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Non-Target Species Management for the Macquarie Island Pest Eradication Project

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Abstract: Mitigation of non-target species impacts is a key challenge of the Macquarie Island Pest Eradication Project (MIPEP). The project aims to eradicate rodents and European rabbits from sub-Antarctic Macquarie Island through the aerial application of cereal-based brodifacoum bait, followed by a hunting program targeting surviving rabbits. Aerial baiting was attempted in winter 2010 but postponed due to sustained adverse weather that suspended helicopter operations. Following limited baiting in 2010 (10% of the island), non-target mortality of 960 individuals across 6 (of 27) seabird and duck species was recorded. In response, the Australian and Tasmanian governments conducted a review of the project. The review established that some species would be adversely affected by the project in the short-term, but that the island's ecosystem and most other island species would substantially benefit from pest eradication, confirming the assessments in the Environmental Impact Statement prepared prior to the operation. Enhanced mitigation measures were recommended to minimise non-target species impacts. Of several potential mitigation measures assessed, two principal measures were adopted: releasing Rabbit Haemorrhagic Disease Virus to reduce the rabbit population prior to baiting, thus minimising the number of rabbit carcasses containing poison residues available for consumption by scavengers; and increasing the effort of field teams during and after baiting to remove carcasses (the primary 2010 strategy), in an attempt to minimise the exposure of scavengers to toxic residues. Baiting resumed in May 2011 and two island-wide drops were completed by July 2011. Seabird mortality was monitored, with over 1,460 dead birds of the same species found that were affected in 2010, primarily scavenging seabirds such as kelp gulls, giant petrels, and skua. No species was considered to have sustained impacts that threatened the viability of the local population. King penguin colonies were closely monitored during helicopter over-flights and only minor and transitory impacts were observed. Wandering albatross nests were cleared of bait and chicks were not affected. No marine mammal impacts were recorded. If successful, the MIPEP will be the largest and most complex sub-Antarctic island rabbit and rodent eradication yet undertaken.

Key Words: brodifacoum, carcass collection, eradication, Macquarie Island, mitigation, non-target hazard, rabbit control, Rabbit Haemorrhagic Disease Virus (RHDV), rodent control, rodents, rodenticide hazard, seabirds

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INTRODUCTION

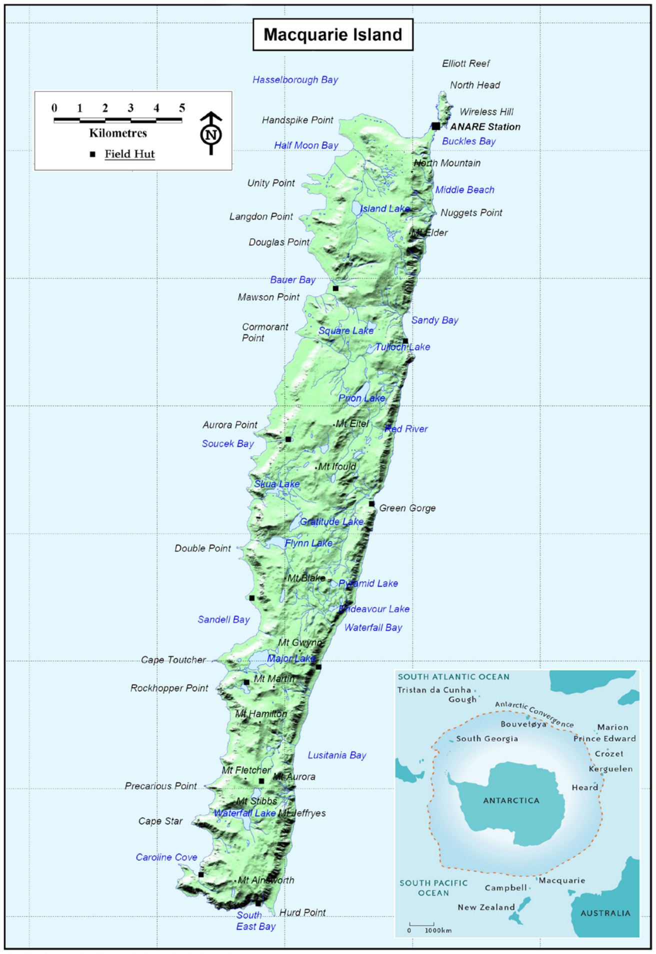
The Macquarie Island Pest Eradication Project (MIPEP) is the largest eradication program for rodents and rabbits ever attempted. The project aims to eradicate rodents (*Mus musculus* and *Rattus rattus*) and rabbits (*Oryctolagus cuniculus*) from sub-Antarctic Macquarie Island (Figure 1) through the aerial application of cereal-based brodifacoum bait over the entire island, followed by a multi-year ground program employing teams of hunters and rabbit-detector dogs to target surviving rabbits (DEWHA and DEPHA 2007).

The goal of pest eradication is to allow natural recovery of impacted vegetation, seabirds, and invertebrates to population levels consistent with natural habitat and food sources, by removal of the destructive impacts of predation and habitat change caused by rabbits and rodents. The mitigation of non-target species impacts was identified from the outset as one of the key challenges of the AUD$25+ million project. The extensive congregations of marine mammals and seabirds breeding on the island pose a challenge to both aerial baiting and ground hunting and have influenced all levels of project planning. With a degree of impact assessed as being unavoidable to at least some extent, a cost/benefit decision needed to be made as to likely positive and negative impacts of the operation. Given that the pest-free benefits would accrue in perpetuity, whereas the impacts caused by the operation would be relatively short term, it was clear that any non-target 'costs' would be significantly outweighed by the high level of 'benefits' to many species if the island could be returned to a pest-free condition, provided no species' long-term population level was put at serious risk.

