Simultaneous rat, mouse and rabbit eradication on Bense and Little Bense Islands, Falkland Islands

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Abstract Bense and Little Bense Islands (144 ha total area) have, for over a century, supported populations of three introduced pest mammals: Norway rat (*Rattus norvegicus*), house mouse (*Mus musculus*), and European rabbit (*Oryctolagus cuniculus*). An operation to eradicate these mammals simultaneously was undertaken in winter 2016. Cereal pellets laced with brodifacoum (25 ppm) were hand-broadcast on both islands in two applications with 3,900 kg of bait applied in total. Baiting transects were spaced at 20 m intervals and bait-throwing positions located every 20 m along each transect. The coastline was also baited at 20 m intervals. Precision bait coverage was aided by programming GPS units to give off an audible alarm when staff reached each correct bait-throwing position. Application 1 resulted in an average bait density of 15.3 kg/ha. Application 2 commenced 10 days later and resulted in an average baiting density of 11.7 kg/ha. Reduced availability of fi eld staff resulted in coverage in Application 2 being less complete than in Application 1 and only the most important mammal habitats were baited a second time. These were: all tussock areas, all coastlines, and some inland heath areas. Areas with no vegetation (e.g. burned zone on Bense) and some inland heath communities were not treated, although all of these retained unconsumed bait from Application 1. Some non-target mortality was recorded, with dolphin gulls (*Larus scoresbii*) being the most common victims. This was also the only species observed to consume bait pellets. Consumption of poisoned mammals or gulls may have killed three turkey vultures (*Cathartes aura jota*), one striated caracara (*Phalcoboenus australis*), and one short-eared owl (*Asio fl ammeus*). The removal of invasive species is part of a broader ecological restoration plan for these islands and will hopefully lead to an increase in native biodiversity, including the re-establishment of the endemic passerines Cobb's wren (*Troglodytes cobbi*) and blackish cinclodes (*Cinclodes antarcticus*).

Keywords: ecological restoration, invasive species

INTRODUCTION

Like the natural biodiversity on most islands, the native plants and animals of the Falkland Islands are vulnerable to catastrophic impacts when non-native mammals are introduced (Tabak, et al., 2014; Carey, 2015). Prior to the arrival of humans, the Falklands had only one species of terrestrial mammal – the Falklands fox, or warrah (*Dusicyon antarcticus*). While people quickly hunted this sole native mammal to extinction by 1876, they also introduced a further nine alien species which have since established feral populations. These are: Norway rat (*Rattus norvegicus*), black rat (*R. rattus*), house mouse (*Mus musculus*), European rabbit (*Oryctolagus cuniculus*), eastern cottontail rabbit (*Sylvilagus* sp.), brown hare (*Lepus capensis*), Patagonian grey fox (*Dusicyon griseus*), domestic cat (*Felis catus*), and guanaco (*Lama guanicoe*), as well as domestic dogs (*Canis lupus*), poultry, and livestock (Strange, 1992; Woods & Woods, 2006). These invasive species have had negative impacts on the native birds (Tabak, et al., 2015) and invertebrates (St Clair, 2011) through direct predation and competition for food.

The Falkland Islands are located in the south-west Atlantic Ocean, approximately 500 km east of Argentina. Spanning 51°–53° S and 57°–62° W, there are 778 islands in the archipelago (FITB, 2016). Eleven islands are permanently inhabited, although only the two largest of these are home to more than one family. The Falklands are unique among subantarctic islands in that much of the land is privately owned, and conservation-minded landowners have been at the forefront of environmental work in the islands (for example Strange, 2007; Poncet, et al., 2011). Invasive species eradications began in 2001 with the removal of Norway rats from two small islands (Brown, et al., 2001). Rats have since been successfully cleared from a further 66 islands, while the Patagonian grey fox was eradicated from one island in 2008 (Poncet, et al., 2011; FIG, 2015). The project covered here is the first Falklands attempt to eradicate mice and rabbits, and the first to attempt the simultaneous removal of three species: *R. norvegicus, M. musculus,* and *O. cuniculus*. These were the only introduced mammal species on the Bense islands.

