Non-target mortality monitoring in South Georgia rodent eradication

Final report to GSGSSI

Photo: G. Parker

Andy Black, Jen Lee, Graham Parker, Kalinka Rexer-Huber

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Non-target mortality in South Georgia rodent eradication. Final report to the Government of South Georgia and the South Sandwich Islands

Contract report to the Government of South Georgia and the South Sandwich Islands

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Executive Summary

Brown, or Norway, rats (*Rattus norvegicus*) and house mice (*Mus musculus*), were the only introduced mammalian land predators on the South Georgia archipelago. Rats had successfully expanded their range to cover most of the vegetated mainland, and mice were found in a discrete area along the south-western coastline.

The South Georgia Heritage Trust's (SGHT) eradication programme aimed to remove introduced mammals from South Georgia using the broad scale application of cereal baits laced with poison. The introduction of large quantities of poison into the environment has the potential to impact non-target species. Therefore, SGHT conducted trials prior to the eradication to estimate the potential for non-target poisoning, and methods to mitigate it.

As part of the eradication programme, monitoring conducted by the Government of South Georgia & the South Sandwich Islands aimed to estimate the non-target mortality of a range of bird species. This report summarises the results of monitoring for non-target mortality associated with the rodent eradication.

Prior to baiting, the number and locations of birds susceptible to non-target poisoning were estimated. Following baiting, a range of areas were repeatedly checked for up to two months. The position of all carcasses found were recorded and carcasses collected for necropsy. Since bait pellets incorporated a pyranine marker that fluoresces bright green under ultra-violet light, the presence of toxin in bird carcasses could be determined.

The first skuas, pintails and sheathbills (*Catharacta antarctica*, *Anas georgicus georgicus*, *Chionis albus*, respectively) were found less than a week after baiting. Kelp gull *Larus domincanus* carcasses were found from the tenth day of monitoring. Fresh carcasses were still being found at the time observations ceased, up to 60 days after baiting, and so the numbers presented in this report are likely to underrepresent mortality to some extent.

In most areas, the number of skuas present (adults and chicks) declined rapidly, likely due to the high mortality rate rather than emigration or post-breeding dispersal. Although non-target mortality of pintails was also high, there was an apparent increase in the number of pintails present within some areas monitored over the course of the study, presumably due to immigration. While the number of dead sheathbills found during the study were low, counts of live birds at field sites decreased. The decrease in sheathbill numbers suggests that the proportion killed as a result of baiting was higher than indicated by the number of sheathbill carcasses found. Due to the generally low number of pipits (*Anthus antarcticus*) present within baited areas and the difficulty of detecting carcasses, no definitive evidence of mortality was recorded. However, some areas containing breeding populations of pipits were baited, notably Grass Island and the mouse zone (Cape Rosa and Nuñez Peninsula). Monitoring was conducted on Grass Island 32 days after the Island had been baited. Although no dead pipits were found, live birds were not found either.

Mortality in some species (skua and pintail) was higher than expected. However, this one-off impact is expected to be outweighed by the long-term benefits of removing non-native rodents from South Georgia. Benefits to pintails should be apparent sooner than in skuas, since rats appear to have had more impact on pintails and pintail productivity is higher than that of skuas. Numbers of skua pairs appear to have recovered in the first seasons following eradication, a result of skua movements and possibly early recruitment, rather than actual population recovery. Benefits to skuas of rat eradication may only become apparent in the longer-term as burrowing petrel populations recover.

Non-target mortality was lower than anticipated in other species, particularly gulls and giant petrels *Macronectes* spp. This finding illustrates how vulnerability to non-target poisoning is not the same throughout widespread species' range, and can be site-specific. Furthermore, preliminary trials need to mimic baiting conditions as faithfully as possible to provide accurate predictions.

Importantly, this work reinforces that the timing of bait drops, relative to life-history traits, can affect the extent of non-target mortality. Specifically, skua mortality was higher when baiting took place during chick-rearing, and pintail mortality was higher in areas where most birds were in primary moult and thus flightless. Future eradications should also consider the potential for bait consumption by non-target species to reduce the amount of bait available to target rodent species. Here, the highest rates of bait consumption by skua and pintail were recorded during breeding and moult, respectively.

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1 Introduction

The introduction of mammalian predators to southern ocean islands results in the extirpation of populations of native avian species from those areas (Shirihai 2007). When introduced mammals have been eradicated from sub-Antarctic breeding sites, bird populations and communities have typically benefited (Schulz *et al.* 2005; Ryan & Ronconi 2011; Dilley *et al.* 2016).

South Georgia & the South Sandwich Islands (SGSSI) is a UK Overseas Territory in the South Atlantic Ocean. The island of South Georgia is situated approximately 1,450 km southeast of the Falkland Islands and 1,900 km east of the southern tip of South America. Mainland South Georgia and its offshore islands comprise a land area of 3,755 km^2. It is mountainous, with the majority of land over 1,000 m above sea level. Approximately 60% of the land is permanently covered with snow and ice and only 8% of the land mass provides a suitable habitat for plants. The Territory is a haven for wildlife and is home to about five million seals of four different species, 65 million breeding birds of 30 different species and 40 species of non-breeding birds, there are also 25 species of native vascular plants and numerous native invertebrates.

Brown, or Norway, rats (*Rattus norvegicus*) and house mice (*Mus musculus*), are the only introduced mammalian land predators on the archipelago. Prior to commencement of the South Georgia Heritage Trust (SGHT) eradication programme, rats had successfully expanded their range to cover most of the vegetated mainland (Pye & Bonner 1980; Poncet & Poncet 2010; Piertney *et al.* 2016) and mice covered a discrete area along the south-western coastline (Parker *et al.* 2016).

The brown rat has had a significant detrimental impact on South Georgia bird species, particularly the endemic South Georgia pipit (*Anthus antarcticus*), which appears unable to breed successfully in the presence of rats (Pye & Bonner 1980). Colonies of small burrowing petrels and prions (family Procellariidae) and the South Georgia pintail (*Anas georgicus georgicus*) are able to coexist to some extent with rats. However, seabird populations are less likely to have been negatively impacted than pintails, as seabird colonies tend to be found in unfavourable rat habitat (inland scarcely-vegetated areas; Black *et al.* 2012). Rats eat native plants, seeds and seedlings, particularly tussac grass *Poa flabellata* which provides habitat for breeding birds (Leader-Williams 1985). There is no evidence that mice have had an impact on the native bird populations (Cuthbert *et al.* 2012; Parker *et al.* 2016). However, the same mouse species depredates birds on sub-Antarctic Gough Island (Cuthbert & Hilton 2004; Cuthbert *et al.* 2013) and Marion Island (Jones & Ryan 2010).

The introduction of large quantities of poison into the environment has the potential to impact non-target species. The severity of any impact will depend on the non-target species present, the potency and persistence of the poison used. As with most island rat eradications, brodifacoum, a second-generation anticoagulant, was chosen as the active toxin to be applied to South Georgia in a cereal based pellet. Brodifacoum works by blocking the synthesis of vitamin K dependent clotting factors in the liver and is toxic to all vertebrates. Death by haemorrhaging follows a build-up of the active ingredient in the liver, with LD_{50} values (the median lethal dose for a species) varying widely between species (Eason & Spurr 1995).

Poisoning of non-target species has been recorded following most rodent eradication projects using brodifacoum (for example, Eason & Spurr 1995; DPIPWE 2010). Although designed to be palatable to rodents, pellets are also attractive to some other species, resulting in primary poisoning. Predators and scavengers that feed on poisoned rats or other primary-poisoned non-target species will succumb to secondary poisoning, and if those predators/scavengers are themselves eaten once weakened by the toxin, tertiary poisoning can occur.

South Georgia is different to other sub-Antarctic island eradications because the harsh winter climate meant that the baiting had to take place in the summer months, and so coincided with the breeding season of many potential non-target species. Therefore large proportions of the breeding population of some species was put at risk.

Due to concern regarding the risk of primary poisoning to South Georgia pintail, bait trials were conducted on two groups of captive birds in the UK between January and March 2009. The results indicated that South Georgia pintail were not attracted to green cylindrical bait pellets, either intact or after weathering had turned them to pulp (SGHT 2010). The birds normal feed was manipulated to induce hunger. Throughout the period, which involved >600 bird days of exposure to the bait, no pellets were seen to be consumed and only one faecal sample was seen to be coloured by the dye in the bait. This had more the characteristics of moorhen faeces than pintail (moorhens occasionally got into the pen) and is not proof that any pintail ate any bait.

A subsequent trial in 2010 with cylindrical pellets died blue produced a different result (SGHT 2010), with the pintails learning to eat the mush after the pellets had lost their physical integrity with weathering. Consequently, green pellets were used on South Georgia.

The results of bait trials were accompanied with a note of caution as captive birds may not behave exactly in the same way as wild birds but concluded that the pellets would unlikely be attractive to South Georgia pintail. However, the importance of monitoring non-target mortality of pintails during Phase 1 was stressed to validate the results and inform future phases (SGHT 2010).

Prior to the eradication of rodents from South Georgia, an Environmental Impact Assessment (EIA) was prepared by SGHT (SGHT 2010). Among other things, the EIA assessed the potential for poisoning of non-target species. The assessment was based on experience from other similar sub-Antarctic eradication attempts and some preparatory work carried out on South Georgia (e.g. Poncet *et al.* 2002). Where few data of direct relevance are available for a species, risk assessment was inferred on the basis of diet, behaviour and population status. A summary of the assessed risk of significant damage to bird populations on South Georgia from the rodent eradication campaign (SGHT 2010) is presented in Table 1. Significant damage was defined as more than 20% of the population being killed by primary or secondary poisoning. The fourth column is the potential medium-term consequence of the baiting campaign to the population, taking into account the abundance and status of the species concerned and the likelihood of population recovery in the event of significant losses. Here, medium-term is broadly used as 5–10 years post-eradication; short-term as <5 years and long-term as >10 years. This time-frame should be considered indicative only as actual durations to recovery will be species-specific, based on each species' life-history traits. For example, 'short-term' is necessarily longer for long-lived slow-reproducing giant petrels *Macronectes* spp. than for short-lived higher-productivity pipits.

The SGHT assessment concluded that the South Georgia pintail faced the most significant medium-term risk, with the risk to giant petrels, skuas *Catharacta antarctica*, sheathbills *Chionis albus*, pipits and speckled teal *Anas flavirostris* assessed as non-trivial (Table 1). Kelp gulls *Larus dominicanus*, skuas, giant petrels and sheathbills were thought likely to suffer losses due to primary or secondary poisoning, but their populations were assessed as likely to fully recover in the medium term. SGHT (2010) concluded that no bird population is expected to suffer negative effects of the baiting campaign in the long term.

Table 1: Assessment of the probability of significant primary and secondary poisoning (defined as killing >20%) of South Georgia birds, and potential medium-term population consequences (from SGHT 2010).

Species	Risk of primary poisoning	Risk of secondary poisoning	Potential medium-term population consequences	References
Penguins, albatrosses, smaller petrels	Negligible	Negligible	Negligible. Some birds on IUCN red list	Ormonde 2007; DPIPWE 2009
Northern and southern giant petrels	Low-medium	Medium	Low. Least concern on IUCN red list	Ormonde 2007; DPIPWE 2009; DPIPWE 2010
Brown skua	Low-Medium	Medium–high	Low. Population expected to recover losses	Eason & Spurr 1995; Torr 2002; DPIPWE 2009; DPIPWE 2010
Kelp gull	High	Medium	Low. Population expected to recover losses	Eason & Spurr 1995; McClelland 2001; Christie & Brown 2007; Woods *et al.* 2009; DPIPWE 2009; DPIPWE 2010
South Georgia shag	Negligible	Negligible	Negligible.	DPIPWE 2009
Snowy sheathbill	Low–Medium	Low–Medium	Low. Population expected to recover losses	Burger 1981
Antarctic tern	Negligible	Negligible	Negligible.	DPIPWE 2009
South Georgia pipit	Low	Negligible	Very low. Endemic species	Eason & Spurr 1995
South Georgia pintail	Medium	Negligible	Medium. Endemic sub-species	Dowding *et al*. 1999; Fisher & Fairweather 2005; Martin 2008; DPIPWE 2009
Speckled teal	Medium	Negligible	Low–medium.	Martin 2008

Note: Some assessments were based on limited data and were intended as a guide and reference point.

SGHT's (2010) EIA proposed the following measures to reduce the risk of non-target mortality:

- Design bait pellets to be as unattractive and unpalatable as possible to likely avian consumers;
- Monitoring of South Georgia pintail ducks during the Phase 1 field season, including ringing and radio tracking a number of ducks to inform future phases of operation;
- Depending on the outcome of monitoring during Phase 1 of the eradication, consider captive maintenance of South Georgia pintails and speckled teal until risk of poisoning has receded;
- Eradication of reindeer, *Rangifer tarandus*, prior to bait spreading, to reduce risk of operational failure through loss of bait and remove the risk of secondary poisoning due to scavengers feeding on poisoned reindeer carcasses;
- Monitoring during first phase of eradication to gain more information on potential of primary poisoning on non-target species other than pintail;
- To the extent possible, time bait application for when wildlife has departed from breeding colonies;
- Collect rodent and bird carcasses for sampling and disposal as widely and frequently as possible, thereby reducing the biomass of contaminated carrion; and
- Monitoring during and after Phase 1 of eradication to gain more information on potential of secondary poisoning on non-target species.

The rodent eradication operation on South Georgia proceeded in three phases, each spaced two years apart. This report summarises the results of non-target mortality monitoring following each phase of the eradication.

2 Methods

2.1 Rat areas

During the South Georgia eradication, brodifacoum toxin was delivered to rat-infested areas within cereal based pellets (13 mm in diameter and weighing 3 g each) containing 25 parts per million of the active ingredient (Bell Laboratories, Wisconsin, USA). The LD_{50} is 0.27 mg/kg and the consumption of a single bait pellet is sufficient to kill most rats (Eason & Wickstrom 2001).

2.1.1 Phase one baiting regime (2011)

This initial trail phase was focused on the central northern coast line in the area in and around the Governments administrative centre at KEP (see Figure 1). Aerial broadcast baiting commenced on 1st March and was completed on 14th March. To bait the Phase 1 area (15,200 hectares, ha), aerial broadcasting from helicopters, supplemented by hand baiting of buildings, shipwrecks and caves was used. Two Bolkow 105 helicopters followed predetermined transects, with the aid of GPS (Global Positioning System), to spread bait from underslung buckets that delivered an 80 m wide swath of pellets on each pass.

The initial bait drop spread 2 kg/ha of bait pellets over the entire Phase 1 area with an additional 4 kg/ha drop made along the entire coastline. Following a gap of a week, the plan was for a second drop of 4.5 kg/ha to be made over all densely vegetated areas (SGHT 2010). In practice the second drop on the Greene Peninsula immediately followed the first, while there was a gap (due to bad weather) between the first and second drops on the Thatcher Peninsula.

2.1.2 Phase two baiting regime (2013)

Phase 2 of the eradication spread bait over all rat-infested areas to the north of Cumberland Bay (Figure 1). The mouse area at Cape Rosa-Nunez Peninsula was also baited in Phase 2 (Figure 1); baiting details for the mouse area are detailed below.

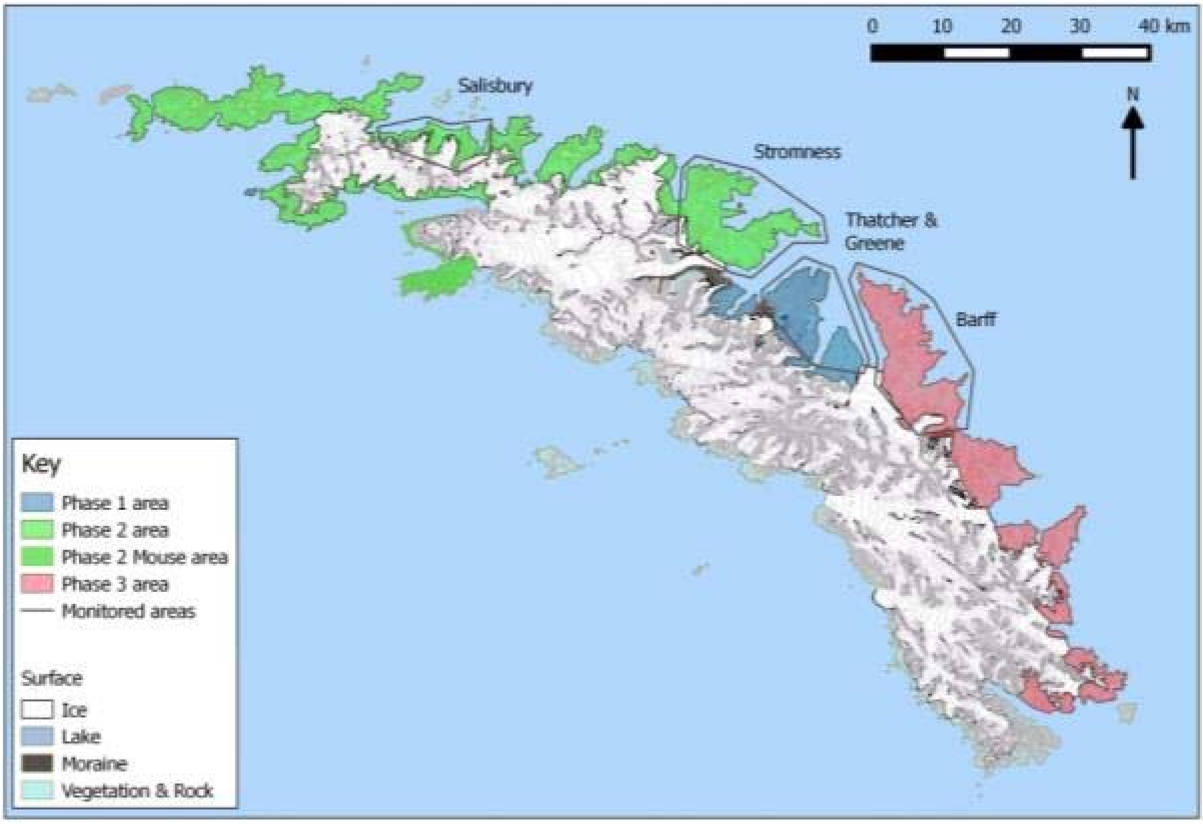

Figure 1: Map of South Georgia showing the areas baited (colours) and monitored for non-target poisoning mortality (inside polygons) in each phase of the rodent eradication.