Aerial baiting was attempted in 2010, but due to late arrival of the team and persistent adverse weather for operating helicopters, was postponed until the following winter. Non-target mortality levels in 2010 prompted reviews of the project, and permission to proceed was contingent on additional mitigation measures being implemented. Baiting recommenced in May 2011 and was completed by mid-July (Springer 2012). Specific measures designed to mitigate non-target impacts are described.

PLANNING

The decision to undertake the aerial baiting program during winter (when days are shortest and the weather least favourable) was largely made to avoid wildlife disturbance during the summer breeding season. There are large penguin colonies around the coastline in summer, and the risk of disruption to these colonies in the breeding season



Spatial data provided by Australian Antarctic Data Centre

Figure 1. Location map for Macquarie Island.

was assessed as too high to warrant further consideration of summer baiting. Other bird species such as giant petrels and albatross are also more susceptible to disturbance by helicopter over-flights during the summer breeding season, so overall impacts could be expected to be much higher in a summer operation. However, other factors also guided a winter operation. Natural food sources – birds, vegetation, and invertebrates – of the target animals are less available during winter, meaning that target animals are more likely to accept bait as an alternative food source.

Brodifacoum can pose a significant risk of primary and/or secondary poisoning to some non-target native species on Macquarie Island, in particular skua (*Catharacta lonnbergii*), kelp gulls (*Larus dominicus*), and northern and southern giant petrels (*Macronectes giganteus* and *M. halli*, both listed as threatened species). Hunting teams, helicopters, trapping equipment, firearms, and the use of dogs on the island also have the potential for additional non-target species impacts.

While brodifacoum is considered highly toxic and may pose a higher risk to non-target animals than some other anticoagulant toxins (Eason and Spurr 1995), the reason it is typically used for eradication projects on islands is that it has the highest success rate at achieving eradication of rodents. Given the high stakes of such projects, where successful pest eradication can literally prevent the extinction of native species, ways to reduce the chances of eradication failure are critical, and use of a method with the highest success rate is one such approach (Howald et al. 2007). Of course, a careful assessment of the extent of non-target impacts is critical, and it may be that in some circumstances the risks to non-target species outweigh potential benefits. In such cases a project may either not proceed, or alternative measures are implemented, albeit possibly with a higher risk of eradication failure.

As a joint Commonwealth and Tasmanian government funded project, the MIPEP has undergone extensive and detailed environmental assessments and approvals at all stages of planning. In preparation for these approvals, and to inform planning requirements, trials were conducted over a period of 5 years to test for factors such as bait weathering, target and non-target species bait uptake, and disturbance to penguins by helicopter operations. Based on these trial results, a range of non-target species impact mitigation strategies were incorporated into the Project's Environmental Impact Statement (Parks and Wildlife Service 2009) and Operational Plan (Parks and Wildlife Service 2010). These included measures to minimise non-target species impacts through:

- Placement of observers when baiting over winter-resident king penguin (*Aptenodytes patagonicus*) colonies
- Placement of observers and removal of baits next to wandering albatross (*Diomedea exulans*) nests
- Collection of target species carcasses by search teams during the baiting operation
- Briefing of hunting teams as to locations of burrow-nesting seabird colonies, and
- Intensive training of rabbit detector dogs in relation to avoiding non-target species such as penguins.

2010 AERIAL BAITING PROGRAM

The aerial baiting program was attempted in the winter of 2010 but was postponed following a delayed arrival on-island and unusually bad weather being encountered during June and July that precluded helicopter flying. Only 5 part-days of baiting were able to be undertaken, with about 8% of the planned 305 tonnes of bait being spread over approximately 10% of the island, as part of the first of two island-wide bait drops. The decision to cease the 2010 baiting was based on the probability of not completing the baiting in the available timeframe and thus nil progress toward eradication, coupled with the likelihood of increased non-target impacts from continuing to bait into the spring. The preferred alternative to achieve both eradication success and limit non-target impacts was to postpone the aerial baiting phase until 2011 and plan for an earlier arrival, as initially intended.

2010 Non-Target Species Mortality

Non-target bird mortality was recorded in subsequent months after baiting, primarily amongst scavenging seabird species such as kelp gulls, giant petrels, and skua. Whilst mortality among these non-target seabirds had been expected as a result of baiting, by March 2011, over 950 birds had been recorded that were likely to have died as a result of primary or secondary brodifacoum poisoning (Table 1).

Table 1. Seabird mortality after treatment with brodifacoum bait in 2010-11.

Species	2010[a]	% of total	2011[b]	% of total
Kelp gull (*Larus dominicus*)	385	40	603	41
Northern giant petrel (*Macronectes giganteus*)	306	32	387	26
Southern giant petrel (*Macronectes halli*)	17	2	21	1.5
Unknown giant petrel		–	31	2
Skua (*Catharacta lonnbergii*)	230	24	282	19.5
Pacific black duck (*Anas superciliosa superciliosa*) and Mallard duck (*A. platyrhynchos platyrhynchos*)	22	2	135	9
Unknown		–	5	–
TOTAL RECOVERED	**960**		**1,464**	

Note that 25 tonnes of bait was spread in 2010 and 305 tonnes of bait in 2011

[a] 2010 records cover the period June 2010 to April 2011 and refer to the carcases recovered associated with 2010 baiting

[b] 2011 records cover the period May 2011 to April 2012 and refer to the carcases recovered associated with 2011 baiting

REVIEW OF PROGRAM

In response to the level of non-target bird mortality, particularly among threatened giant petrel species, the Australian and Tasmanian governments conducted a review of the project in late 2010 (DSEWPaC and TDPIPWE 2010). The review found that whilst some species were likely to be adversely affected by the project, the island's ecosystem and most other island species would substantially benefit from the continuation of the project, and it recommended that enhanced mitigation measures be introduced to minimise non-target species impacts. It was acknowledged that the environmental cost of not implementing the project exceeded the short-term impacts.