Although conservation gains can be made by eradicating a single mammal species where more than one invasive species is present (Helmstedt, et al., 2016), eradication attempts that simultaneously target all invasive species are desirable when logistically and financially feasible. Simultaneous multi-species eradications can avoid magnifying the problems caused by one pest species when another is removed. On subantarctic Macquarie Island, the removal of cats prior to the eradication of rabbits may have contributed to a population increase of the latter species, which in turn exacerbated grazing pressure on plants and soil erosion (Bergstrom, et al., 2009; but see Springer (2016) for a discussion of the role of rabbit population fluctuations).

METHODS

Site description

Bense (c. 107 ha) and Little Bense (c. 37 ha) Islands are found in Port North, in the north-west Falkland Islands at 51°29'S 61° 31'W. These two islands have been home to Norway rats, house mice, and European rabbits for more than 100 years. Rabbits were deliberately introduced by whalers whereas rats and mice arrived as stowaways on vessels anchored in the nearby harbour or used to move livestock (R. Napier pers. comm.). The islands are joined by a rocky reef, exposed at low tide, and therefore were treated as a single island for eradication purposes (Fig. 1).

The vegetation is broadly similar across the two islands, with at least 20 species of vascular plants recorded (Table 1). The coastal zone is maritime tussock formation, with lush stands of tussock grass (*Poa flabellata*) growing to 3 m in height. The interior is low-growing oceanic heath

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Fig. 1 Bense Island (bottom left), Little Bense Island (top) and West Falkland Island (bottom right). Note the dark, burned area along much of the east coast of Bense. At low tide, Bense and Little Bense Islands are connected by a rocky reef. Bense is 750 m away from West Falkland at its closest point.

formation, dominated by diddle-dee (*Empetrum rubrum*) (Moore, 1968). Bense Island has had greater grazing pressure with horses, cattle, and sheep wintering on the island at various times during the 20th century. These same species were also placed on Little Bense but would quickly migrate to Bense Island as Little Bense has no water on it. (W. Goodwin, pers. comm.) This may explain why palatable species such as boxwood (*Hebe elliptica*) are more prevalent on Little Bense, and why there are also greater expanses of dense tussock on the smaller island. Both islands have been free of livestock since 1985. Also in 1985, a fire burned about 20% of Bense Island. The scorched area remains an unvegetated barren zone of peat and ash, with loose peat creeping downwind and smothering some areas of unburned vegetation.

The western coast of Bense Island has vertical cliffs up to c. 25 m in height. The terrain gradually tilts lower as one moves east, with gentle cobble or sand beaches found on the east coast. Little Bense is lower (c. 18 m maximum height) with a coastline of sloping rocks in the west and north, and sand beaches in the east and south. At its closest point, the mainland of West Falkland Island is 750 m away from Bense Island.

Despite the presence of invasive mammals, the avifauna of these islands is not completely extirpated (Table 1) and the islands were listed within the Falklands as a top priority for mammal eradication (Miller, 2008). While 26 land and sea bird species were commonly found on the

Table 1 Plants and birds commonly found on Bense and Little Bense Islands.