Baiting commenced on 1st March 2013 and followed a similar methodology to Phase 1 (SGHT 2012) but with a few key differences. Firstly, exposure time of non-target species to the toxin during Phase 2 was reduced by undertaking the second pass over vegetation as soon as possible after the first pass (see SGHT 2012 for further details). Secondly, the revised baiting strategy used in Phase 2 and Phase 3 rat areas was split into three parts. The first bait drop consisted of parallel runs of 2.15 kg/ha with 25 m overlap over all areas of dense vegetation, giving an average of 3.5 kg/ha. The second pass spread 1.5 kg/ha for all land not covered in permanent ice, with no overlap between adjacent runs. The third pass was a narrow (40 m) 'headland' run of 3.0 kg/ha along the coastline (marine and freshwater), with the outer margin of the swath just entering the water. This means that higher bait densities (of at least 5 kg/ha) were sown in coastal areas previously identified as having the highest rat concentrations (Poncet *et al.* 2002; Christie & Brown 2007; Poncet & Poncet 2010), and where there is significant tussac grass cover.

2.1.3 Phase three baiting regime (2015)

To avoid some of the weather related issues encountered during Phase 2 of the eradication, baiting commenced in mid-February. The baiting regime was otherwise the same as that adopted in rat-infested areas during Phase 2 of the eradication.

2.2 Mouse areas

Since mice covered a discrete area on the north-western coastline where there were no rats (Figure 1; Parker *et al.* 2016; Cuthbert *et al.* 2012), the eradication strategy used for the removal of mice differed from that in rat-infested areas. The pellets for the mouse zone were smaller than for rats (9.4 mm diameter, ~10 mm long), and the brodifacoum concentration twice that of the rat bait (50 parts per million). A single application of 10 kg/ha in parallel runs with 60% overlap was followed by a coastal application of 3 kg/ha, using a deflector. Bare rock areas at higher altitude were ignored. A total of 3,070 ha were covered.

2.3 Non-target mortality monitoring

2.3.1 Non-target monitoring priorities

2.3.1.1 Estimating pre-baiting populations

Although there was information about pre-baiting population levels for some species (e.g. giant petrels counted in 2008, S. Poncet unpublished data), for most species there was very little data available and/or information was not at a relevant spatial scale for this project. Therefore, prior to baiting, priority was placed on estimating the number and location of birds susceptible to non-target poisoning. The positions of skua territories and clubs, pintail habitat, kelp gull and sheathbill breeding sites/roosts and the number of each species present recorded on each subsequent visit. Giant petrels were not re-counted, since suitable recent counts were available (S. Poncet 2008, unpublished data). It is accepted that this small snap-shot of population levels would not capture seasonal and annual variability (migration, dispersal, natural mortality, etc), but still provides some baseline against which to measure change.

2.3.1.2 Systematic searches

After bait was applied, sites were regularly visited to search for carcasses and count the number of live birds present. To determine the timing and extent of non-target species impacts over time, field teams (two people) systematically searched relevant habitat types such as beaches, freshwater margins, knolls, skua breeding sites and clubs, and wetlands with dense tussac grass for bird carcasses. Field teams defined fixed search areas (see maps in Section 2.5 below) which were systematically searched at 2–4 day intervals in Phases 1 and 2. Systematic searches took place at approximately ten-day intervals in Phase 3, due to distance travelled between sites.

At sites where a large number of pintails or skuas were seen on a regular basis, field teams made counts of the number of birds present to get an indication of how mortality affected local populations.

2.3.1.3 Carcass collection

The position of each carcass found was recorded, and the carcass collected for necropsy. Each carcass was numbered and species, age, date found, location, sex, freshness, weight, primary length, toxin present, and ring number was recorded.

In addition, carcasses were scored according to the degree of scavenging (an indication of the extent of secondary poisoning) and freshness (to give an indication of the chronology of non-target mortality). Six categories were used from very fresh to very old (see results).

For South Georgia pintail, moult stage was also noted as pintail become flightless during the moult, which influences foraging behaviour. If baiting is conducted during the primary moult February to early April, when the ducks are at maximum physiological stress, cannot fly and do not feed in the open during the day, it would seem likely that cereal baits may be more attractive to them (SGHT 2010).

In Phase 1 carcasses were stored at -20ºC after examination and frozen samples sent to the Scottish Museum of Natural History or incinerated.

In Phases 2 and 3, monitoring teams were field based and incineration facilities were not available. Instead carcasses were removed and disposed of by burying to prevent further secondary or tertiary poisoning. Although this will have locally reduced the level of secondary and tertiary poisoning in the monitored areas, this was deemed the responsible thing to do by the Government of South Georgia & the South Sandwich Islands (GSGSSI) and also formed part of the mitigation proposed in SGHT's EIA (SGHT 2010).

Field teams were confident that a high proportion of carcasses in the areas searched were found. However, given the large areas over which bait was spread, the difficulty in accessing some parts of the baiting zones, and the complex habitat, not all carcasses would not have been found within the baiting zone. An unknown proportion of birds would have consumed bait in a baiting zone and died outside the primary search areas. Therefore, the results presented here should be regarded as conservative estimates.

2.3.1.4 Necropsy

Bait pellets incorporated a marker (pyranine) that fluoresced bright green under ultra violet light, so toxin ingestion could be detected on necropsy of bird carcasses. The easiest place to detect the presence of the marker was the lining of the gizzard. During necropsy the abdominal cavity was opened to expose the gizzard and cut to reveal the lining. An ultraviolet torch was used to illuminate the gizzard lining to test for the presence of pyranine marker.

2.4 Overflight monitoring

Although the king penguin *Aptenodytes patagonicus* colony in Fortuna Bay is relatively small (ca.7,000 pairs; Poncet & Crosbie 2005), it was selected for overflight monitoring since it was one of the first to be baited during Phase 2 of the project. As such, it provided valuable information about penguin behaviour during baiting before the overflights of larger colonies later in the baiting programme. Salisbury Plain was also monitored as it is a large penguin colony as well as an important visitor landing site. Monitoring to ensure that baiting caused minimal disturbance at Salisbury Plain thus also served to reassure visitors that baiting operations were appropriately monitored

During the overflight monitoring, observers positioned themselves at vantage points that provided a good view of the colony and used a video camera to film the reaction of the birds as the aircraft flew over. Pilots relayed information about the height of the aircraft to observers via VHF radio, and if necessary, observers could feed back information on penguin behaviour to pilots, allowing them to adjust their height. During overflights, any changes in colony behaviour were noted, particularly movement of birds that were incubating eggs or attending to young chicks. After the overflight, a search was made of the margins of the colony and any newly dead chicks or abandoned eggs noted. The interior of the colony was not searched, as this would have likely caused an unacceptable level of disturbance. Observations indicated negligible short-term and no long-term impact on the individuals or king penguin populations concerned.

2.5 Sites at which non-target mortality data was collected

2.5.1 Phase one

Sites for non-target monitoring were selected on the basis of their accessibility and the bird species at each site. The sites visited on the Thatcher Peninsula are shown in

Figure 2. Areas between sites (particularly the coastlines) were also searched while in transit, but for clarity are not marked on the map.

Initially, the sites chosen were Sooty Bluff (the coast from the jetty at King Edward Point, KEP, to Sooty Bluff), King Edward Cove (the coast from the KEP jetty to Penguin River), and Maiviken (a route from the around the coast and the shoreline of the larger lakes) (Figure 2) as well as the east and west coasts of Greene Peninsula (

Figure 3). Once it became clear that pintails were suffering a high rate of non-target mortality greater survey effort was focused on tussac covered areas behind beaches since these are prime pintail habitat. Prime pintail habitat in the Phase 1 area include Horse Head, Penguin River South, Zenker Ridge, Discovery Point and Harpon (

Figure 2).

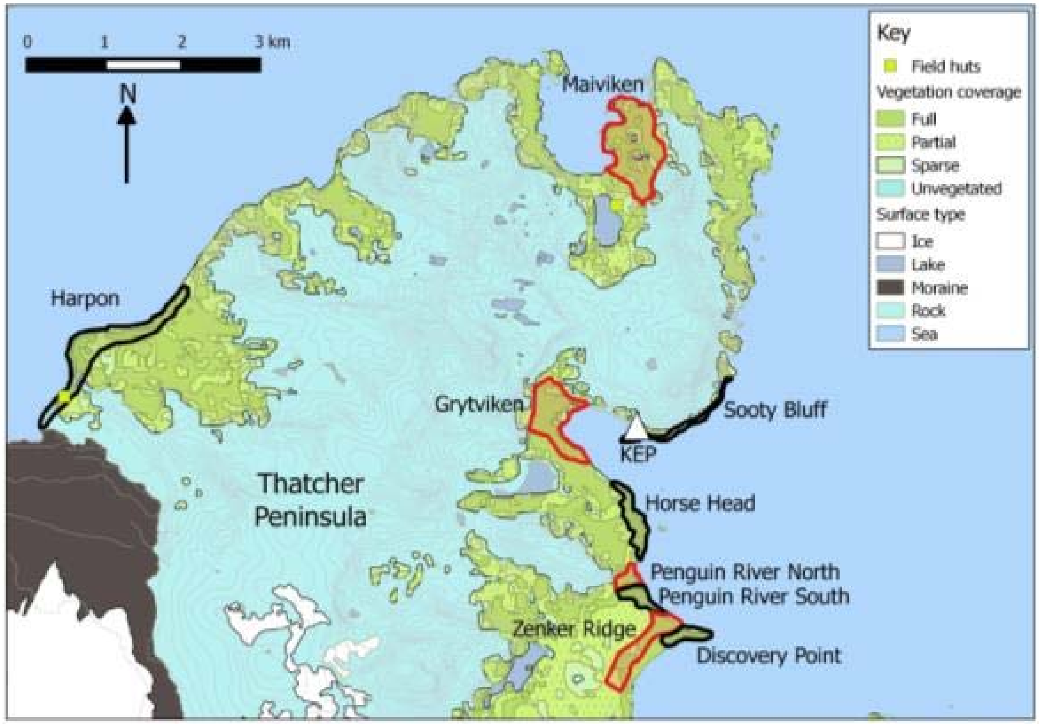

Figure 2: The distribution of the sites monitored on the Thatcher Peninsula in Phase 1. Red and black lines represent areas surveyed for corpse collection.

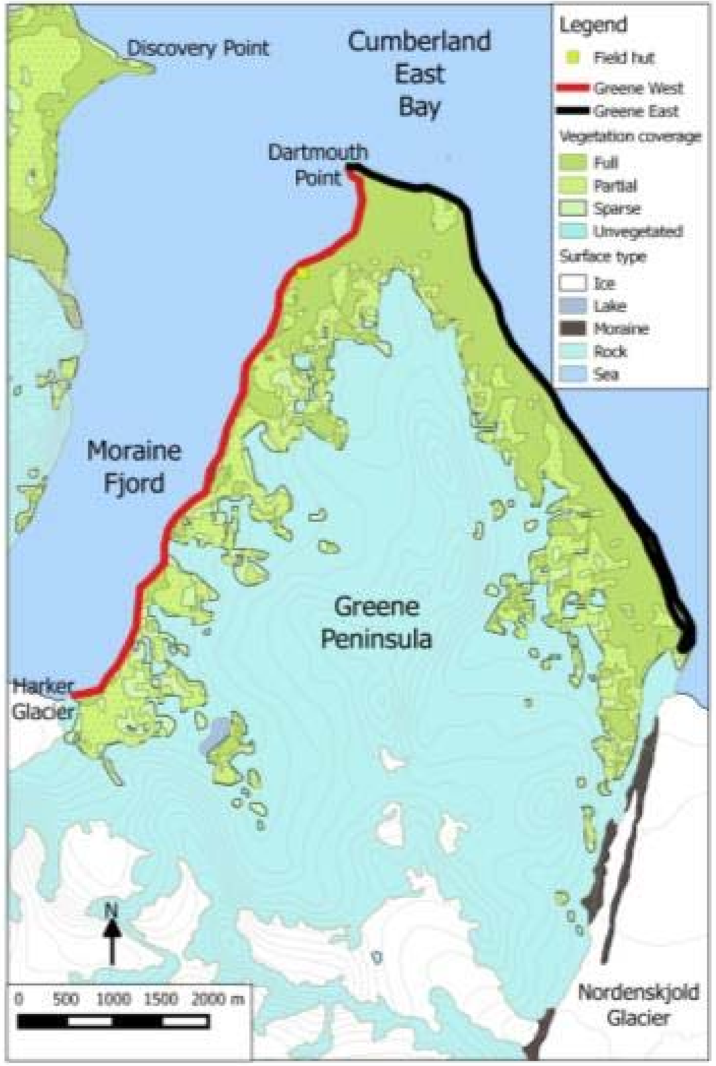

Figure 3: Monitored areas on the Greene Peninsula in Phase 1

Methods

Non-target impacts

2.5.2 Phase two

Phase 2 of the eradication spread bait over a very large area so it was not logistically feasible to monitor non-target mortality in all areas. Instead, two field teams were deployed in two of the baiting zones (Stromness and Salisbury Zones) (Figure 4 and 5). These zones were selected to allow monitoring of non-target mortality for the maximum length of time possible and to cover areas that contained the full suite of species that were likely to be at risk.

2.5.2.1 Stromness Zone

The Stromness Zone (Figure 4) was selected as it was the first area to be baited and therefore allowed the field team to intensively monitor non-target mortality for at least two full months post-baiting, prior to the onset of winter. This was important as the results from Phase 1 indicate that fresh carcasses were still found eight weeks after the bait had been applied. The timing of the monitoring in the Stromness Zone was also significant, as many of the species at risk from non-target mortality were still breeding/provisioning dependent chicks in March when baiting commenced. Although the area is relatively large, it was mostly accessible on foot from a field hut approximately 1 km west of Tønsberg Point (area 5 in Figure 4), which allowed a single field team to monitor a large area.

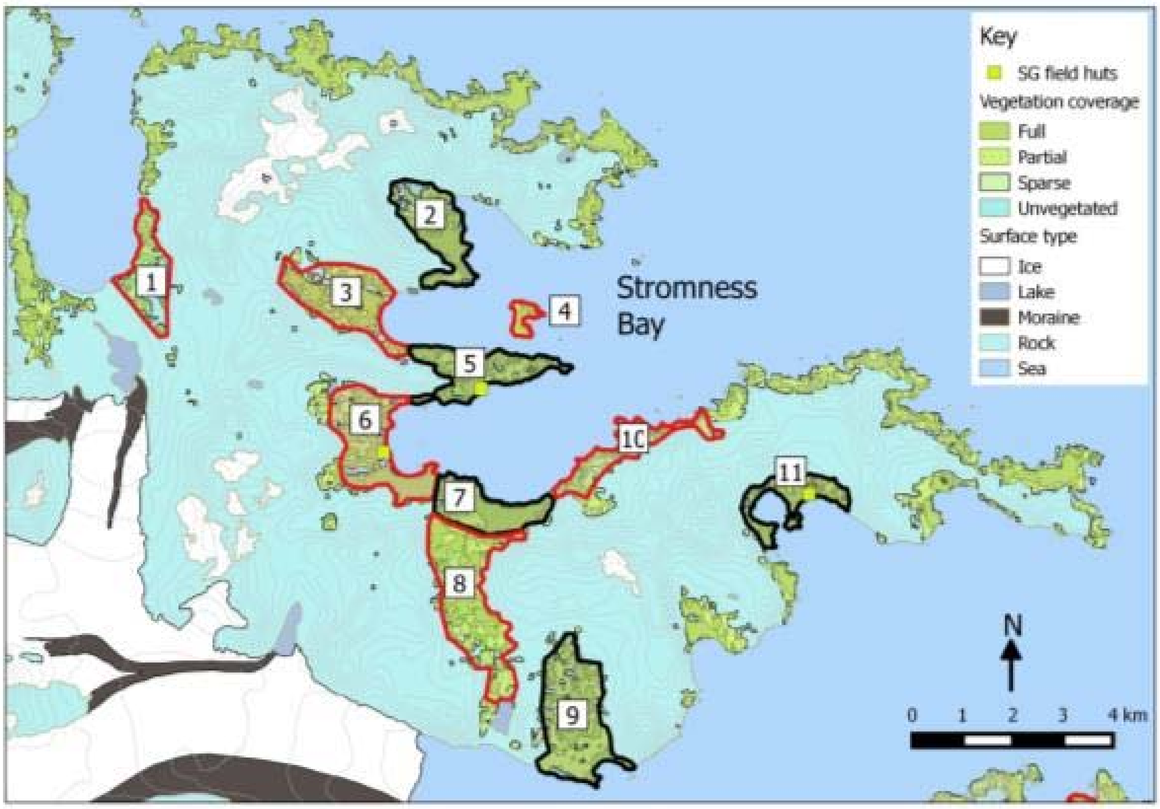

Figure 4: The distribution of sites monitored within the Stromness Zone in Phase 2 (Key: 1. Fortuna Bay, 2. Leith, 3. Stromness, 4. Grass Island, 5. Tønsberg, 6. Husvik, 7. Olsen Beach, 8. Olsen Valley, 9. Carlita, 10. Kelp Point and 11. Jason)

The Stromness Zone was the largest to be baited in Phase 2 and consisted of a treatment area of 16,267 ha, of which 4,400 ha was vegetated. Baiting operations took place between 3 March and 17 March and a dedicated monitoring team was in place 3 March–8 May.

2.5.2.2 Salisbury Zone

The Salisbury Zone (Figure 5) consisted of a treatment area of 3,581 ha, of which 342 ha was vegetated. Baiting operations took place 29 March–8 April (although there was a gap between 30 March and 6 April due to adverse weather conditions), and the monitoring team was in place 29 March–13 May.

The zone was selected for monitoring because it is home to large wildlife aggregations, including king penguin colonies at Salisbury Plain (the largest to be baited during Phase 2) and Sea Leopard Fjord. In addition to non-target monitoring, these were important sites for overflight monitoring.

Much of the Salisbury Zone could be accessed on foot allowing a single field team to monitor the entire zone from a field camp in Sea Leopard Fjord (Figure 5). The zone was divided into seven main search areas (Figure 5), although Sea Leopard East was actually in the Prince Olav Zone. Each area was typically visited every 3–4 days except Ample Bay, which was only visited once because the distance made more regular searches of the area impractical.