Concurrently, the project team also investigated options amongst other eradication practitioners faced with similar issues, and it resolved to continue with and expand planned non-target mitigation search and removal of carcases and to implement aerial searches to complement this. The cornerstone non-target mitigation strategy, however, was the release of the rabbit-specific Rabbit Haemorrhagic Disease Virus (RHDV) to reduce the rabbit population prior to baiting, and thus the number of poisoned rabbit carcasses available for scavenging by seabirds. The importance of arriving on the island at the preferred time was already considered a major factor in increasing the likelihood of eradication success and reducing non-target mortality.

MITIGATION MEASURES

Combining the project team initiatives, prior established measures from 2010, and the review panel recommendations, the principal mitigation measures proposed for the 2011 aerial baiting (Parks and Wildlife Service 2011a) were:

- The release of Rabbit Haemorrhagic Disease Virus (RHDV)
- A planned and resourced carcass collection process undertaken by a dedicated team
- Regular aerial searches for poisoned carcasses following bait drops
- Monitoring and filming of king penguin colony over-flights
- Removal of baits adjacent to Wandering albatross nests
- An increase in the duration of the approved baiting window to between 20 April and 10 September 2011, compared with May to August 2010, and
- The establishment of a Bird Technical Advisory Group to provide ongoing specialist advice on seabird poisoning mitigation.

Other Mitigation Measures Considered

A number of other potential mitigation methods were examined including:

- Captive management of vulnerable non-target species (such as giant petrels)
- Provision of alternate food sources for non-target species to reduce scavenging on rabbit carcasses
- The addition of Vitamin K (brodifacoum antidote) to natural food or alternative food sources offered to non-target species
- Reducing bait application rates
- Veterinary treatment of poisoned non-target species, and
- The habituation of some non-target seabirds through the introduction of a feeding deterrent agent.

These measures were considered to be either impractical or unjustified, as they increased the risks of eradication failure if implemented.

Non-Target Species Impact Mitigation Plan

A Non-target Species Impact Mitigation Plan (Parks and Wildlife Service 2011b) was developed in response to the 2010 Eradication Review and provided a guide for MIPEP field staff on mitigation measures. Acceptance of the plan by the Commonwealth Department of Sustainability, Environment, Water, Population and Communities was a pre-requisite to issuance of environmental approvals.

Rabbit Haemorrhagic Disease Virus (RHDV)

Separate to the federal and state government review, project staff explored the issue of non-target mortality management with the Island Eradication Advisory Group (IEAG) of the New Zealand Department of Conservation.

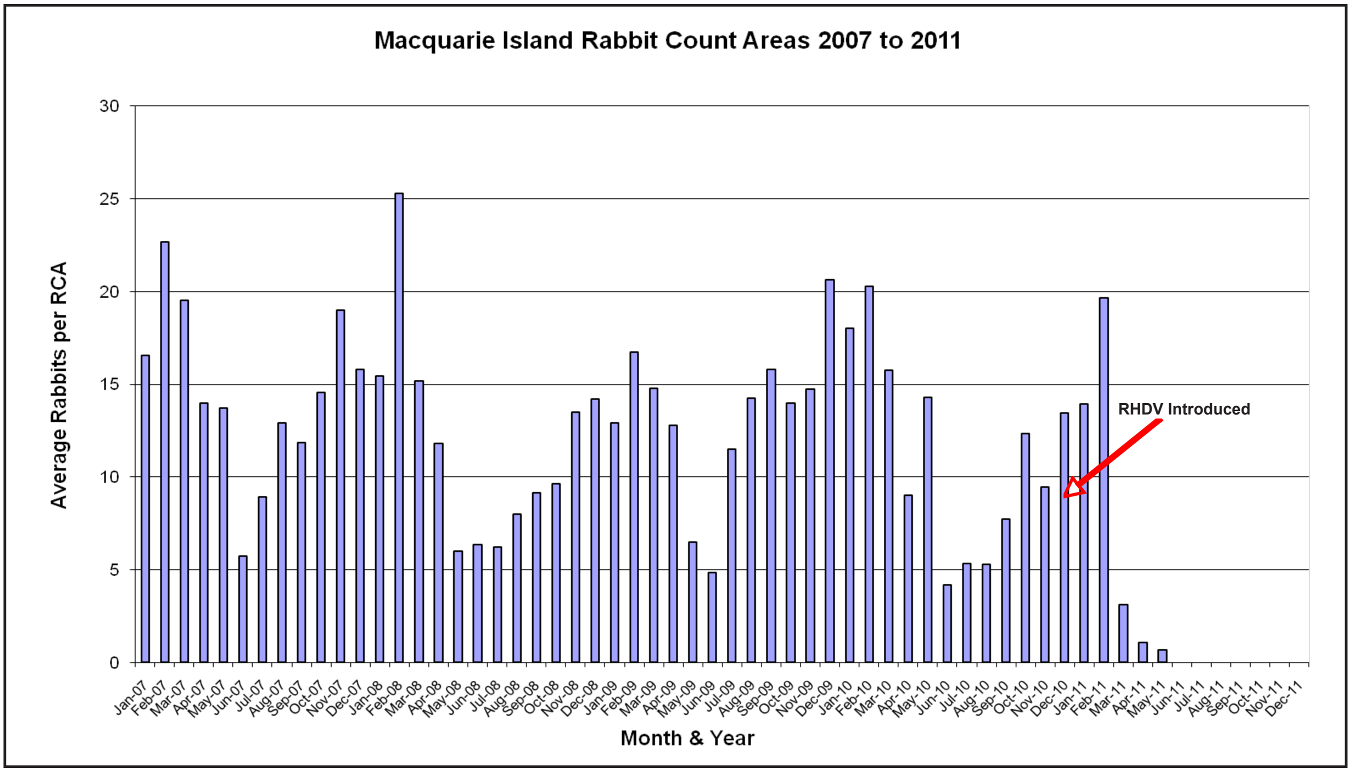


Figure 2. Macquarie Island Rabbit Count Areas 2007 to 2011.