Birds		**Plants**	
Magellanic penguin	*Spheniscus magellanicus*	Tussock grass	*Poa flabellata*
Rock shag	*Plalacrocorax magellanicus*	Couch grass	*Agropyron pubiflorum (magellanicum)*
Imperial shag	*Phalacrocorax atriceps albiventer*	Common bent grass	*Agrostis tenuis*
Black-crowned night heron	*Nycticorax nycticorax falklandicus*	Hair grass	*Aira* sp.
Upland goose	*Chloephaga picta*	Small fern	*Blechnum penna-marina*
Kelp goose	*Chloephaga hybrida*	Chickweed	*Cerastium arvense*
Ruddy-headed goose	*Chloephaga rubidiceps*	Wavy hair grass	*Deschampsia flexuosa*
Falklands steamer duck	*Tachyeres brachypterus*	Diddle-dee	*Empetrem rubrum*
Crested duck	*Lophonetta specularioides*	Tufted fescue grass	*Festuca cirrosa (erecta)*
Turkey vulture	*Cathartes aura jota*	Cudweed	*Gamochaeta nivalis*
Variable hawk	*Geranoaetus polyosoma*	Pig vine	*Gunnera magellanica*
Striated caracara	*Phalcoboenus australis*	Native boxwood	*Hebe elliptica*
Magellanic oystercatcher	*Haematopus leucopodus*	Mountain berry	*Pernettya pumila*
Blackish oystercatcher	*Haematopus ater*	Meadow grass	*Poa* sp.
Two-banded plover	*Charadrius falklandicus*	Sheep's sorrel	*Rumex acetosella*
Magellanic snipe	*Gallinago paraguaiae magellanica*	Sea cabbage	*Senecio candicans*
Brown skua	*Catharacta antarctica*	Procumbent pearlwort	*Sagina procumbens*
Dolphin gull	*Larus scoresbii*	Groundsel	*Senecio vulgaris*
Kelp gull	*Larus dominicanus*	Christmas bush	*Baccharis magellanica*
South American tern	*Sterna hirundinacea*	Wood rush	*Luzula alopecurus*
Dark-faced ground tyrant	*Muscisaxicola maclovianus*		
Grass wren	*Cistothorus platensis*		
Falklands thrush	*Turdus falcklandii*		
White-bridled finch	*Melanodera melanodera*		
Long-tailed meadowlark	*Leistes loyca*		
Black-chinned siskin	*Spinus barbatus*		

islands, conspicuously absent were the only Falklands endemic passerines: Cobb's wren (*Troglodytes cobbi*) and blackish cinclodes (*Cinclodes antarcticus*). Neither of these species breeds on islands with rats (Tabak, et al., 2016). The islands are also bereft of burrowing seabirds such as sooty shearwater (*Puffinus griseus*) and thin-billed prion (*Pachyptila belcheri*), both of which breed on nearby rat-free islands (Woods & Woods, 1997).

Bense and Little Bense have never had a resident human population, but because they were a desirable site for wintering livestock, for much of the 20th century they were occasionally home to shepherds and farmhands for a few days at a time. A small shanty, built on Bense in 1926, was the only building found on either island until 2002, when a second shanty was built next to the original structure. All farming ceased in 1996, when Bense and Little Bense Islands (along with neighbouring Cliff Island and Bradley Islet) were purchased by the SubAntarctic Foundation for Ecosystems Research (SAFER) with a goal to restore the islands' ecology and improve them as wildlife habitat.

Index trapping

Index trapping to ascertain habitat preferences and relative abundance of rodents was conducted on Bense Island over eight visits, spanning 10 years and most seasons (i.e. November 2004, October 2006, July 2007, August 2007, September 2008, March 2010, January 2013, January 2014). Trap lines followed the methods described in Cunningham and Moors (1996), using Victor Easy Set wooden snap-traps (Woodstream Corp., Lititz, Pennsylvania, USA), with an interval of 25 m between trapping stations. A trap which caught an animal or which was sprung with no catch, was deemed to have been effective for half the night, and was therefore counted as 0.5 of an effective trap-night. Trap lines were placed in two different habitats: coastal tussock formation (1,612.5 effective trap-nights), or inland heath communities (1,077 effective trap-nights).

Eradication Operation

Following basic ecological studies, including surveys of birds and invertebrates, an operation to eradicate rats, mice, and rabbits was undertaken in winter 2016. For bait distribution, local field staff were hired in Stanley, the Falklands capital. None had previous experience with hand-baiting so training was provided the day prior to the beginning of operations. The operation ran from 8 August to 3 September and was timed to coincide with the period when natural food on the islands is most scarce. Cereal pellets laced with brodifacoum at 25 ppm (25-W Conservation Pellets, manufactured by Bell Laboratories) were hand-broadcast along parallel transects in two applications, with an interval of 10 days between them.

A baiting map of the islands, comprising a series of parallel transects spaced at 20 m intervals laid over a high-resolution satellite photo, was created using QGIS software. Along each of these transects, baiting points were located every 20 m (Fig. 2). This resulted in an imaginary grid with 20m squares across both islands. Baiting points were also created at 20 m intervals along the coastlines of both islands, following the natural contours of the shoreline. Map data were loaded onto handheld GPS units (Garmin GPSMAP64) with an audible alarm set to sound whenever the unit reached a baiting point. Field personnel could then navigate to a desired transect line and follow it exactly, with the alarm telling them when they had reached a baiting point. GPS units were accurate to around 2 m. The walking tracks of field staff were monitored using GPS tracking and were checked each night against a base map.