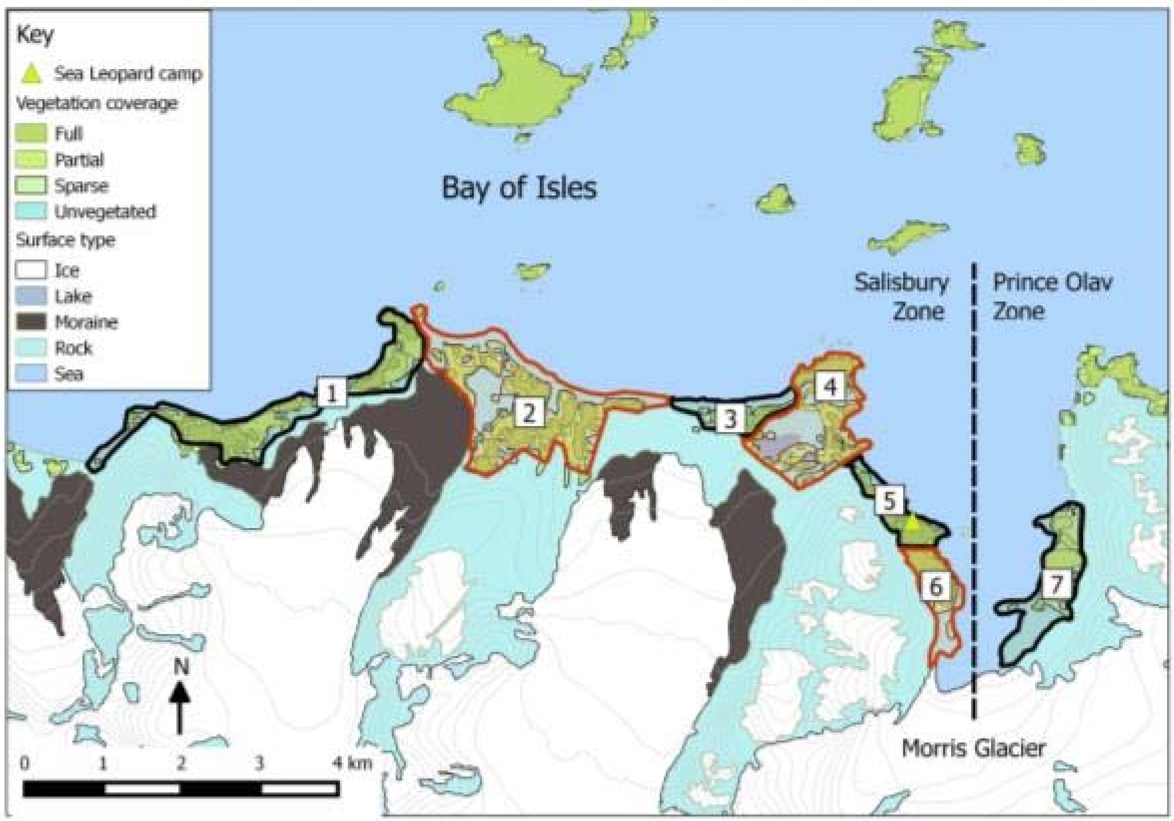

Figure 5: The distribution of sites monitored within the Salisbury Zone in Phase 2 (Key: 1 = Ample Bay, 2 = Salisbury Plain, 3 = Echo Beach, 4 = Luck Point, 5 = Camp Tussac, 6 = Sea Leopard West and 7 = Sea Leopard East).

2.5.3 Phase three

During Phase 3 of the eradication, bait was applied to all zones south of Cumberland Bay. Non-target monitoring was in the northern Barff Peninsula (Figure 6). The Barff Zone was the largest area baited during Phase 3 of the eradication and consisted of a treatment area of 23,300 ha. The Barff study area enabled monitoring of non-target mortality to be carried out for the maximum length of time possible in areas that contained the full suite of species that were likely to be at risk.

Phase 3 baiting commenced in the Barff Zone in mid-February, which allowed the field team to intensively monitor non-target mortality for two full months post-baiting. The timing of the monitoring was important, as many of the species at risk from non-target mortality were still breeding (mostly provisioning dependent chicks) at the time the bait was broadcast.

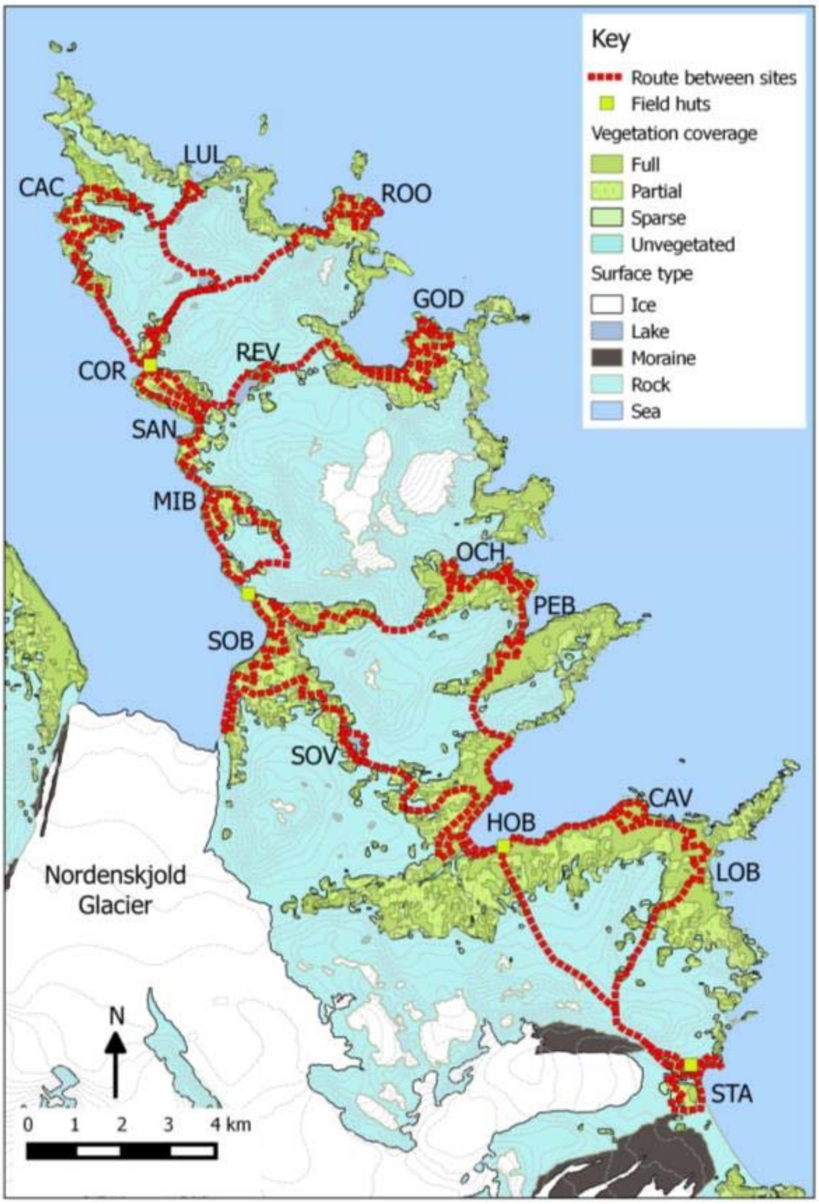

Figure 6. The distribution of sites monitored within the Barff Zone in Phase 3. Locations are named in full in species accounts (from Figure 13 onward)

3 Results

Periods when non-target monitoring was conducted are summarised for each zone in Table 2. The time spent in each search area on a given day varied depending on the number of carcasses found and weather conditions (longer following ice cover or snowfall), but was typically between four and six hours. Field teams ended each search period when confident that a thorough search had been conducted, such that each visit to a site represented a similar amount of search effort.

Table 2: The timing of non-target monitoring in each phase of the rodent eradication project

Phase	Monitored zone	Date baiting started	Extent of monitoring	No. days monitored post-baiting
1	Thatcher	06/03/2011	11/03/2011 to 05/05/2011	61 days
1	Greene	01/03/2011	10/03/2011 to 07/04/2011	38 days
2	Stromness	03/03/2013	03/03/2013 to 08/05/2013	67 days
2	Salisbury	29/03/2013	29/03/2013 to 13/05/2013	46 days
3	Barff	13/02/2015	21/02/2015 to 10/04/2015	57 days

Distance searched and/or time spent searching were of limited use in quantifying search effort, because of the varying complexity of the habitat. In some habitats (such as open grassland or beach) large areas could be searched effectively relatively quickly, while in others (such as tussac pools) a relatively small area took a considerable amount of time to search effectively.

3.1 Overall estimation of impact on non-target species

The results of non-target monitoring can be found in Table 3. Minimum numbers of non-target species killed, based on carcasses found, ranged from two giant petrels to at least 446 skuas (Table 3). The extent of non-target mortality was difficult to quantify accurately, since logistical constraints meant that estimates of the local population of live birds were coarse. Therefore, species were assigned to broad categories of risk: High, Medium, Low and Negligible (Table 3). For the purposes of this report, a species is regarded to be at a *high* risk of mortality where it was estimated that greater than 25% of the local population died following consumption of brodifacoum. *Medium* risk is regarded as anything between 10–25% of the local population mortality. Where less than 10% of the local population of a species died the risk was deemed to be *low*, and where less than 1% of the local population died the risk was deemed *negligible* (Table 3).

Table 3: Minimum extent of non-target mortality of South Georgian birds from non-target monitoring, and assessment of the risk of primary and secondary poisoning

Species	IUCN Status	South Georgia population (breeding pairs)	Percentage of world population	Zone monitored								Risk of primary poisoning	Risk of secondary poisoning
				Thatcher & Greene		Stromness		Salisbury		Northern Barff Peninsula			
				Est. local pop.[b]	Min. # dead	Est. local pop.[b]	Min. # dead	Est. local pop.b	Min. # dead	Est. local pop.[b]	Min. # dead		
Northern giant petrel	LC	17,200 [a]	45% [a]	50	0	175 [c]	0	126 [c]	1	60 [c]	0	Neg.	Neg.
Southern giant petrel	LC	8,700 [a]	15% [a]	250	0	292 [c]	0	236 [c]	0	350 [c]	1	Neg.	Neg.
Brown skua	LC	2,000 [a]	10–20% [a]	40–60	28	200–250	134	150–200	48	400–450	236	High	High
South Georgia pintail	LC	6,000 [a]	Endemic sub-species	>300	113	200–250	115	350–400	148	400–500	60	High	Low
Speckled teal	LC	<20	Unknown	20–30	2	0	0	0	0	0	0	Medium	Low
Kelp gull	LC	2,000 [a]	<1% [a]	>300	4	200–300	7	200–250	1	300–400	12 [d]	Low	Low
Snowy sheathbill	LC	2,000 [a]	20% [a]	6	6 [d]	20	12	250–300	36 [d]	>500 [e]	16 [d,e]	Low to High[†]	Low
South Georgia pipit	NT	3,000 [a]	Endemic 100% [a]	10	0	25	0 *	10	0	10	0	Unknown *	Unknown *

Key: neg. = negligible, [a] Clarke *et al*. (2012); [b] This study; [c] Poncet (2008, unpublished); [d] Mortality ongoing at the end of the study period; [e] Figures relate to St Andrews Bay only.
[†] In areas with no large king penguin colony the risk of non-target is high, in areas with large aggregations of king penguins, the risk of non-target mortality is low to moderate
* Although no carcasses were found there are residual concerns about the susceptibility of pipits to baiting (see text).

The evaluation of the risk of primary and secondary poisoning to South Georgia birds derived from non-target mortality monitoring (Table 3) differs from the risk predicted before the start of the eradication (Table 1; SGHT 2010). The risk to brown skua and South Georgia pintail proved to be higher than expected (Table 1, 3). Conversely, the risk to kelp gulls was far lower than expected.

However, assessing non-target mortality in isolation gives an incomplete picture of the true longer-term impact on local populations, since impacts will be more than a simple reduction in numbers of birds. The impact on a species depends on a number of factors, such as species distribution and breeding parameters (e.g. productivity and age at first breeding). Endemic species, or sub-species, are at higher risk as the global population is contained within a restricted area. Splitting the island of South Georgia into baiting zones, that were not all baited in the same year, was thought to help reduce the overall impact on any one species (SGHT 2012).

3.2 Chronology of non-target mortality

All species' data were combined to examine the chronology of non-target mortality (Figure 7). Only data from fresh carcasses were used to avoid bias from older carcasses found late in the monitoring period, when infrequently searched areas were sometimes revisited. Skua, pintail and sheathbill carcassess were found during the first week of monitoring, however, kelp gull carcasses were not found until ~10 days into monitoring.

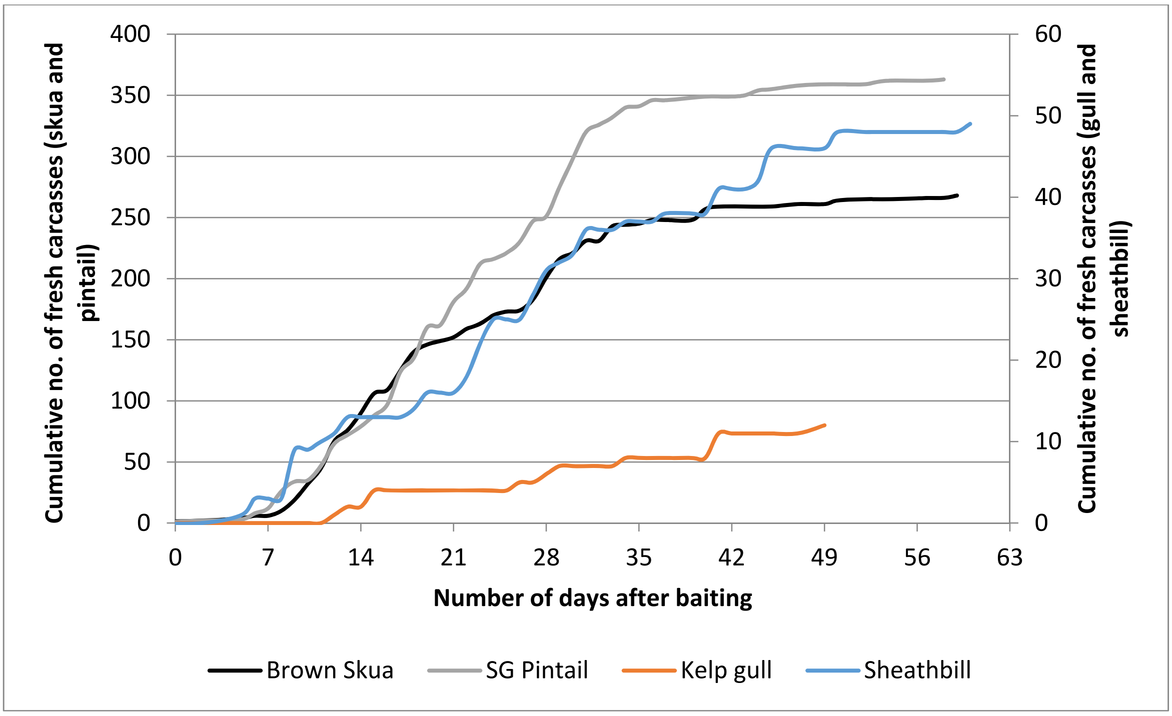

Figure 7: The cumulative number of fresh carcasses collected throughout the non-target monitoring project, all years combined

Mortality of skua and South Georgia pintail, the two most numerous species, appears to have tailed off after about 35 days after baiting (Figure 7). Although the number of sheathbills and gulls collected was lower (note cumulative numbers for these species are plotted against the second y-axis in Figure 7), mortality continued for a longer period, and appeared ongoing at the end of monitoring.

3.3 Degree of carcass scavenging

Observations revealed that brown skuas were responsible for most scavenging, although giant petrels, kelp gulls, sheathbills and pintail were also seen to scavenge birds that had died of consuming toxin.

The proportion of carcasses that had been scavenged differed by species, and among age groups in skuas (Figure 8). Younger skuas were more likely to be found scavenged than adult skuas (Figure 8). Where chicks were present at the time of baiting, virtually all succumbed to brodifacoum poisoning and a high proportion of these carcasses were scavenged, mostly by other skuas.

A very high proportion of sheathbills were scavenged (c. 83%; Figure 8), probably due to their conspicuous plumage. The only intact sheathbills found were either extremely fresh or hidden from view in buildings or under rocks. Adult kelp gulls are similarly conspicuous and usually died in the open (on beaches), and a high proportion of kelp gulls were scavenged (c. 65%; Figure 8). In contrast, a lower proportion of pintails were scavenged (c. 33%; Figure 8), probably due to carcasses being concealed in vegetation.

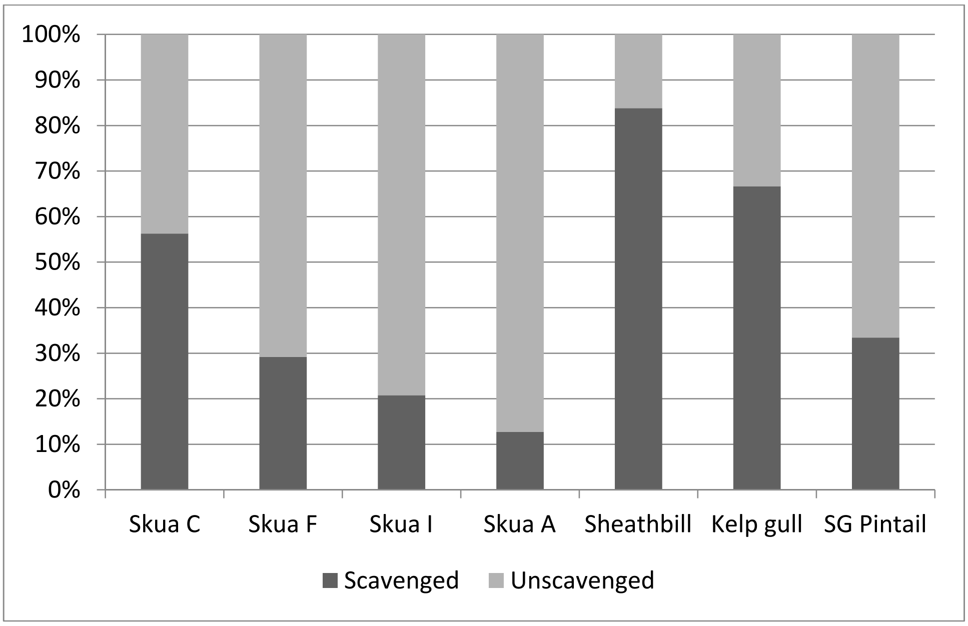

Figure 8: The degree of carcass scavenging by four species during all phases of the eradication. Age groups within skuas: C = chick, F = fledgling, I = immature, A = adult.

In should be noted that there is a bias regarding the proportion of scavenged carcasses recovered as skuas and fieldworkers are more likely to find carcasses that are in the open. It was apparent that carcasses hidden in dense vegetation were more likely to be intact and it is assumed that they were also less likely to be found.

3.4 Species accounts for each eradication phase

3.4.1 Brown skua

3.4.1.1 Phase one

In total, the carcasses of 32 brown skuas (26 adult and six juvenile birds) were recovered. The areas baited and monitored during Phase 1 did not support a large number of breeding pairs, but the number of adult brown skua carcasses recovered accounts for the majority of the breeding population. For example, at Maiviken five or six skua territories were identified prior to baiting (i.e. 12 adult birds), and 12 adult carcasses were recovered from this site, despite skuas being quite cryptic when dead.

Secondary poisoning appeared to be the main cause of skua mortality in Phase 1. Five to six days after the bait was dropped (11 and 12 March 2011), skuas were seen consuming rats in and around King Edward Point. In the following weeks skuas were also seen feeding on carcasses of South Georgia pintail and brown skua. Virtually all of the scavenged carcasses (26% of all carcasses recovered) had been scavenged to some extent by skuas (the only bird species on South Georgia that plucks a bird carcass before feeding). Brown skuas were not observed feeding directly on bait pellets during Phase 1 monitoring and therefore it was thought that they were more likely to be secondarily poisoned. However, this assumption proved incorrect in Phases 2 and 3.