Members of the group have wide New Zealand and international experience in eradication projects and were familiar with a number of operations where non-target impacts needed to be managed. Following the IEAG's suggestion of releasing RHDV as a non-target mitigation strategy, an environmental risk assessment was undertaken, and following approval, the virus was released amongst the island's rabbit population in February 2011. The aim was to reduce the rabbit population prior to baiting and thereby minimise the number of poisoned rabbit carcasses subsequently available for consumption by scavenging seabirds. Testing of RHDV susceptibility had been undertaken in 2004 and had shown that the rabbit population was naive to the disease. Being specific to rabbits, the virus was not expected to affect native bird or marine mammal species.

To initiate the virus release, 200 kg of carrots were sent to the island along with 10 vials of the virus. About a third of the carrots were grated into strips and used as pre-feed, with the remainder treated with virus and divided into amounts for release at 10 sites around the island where rabbit densities were very high. A number of rabbits were captured and the virus applied directly via injection. The virus spread very quickly and effectively and reduced the rabbit population, estimated at 100,000-150,000, by about 80-90% within only 3 months (Figure 2). For example, the average monthly count of rabbits per long-term Rabbit Count Area over the 3 years from 2007 to 2010 was 12.8, whereas by April 2011 it had dropped to only 1. No further rabbits were recorded in the count areas from June to December 2011, when monthly counts ceased.

The rapid spread of the virus outside of the initial release sites indicated that effective non-human vectors were present on the island. These are likely to have included the European rabbit flea (*Spilopsyllus cuniculi*) that was widespread, having been introduced from the late 1960s as the vector for the myxoma virus, previously used for rabbit control. Rabbit-scavenging birds such as skua may have also provided a means of spreading the virus.

Timing of the release of the virus was critical. The expected major reduction in rabbit numbers would allow regrowth of vegetation, providing a natural food source over the winter and potentially affecting uptake of bait by rabbits. Thus, the release needed to be after the main summer growing season when regrowth would be minimal before the approaching winter. Secondly, rabbit carcasses dead from RHDV would provide a vast food resource for scavenging birds, and it was important that these were either scavenged or decomposed before bait was applied. There was also the risk of altering rabbit behaviour through massive disruption to their social structure, with unknown consequences to subsequent feeding behaviour and bait uptake. Balancing these factors indicated that a February virus release would be a reasonable compromise.

Timing of Brodifacoum Baiting

Spreading bait in winter has distinct advantages. Bait uptake is increased due to target species having reduced natural food sources, and pest numbers are at the lowest point in their annual cycle and pests are not breeding. Many native species are also absent during winter, so non-target impacts are reduced. However, the winter period between April and September has the shortest days and poor weather conditions and presents significant challenges for helicopter baiting operations. Snowfall is more likely to blanket the island, which can constrain baiting operations for long periods. The challenge is to select a baiting window that minimises non-target impacts, whilst maximising the probability of suitable aerial baiting weather and allowing for seasonal variation in daylight.

As a non-target mitigation factor, baiting earlier in the winter has clear advantages. Baiting in early winter (May) means that by the time rabbits are dying from the poison, skua are preparing to leave the island for the winter. While some skua will still have the opportunity to scavenge rabbits and die from secondary poisoning, most will leave before extensive scavenging opportunities are present. In this sense, the impacts to skua are transferred from the spring and early summer (if baiting occurred in late winter) to late winter after they return. However, the main benefit is that with skua away over the winter, mitigation teams have a greater chance of finding and removing rabbit carcasses before skua return in spring, and dead animals have a greater period to decompose before skua return. In addition, foraging behaviour amongst scavenging birds can change as they approach the breeding season and need to gather more food reserves prior to breeding and incubation, so again baiting earlier in winter can provide a better outcome for non-target birds than baiting in late winter, as the birds can consume more as they approach the breeding season.

Carcass Collection

A team of carcass collectors comprised part of the aerial baiting team and was employed for the aerial baiting phase. The team's task was to search for and bury poisoned pest carcasses, in an attempt to minimise the incidence of secondary poisoning of non-target species. Other MIPEP staff from the baiting teams assisted with this work as baiting operational requirements permitted, and this allowed for the majority of the island's coast and coastal slopes to be thoroughly searched over a 3-month period. The majority of target species individuals were expected to die underground, as has been noted in similar operations elsewhere, and this was borne out in the Macquarie Island situation. The deployment of these mitigation teams during and after aerial baiting resulted in 1,464 non-target carcases and 1,428 target species carcasses (including 1,347 rabbits) being collected by the end of April 2012. Following the departure of the aerial baiting team, the hunting team of 15 people incorporated non-target mitigation duties into their hunting coverage of the island, cumulatively covering 28,547 km search effort distance on an island 33 km long by 4 km wide.

Aerial Searching

Following completion of each island-wide bait drop, observers in helicopters were used to search for poisoned rabbit and bird carcasses from the air. Few target species were recovered but some kelp gulls and giant petrels were found, as their size and colouration made them easier to detect from the air than the few rabbits and rodents found.

OTHER NON-TARGET SPECIES

Mitigation measures designed to minimise impacts on other species were also undertaken. Baiting over all king penguin colonies was monitored by an observer on high ground above each colony who filmed flights and relayed penguin behaviour or disturbance to the pilot. Trial over-flights in 2008 and 2009 at measured altitudes descending in 100-foot increments had informed planning and established parameters for flying operations. Baiting within 1,000 metres of king penguin colonies was undertaken at a minimum altitude of 160 metres, higher than baiting undertaken elsewhere on the island. Flight lines commenced at the inland edge of colonies so that birds escaping the noise had unfettered access to the sea as an escape zone. All penguin colony baiting flights were filmed. While there were marked responses to the helicopter passing overhead on occasion, no stampede events were witnessed, and once helicopters had passed over, bird behaviour gradually returned to normal. Based on such observations, king penguins were likely to have been subjected to only short-term disturbance impacts.

