Predator Free Rakiura Halfmoon Bay Project—methods for predator removal

Richard Ewans

Eco-South
44 Mackinnon Loop, Te Anau, 9600

Eco-South

PREDATOR FREE RAKIURA

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CONTENTS

Summary

This report presents detailed scenarios for the removal of predators (rodents (Norway rats, ship rats, kiore), possums, feral cats and hedgehogs) from two proposed Predator Free Rakiura Halfmoon Bay Project options (4800 ha or 2150 ha) on Stewart Island/Rakiura (hereafter Rakiura). All scenarios presented in this report are considered to be technically achievable and presumed to have some level of acceptance by Ngāi Tahu whānui, the local community and stakeholders. This presumption needs to be tested through effective engagement and consultation with each group, led by the Predator Free Rakiura Governance Group (PFR Governance Group).

The relative efficacy of a range of available predator removal methods, including aerial or hand broadcast of toxic baits, bait station application of toxic baits and trapping were assessed by the technical working group. However, aerial and hand broadcast of toxic baits (brodifacoum or 1080) were not developed as scenarios due to a presumed lack of social acceptance for their application within the Halfmoon Bay (HMB) Project area and a low chance of achieving the complete removal of rats (1080).

National and international achievements in the removal of invasive predators (and other pests) from islands indicate that this project is technically feasible. Two key projects provide an indication of what can be achieved with meticulous planning and full commitment to execution: the eradication of multiple rodent species as well as stoats, feral cats and hedgehogs from Rangitoto/Motutapu Islands (3842 ha) near Auckland in 2009 (using aerial broadcast of brodifacoum baits to target rodents), and the eradication of Norway rats from Langara Island (3100 ha) in British Columbia, Canada in 1995 using brodifacoum baits in bait stations.

For the HMB Project, the size of the operational area, presence of a permanently settled township, mix of predator species targeted, and the proposed methods make it unique. There are no comparable national or international examples of multiple rat species being removed from such a large area using bait stations and/or trapping, and none where three other predators are targeted at the same time. Therefore, the HMB Project carries appreciable risk around its ability to fully remove rats from the area and then keep them out. However, the removal of cats, possums and hedgehogs is more certainly achievable based on previous work within New Zealand and elsewhere, with relatively little risk of future incursions by these species from the mainland (i.e. the South Island).

Hedgehogs are presumed to have a limited distribution around Halfmoon Bay and could be removed before the main HMB Project commences, or at the same time using targeted trapping and spotlight search-and-remove with the aid of predator detection dogs. It is proposed to remove all other predators simultaneously or sequentially, using ground-based techniques, primarily toxic baits in bait stations or trapping.

Residents and other landowners would need to have risk assessments and property action plans developed for each property. Every building, structure, vessel and vehicle on the island would need to be treated during the operation. Buildings may require devices (traps and/or bait stations) to be deployed for 6 months or more during the predator removal phase.

Four scenarios are presented for consideration for the two different-sized project areas. The three bait station scenarios use brodifacoum and/or diphacinone cereal pellet baits and block baits to target rats on a grid. The optimum scale of the grid should be determined; figures in this report and the companion finance report are based on a 50 m × 50 m or a 25 m × 25 m grid.

Possums would be primarily targeted with cyanide capsules dispensed amongst non-toxic pre-feed cereal pellet baits on the same grid at 100 m × 100 m spacings before the rat operation commenced to avoid competition between the different predators for bait. Feral cats would likely be knocked down via secondary poisoning if brodifacoum is used and would be further

targeted using specialist teams with predator detection dogs utilising 1080 or PAPP baits, leg-hold trapping and hunting/spotlighting. Follow-up work to remove the last few individuals would require a wide range of methods. The trapping-only scenario would primarily use DOC200™ kill traps to target rats and hedgehogs, Trapinator™ kill traps and leg-hold live capture traps to target possums, and leg-hold live capture traps to target feral cats.

Indicative costs for the HMB Project using the scenarios outlined in this report vary depending on the size of the operational area, grid spacing used, and the methods chosen. The logistics would be challenging, with between several hundred to more than 1500 individuals required for short periods (weeks to several months) during the main predator removal phase, also depending on the size of the grid and the methods chosen. Huge amounts of data would need to be collected and managed, possibly using hand-held electronic devices with GPS capability as well as staff with GIS expertise.