Important skua behaviours associated with brodifacoum poisoning (confirmed by post-mortem examination) included a reluctance to fly when approached, an unsteady gait while walking, and in severe cases an inability to stand. These birds were observed drinking fresh water and being attacked by healthy individuals. In some cases, skuas showed symptoms days before they died.

Although egg laying dates can vary considerably between skua pairs on South Georgia, likely due to the availability of local food sources, most ‘successful’ pairs were still raising young at the time bait was dropped. The data collected strongly suggests that a high proportion of the skuas present within the Phase 1 area were victims of non-target mortality.

3.4.1.2 Phase two

Stromness

Counts of live birds suggested that the pre-baiting local population was between 200 and 250 individual skuas. In total, 134 skua carcasses were found in the Stromness Zone (Table 3; Figure 9), of which 15% had been scavenged before they were located. All 123 skuas that were sufficiently intact to allow examination of the gut tested positive for pyranine (the marker used in the bait pellets). By the end of the monitoring period, very few live skuas were present in the

Stromness Zone. The small number of live skuas that remained had still not left South Georgia in early May, and were observed depredating white-chinned petrel (*Procellaria aequinoctialis*) fledglings.

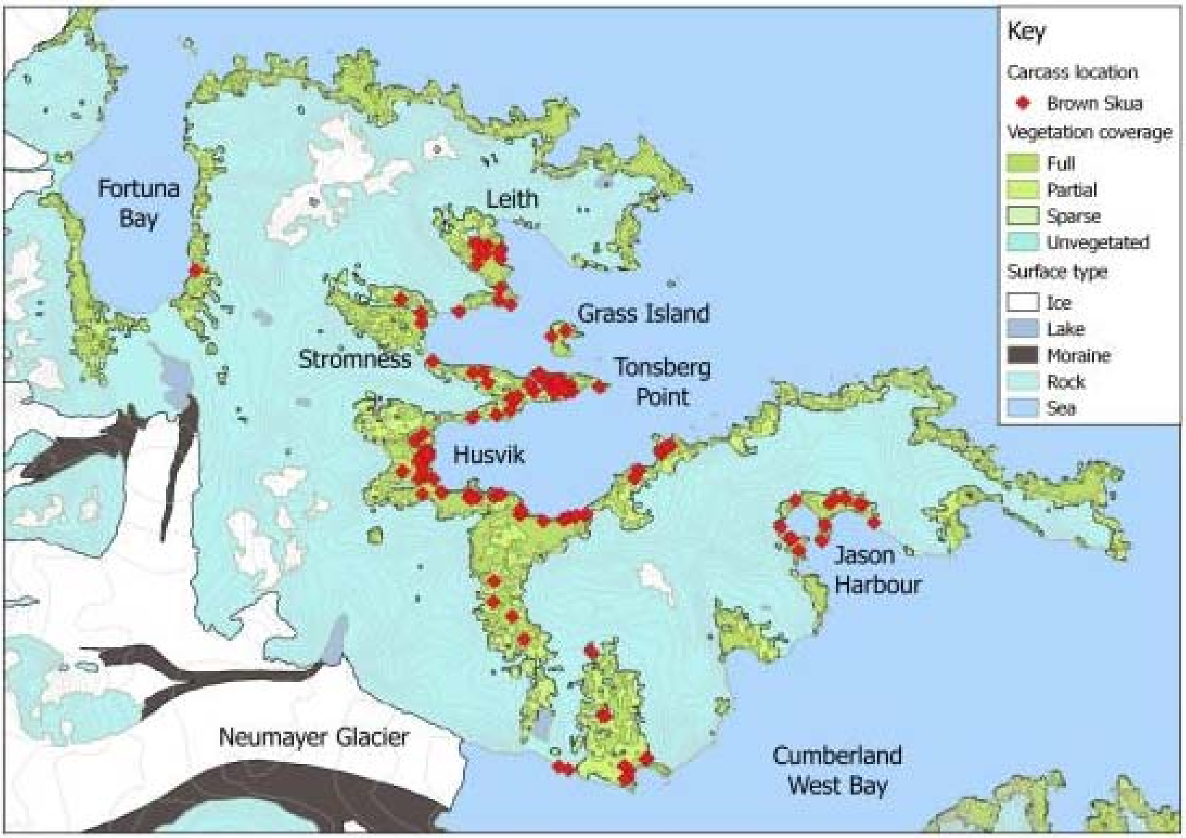

Figure 9: Location of skua carcasses in the Stromness Zone

Many of the skua carcasses were found near SGHT's main camp at Husvik and near Tønsberg Point (Figure 9). Adult birds may have been drawn to the human activity in those regions in January and February during the reindeer eradication project and remained during March because of the large SGHT Forward Operating Base at Husvik.

The adult sex ratio was approximately equal (26 female: 28 male). There were equal numbers of adult and immature skuas (mostly this season's chicks found close to a nest cup, plumage still with traces of down). A high proportion of the immature skuas were found with another immature within c. 5 m, apparently from the same brood. In almost all cases, green faeces were clearly visible around the nesting area, sometimes with clumps of pasted together bait pellets (4–8 pellets per clump). Clumps appeared to have been regurgitated, as clumps of that size would have been too large to have passed through the bait-spreading hopper (P. Garden pers. comm.). This is indicative of primary poisoning, and was supported by observations of skuas eating pellets throughout the Zone.

The first skua carcass was found eight days after bait was dropped, and fresh carcasses (i.e. those which showed no sign of decay and likely died 24–48 h before discovery) were still being found 51 days later (Figure 10). Some birds had obviously been dead for a number of days or weeks before discovery, especially when found in an infrequently-visited area e.g. Jason Harbour (Figure 9). After approximately 30 days, the slope of the discovery curve reduced considerably (Figure 10), which suggests that few skuas died within the monitored area during the second month of monitoring.

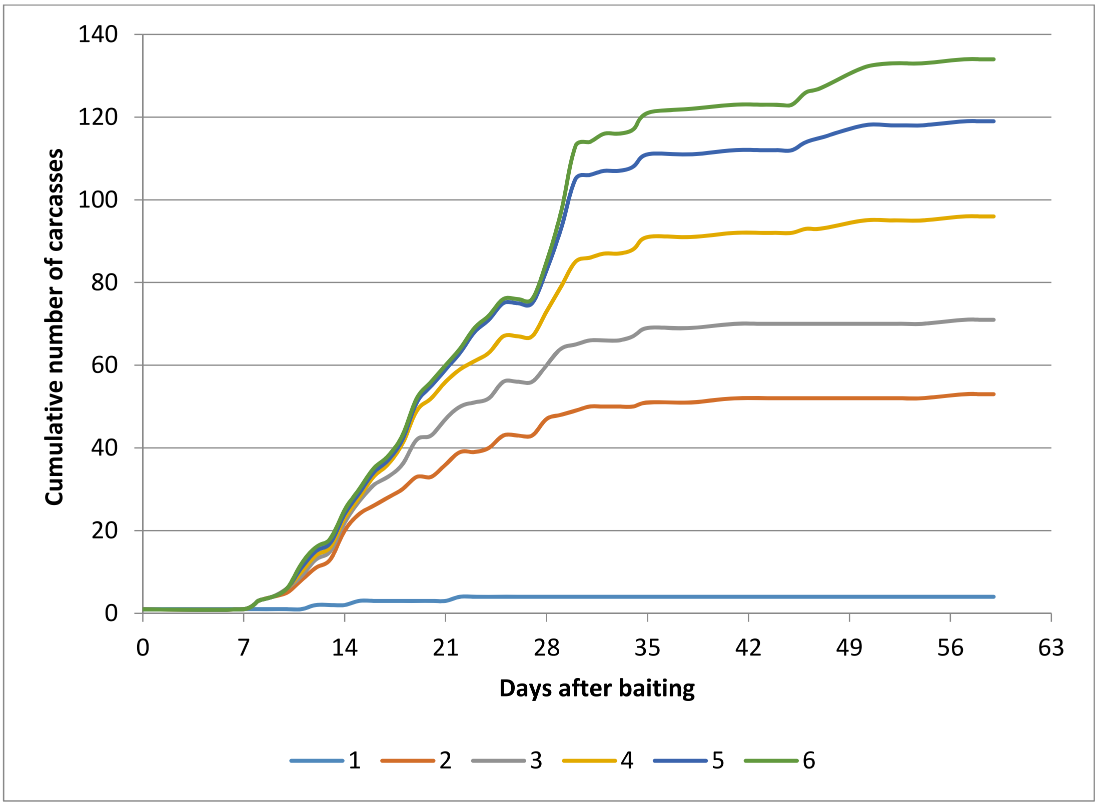

Figure 10: Discovery curves for the cumulative number of skua carcasses found, showing the degree of freshness, in the Stromness Zone. (Key: 1 Very fresh no maggots, 2 Very small maggots, 3 Large established maggots, 4 Large maggots throughout, 5 Stripped carcass no maggots, 6 Very old and desiccated)

Salisbury

In total, 48 skua carcasses were found, of which one was a fledgling bird. Birds were typically found out in the open, often in close proximity to freshwater pools and known skua clubs (Figure 11).

Of the 48 skua carcasses recovered, 34 birds (71%) were found intact and 14 (29%) had been scavenged either by other skuas or by giant petrels. All of the 39 birds that were sufficiently intact to be examined for pyranine proved to be positive. Twenty-three birds were either too scavenged or had too much internal bleeding to allow them to be sexed (skuas typically suffered heavy abdominal bleeding, which made sexing birds problematic). Of the 25 birds that were sexed by internal examination of gonads, four were female and 21 were male. The sex bias is unexpected, and differs from the ratio recorded in the Stromness Zone.

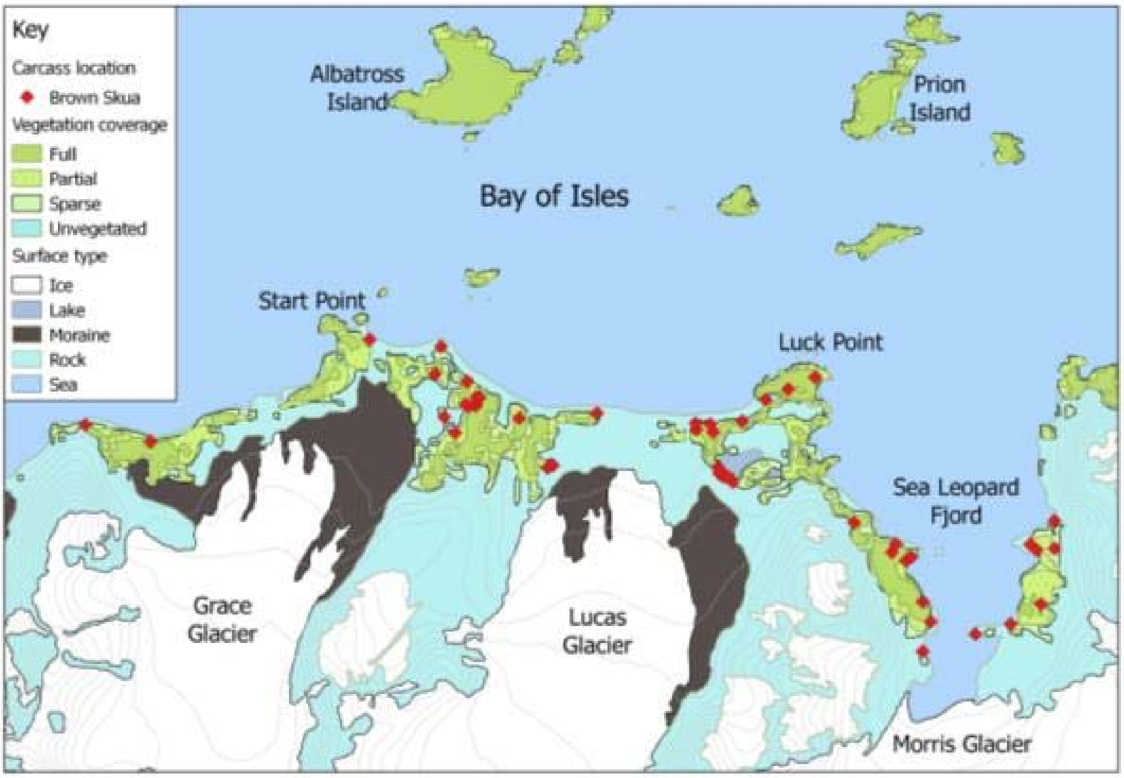

Figure 11: Location of skua carcasses in the Salisbury Zone

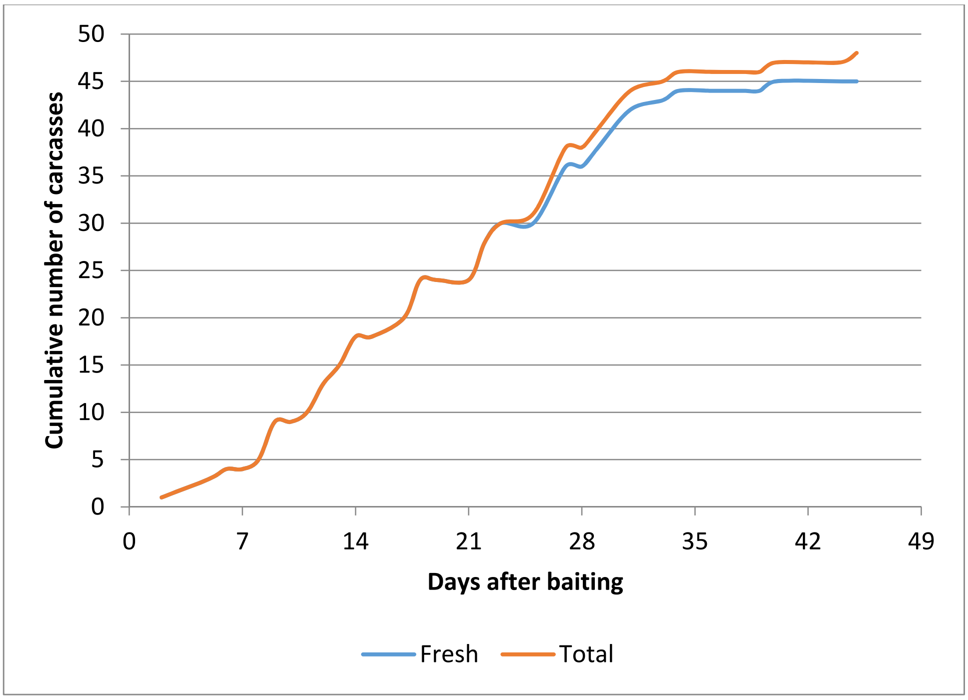

Figure 12: Discovery curves for the number of fresh skua carcasses (blue line) and all skua carcasses (red line) found in the Salisbury Zone.

The first skua carcass was found six days after bait was dropped and fresh carcasses were still being collected 40 days post-baiting (observations ceased shortly after) (Figure 12). The majority of skua carcasses found were fresh, although some of these had been scavenged. Towards the end of the sampling period some older, more decayed, birds were found (Figure 12).

Counts of live skuas, especially around large king penguin colonies, remained high throughout the observation period. It was estimated that approximately 150–200 individual skuas occupied the core study area (excluding Ample Bay) at the time bait was dropped. Many more skuas are known to breed in the wider Bay of Isles area, with approximately 120 pairs breeding on Albatross and Prion islands alone (Poncet 2012). Forty-eight carcasses were recovered, which gives an approximate mortality rate of 25–30% on the mainland population; i.e. excluding birds on the offshore islands in the wider Bay of Isles area.

3.4.1.3 Phase three

In total, 234 brown skua carcasses were found in the monitored area, consisting of 61 young of this year (chicks or fledglings) and 173 adult birds (Figure 13). Most birds observed alive as chicks were later found dead, and it is believed that very few young from this year survived in the northern Barff Peninsula.

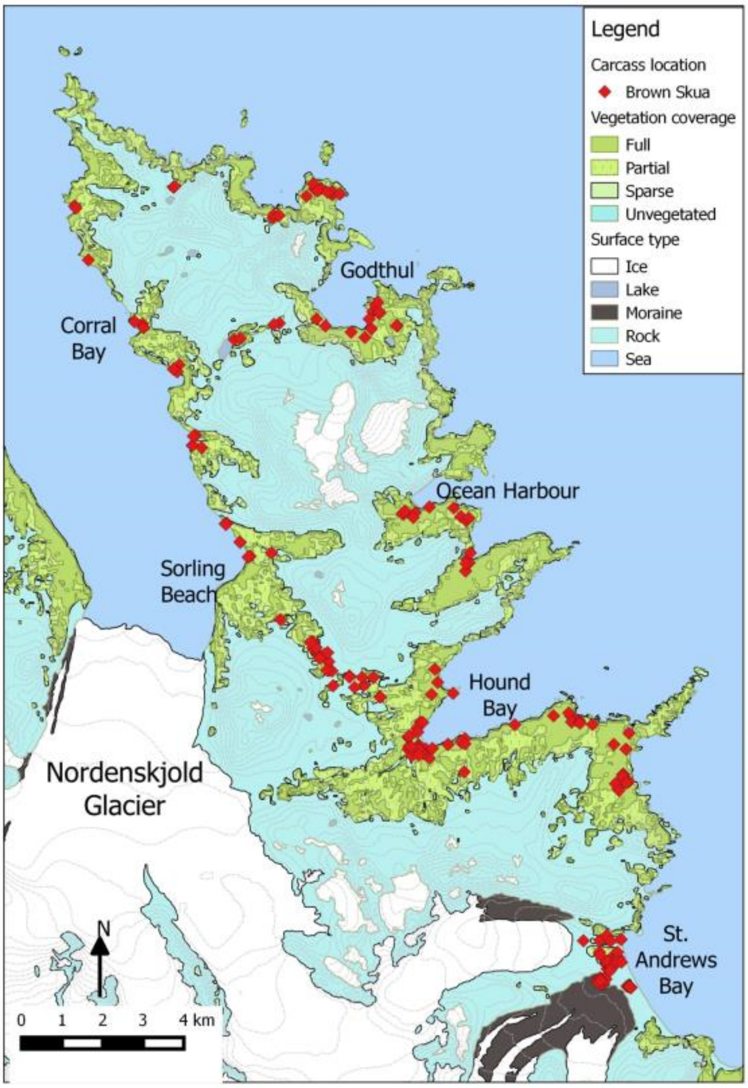

Figure 13: Location of skua carcasses in the Barff study area in Phase 3

The distribution of carcasses in Figure 13 largely reflects the distribution of known breeding sites, which are generally coastal and associated with food sources such as penguin colonies. Carcasses were also found in some inland areas, particularly Sörling Valley but also Reindeer Valley and near Lurcock Lake. These inland areas are used as 'clubs' by loafing birds; or are pairs breeding near prion and diving-petrel colonies (e.g. Sörling Valley). Fieldworkers attempted to thoroughly search the areas favoured by skuas on each monitoring trip. Knowledge gained in previous field seasons helped to locate carcasses on return visits, but it is unlikely that all carcasses were found.