Wandering albatross chicks are present throughout winter, with parents returning intermittently to feed them. While trials with non-toxic bait had demonstrated that chicks were not inclined to consume bait, they did move pellets around with their beaks in the course of grooming the nest pedestal. Given the critically endangered status of this bird, an observer was stationed at each nest to remove baits after the helicopter had passed to avoid any risk of bait ingestion, even though a considerable number of pellets would need to be ingested to cause symptoms, and the chicks were not mobile off the nest at this stage. Bait was removed from a 5-metre radius of the nest and Talon® wax block baits were placed in enclosed bait stations at a 2-metre distance from the nest, with 4 bait stations covering the 10-metre diameter of the cleared zone. Rodents thus still had access to bait, and risk to albatross was removed. The need to place bait stations within the cleared zone reflected that mice can have very small home ranges and could theoretically exist within the cleared area centred on each nest without coming into contact with a bait pellet, thus risking eradication failure. These precautionary mitigation measures were successful insofar as no wandering albatross chicks were observed to take bait or suffer baiting-related mortality, although it is likely that no mortality would have occurred had no mitigation measures been implemented.

2011 AERIAL BAITING PROGRAM

Timing

The planned earlier arrival of the aerial baiting team at the island in late April 2011 allowed aerial baiting operations to commence on the 2 May, as opposed to 5 June in 2010. With significantly better weather conditions than the previous year, the first bait drop was completed by 26 May and the second by 19 June, a timeframe significantly in advance of the 2010 baiting period. Some additional baiting was undertaken in small areas considered at high risk of harbouring target animals, and this was completed by 11 July.

RESULTS AND DISCUSSION

Mortality of non-target individuals was proportionately much lower in 2010 to 2011 when the amount of bait spread and the area baited are considered. For example, while 306 northern giant petrel carcasses were recovered in 2010 following application of 25 tonnes of brodifacoum bait over 1280 ha, 387 northern giant petrels were found in

Table 2. Summary of non-target mortality by estimated population.

Common name	Species Name	Population on Macquarie Island (annual breeding pairs)	Population size accuracy	Number carcasses found (% of total carcasses)
Northern giant petrel	*Macronectes halli*	1,922 (2010/11)	High	387 (26.4%)
Southern giant petrel	*Macronectes giganteus*	2,671 (2010/11)	High	21 (1.4%)
Giant petrel (species unconfirmed)				31 (2.1%)
Kelp gull	*Larus dominicanus*	"hundreds"	Low	385 (41%)
Subantarctic skua	*Catharacta lonnbergi*	1,030	Medium	279 (19.1%)
Black duck and Mallard duck	*Anas superciliosa / A. platyrhynchos*	Unknown		135 (9.2%)
			Total	**1,464**

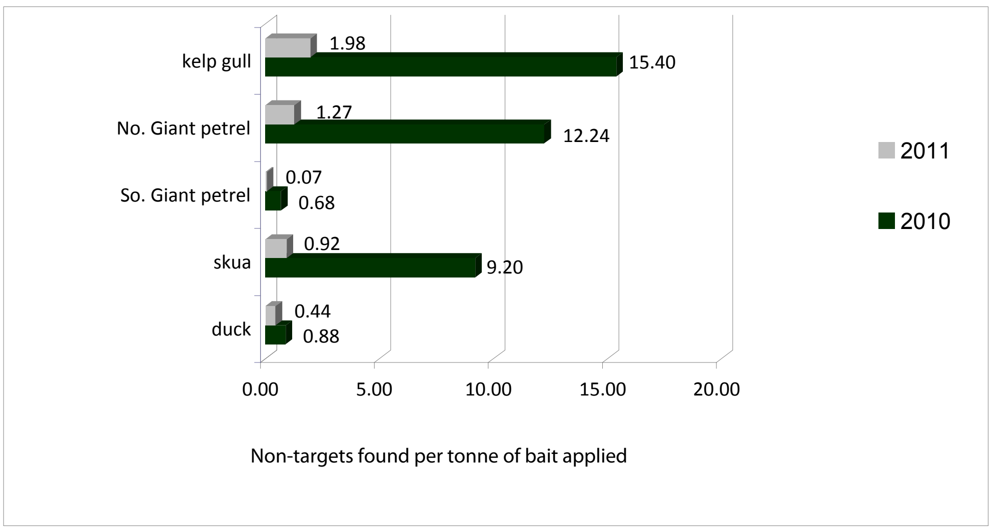


Figure 3. Comparison of non-target mortality from 2010 and 2011 baiting, based on collected individuals per tonne of brodifacoum bait applied.

2011 following application of 305 tonnes of bait over 12, 865 ha (Table 2, Figure 3).

Assessing the effectiveness of the mitigation methods used is difficult in absolute terms; however, relative results can be assessed from a range of factors. The earlier arrival on the island, and the completion of baiting by the mid-June period played a part in minimising non-target mortality, because there was more time for above-ground rabbit carcasses to be found by search teams (and winter-resident giant petrels) before return of skua in the spring, and more opportunity for such carcasses to decompose before return of many migratory birds. In addition, bait pellets had a longer time period on the ground to begin breaking down, although this was of limited benefit because those species most likely to consume pellets had predominantly over-wintering populations (kelp gulls and ducks).