Fig. 2 Detail of the baiting map of Bense Island. Each white or purple dot represents a baiting point. Baiting points are 20 m apart.

Any areas not covered properly were thus identified, and targeted for remedial attention the following day.

At each baiting point, five full scoops of bait were flung in five different directions as per hand broadcast best-practice (Broome, et al., 2011). Thus, coverage at each baiting point overlapped with bait thrown from neighbouring baiting points. Bait pellets were thrown with plastic scoops cut to hold 100 g when full. Staff carried the pellets in 20-litre plastic buckets, which could hold about 15 kg of bait. Rubber gloves, Tyvek coveralls, and dust masks were available to all field personnel.

Bait was transported to the islands from Stanley. It first went by barge to a protected bay on West Falkland Island, and from there it was moved to Bense and Little Bense in loads slung under a Chinook helicopter. The helicopter deposited the bait in six depots across the approximate midline of Bense Island, and at one location in the centre of Little Bense Island. A total of 4,400 kg of bait was delivered to the islands for this operation.

At the end of the operation, seven bait stations were established along the north-eastern coast of Bense Island, in areas thought to be the most likely zone of landfall for any rats that might swim from West Falkland Island. Bait was placed inside lengths of polyethylene pipe, 15 cm in diameter. Wax baits (containing 0.0005% w/w difenacoum and 0.001% w/w denatonium benzoate) were wired to the inside of the pipe and a handful of brodifacoum cereal pellets were also added. Bait stations were secured to the ground with wire staples and rocks.

Post-eradication monitoring

The islands were re-visited briefly in December 2016 (three months post-baiting) and in November 2017 (14 months post-baiting) to search for survivors of the baiting operation. During the latter visit, two hundred chewsticks (PCR Wax Tag, Pest Control Research) with peanut butter-flavoured wax attractants were installed in all coastal areas and in vegetated interior zones, with preference given to those areas known to be good rodent habitat. Chewsticks were checked for bite marks from rabbits and rodents before departure (up to 14 days after installation) and were left in place to be checked on subsequent visits to the islands. Staff actively searched for tracks, fresh droppings, and other signs of mammals throughout the visit. Daytime searches for rabbits were made by a dedicated hunter, including extensive observations by binoculars from a camouflaged position on high ground and by careful downwind stalking through areas known to be favoured by rabbits. A thermal camera (Thermapp) was used to replicate these searches at night without the use of lights that could frighten rabbits.

Weather during eradication operation

Temperatures ranged from -3° C to +7° C, with moderate to strong winds on all days. Snow and sleet showers frequently swept the islands but accumulation was slight and short-lived. No precipitation fell as rain. Weather did not prevent baiting except for one half-day during Application 1 and one full-day during Application 2, when wind speeds were too high to cast bait effectively.

RESULTS

Index trapping

Index trapping showed rats were much more prevalent in coastal tussock areas, with 82 rats caught there from 1,612.5 effective trap nights, whereas on inland heath areas, only three rats were recorded from 1,077 effective trap nights. Mice were more evenly distributed between the two habitats sampled, with 50 caught in coastal tussock, and 32 caught in inland heath.

Rabbits were not targeted with snap traps but individuals were observed on most parts of Bense, except the denuded burn-zone. Rabbits were not thought to be present on Little Bense until a single animal was observed there in February 2015. This was the only time in 18 visits that a rabbit was seen on Little Bense, suggesting that if there was a resident population on the island, it was likely much smaller than that on Bense.

Effectiveness and coverage of Application 1

For the first application (8–16 August), a team of five field staff covered Bense and Little Bense with bait, resulting in a mean density of 15.3 kg/ha. However, bait was more densely applied along the shoreline and in dense tussock, while it was applied less densely in the burn zone, which is devoid of vegetation. All cliffs were baited along their top edges and on all lower ledges that were safely accessible. Where safe access was not possible, pellets were thrown from above. Along accessible shorelines, particular attention was paid to the beach margin where vegetation began and to areas just above the high tide line where debris had accumulated.