The sex ratio of the adult birds sexed by internal examination of gonads was 37% female and 63% male, a further 39 adult birds (23% of all adults) were not sexed due to the loss of sex organs to scavengers or in some cases excessive bleeding in the abdominal cavity.

Some skua carcasses recovered had been scavenged, mostly by other skuas but there was also evidence that giant petrels also scavenged some carcasses (A. Black pers. obs.). However, there was a large difference in the percentage of adults that were scavenged compared with chicks and fledglings, with 13% of adults and 38% of chicks and fledglings scavenged. As observed elsewhere, it is likely that birds weakened by brodifacoum poisoning were depredated by other skuas. The age of the carcass (time elapsed between death and discovery) is also an important consideration. For fresh adult carcasses, those thought to be a few days old, only 5% had been scavenged compared with 32% of young birds. For older carcasses, 22% of adults and 46% of young birds had been scavenged. These observations have some implications for the potential for brodifacoum to be passed through the food chain, and thus the potential for secondary poisoning.

On 20 February, only two days after the first bait drop, adult skuas were observed feeding bait pellets to chicks at St Andrews Bay. Clumps of regurgitated pellets were also found, similar to those reported during Phase 2 (Lee *et al.* 2013). This is indicative of primary poisoning and was supported by observations of skuas eating pellets throughout the Zone.

During the course of this study, skuas naturally dispersed away from breeding sites, making it difficult to accurately quantify the degree of adult mortality. Along with the number of dead birds recorded during each visit, the number of live birds was also noted. The data suggest that somewhere in the order of 50–60% adult mortality was caused by brodifacoum poisoning on the Barff Peninsula. However, it is inevitable that some carcasses will not have been found and birds may still succumb to the toxin following the end of this study.

The first skua carcass was found eight days after bait was a dropped and fresh carcasses (i.e. those which showed no sign of decay and likely died within a few days of discovery) were still being found 51 days later (Figure 14). However, the proportion of fresh carcasses discovered more than 30 days post-baiting was low, possibly due to the very low number of live birds remaining.

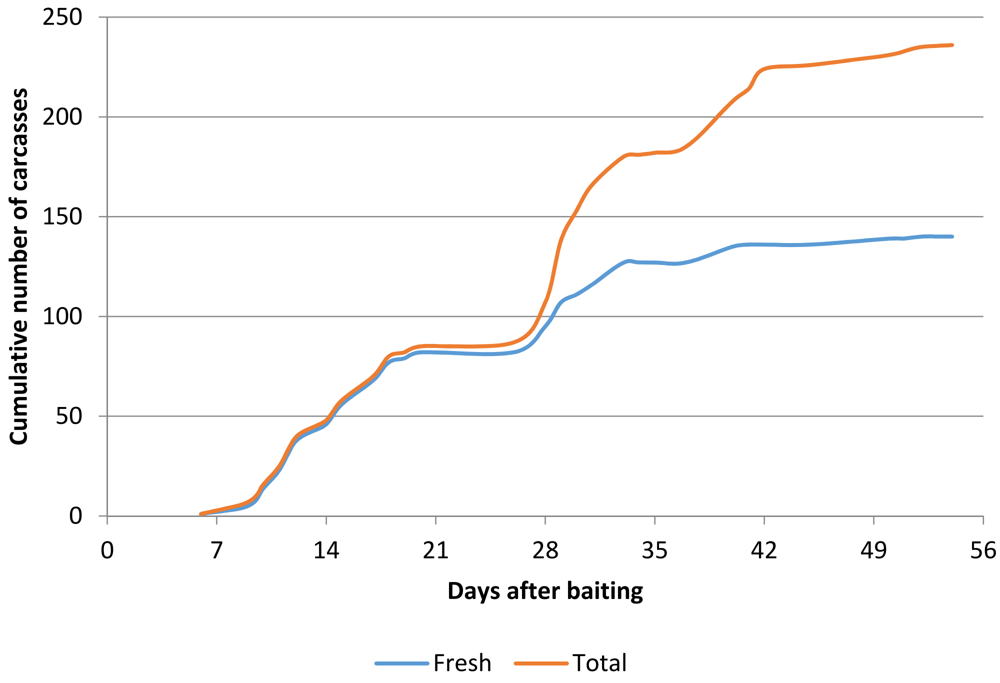

Figure 14: Discovery curves for the number of fresh skua carcasses (blue line) and all skua carcasses (red line) found in the Barff Zone.

By the end of the monitoring period, very few live skuas were present in most of the Barff Zone. The only exception was St Andrews Bay (Figure 13) where in excess of 100 live skuas remained at the end of the study. St Andrews Bay holds South Georgia's largest king penguin colony and is the focal point for scavenging birds, such as skuas and giant petrels.

3.4.1.4 Skua ring recovery

A ringed skua was found at St Andrews Bay on 18 March. Further investigation showed that the bird was ringed as a chick in 1987 at St Andrews Bay by a Dutch expedition (A. Wood pers. comm.).

3.4.1.5 Skua summary

In most areas, the number of skuas present declined rapidly after bait spreading. Around large penguin colonies, such as Salisbury Plain and St Andrews Bay, there was no apparent decline in skua numbers despite a large number of carcasses being found. It is likely that the feeding opportunities associated with the large king penguin colony provide a focal point for birds dispersing following the breeding season, which may mask the impact on the local breeding population.

3.4.2 South Georgia pintail

3.4.2.1 Phase one

South Georgia pintail were widely observed throughout the area baited in Phase 1. Although they were seen on the beach and in coastal waters during the day, much of the time these birds are hidden in dense tussac grass or on freshwater ponds. Searches of favoured pintail habitat (fringes of ponds and adjacent tussac grass) invariably found dead ducks. In total, 113 adult, one juvenile and 13 duckling South Georgia pintail were recovered in Phase 1.

Necropsy confirmed that virtually all of these pintails had consumed brodifacoum, presumably through the direct consumption of pellets. Although difficult to observe in thick tussac grass, a clear demonstration of the attractiveness of bait pellets, to at least some ducks, was witnessed by the habitat restoration team when a duck flew to the helipad and proceeded to consume a number of spilt pellets lying on the ground. However, it was clear that not all ducks were consuming bait pellets since throughout post-baiting monitoring, live and apparently well pintail were regularly observed. Individual variation in the feeding behaviour of this and other species is unsurprising. Bait consumption could however become a learned behaviour in gregarious species like South Georgia pintail.

The range of the local South Georgia pintail population on the Thatcher and Greene Peninsulas almost certainly extends to the wider Cumberland Bay area, beyond the limits of the areas baited during Phase 1. There appears to be considerable movement of individuals in and out of the areas covered by post-baiting surveys. Combined with their secretive habits, this makes an accurate population estimate very difficult. It is also not possible to assess how many dead pintail remained undiscovered in the field. It is therefore very difficult to make an accurate assessment of the impact of brodifacoum related mortality on the local population. A comparison between the number of dead pintail recovered and the number of apparently healthy pintail recorded indicates that the mortality was probably less than 50% of the population, possibly higher for that proportion of the population present in the days following the bait drop. The available information suggests mortality was somewhere between 33–50% of the population.

3.4.2.2 Phase two

Stromness

In total, 115 South Georgia pintails were collected during the Stromness Zone monitoring period. Most carcasses were of adult ducks (97%) but two were immature and one was a duckling (although no pyranine was detected in the duckling). Carcasses were mostly found in pools and marshy areas with dense overhanging tussac grass, but occasionally also in the open areas that ducks frequent at night to graze. Pintail carcasses were concentrated in tussac-fringed pools at Kanin Point, Tønsberg Point, the area opposite Brain Island, and were also numerous on Grass Island (Figure 15).

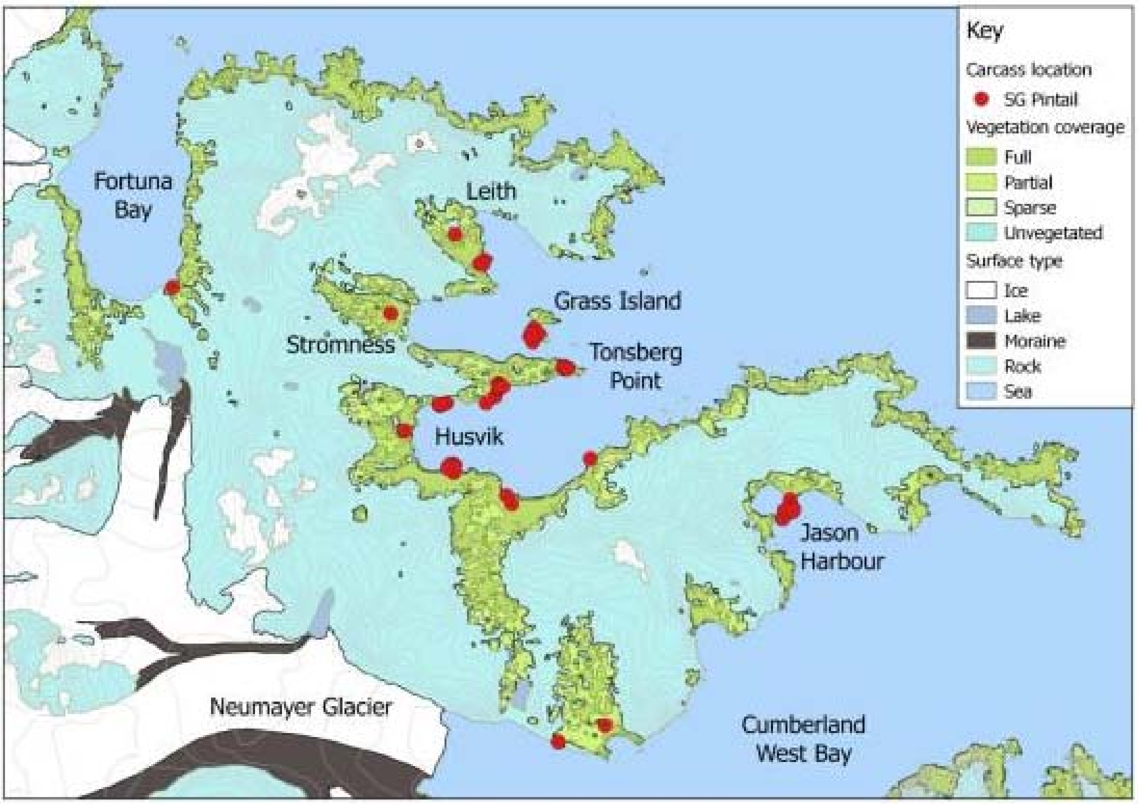

Figure 15: Location of South Georgia pintail carcasses in the Stromness Zone. NOTE: location of pintail carcasses is highly aggregated around areas with suitable pools, so points are overlapping.

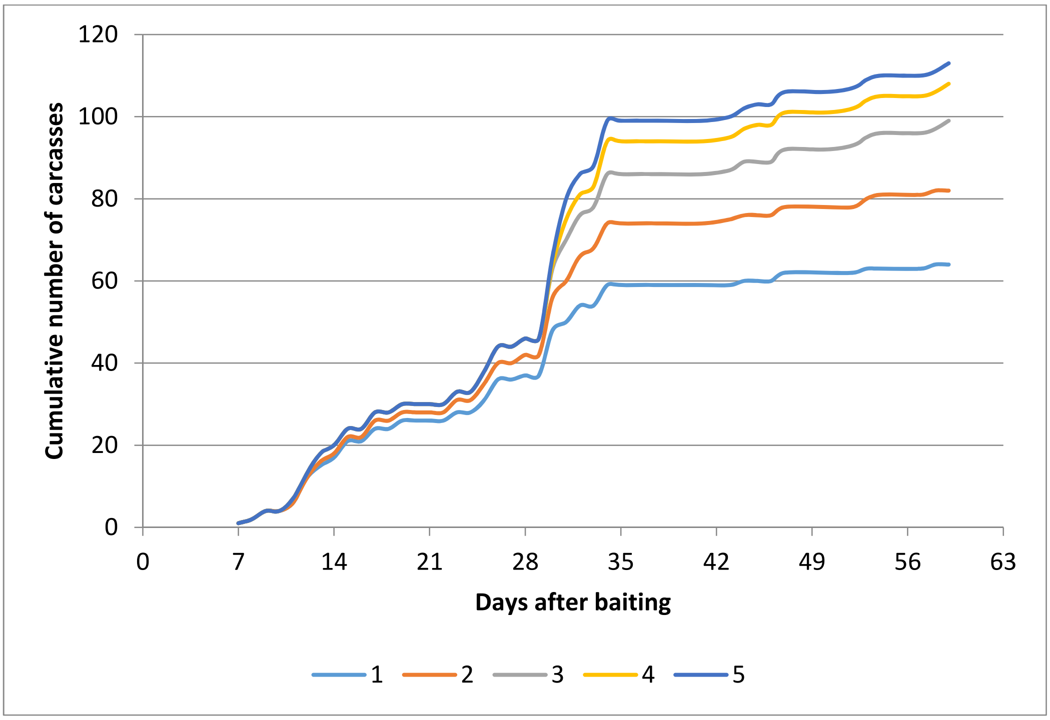

Figure 16: Discovery curves for the cumulative number of South Georgia pintail carcasses found, showing the degree of freshness, in the Stromness Zone. (Key: 1 Very fresh no maggots, 2 Very small maggots, 3 Large established maggots, 4 Large maggots throughout, 5 Stripped carcass no maggots, 6 Very old and desiccated).

The sex ratio of pintail carcasses collected in the Stromenss Zone was 1:1.3 (F:M), which is consistent with the male-biased sex ratio observed elsewhere on South Georgia (T. Martin pers. comm.). Ninety-two pintails (80%) were found before they were scavenged. Detection of birds in primary moult was challenging as these birds typically sought refuge in deep tussac. However, moulting birds were regularly encountered throughout the search period, and 24 (21%) of the carcasses were in active moult at the time of death.

The first pintail carcass was found seven days after bait was dropped and fresh carcasses were still being found 59 days post-baiting (Figure 16). However, the rate of carcass recovery declined considerably at approximately 35 days after bait was deployed in an area (Figure 16). Like skuas, some carcasses were found which had obviously been dead for a number of days or weeks, especially if they were found in an area that was visited infrequently. All of the 91 carcasses that were sufficiently unscavenged to allow dissection of the gut, tested positive for pyranine (the marker used in the bait pellets).

Despite pintail mortalities, point counts of live ducks remained fairly constant over time, suggesting replacement via duck movement into the Stromness Zone. Counts of live birds suggested that the local population was between 200 and 250 individuals.

Salisbury

In total, 148 adult pintail carcasses were found in the Salisbury Zone. Carcasses were almost exclusively found in areas of freshwater pools with overhanging tussac grass. A high proportion of pintail carcasses were found around large ponds at Luck Point, Echo Beach and Sea Leopard Fjord (Figure 17).

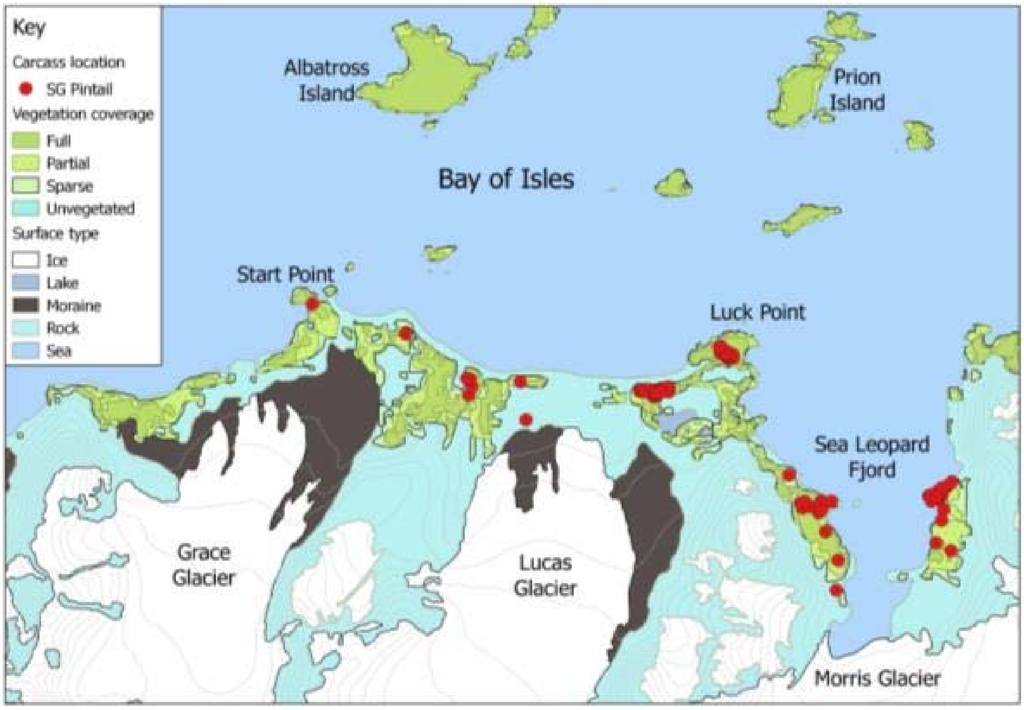

Figure 17: Location of South Georgia pintail carcasses in the Salisbury Zone. Note: location of pintail carcasses is highly aggregated around areas with suitable pools and so points are overlapping.

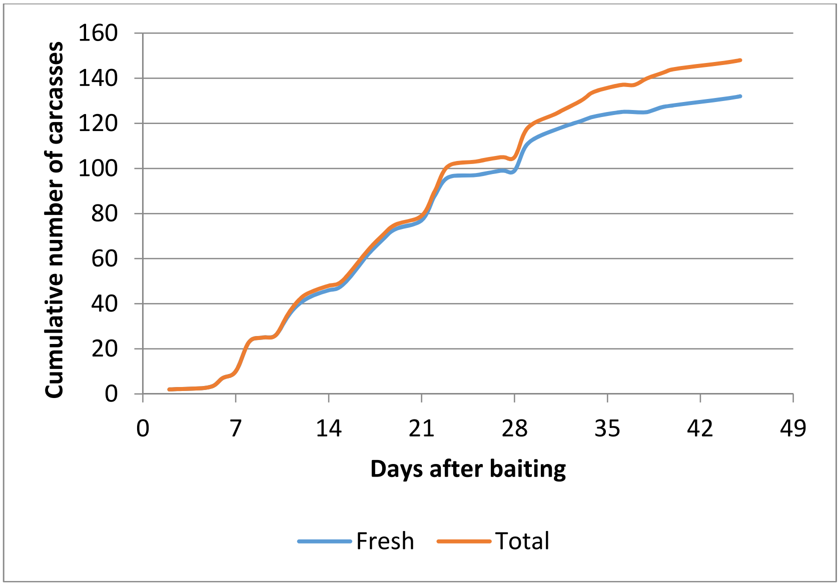

Figure 18: Discovery curves for the number of fresh South Georgia pintail carcasses (blue line) and all South Georgia pintail carcasses (red line) found in the Salisbury Zone

Ninety-one pintails (61%) were unscavenged, whereas 57 (39%) showed some level of scavenging. From a sample of 77 adult birds that were sexed by internal examination, a sex ratio of 1 : 1.26 (F : M) was found. This is comparable with the sex ratio of birds found within the Stromness Zone. Only 13 carcasses (approximately 9%) were found that exhibited active primary moult, which is probably a consequence of the late timing of the bait drop.

