradication of Invasive Species'. (Eds C. R. Veitch and M. N. Clout.) pp. 199–205. (IUCN SSC Invasive Species Specialist Group, IUCN: Gland, Switzerland.)

Miskelly, C., and Fraser, J. (2006). Campbell Island snipe (*Coenocorypha* undescribed sp.) recovery following rat eradication. Department of Conservation Science Poster No. 92. Available at http://www.doc.govt.nz/upload/documents/science-and-technical/SciencePoster92.pdf [verified September 2010].

Ortiz-Catedral, L., Ismar, S. M. H., Baird, K., Brunton, D. H., and Hauber, M. E. (2009). Recolonization of Raoul Island by Kermadec red-crowned parakeets *Cyanoramphus novaezelandiae cyanurus* after eradication of invasive predators, Kermadec Islands archipelago, New Zealand. *Conservation Evidence* **6**, 26–30.

Parkes, J. (2008). A feasibility study for the eradication of house mice from Gough Island. RSPB Research Report No. 34. Royal Society for the Protection of Birds, Sandy, UK.

Parks and Wildlife Service (2007). 'Plan for the Eradication of Rabbits and Rodents on Subantarctic Macquarie Island.' (Parks and Wildlife Service, Department of Tourism, Arts and the Environment, Tasmania and Biodiversity Conservation Branch, Department of Primary Industries and Water, Tasmania: Hobart.)

Parks and Wildlife Service (2008). 'Macquarie Island Pest Eradication Plan. Part A Overview March 2007.' (Parks and Wildlife Service, Department of Environment, Parks, Heritage & the Arts, Tasmania: Hobart.)

Ryan, P.G. (2007). 'A Field Guide to the Animals and Plants of Tristan da Cunha and Gough Island.' (Pisces Publications: Newbury, UK.)

Ryan, P. G., and Bester, M. N. (2008). Pelagic predators. In 'The Prince Edwards Archipelago: Land–Sea Interactions in a Changing Ecosystem'. (Eds S. N. Chown and W. Froneman.) pp. 121–164. (Sun Media: Stellenbosch, South Africa.)

Ryan, P. G., and Cuthbert, R. J. (2008). The biology and conservation status of Gough bunting *Rowettia goughensis. Bulletin of the British Ornithologists*' *Club* **128**, 242–253.

Shepherd, I. (2007). The long journey home for Campbell Island teal. *Ecos* **134**, 8–11.

St Helena Government (2006). The Conservation of Native Organisms and Natural Habitats (Tristan da Cunha) Ordinance 2006. *St Helena Government Gazette Extraordinary* **44**, 1–13.

Torr, N. (2002). Eradication of rabbits and mice from subantarctic Enderby and Rose Islands. In 'Turning the Tide: the Eradication of Invasive Species'. (Eds C. R. Veitch and M. N. Clout.) pp. 319–328. (IUCN SSC Invasive Species Specialist Group, IUCN: Gland, Switzerland.)

Towns, D. R., and Broome, K. G. (2003). From small Maria to massive Campbell: forty years of rat eradications from New Zealand. *New Zealand Journal of Zoology* **30**, 377–398. doi:10.1080/03014223.2003.9518348

Towns, D. R., Atkinson, I. A. E., and Daugherty, C. H. (2006). Have the harmful effects of introduced rats on islands been exaggerated? *Biological Invasions* **8**, 863–891. doi:10.1007/s10530-005-0421-z

Veitch, C. R., and Clout, M. N. (Eds) (2002). 'Turning the Tide: the Eradication of Invasive Species.' (IUCN SSC Invasive Species Specialist Group, IUCN: Gland, Switzerland.)

Wanless, R. M. (2007). Impacts of the introduced house mouse on the seabirds of Gough Island. Ph. D. Thesis, University of Cape Town, Rondebosch, South Africa.

Wanless, R. M., and Wilson, J. W. (2007). Predatory behaviour of the Gough moorhen *Gallinula comeri*: conservation implications. *Ardea* **95**, 311–315.

Wanless, R. M., Cunningham, J., Hockey, P. A. R., Wanless, J., White, R. W., and Wiseman, R. (2002). The success of a soft-release reintroduction of the flightless Aldabra rail (*Dryolimnas [cuvieri] aldabranus*) on Aldabra Atoll, Seychelles. *Biological Conservation* **107**, 203–210. doi:10.1016/S0006-3207(02)00067-8

Wanless, R. M., Angel, A., Cuthbert, R. J., Hilton, G., and Ryan, P. G. (2007). Can predation by invasive mice drive seabird extinctions? *Biology Letters* **3**, 241–244. doi:10.1098/rsbl.2007.0120

Wanless, R. M., Fisher, P., Parkes, J., Cooper, J., Ryan, P. G., and Slabber, M. (2008). Bait acceptance by house mice: an island field trial. *Wildlife Research* **35**, 806–811. doi:10.1071/WR08045

Williamson, M. (1996). 'Biological Invasions.' (Chapman and Hall: London.)

Wilson, A. E., and Swales, M. K. (1958). Flightless moorhens *(Porphyriornis c. comeri)* from Gough Island breed in captivity. *Avicultural Magazine* **64**, 43–45.

Zavaleta, E. S. (2002). It's often better to eradicate, but can we eradicate better? In 'Turning the Tide: the Eradication of Invasive Species'. (Eds C. R. Veitch and M. N. Clout.) pp. 393–434. (IUCN SSC Invasive Species Specialist Group, IUCN: Gland, Switzerland.)

Manuscript received 20 January 2010, accepted 5 September 2010