The scenario that uses brodifacoum baits in bait stations to target rats is most likely to achieve success and may be considered socially acceptable if non-target issues and concerns held by the community can be mitigated, particularly those related to sub-lethal exposure of white-tailed deer and secondary poisoning of domestic cats. Using the less-persistent but also less-proven toxin diphacinone would present higher uncertainty in achieving complete predator removal. While it is likely to be the most socially acceptable method, trapping without using toxins is the most expensive scenario and the least-likely to achieve complete removal of rats. Such risk may not be acceptable given the size and complexity of the project, and the level of resourcing that would be required.

The presence of kiore presents a challenge for recommending an appropriate grid spacing size; for Norway and ship rats a 50 m × 50 m grid would be sufficient, but kiore may need a smaller sized grid—we just don't know. Research and pilot trials would be required on Rakiura to establish the minimum home ranges of the three rat species before and after rats are taken out of a trial area. This information would provide a good understanding to determine the optimal grid spacing for the proposed larger HMB Project options which would, in turn, greatly influence the financial resources required to undertake the work and a decision about the scale of the programme. Other pre-operational research work should include distribution surveying for hedgehogs, a risk assessment and possible survey for mice, development of a streamlined testing regime for toxin residues in the meat of deer carcasses, baseline monitoring of toxins already present within animals in the HMB Project area and DNA sampling of rats (and, possibly, the other target species) for future comparison.

This report is not an operational plan rather it attempts to provide the most realistic proposal of methodologies for removal of predators from the HMB Project area, within the constraints of social acceptability, likelihood of success and the scale and corresponding budget of effort. In making informed decisions about the proposed project for Halfmoon Bay, Ngāi Tahu whānui, the local community and stakeholders should consider this report alongside the other technical discussion reports on predator fencing, biosecurity and costs, as well as the Predator Free Rakiura economic impact report.

1. Background/context

1.1 Introduction

Stewart Island/Rakiura (hereafter Rakiura) lies 30 kilometres (km) south of the South Island and is the third largest of New Zealand's islands with a total land area of 174 600 hectares (ha). Most of Rakiura is covered by podocarp-broadleaved forest and 80% of the island is administered as National Park by the Department of Conservation (DOC). The island has one major permanent settlement—the township of Halfmoon Bay/Oban, which has a resident population of about 400 people. Rakiura has exceptionally high conservation values because of the high proportion that is covered by relatively unmodified and contiguous indigenous ecosystems, and the diversity of flora and fauna (some of it threatened) present. These qualities are partly attributed to the absence of some of the invasive mammalian predators present on the New Zealand mainland—most notably, stoats.

However, the invasive mammalian predators that have established on Rakiura have documented negative impacts on indigenous ecosystems on the island and/or elsewhere in New Zealand. These include rodents (Norway rats, ship rats, kiore), feral cats, possums, hedgehogs, white-tailed deer and red deer [1][1]. The potential to remove the most harmful introduced predators (i.e. rats, feral cats and possums[2]) from Stewart Island was scoped in 2008 [1] and was considered most technically feasible using aerial broadcast of brodifacoum baits, but the scoping study also recognised that there would be significant logistical and community acceptability constraints inherent in operational implementation of this method of predator removal.

Further support for a Rakiura predator-free project from the Morgan Foundation and DOC led to the establishment of a governance group to further co-ordinate an evaluation of the project at the community level, with the aim of representing and engaging Ngāi Tahu whānui, the local community and stakeholders. The PFR Governance Group met for the first time in January 2014[3]. They proposed taking a precautionary approach by first attempting predator removal in a smaller operational area of approximately 4800 ha around the township (the Halfmoon Bay 'project area'), which would be separated from the rest of the island by a predator fence. In February 2015, an even smaller operational area of 2105 ha was included for consideration. Predator removal was proposed to take place in the Halfmoon Bay (HMB) Project area first, as a 'pilot', to further scope the significant logistical and social issues surrounding removal of predators from the rest of the island, including thorough development of the biosecurity requirements to prevent reinvasion.