Although the frequency of finding pintail carcasses declined over time, pintail mortalities were ongoing at the time surveys ceased, 46 days post-baiting (Figure 18). Typically the field team found ducks within a few days of death; however, following heavy snow ducks became more difficult to locate and some slightly more decayed (but still pyranine-positive) carcasses were found later in the study period.

Part way through the study period, a period of cold weather resulted in the freezing of freshwater ponds, which resulted in a redistribution of pintails. Although the ponds subsequently thawed, the number of pintail present did not return to previous levels.

3.4.2.3 Phase three

Initial searches indicated that good pintail habitat in the study area was limited, in part due to grazing by reindeer and the resultant tussac degradation. However, small groups of birds were sighted in most coastal areas and three areas containing 'pintail ponds' were identified. These were located at Corral Bay, Ocean Harbour and near Cape Vakop (Figure 19). At first, counts indicated that the study area supported a population of approximately 200 South Georgia pintail; however, as the study progressed the number of birds observed on these ponds increased and the population towards the end of the study was thought to be closer to 500 individuals. Although some of the small ponds would sometimes hold 200 pintail, the surrounding habitat did not seem to be extensive enough to support this number of birds. Together with the varying number of birds observed at each location, it is assumed that there is a lot of movement of pintail within and perhaps outside the study area. The ponds may be the focal point for resting ducks during the day, before dispersing to feed at night.

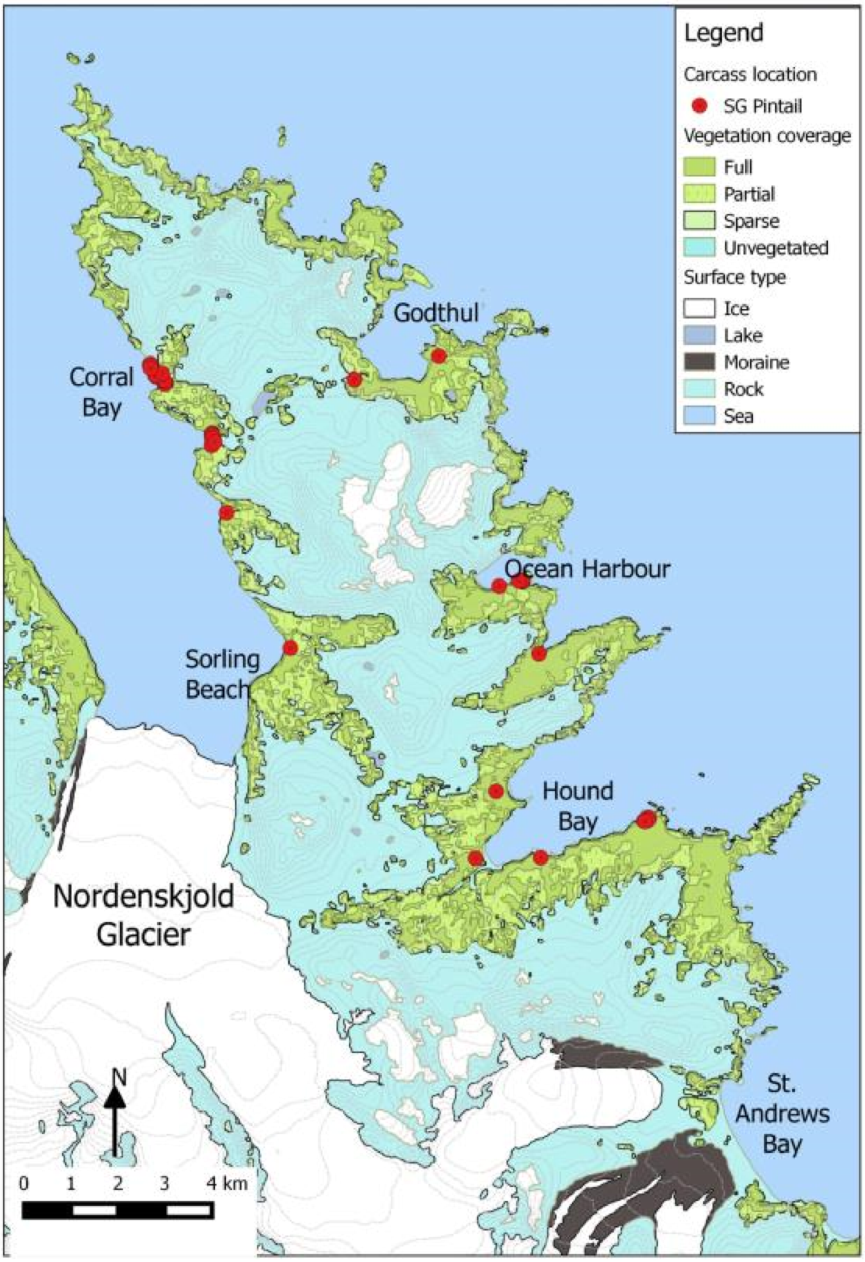

Figure 19: Location of South Georgia pintail carcasses in the Barff study area

In total, 60 South Georgia pintail carcasses were found (Figure 19). All carcasses were of adult ducks, and 39% of carcasses had been scavenged before being found. Carcasses were mostly found in marshy areas and pools with dense overhanging tussac grass, but occasionally in the open areas where ducks graze at night. Most of the pintail carcasses recovered were associated with the previously identified 'pintail ponds' at Corral Bay, Sandebugten, Ocean Harbour and Cape Vakop (Figure 19).

Detection of birds that are in primary moult was challenging, as elsewhere, as these birds typically sought refuge in thick tussac grass. Although moulting birds and evidence of moulting (shed feathers) were regularly encountered during the latter part of the search period, only 11% of the carcasses recovered were in active moult.

The first pintail carcass was found nine days after bait was dropped, and very few fresh carcasses were found more than 31 days post-baiting (Figure 20). This differs from the results obtained during Phases 1 and 2 of the habitat restoration project, which showed mortality continuing for a longer period following the bait drop and impacted on a higher proportion of the population (Lee *et al.,* 2013).

Given the large number of live ducks observed at the end of the study period, the number of carcasses recovered was estimated as approximately 12% of the adult population.

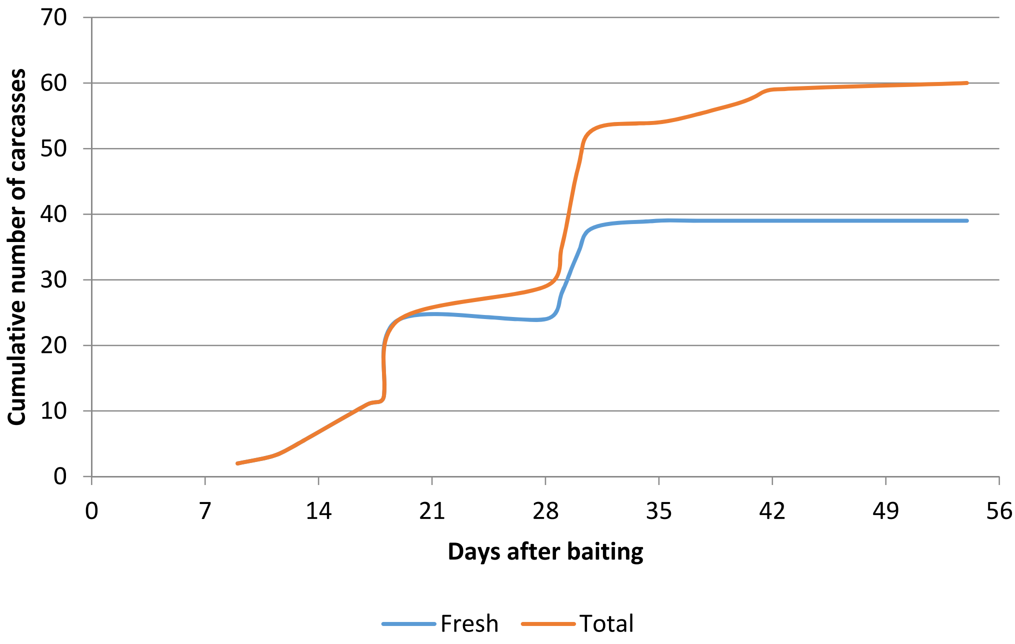

Figure 20: Discovery curves for the number of fresh South Georgia pintail carcasses (blue line) and all South Georgia pintail carcasses (red line) found in the Barff Zone.

3.4.2.4 Pintail summary

There was an apparent increase in the number of pintail present within some areas monitored over the course of the study. This could be due to immigration into the area or associated with moulting behaviour. Pintails moulting during the study period were flightless and less conspicuous. During the winter, pintail become more coastal in distribution due to the freezing of freshwater pools. Mid-way through the Salisbury monitoring, a cold spell resulted in redistribution of the local pintail population, which made it difficult to determine the fate of those birds.

3.4.3 Speckled teal

Cumberland Bay appears to be a stronghold for this species on South Georgia but they are still relatively rarely seen. Two speckled teal carcasses were collected. Both were found in the same general area close to Discovery Point.

Speckled teal appear to favour more open water than South Georgia pintail, but are thought to have similar feeding behaviour. Therefore it is plausible that they are similarly vulnerable to brodifacoum poisoning, and that speckled teal mortality was underestimated here.

3.4.4 Snowy sheathbill

3.4.4.1 Phase one

Snowy sheathbills were only encountered in a few specific locations within the Phase 1 area. In the early stages of monitoring six live sheathbills were recorded. In the weeks that followed baiting, six sheathbill carcasses were recovered. All but one of the carcasses recovered had been scavenged; therefore, positive confirmation of brodifacoum ingestion was not possible those five sheathbills.

Notably, a sheathbill was observed on a daily basis throughout April around the base at KEP. On several occasions this bird was observed feeding on bait pellets and produced green faeces as a result. However, the bird appeared to be in good health for over a month until it died on 5 May. This was the only fresh sheathbill carcass recovered. Examination of the digestive tract confirmed that the bird had consumed brodifacoum.

Away from the areas monitored, groups of sheathbills were observed from the sea, while hand-baiting caves, on rocks off the coast of Maiviken. These areas were not visited post-baiting and therefore the fate of these birds is unknown.

3.4.4.2 Phase two

Stromness

Generally, sheathbills appeared to be present in low numbers within the Stromness Zone, probably because of a lack of a penguin or seal colonies in the area. Counts of live birds suggested that the pre-baiting local population was approximately 20 individuals.

Twelve sheathbill carcasses were found, of which seven were intact and five were scavenged. Nine tested positive for pyranine, but the other sheathbill carcasses were either too degraded to test, or were unreachable and could not be collected. A low number of live sheathbills were still present in early May. Many of the sheathbills observed were in and around the old whaling stations at Husvik, Leith and Stromness (Figure 21), where they often associated with groups of southern elephant seals (*Mirounga leonina*).

Salisbury

In total, 36 sheathbill carcasses were found; all but one of these was scavenged. Sheathbills were found almost exclusively in the immediate vicinity of king penguin colonies (Figure 22), often near to freshwater.

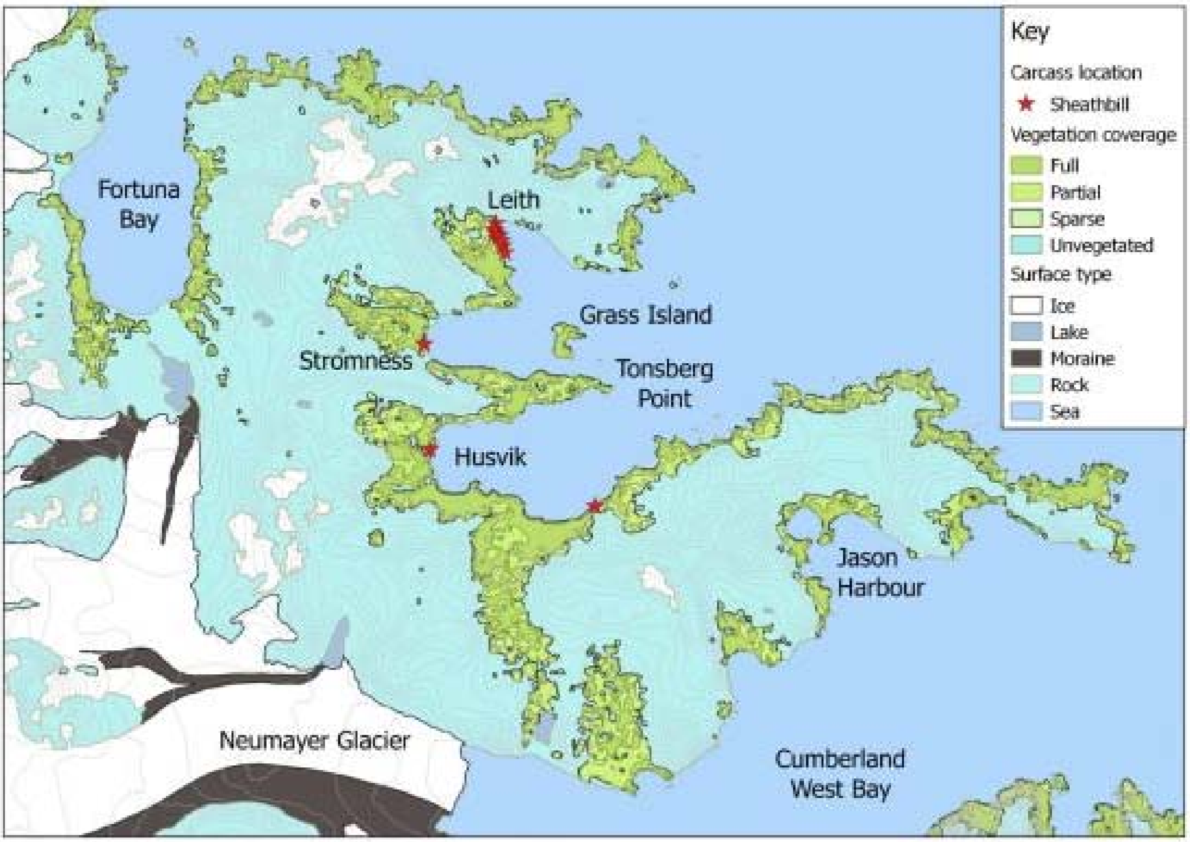

Figure 21: The distribution of sheathbill carcasses recovered in the Stromness Zone

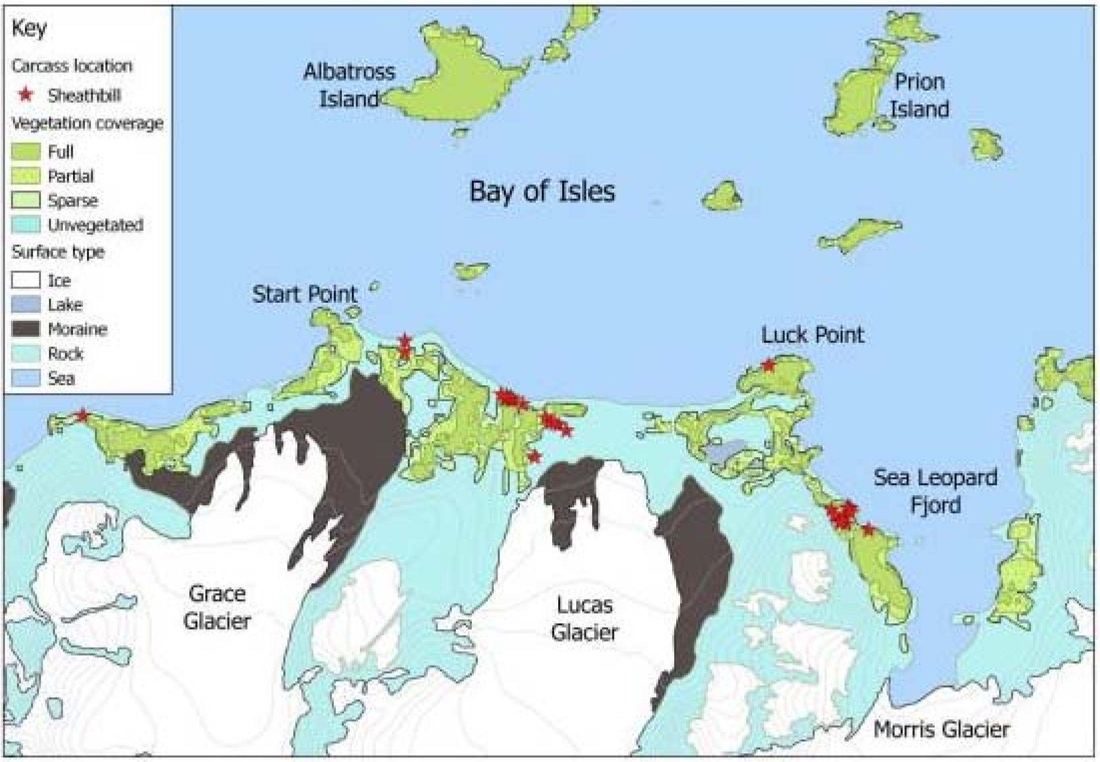

Figure 22: Location of snowy sheathbill carcasses in the Salisbury Zone

Although virtually all of the sheathbill carcasses recovered in the Salisbury Zone had been scavenged, the areas where carcasses were found were searched regularly and the field team are confident that the birds died during the study period. The abundance of scavenging birds at Salisbury and the conspicuous nature of sheathbill plumage made finding intact carcasses extremely difficult. The only intact carcass found was hidden under a rock.

Several hundred live sheathbills were observed in the Salisbury study area and this number did not appear to change throughout the period of observations. Birds appeared to be primarily foraging in the immediate vicinity of penguin colonies and roosted on nearby scree or cliffs. Sheathbill carcasses were found in low numbers more or less continuously throughout the study period (Figure 23).