Although Little Bense is only a third the size of Bense, baiting there proved to be much more challenging due to the extremely dense tussock grass and the fragmented, convoluted northern coast. Overland access to the many coastal chasms and rock slabs was particularly difficult since it required climbing through or over the worst of the tussock (over 2 m high). To apply bait to this northern coast more efficiently, a small boat was used. In some chasms the boat could be used as a mobile baiting platform, with pellets broadcast into the tussock from the deck. In other areas, personnel were landed to climb to the vegetated margin, then re-boarded and moved to the next position.

Effectiveness and coverage of Application 2

For the second application (26 August–3 September), a team of three field staff attempted to duplicate the coverage achieved in Application 1. However, due to the smaller team and staff injuries, this was not possible. Instead, Application 2 made selective coverage, with priority given to areas known from index trapping to be the best rodent and rabbit habitat. On Bense Island, Application 2 covered all tussock areas, all shorelines, and all areas north of the island's midline, regardless of vegetation type. Not covered were some areas of inland heath south of the midline, and the denuded burn zone. These latter areas still had intact bait remaining from Application 1.

On Little Bense Island, Application 2 covered all tussock areas and all shorelines, but did not cover inland heath areas. As on Bense, the inland heath here still had intact, uneaten bait remaining from the first application. On Little Bense, staff injuries also curtailed coverage in the tussock area: bait was applied on every second transect, meaning there was a gap of 40 m (instead of the normal 20 m) between each baiting line. To help reduce the size of the potentially un-baited space between transects, bait was thrown wider on lateral throws, and a greater quantity was thrown. The coastline was baited as in the first application, including the use of the boat to access the north coast. Mean baiting density on Application 2 was 11.7 kg/ha. Over the whole operation, c. 3,900 kg of bait were applied to the islands.

Daily reviews of the GPS tracks of workers revealed that some areas were missed in the earliest days of baiting but these were easily remedied the following day. After the first two days, all workers had mastered navigation and no further areas needed remediation.

Mammal and non-target mortality

Staff stayed on the islands from the start of Application 1 until seven days after the completion of Application 2 and during this time staff searched for animals killed in the operation. In total, 64 dead rabbits were found on Bense Island but none was found on Little Bense. All intact carcasses found were placed under heavy tussock grass or in burrows to hide them from scavenging birds. However, many carcasses were discovered after they had been scavenged, so some secondary poisoning is likely to have occurred. Three dead mice were found on Bense Island and one was found on Little Bense. No dead rats were found on either island, presumably because they died in their burrows.

Dolphin gulls (*Larus scoresbii*) were the most common non-target casualty with a total of 23 carcasses discovered. This species was observed to eat bait pellets directly, often fighting conspecifics for them. Dolphin gulls were the only species seen to eat the pellets. Three dead adult turkey vultures *(Cathartes aura jota)* were found, as was one adult striated caracara (*Phalcoboenus australis*) and one short-eared owl (*Asio flammeus*). The owl had been scavenged before discovery. Dissection of the striated caracara showed no visual evidence that it had directly ingested bait pellets, so perhaps it died from eating parts of a poisoned animal, most likely a rabbit or dolphin gull. Striated caracaras were observed playing with pellets but were never observed to ingest them. Two dead flightless steamer ducks (*Tachyeres brachypterus*) were found (one on

each island). Direct consumption of bait may explain these deaths, but this species is known to eat offal occasionally (Woods, 1975) so it is also possible they were victims of secondary poisoning from eating a dead dolphin gull. Kelp gulls (*Larus dominicanus*) and snowy sheathbills (*Chionis alba*), two birds known for their curiosity and scavenging habits, were both present but were not seen to touch the pellets and no dead kelp gulls or sheathbills were recorded during the operation.

Post-operation follow-up

During the December 2016 follow-up visit, informal observations did not detect any live mammals, and no footprints were found despite careful examination of areas with soft soil or wet sand, where rabbit or rat tracks had been commonly seen in the past. The bait stations on Bense were also completely undisturbed with no evidence of gnawing on the wax baits. Three freshly-dead kelp gulls were found and evidence of pellet consumption was discovered upon dissection: the crops of two of the birds were discoloured with the bright green biomarker found in the pellets. It is thought these birds consumed bait that was inadvertently exposed during this visit when stored bait was moved near the campsite.