The deployment of search teams in an attempt to remove toxic carcasses before scavengers could access them was carried on throughout the winter, in often arduous conditions. These searches were a visible demonstration that the non-target issue was being taken seriously, and that all attempts were being made to reduce baiting impacts. The teams collected over 1,400 target animals and nearly 1,500 non-target animals; the cumulative collection total of non-targets is shown in Figure 4. However, while the effect of this collection was undoubtedly positive, the degree to which it was able to reduce non-target mortality is less clear. There are a number of reasons for this. First, scavenging birds are vigilant and highly adept at locating carcasses, and often find them before search teams can. Scavenging seabirds can be active all day every day, have an attuned eye, an aerial view, and cover ground faster and more frequently than any number of ground searchers can hope to. This is reflected in the fact that about 75% of target species carcasses (primarily rabbits) had already been scavenged to some extent when located by search teams by the end of the aerial baiting phase, thus reducing the benefits of such carcass removal in terms of reducing scavenger mortality. Second, once skua returned to the island in spring, they adopted their usual hunting technique of stalking burrows to find rabbit kittens or the small petrels (genera *Pachyptila* and *Halobaena*) referred to as 'prions'. Skua were able to find rabbits that had died within the first half-metre of burrows and drag out and consume the carcass. Search teams were rarely able to locate such underground carcasses, although the dogs used in the rabbit hunting phase found a considerable number, so while it added to the number of carcasses found, underground carcasses were not necessarily available to all scavengers.

In contrast to target species, the majority of non-target species found were not scavenged (also about 75%), indicating that birds scavenged other birds to a lesser degree compared with target species carcasses. Consequently, locating and removing non-target carcasses probably also had a more limited effect on reducing further mortality. Search and removal of carcasses was maintained as a mitigation effort for 12 months, by which time very few if any carcasses were being found, and those that were did

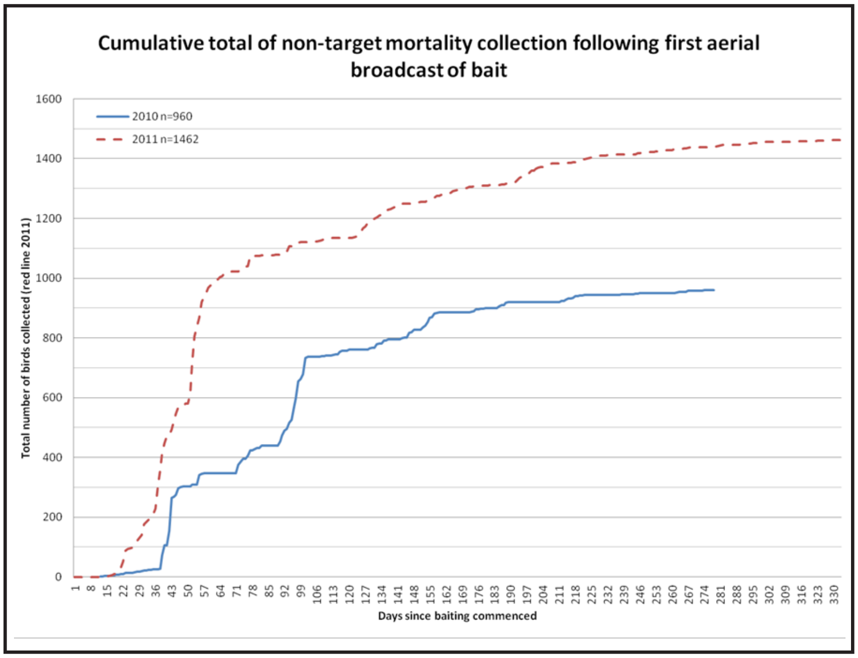


Figure 4. Comparison of cumulative non-target mortality for 2010 and 2011.

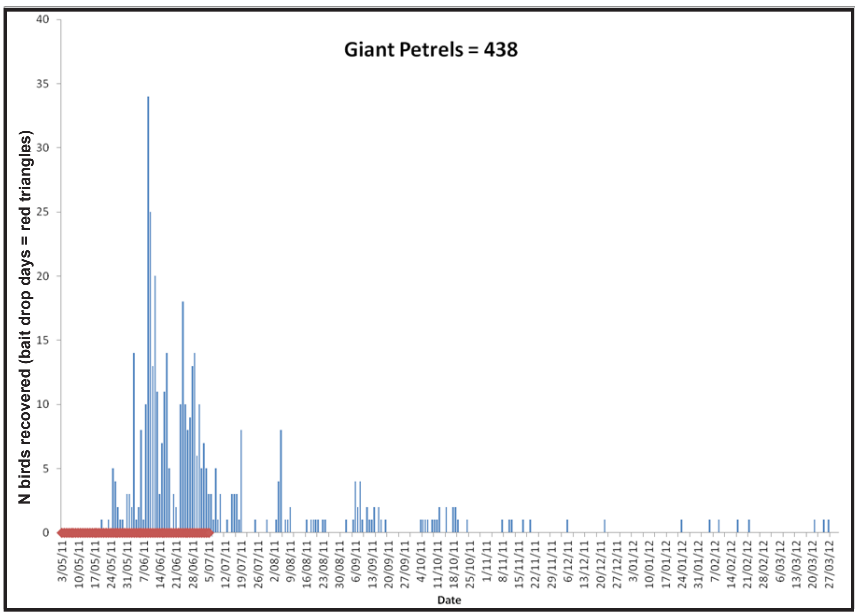


Figure 5. Giant petrel mortality following 2011 baiting showing trend of higher mortality in winter during baiting period. Solid line on X-axis from 3 May 2011 to 5 July 2011 denoted bait application period.

not display visible symptoms of anticoagulant poisoning.

Aerial searching for carcasses was undertaken after each bait drop was completed, with about 8 sorties being completed. These concentrated on the coastal areas where most non-target species had been found. Very few target species were found, reflecting the difficulty of observing small dead animals against a cryptic background when searching from the air, even though low slow search patterns with 3 observers were employed. More frequently, kelp gulls were found, their black-and-white colouration showing up more boldly against the green and browns of the vegetation. Giant petrels were also found, their larger size and the open areas they frequented making them easier to spot. Given that many of these carcasses were not scavenged, it is difficult to ascertain whether there was much benefit in reducing non-target mortality. In addition, low flights directly over living giant petrels during aerial searches entailed increased disturbance of those birds.