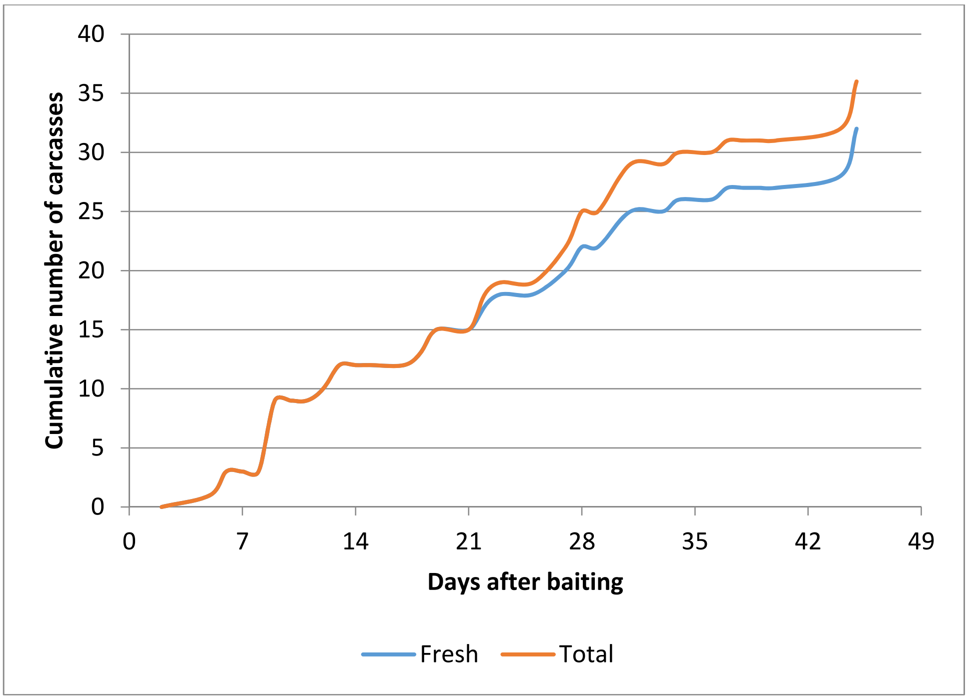

Figure 23: Discovery curves for the number of fresh (blue line) and all snowy sheathbill (red line) found in the Salisbury Zone

Observations on the ground and the slope of the discovery curve (Figure 23) indicate that sheathbill mortality would have continued for some time following the cessation of fieldwork. The overall impact on the species is therefore difficult to quantify; however, the number of carcasses collected represented a small proportion (about 12%) of the overall number of live birds that were present at the time of baiting.

3.4.4.3 Phase three

Generally, sheathbills appeared to be present in low numbers within the Barff study area; the only exceptions were near the king penguin colony at St Andrews Bay and the macaroni penguin (*Eudyptes chrysolophus*) colony at Rookery Bay (Figure 24) where sheathbills were locally abundant. However, both of these locations presented monitoring issues. The macaroni colony at Rookery Bay is amongst dense tussac and searching for carcasses would be very difficult and cause disturbance to the penguin colony. It was therefore decided to concentrate sheathbill monitoring efforts at St Andrews Bay (Figure 24). Although the king penguin colony there is far more open with very little surrounding vegetation, the vast scale of the penguin colony makes an accurate assessment of the sheathbill population difficult. There are a number of areas where sheathbills group together to rest (clubs), and it was possible to count the number of live birds at those sites. The number of sheathbills present in St Andrews Bay was estimated to be more than 500 birds, but counting birds active within the penguin colony was not attempted.

Similarly, searches for carcasses were also confined to the perimeter of the penguin colony and surrounding areas, to avoid disturbance to breeding king penguins. In total, 17 sheathbill carcasses were recovered, of which 16 were associated with St Andrews Bay (Figure 24).

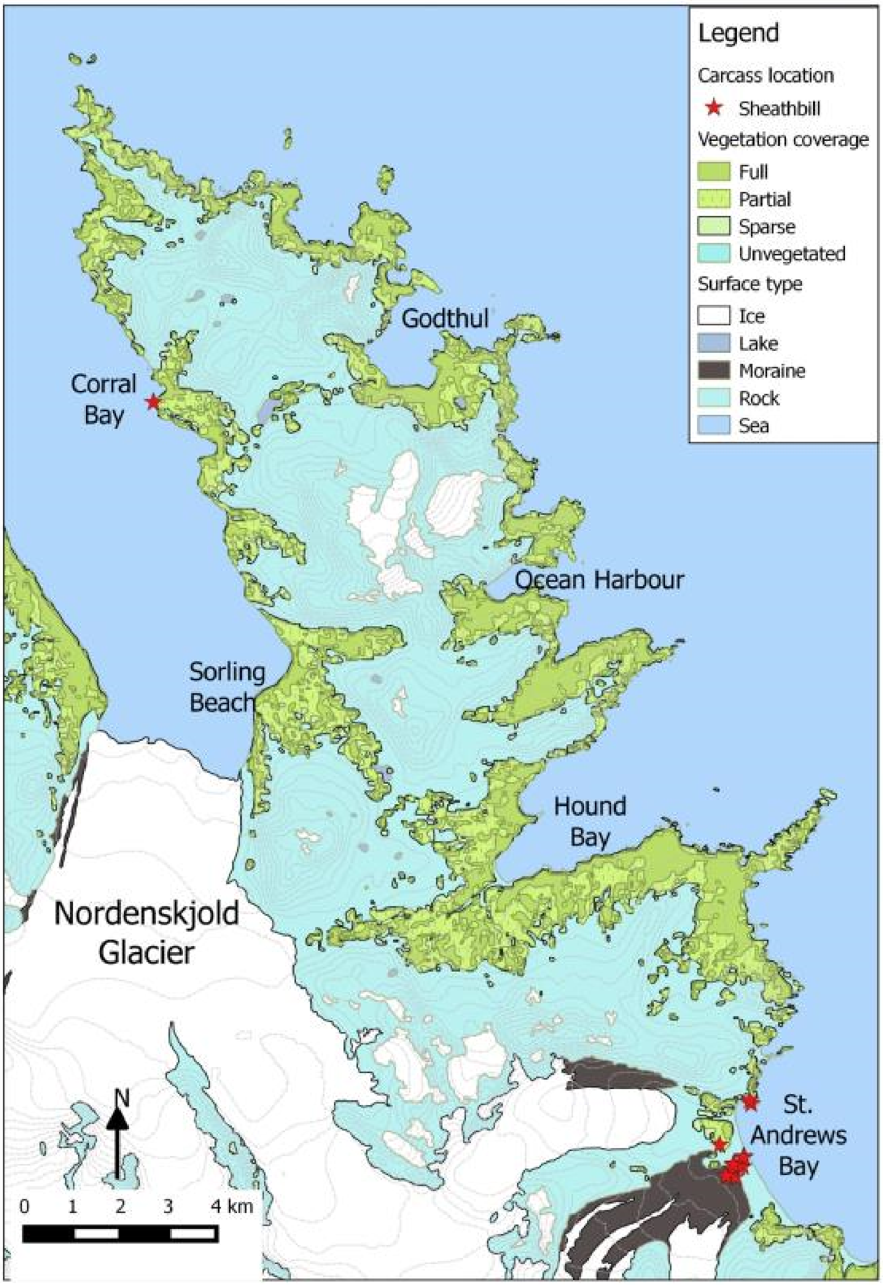

Figure 24: The distribution of sheathbill carcasses found on the Barff Peninsula

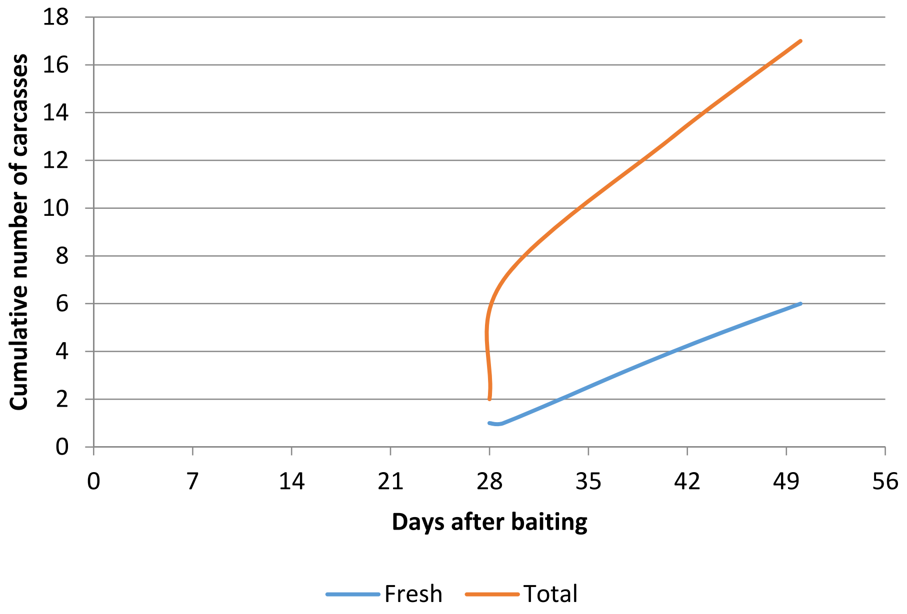

Figure 25: Discovery curves for the number of fresh sheathbill carcasses (blue line) and all sheathbill carcasses (red line) found in the Barff Zone.

In line with the observations recorded in the Salisbury Zone following Phase 2 of baiting, sheathbill mortality appeared ongoing at the end of the study period (Figure 25), so the true extent of non-target mortality on this species is unknown. Although the apparent impact is low, brodifacoum will have still been present in the environment at the end of monitoring, thus presumably have been ingested for some time.

3.4.4.4 Sheathbill summary

Where sheathbills were common, usually associated with large king penguin colonies like at St Andrews Bay, the number of birds present did not appear to change significantly. However, where sheathbills were found in low numbers, the proportion of birds killed appeared to be far higher (Thatcher and Stromness Zones).

3.4.5 Kelp gull

3.4.5.1 Phase one

Four adult carcasses were recovered from a population of several hundred (suggesting a mortality rate of 1–2%). Additionally, the carcass of a single juvenile kelp gull was recovered.

Throughout the post-baiting period, the number of kelp gulls recorded remained high. Most birds were observed sitting on the water in the vicinity of kelp patches where they forage. Evidence from roost sites indicates that small limpets form a large part of their diet. Kelp gulls were also seen foraging between high- and low-water marks. Although gulls in other regions are recorded scavenging the carcasses of dead birds, this behaviour was not observed.

3.4.5.2 Phase two

Stromness Zone

Seven kelp gull carcasses were collected, of which five were adults and two were immature birds. Four of the five kelp gulls, where an examination for pyranine was possible, were positive. One intact kelp gull did not have obvious pyranine but did have signs of internal bleeding, suggesting that toxin had been consumed. Kelp gulls were seen throughout the baiting period foraging close to the shore and roosting on coastal scree slopes suggesting that the species was not heavily affected by either primary or secondary poisoning. Counts of live birds suggested that the local population was between 200 and 300 individuals.

Salisbury Zone

A single kelp gull carcass was found on the strand line at Salisbury Plain 31 days after baiting. It had been completely scavenged (only wings left) and therefore it was not possible to determine sex or whether it had died as a result of brodifacoum poisoning. Kelp gulls were seen throughout the baiting period foraging over inshore waters and in the intertidal zone, suggesting that the species was not heavily affected by either primary or secondary poisoning, although flocks of several hundred kelp gulls were also regularly observed roosting ashore and therefore would have been exposed to bait pellets.

3.4.5.3 Phase three

Live kelp gulls were regularly observed throughout the northern Barff Peninsula with highest numbers at Hound Bay and Corral Bay. As observed elsewhere on South Georgia, kelp gulls appeared to feed mostly along the shoreline or over inshore waters. In total, 12 kelp gull carcasses were found with most associated with Hound Bay (Figure 26).

The carcass discovery curve (Figure 27) shows that the first kelp gull carcass was found 28 days after the bait was dropped and fresh carcasses were still being found towards the end of the observation period (41 days post-baiting). The slope of the discovery curve hints that kelp gull mortality continued beyond 41 days post-baiting but none were found in the last week of fieldwork.

Kelp gulls were seen throughout the baiting period foraging close to the shore and roosting on coastal scree slopes, suggesting that the species was not heavily affected by either primary or secondary poisoning.

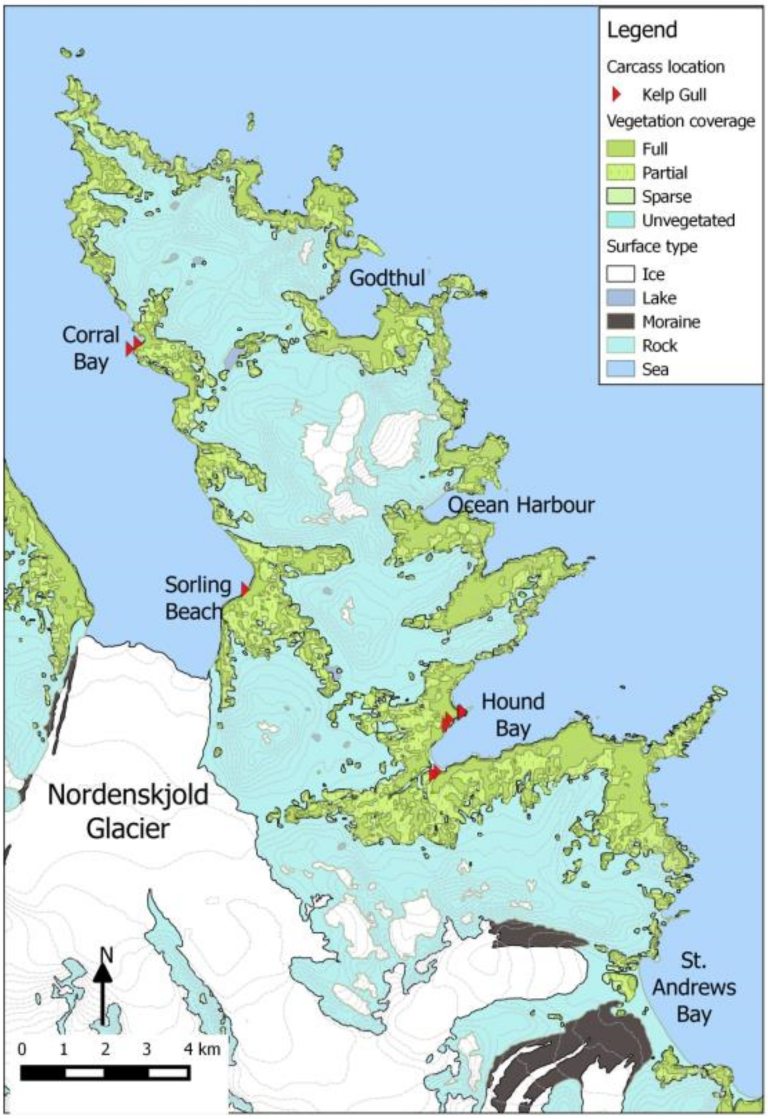

Figure 26: Location of South Georgia kelp gull carcasses in the Barff study area

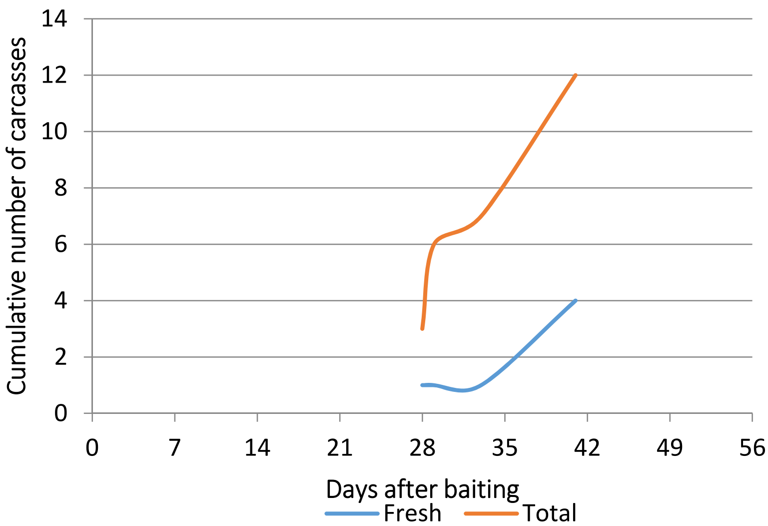

Figure 27: Discovery curves for the number of fresh kelp gull carcasses (blue line) and all kelp gull carcasses

3.4.6 Giant petrels

3.4.6.1 Phase one

Giant petrels were regularly observed feeding on fur seal (*Arctocephalus gazella*) carcasses on several beaches within the Phase 1 area, but they were not observed scavenging bird carcasses that had died following the ingestion of brodifacoum. A brown skua carcass showed signs that it may have been scavenged by a giant petrel, but no other evidence that giant petrels consumed brodifacoum was found. Nest sites were visited before baiting commenced and revisited several times post-baiting. No evidence of giant petrel mortality was found.

The majority of the giant petrels breeding in the Phase 1 area are southern giant petrels *Macronectes giganteus*. On South Georgia, northern giant petrels *Macronectes halli* are concentrated on the north-west of the island, where highest fur seal densities occur. The number of northern giant petrels encountered within some of the Phase 2 area will therefore be far higher than that found in Cumberland Bay. The Phase 1 area was considered to be atypical of South Georgia as a whole with regard to giant petrel distribution. Continued monitoring of these species, in future phases, was considered to be important.

3.4.6.2 Phase two

Stromness

Four southern giant petrel chicks were found dead. Three of these were on Grass Island and the other was found at Tønsberg Point. The bird found at Tønsberg Point showed patchy fluorescence around the bill, but the other birds did not test positive for pyranine. None of the chicks showed signs of internal bleeding suggesting that the mortality was natural, rather than as a result of the baiting operation; therefore the carcasses were not included in final counts. The pre-baiting population was not surveyed here, but counts in 2008 indicated there are 175 breeding northern giant petrels and 126 breeding southern giant petrels in the Stromness Zone (S. Poncet 2008, unpubl. data).

Salisbury

At the start of the observation period, southern giant petrel chicks were close to fledging and northern giant petrel chicks had already fledged. The pre-baiting population was not surveyed here but counts in 2008 (S. Poncet, in prep.) indicated there were 292 breeding northern giant petrels and 236 breeding southern giant petrels in the Salisbury area.

A single female northern giant petrel was found dead 21 days post-baiting on the west side of Sea Leopard Fjord, an area where giant petrels were infrequently observed feeding. The bird tested positive for pyranine and showed signs of internal bleeding. On several occasions giant petrels were observed scavenging skua and pintail carcasses that subsequently tested pyranine positive. Secondary exposure to brodifacoum suggests that the results of monitoring may have underestimated the impact on giant petrels.

3.4.6.3 Phase three

There were small scattered groups of giant petrels nesting within the north Barff study area (at locations such as Godthul, Rookery Bay, Sörling Beach and Hound Bay). Additionally, many giant petrels were observed feeding in association with the large king penguin colony at St Andrews Bay. A number of giant petrel carcasses were found during the course of fieldwork; however, only one showed any signs of internal bleeding and proved to be pyranine positive. This bird was found on the beach at Ocean Harbour 45 days after the area was baited.