The more thorough post-operation visit in November 2017 did not discover any evidence of rodents or mammals on the islands. No live rodents or rabbits were seen, nor were any fresh droppings or tracks discovered. No chewsticks had been sampled by rodents, although the bite marks of striated caracaras and other birds were found on 10 sticks. Nocturnal observations with the thermal camera also found no mammals. However, bait blocks inside bait stations were found to be heavily sand-blasted and in need of replacement.

DISCUSSION

The first application of bait achieved 100% coverage as per the project design. However, Application 2 was less complete and several compromises were made, with priority given to bait the areas shown by index trapping to be the most important as habitat for invasive mammals. However, one area of concern was the dense tussock on Little Bense where the second application of baiting could have left gaps between baiting lines.

Rats have proved easier to eradicate from islands than mice, with rats successfully removed from islands in 92% of the operations attempted (Howald, et al., 2007), whereas early reports found success was achieved in only 62% of mouse operations (MacKay, et al., 2007). However, recent findings show a more optimistic picture, with mice successfully eradicated in 77% of operations in New Zealand, and this figure rises to 100% when considering only operations that followed current best-practice techniques (Broome, et al., this volume). Mice may be harder to eradicate because of behavioural traits such as aversion to cereal (Humphries, et al., 2000) or smaller home range (Clapperton, 2006; MacKay, et al., 2011). This necessitates a denser and more meticulous application of bait to ensure that all mice encounter pellets. The possible gaps in bait availability in dense tussock areas on Little Bense are thus a cause for concern.

Eradication operations carry a risk of killing non-target species through direct ingestion of poison pellets or by eating an animal that was poisoned. At South Georgia, brodifacoum pellets were consumed directly by skuas, sheathbills, and pintails, while other scavengers such as kelp gulls and giant petrels were less likely to eat baits (Lee, et al., 2013). In contrast, at Campbell (McClelland, 2011) and Macquarie Islands (Springer & Carmichael, 2012) kelp gulls were found to be extremely vulnerable to primary poisoning. In the Falklands, the death of non-target species is not well known since most islands have been without observers immediately after the completion of baiting operations. However, on Great Island, the bodies of many kelp and dolphin gulls were found following a rat eradication operation in July 2016 (T. Poole, pers. comm.). Dolphin gulls were the most common bird species poisoned on Bense and Little Bense Islands and their corpses were possibly a source of secondary poisoning of turkey vultures and striated caracara. It is suggested that future eradication operations in the Falklands plan for some personnel to remain on the island after the completion of baiting in order to improve understanding of non-target mortality.

That no evidence of mammals could be found on the island 14 months post-baiting is cause for optimism. However, the overall success of this operation will not be known until late 2018 (26 months post-baiting) after further monitoring has taken place. Elsewhere, rabbits have proven particularly difficult to eradicate using poison alone (Torr, 2002) and monitoring may reveal the need to use additional techniques on Bense and Little Bense Islands. There are no trained detection dogs in the Falklands and snares and fumigants are not advised as they could have an impact on burrowing penguins. In addition, biosecurity concerns prevent the import of rabbit-specific pathogens, thus leaving spotlight shooting as the most effective tool available for eliminating any remaining rabbits.

This Bense and Little Bense islands operation was intended to help restore native biodiversity with the potential to re-establish populations of the endemic Cobb's wren and blackish cinclodes. However, it will also contribute to future operations on other Falkland islands by allowing landowners to understand which eradication techniques do, or do not, work. As the first attempt to eradicate mice in the Falklands, the results will be especially helpful in planning for eradications on mouse-infested islands such as Steeple Jason Island, which is home to many seabird species and has been identified as an Important Bird Area. (Falklands Conservation, 2006). In the Falkland Islands, private landowners have been a driving force in many ecological restoration projects, so the training and experience gained by local residents in the course of the Bense operation also serves to increase the pool of skilled staff who can participate in future eradications on other islands.

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