The mortality of different species as a result of the baiting varied according to the behavioural patterns of the species and the mechanism of the toxin. For example, kelp gull and duck mortality was expected to peak within a few weeks of the first bait drop, because kelp gulls and ducks were mostly affected by direct bait consumption. The main impact on giant petrels was considered likely to be several weeks after baiting, once rabbits had died and any exposed carcasses consumed by the birds (Figure 5). Skua mostly migrate from the island during the winter, so the greatest impact on them was expected to be several months later, following their return in spring and summer, once they began to consume any remaining carcasses (Figure 6). While most carcasses on the surface were expected to have been found or started to decompose by then, skua hunting techniques meant they found more carcasses down rabbit burrows, where they were not seen by search teams or giant petrels.

Several factors are likely to have affected the accuracy of the recorded non-target species mortality figures. Because all carcasses were collected and recorded, all natural mortality is included in the figures over an 11-month period. Brodifacoum poisoning symptoms can be cryptic (Shlosberg and Booth 2006), and it is not always possible to be sure that collected carcasses had been poisoned. Consequently, not all carcasses found were baiting-related but included those dead from natural causes. Conversely, it is likely that some birds also died at sea and therefore were not recorded. For example, in 2010, 4 male giant petrel carcasses recovered from Enderby Island tested positive for brodifacoum residue in liver samples, one of which was banded on Macquarie Island, demonstrating that these birds must have consumed a lethal dose of toxin via scavenging and then flown nearly 700 km before succumbing to the toxin. The extent to which off-island mortality occurred reflects the foraging and migratory behaviour of species with an oceanic distribution, and it

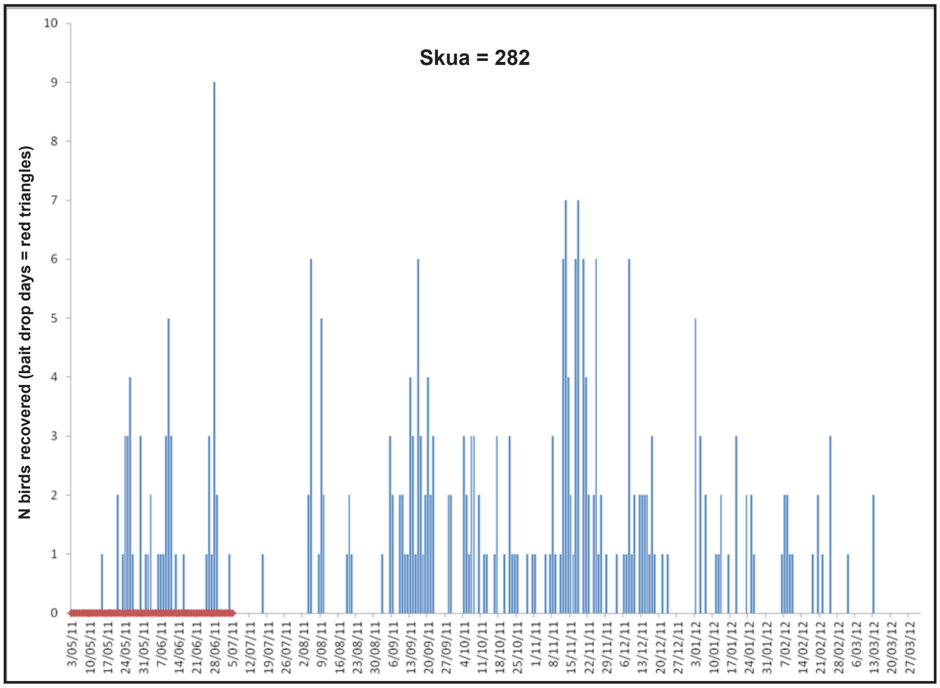


Figure 6. Skua mortality following 2011 baiting showing trend of higher mortality in summer following baiting. Solid line on X-axis from 3 May 2011 to 5 July 2011 denoted bait application period.

cannot be accurately estimated.

Non-target impacts need to be considered in the context of total eradication benefits, which generally accrue into perpetuity (as long as effective biosecurity measures are implemented and able to be maintained). Non-target mortality is an unavoidable consequence of large-scale eradication projects using aerial baiting, which is currently the only reliable way of ensuring accurate and sufficient bait coverage over large areas to ensure eradication. However, non-target impacts are predominantly short to medium term in effect, which is important when considering the long-term gains made possible by eradication of invasive pests.

In some species, population estimates were available and mortality could be expressed against these (Table 2), but in other species, population estimates were either unavailable or long out of date, making an accurate assessment of impact much more difficult. For all species impacted by mortality except ducks, breeding was confirmed in the following summer and many individuals still sighted around the island. Although numbers have not been accurately surveyed, a rough historic estimate reported in 1987 assessed numbers at 100-300 (Norman 1987). Given 135 carcasses found, and a relative paucity of sightings by experienced observers post-baiting, it is clear that ducks sustained the greatest impact of in terms of proportion of the population affected.

MIPEP non-target mitigation strategies have focused on the mitigation of secondary poisoning potential, because it is very difficult to mitigate against primary poisoning without reducing the probability of eradication success. Mitigation options are more limited when targeting three different pest species simultaneously.

One of the main reasons for non-target mortality in the Macquarie Island context was the presence of a large rabbit population. Rabbits can eat many times a lethal dose of bait before succumbing to the poison, meaning that high concentrations of the toxin may be present in the liver and other organs. On a unit weight basis, fewer rabbits need to be consumed by scavenging birds for mortality to occur through secondary poisoning. On Macquarie Island, skua in particular have relied on rabbits as a primary food source (Jones and Skira 1979), and they are active predators as well as scavengers. They are also adept at recognising rabbits infected with the myxoma virus and will feed on them. Thus, the skua population is used to relying on rabbits as a food source and are very capable at finding them. This places them at particular risk if toxic carcasses are present when skua are, and mitigation team members observed skua catching sick rabbits before the team members could intercept them. This behaviour is a learned strategy on the part of skua, as they had developed it over the previous 30 years, when rabbits blinded and weakened by the myxoma virus could easily be caught. Islands where rabbits are not present (as a target species or a non-target species that would also consume the same bait) should anticipate significantly reduced mortality amongst scavenging birds.