A number of giant petrels were observed feeding on skua carcasses. These giant petrels are likely to have consumed brodifacoum, possibly in sufficient quantities to cause death. These observations are similar to those made during Phase 2 of the rodent eradication (Lee *et al.* 2013). It is likely that the true number of giant petrel deaths associated with Phase 3 is greater than the single carcass found. Nonetheless, the size of the South Georgia giant petrel population means that non-target mortality from the rodent eradication has been negligible at the population level.

One of the carcasses found had a broken lower bill, which was likely to have indirectly resulted in the bird's death. The injury was characteristic of secondary hooking on a longline fishing vessel.

3.4.7 South Georgia pipit

3.4.7.1 Phase one

Throughout the post-baiting period a number of pipits were regularly seen around King Edward Cove and Maiviken. It is likely that these birds originated from rat-free islands at the mouth of Cumberland Bay. The sighting of pipits in small numbers, particularly in the autumn, is not exceptional. However, repeat sightings over a prolonged period are quite unusual as pipits on other sub-Antarctic islands are known to have low likelihood of survival in the presence of rats. Although very difficult to be sure, there were no obvious signs that pipits were affected by primary or secondary poisoning in the Phase 1 area.

3.4.7.2 Phase two

Stromness

Although pipits have rarely been recorded breeding in areas of South Georgia where rats are present, some individuals are known to disperse to the mainland from rat-free offshore islands. Pipits are known to be present on Grass Island (Poncet 2006) and were observed most days in the Tønsberg area throughout January and February. Pipits were still conspicuous on the coast between the field hut and Tønsberg Point at the start of the baiting period, and two adult pipits with recently fledged juveniles were observed daily for approximately one week.

Counts of live birds suggested that the local population was approximately 25 birds. After the 19 March, pipits disappeared from the Tønsberg area and were not observed again until mid-April when one individual was seen at Tønsberg Point on three occasions. Pipits could be vulnerable to primary poisoning, or secondary poisoning from eating invertebrates that had eaten bait (Bowie & Ross 2006), or even tertiary poisoning from eating invertebrates that are feeding on carcasses of poisoned rats or non-target species. Therefore, a survey of Grass Island was undertaken, with the entire island searched thoroughly 32 days post-baiting (10 person hrs on 12 April; Figure 28). No live pipits were detected.

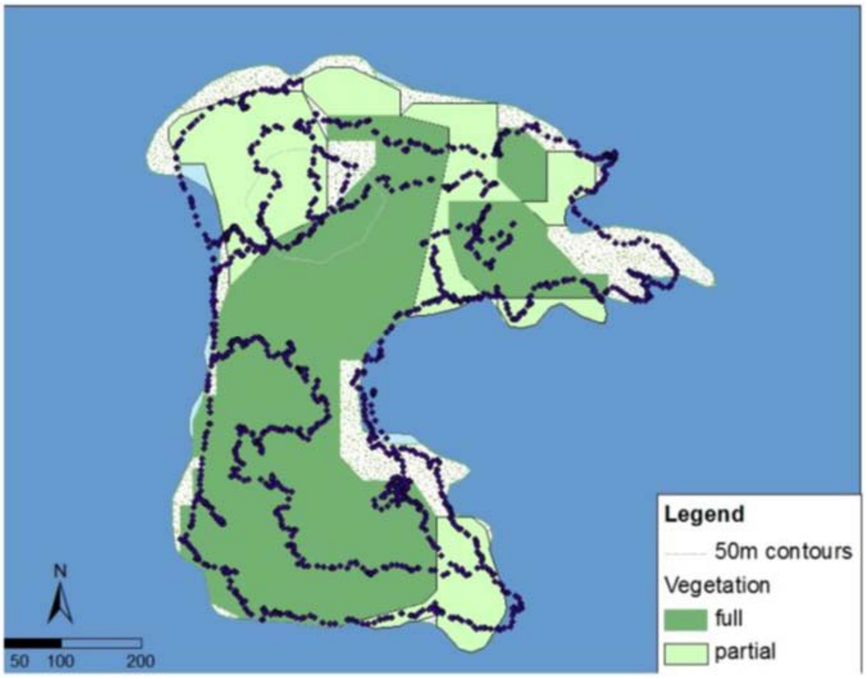

Figure 28: Post-baiting survey for South Georgia pipits on Grass Island, showing search lines. NOTE: tracks followed coastline.

3.4.7.3 Phase three

Prior to the bait drop, South Georgia pipits were a rare sight on the Barff Peninsula. However, towards the end of the monitoring period they became a regular sight. It is presumed that the birds sighted had dispersed from breeding populations from rat-free islands off the coast of the Peninsula.

4 Discussion

The chronology of the non-target mortality showed that birds started to die from brodifacoum poisoning six days after the initial bait drop and that the majority of mortality occurred within the first 30 days post-baiting. However, fresh carcasses were still being found at the time observations ceased and so the numbers reported here are likely to underrepresent mortality to some extent, particularly mortality of sheathbills and kelp gulls. It is also clear that not all carcasses were recovered from the areas searched, despite best efforts. The removal of carcasses also acts as a mitigation measure against further secondary or tertiary poisoning. Together, chronology, detection and mitigation factors clearly indicate that the non-target mortality estimates presented in this report are conservative.

4.1 Brown skua

The time of baiting differed between monitored areas from mid-February to late March. The egg laying dates of brown skuas on South Georgia varies considerably, between early November and mid-December (Osborne 1985), and consequently fledging date also differs. Therefore the proportion of skuas with dependent chicks/fledglings present at the time of baiting varied between monitored areas. Where chicks were present at the time of baiting, virtually all succumbed to brodifacoum poisoning. This can be stated with reasonable confidence as nest sites were revisited on a regular basis. On numerous occasions, chicks were observed eating and being fed bait pellets by adult birds. In some locations, such as the Busen and Barff Peninsulas, virtually all chicks hatched during the monitored breeding season were lost. Although unfortunate, chick deaths are not catastrophic for a long-lived species such as skuas. However, the loss of a large number of adult birds is of greater concern, as under natural conditions adult skua mortality rates are low. It was clear that chicks and fledglings succumbed to brodifacoum poisoning relatively quickly after bait was applied, with the majority of fresh carcasses located within three weeks of the bait drop. Many of these carcasses had been scavenged, which may have contributed to the overall high mortality rate (via secondary poisoning).

Overall, skua mortality appears to have been higher during Phase 3 than during Phases 1 and 2, which could be associated with the earlier start date of Phase 3. Furthermore, recorded mortality in Phase 3 was lowest in the zone baited latest (Salisbury Zone; baiting only commenced late March). At this time, there were no chicks and very few fledglings present; however, adult birds were still present in large numbers. A factor in the Salisbury Zone may also been the presence of a large king penguin colony which provided an alternate and abundant food source. This may have meant birds were less likely to scavenge outside the colony's and so would be less likely to encounter bait.

In the years following baiting, many of the previously known territories were once again occupied by breeding birds that moved in to take over unoccupied territories, giving the impression that the breeding population had recovered. This appears to have been possible because of the large numbers of juvenile and non-breeding birds in the South Georgia skua population. The number of occupied territories indicate that the breeding population may not have changed as much as the results of non-target monitoring suggest. However, the removal of hundreds of adult skuas and associated early recruitment must have a demographic impact on the population as a whole. The scale of skua mortality on South Georgia was as high, if not higher, than that recorded on Enderby Island (New Zealand subantarctic) following a similar brodifacoum rodent eradication (Torr 2002). Since the Enderby skua population took eight years to recover, we anticipate that South Georgia population numbers could recover in the medium-term (5–10 breeding seasons). South Georgia skua populations may benefit in the long-term once burrowing petrel populations recover.

4.2 South Georgia pintail

Pintails lost more individuals to primary poisoning than any other taxon in Phase 1. Losses were estimated to be in the low- to mid-hundreds (Black 2011). The number of birds exposed is uncertain because of substantial movement in and out of the baited area, but it is likely that at least 50% succumbed, and plausibly 60–70% (based on ringing and radio-tracking data). Some birds of both sexes were known to have been resident in the baited area and to have survived (radio-tracking data and sightings of females with broods; A. Martin pers. comm.).

The significant mortality encountered after Phase 1 baiting was contrary to most results of earlier trials on two groups (of unknown size) of a captive flock of this species, reported in SGHT (2010). There are several possible reasons for this discrepancy.

- Pellets in shallow water would have been visible and accessible to the wild birds, but the water accessible to the captive birds was opaque so pellets were not visible;
- The pellets in the trial were not identical to those used in Phase 1 (they were of a similar colour and appearance but made by two different manufacturers);
- The wild birds were in, or approaching, the primary moult after the breeding season, and were probably nutritionally challenged; and
- Wild and captive birds do not share a common lifetime's experience of foraging, and could therefore behave differently when faced with similar circumstances.

Similarly, bait trials undertaken on Macquarie Island to assess whether black ducks (*Anas superciliosa*) would consume bait pellets also showed no evidence of direct bait consumption (DPIPWE 2009). As with pintails, the actual bait drop on Macquarie showed that black ducks are susceptible to primary poisoning after all (DPIPWE 2010). The evidence suggests that experimental trials, especially on captive birds, cannot be relied on to predict the behaviour of wild birds under real-life conditions.

During non-target monitoring in Phases 2 and 3 of the habitat restoration project, South Georgia pintail mortality continued to be recorded. However, mortality in Phase 3 (Barff Peninsula) was lower than that following Phases 1 and 2 (Black 2011; Lee *et al.* 2013). Release from depredation by rats, together with the species' ability to reproduce rapidly (large clutch size and multiple clutches per year), suggest that South Georgia pintail numbers will recover quickly.

An important consideration for future eradication attempts that bait eaten by non-target species could markedly affect the amount available for the target species. This is particularly the case for a species like South Georgia pintail that favour the same habitat (dense coastal tussac grass) as the targeted brown rats (Black *et al.* 2012).

Previous rodent eradication projects have recorded non-target mortality in ducks (Dowding *et al.* 1999; DPIPWE 2010), although bait density was substantially higher than that dropped on South Georgia. The LD_{50} for South Georgia pintail is unknown, however, the LD_{50} for mallard ducks (*Anas platyrhynchos*) is 4.6 mg/kg, which means that 203 g (68 pellets at 3 g each) of 0.025 g/kg bait would need to be consumed by a mallard of average weight to have a 50% probability of dying (Fisher & Fairweather 2005). Although this estimate might not be directly applicable to South Georgia pintail, since LD_{50} values appear to vary considerably between species, a pintail weighing 600 g would need to consume 37 pellets. However, it does indicate that large quantities of bait could have been removed by South Georgia pintails from prime rat habitat. This is particularly the case if baiting coincided with primary moult, when pintail cannot fly and are thus restricted to small areas at a time of high food demand.

Where large aggregations of pintail were regularly encountered, there appeared to be lower mortality rates than in areas with lower numbers or dispersed populations. It is possible that a large number of pintail in a small area rapidly consume any surplus pellets; thus a relatively small proportion of the flock consume a lethal dose. However, this theory may not hold since flocks that congregate on freshwater pools during the day appear to disperse widely to feed at night, and would therefore be exposed to bait elsewhere. It was noted that most pintails seen in the large flocks were not in primary moult (they were able to fly). The moult and associated physiological demands may be more important in explaining higher pintail mortality in areas with lower pintail densities.

Previous eradications have saturated an area with bait, but baiting densities are gradually being refined. The baiting regime employed on South Georgia was thus lower than that used on any other eradication project. At some point the reduction in bait density will reach a level that jeopardises the success of the eradication. This is apparently not the case yet, but in future the consumption of bait by non-target species may become of greater concern to the success of the eradication attempt.

4.3 Snowy sheathbill

Like several other species, the risk of mortality to snowy sheathbills appears to be linked to the density of this species present and the feeding opportunities exploited by the local population. In areas where there were relatively few sheathbills and there were no large penguin colonies (Thatcher and Stromness Zones), the sheathbill mortality rate was very high. Where large king penguin colonies (supporting large numbers of sheathbills) were monitored, the risk was apparently lower, although carcasses were still recovered at a steady rate throughout the monitoring period. It is thought that sheathbills associated with a large penguin colony have access to an abundance of food, and as they are a species which scavenges opportunistically, sheathbills at large penguin colonies may be less likely to consume bait pellets directly. Additionally, king penguin colonies supported the largest aggregations of rats on South Georgia (Black *et al.* 2012), which would remove many of the pellets from the food chain. Those bait pellets remaining on the ground would be rapidly trampled into the mud by penguins and no longer be visible or accessible to sheathbills. There was little evidence of intact bait pellets around and within the penguin colony. However, brodifacoum will remain in the mud for several months (US EPA 1998 in Fisher 2010), and sheathbills are often seen eating soiled objects. The mechanisms and pathways of brodifacoum degradation in soil are not well described, but half-life estimates (the time taken for the residual concentration of brodifacoum to decrease by half) in soil range from 12 to 25 weeks (US EPA 1998 from Fisher 2010).

Fresh sheathbill carcasses were found at the end of the study period (50 days post-baiting), indicating that sheathbills were still consuming brodifacoum (presumably pellet fragments). It is very likely that mortality continued beyond the scope of this study.

It is worth speculating that since sheathbill mortality only occurred after a considerable time in which bait pellets were abundant, snowy sheathbills may have a relatively high LD_{50}. As sheathbills also live in prime rat habitat, their potential to consume a substantial amount of bait may also impact likely success of a rodent eradication operation. This could be particularly relevant in areas where other non-target species also consume bait, such as South Georgia pintails.

4.4 Kelp gull

Relatively few kelp gull carcasses were recovered in all three phases of the South Georgia habitat restoration project. This contrasts with observations following eradications on other sub-Antarctic islands. Kelp gull mortality rates were high on Campbell Island (McClelland 2001), Macquarie (DPIPWE 2010), and Rat Island in Alaska (Woods *et al.* 2009).

Kelp gull mortality was also expected on South Georgia. During a trial on South Georgia in 2007, kelp gulls were seen consuming non-toxic bait (Christie & Brown 2007). The LD_{50} of kelp gulls in New Zealand was 0.75 mg/kg (Eason & Spurr 1995), so for a large kelp gull weighing 1 kg, around 10 pellets would need to be consumed to have a lethal effect on 50% of birds. Kelp gulls consume large amounts of food, are attracted to cereal and could easily eat whole baits, so fatalities due to primary poisoning were anticipated (SGHT 2010).

The reason for the difference between the expected and observed mortality rate in kelp gulls is not clear. Low kelp gull mortality may have been because most kelp gulls around South Georgia display maritime foraging habits, chiefly within kelp beds, where brodifacoum is unlikely to be found. However, kelp gulls do roost ashore and are seen foraging along the shoreline and around penguin colonies. Kelp gull exposure to brodifacoum in these restricted areas and periods would explain the limited mortality detected.

4.5 Giant petrel

Giant petrel colonies and feeding areas were regularly visited throughout the monitoring periods. In total, only three giant petrel carcasses that proved positive for brodifacoum poisoning were found. This contrasts markedly with the high northern giant petrel mortality following eradication on Macquarie Island (DPIPWE 2010). Secondary poisoning from the rabbits, present on Macquarie and not on South Georgia, partly explains the higher Macquarie giant petrel mortality. In addition, the differences in the timing of bait drops (baiting conducted in winter on Macquarie cf. late summer on South Georgia) will have contributed to the different giant petrel mortality rates observed on the two islands.

On several occasions, giant petrels on South Georgia were observed feeding on carcasses of skuas that subsequently tested positive for pyranine. It seems highly likely that more giant petrels died than the three birds found, but the overall impact of the South Georgia habitat restoration project on giant petrels is negligible at the population level.

4.6 South Georgia pipit

Due to the generally low number of pipits present within baited areas and the difficulty of detecting carcasses, no definitive evidence of mortality was recorded. However, some areas containing breeding populations of pipits were baited, notably Grass Island and the area where mice occurred (Cape Rosa and Nuñez Peninsula). Monitoring was conducted on Grass Island 32 days after the Island had been baited. Although no dead pipits were found, live birds were not found either. Subsequent visits to Cape Rosa and Nuñez Peninsula in 2014 and 2015 found pipits present, but at lower than expected numbers (A. Black, pers. obs.).

Research elsewhere (reviewed in Fisher 2010) indicates that invertebrates consume cereal bait laced with brodifacoum but appear to be at low risk of primary poisoning. Although brodifacoum appears less persistent in invertebrates than in mammalian liver, invertebrates can carry residual concentrations in their bodies. The duration of brodifacoum in invertebrates varies among species: in captive weta, residues were no longer detectable four days after exposure (Booth *et al.* 2001), and were not detectable after six days in captive locusts (Craddock 2003), but residues took one month to clear in land crabs (Pain *et al.* 2000).

It seems likely that pipits within baited zones would consume invertebrates carrying brodifacoum. However, the long-term benefits of removing rodents and opening huge areas to recolonisation by pipits will far outweigh this short-term impact.

5 Conclusions

For non-target species affected by the rodent eradication, such as South Georgia pipits and South Georgia pintails, increases in survival and productivity in a rat-free environment would be expected to compensate for any non-target mortality. For those species that were impacted by rats (e.g. pintails), removal of rodent depredation pressure is expected to aid rapid recovery to exceed previous population sizes. Species not directly impacted by rats, like skuas, may recover more slowly since a newly rat-free environment is unlikely to benefit their survival and productivity. Skua longevity and low productivity also indicate that population growth should be relatively slow, but skuas should eventually benefit from increasing pintail and petrel numbers.

However, ultimately all species are expected to recover, despite mortality in some species (skua and pintail) being higher than expected. Overall, it is clearly beneficial to rid South Georgia of rodents despite non-target effects: the long-term benefits of removing non-native rodents from the island will almost certainly far outweigh the short-term impact on most non-target species. Nonetheless, every effort should be made to minimise the impact on non-target species and the findings of this monitoring programme may help in the planning of future rodent eradication projects.

5.1 Recommendations for future eradications: South Georgia and beyond

- Trials of captive or wild non-target bird species may not accurately represent bait consumption in a full-scale eradication. Trials should mimic the distribution, density and duration of bait pellet availability in full-scale eradication as closely as possible to more realistically indicate potential risk.
- Non-target bird species can potentially consume a significant amount of bait (e.g. South Georgia pintails). This should be considered when calculating baiting densities.
- Spilled bait pellets at helicopter hopper-loading and bait storage sites should be cleaned up immediately, as spills present an easy opportunity for non-target species to consume a large amount of bait at one location.
- Eradications should ideally take place after the breeding season, when juveniles and breeding adults of affected non-target species have dispersed from breeding sites (e.g. skuas) and primary moult is complete (e.g. ducks). However, delayed baiting must balance the risk of baiting failure; for example, if conditions suitable for baiting are no longer available post-breeding, as in the short summer season on South Georgia. Baiting failure—with ongoing predation of chicks and eggs by rats on top of a high level of non-target mortality—could have catastrophic effects for some species.

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