Release of RHDV and the subsequent death of the majority of rabbits from the virus clearly delivered the greatest benefit in minimising non-target mortality from secondary poisoning, because there were so many fewer toxic carcasses available for scavenging after aerial baiting than would otherwise have been the case. Although the great majority of rabbits died underground, the rabbit population on Macquarie Island was so great that even a small proportion dying above ground exposed scavenging birds to risk of ingesting toxins. Birds tended to scavenge internal organs first, where toxin residues are higher – especially the liver. Toxin concentrations in muscle tissue are generally much lower and were consumed after the carcass had been disembowelled. Reducing the overall population prior to baiting therefore had a major impact in reducing the number of rabbits dying above ground from subsequent poisoning.

Rats and mice provide far smaller quantities of toxin in their systems and would take commensurately more carcasses consumed to poison scavenging birds. Non-target mitigation teams searching Macquarie Island found very few dead rats, and those found were mainly around buildings. Relatively few mice were found.

Challenges of Multiple Regulatory Agencies and Sponsors

Different goals amongst parts of agencies can lead to different expectations regarding project methods and outcomes. With the Macquarie Island project, the added complexity of having two project sponsors and overlapping regulatory regimes often became apparent.

After deferring the project due to poor weather in 2010, and the near-certainty that funding would not be provided for a third attempt if the 2011 baiting was similarly curtailed, it was critical that the team arrive on the island earlier in 2011than in 2010, and use all suitable weather to ensure that baiting was completed as soon as possible – itself a major non-target mitigation measure. Whilst both the Tasmania Parks and Wildlife Service and the sponsoring part of the Commonwealth Department of Sustainability, Environment, Water, Population and Communities were focused on the successful completion of the aerial baiting phase and minimising non-target impacts within that goal, other regulatory agencies had a mandate based solely on minimising non-target mortality, particularly of threatened species. This had the potential to cause project failure, because of the imposition of permit approval conditions that prioritised non-target mitigation measures ahead of eradication progress, and that failed to acknowledge that expediting aerial baiting not only was a non-target mitigation measure in itself, but also locked in conservation gains, if successful. The lack of experience in eradication operations amongst some regulatory bodies, and unwillingness to heed those with such experience, also led to conditions imposed that had the potential to increase the risk of project failure. There are lessons here for future projects operating in a regulatory environment unaccustomed to dealing with pest eradication projects, while working under legislation that was not created to support this type of relatively novel management action, thus exposing conflicting goals within the same legislation.

These aspects posed additional project risks, because not taking advantage of every occurrence of suitable baiting conditions increased risk of project failure. Of course, a failed baiting attempt would still incur substantial non-target mortality, all for no benefit if the project was not completed. For example, if baiting had ceased despite suitable weather conditions, the same scenario as in 2010 may have occurred, with the weather conditions required for baiting not eventuating and the project again failing to complete the baiting. Some regulatory agencies also had a narrow focus on preventing or minimising impacts to current listed species on Macquarie Island, and therefore they gave no recognition to the long-term benefits accruing to other native species if the project successfully eradicated rodents and rabbits. In short, the emphasis was often on reducing short-term impacts rather than investing in long-term benefits.

A notable aspect of both the review panel and also the Bird Technical Advisory Group was that membership did not include any eradication practitioners. While these groups could access this expertise if they wished (but didn't), it reflected an assumption that only non-eradication practitioners were best placed to advise on minimising mortality from aerial baiting operations. The inclusion of people with previous experience in managing non-target issues in other eradications could have enhanced the collective experience and provided examples of how similar issues had been managed elsewhere. In contrast, the South Georgia Habitat Restoration Project was faced with similar non-target issues and also formed a group to advise on mitigation measures to reduce non-target impacts; however, that group included eradication practitioners who had faced similar issues, as well as seabird biologists, thus gaining a broader suite of relevant practical experience.

While eradication of rodents and rabbits from Macquarie Island is not yet confirmed, it is clear that the vast majority have been removed by aerial baiting. No rodents and rabbits have been seen since May 2011 (rats), June 2011 (mice), or December 2011 (rabbits). Recovery of the islands ecosystem has been marked, with extensive improvement in vegetation condition around the island. The removal of vertebrate pests has improved reproduction in many bird species impacted by pests. Grey petrels (*Procellaria cinerea*), white-headed petrels (*Pterodroma lessonii*), blue petrels (*Halobaena caerulea*), and Antarctic terns (*Sterna vittata bethunei*) have either increased their breeding success in the absence of rodent predation, or have recolonised areas for breeding where they have not previously been recorded.

CONCLUSION

Non-target mortality is an unavoidable consequence of large-scale eradication projects, especially when using aerial baiting as the application method, which is often the only feasible method for large-scale projects targeting rodents and rabbits. Prior to an eradication project commencing, anticipated non-target impacts need to be assessed and then weighed against total eradication benefits.

MIPEP non-target mitigation strategies have focused on the mitigation of secondary poisoning potential, as it is virtually impossible to mitigate against primary poisoning without reducing the probability of eradication success. Mitigation options are more limited when targeting three different pest species simultaneously. Mitigation measures that reduce non-target impact may be need to be implemented. They can take many forms and often involve a suite of measures, each of which will have varying degrees of effectiveness.

Successful removal of vertebrate pests from island ecosystems can have long-term conservation benefits, assuming pest-free status can be maintained, allowing expansion or re-establishment of native species. Positive population and habitat changes can be rapid in the period following eradication. Non-target impacts are usually short to medium-term, whereas benefits of pest eradication are usually medium to long-term.

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