Predator Free Rakiura is a joint initiative by Gareth Morgan (Morgan Foundation) and DOC, although it relies on acceptance by Ngāi Tahu—tangata whenua of Rakiura and the surrounding islands. On a range of levels—traditionally, spiritually and within the contemporary setting—these islands are of huge significance to Ngāi Tahu. In addition, responsibilities under section 4 of the Conservation Act 1987 require the Crown (via DOC) to honour the principles of the Treaty of Waitangi and therefore take into account and work to actively protect Ngāi Tahu interests. DOC also has obligations to Ngāi Tahu under the Ngāi Tahu Claims Settlement Act 1998. No other partners, community members and/or groups or stakeholders have this kind of relationship with the Crown in respect to Rakiura.

The Predator Free Rakiura Halfmoon Bay Project (HMB Project) proposes to remove all mammalian predators (Norway rats, ship rats, kiore, feral cats, possums and hedgehogs) from an area of either 4800 ha or 2150 ha encompassing the Halfmoon Bay township (Fig. 1). It is proposed that the area is separated from the rest of the island by a predator fence along the

[1] Numbers in brackets refer to references in the reference list (section 9).

[2] The scientific names of these and all other species mentioned in this report are listed in section 7.

[3] See http://predatorfreestewartisland.org.nz/the-governance-group/ for details.

Figure 1. Map showing the two proposed fence options for the Halfmoon Bay Project.

boundary with the rest of the island, with the remaining boundary being the sea. While highly valuable on its own merits, the successful completion of the HMB Project is envisaged as a staging point for a consultation process, that asks whether making the whole of Rakiura predator free at a later stage is acceptable and feasible [1].

1.1.1 Objectives

Our understanding of the objectives of the HMB Project are outlined below[4]:

- To develop a technically robust and socially acceptable plan for predator removal and biosecurity measures to prevent reinvasion through meaningful consultation with Ngāi Tahu whānui, the Rakiura community, stakeholders, and technical experts in the field of predator control, island eradication and biosecurity.
- To achieve the complete removal of three species of rat, possums, feral cats and hedgehogs from either a 4800 ha or 2150 ha area of Rakiura encompassing the Halfmoon Bay township.
- To maintain this area in a predator-free state in perpetuity through effective biosecurity measures.

1.1.2 Context of this document

This report addresses the methods for the primary objective of the project—predator removal. The details of the predator fence, biosecurity requirements and cost components of the project are addressed in separate technical documents [2], [3], [4]. Response to incursions (reinvasion of pests) is treated as part of biosecurity planning. This document is not an operational plan; rather, it is a detailed discussion document building on previous work to provide realistic scenarios which Ngāi Tahu whānui, the Rakiura community and stakeholders can use to assess their level of support for the project. Several topics which could be expected in a full operational plan are not addressed here:

- Aspects of advocacy, education or community relations which will be required to support the project.
- Description of the ecology or environment of the HMB Project area, or the potential outcomes of the project in terms of species protection and/or potential re-introductions.
- Thorough risk assessments of all aspects of the work.
- Co-ordinated Incident Management System (CIMS) planning or operational team structures.

The brief and content for this consultation paper was developed over a 2-day technical planning workshop held in Invercargill on August 6–7 2014. This workshop brought together a small group of technical specialists[5] with relevant experience in planning and delivering multi-species eradication programmes, research and development of predator control and elimination tools, island biosecurity, and statutory land management responsibilities for the public conservation land (DOC), private land and the township of Halfmoon Bay (Environment Southland). Additional writing and research for this document was undertaken by Richard Ewans (Eco-South), with peer-review by the original technical group. External review for the purpose of assessing the technical efficacy of what we are proposing was undertaken by Keith Broome (DOC) and Penny Fisher (Landcare Research).

A number of key assumptions are implicit in the scenarios presented here:

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4 At this time our technical group have not been provided with a statement of project objectives. We have developed these objectives for the HMB Project based on the existing papers and reports and our own understanding of what the Governance Group wish to achieve.

5 Andy Cox (DOC), Pete McClelland (private), Phil Bell (DOC), Sandy King (Predator detection dog specialist with local knowledge of Rakiura and member of PFRGG), Darren Peters (DOC), Richard Bowman (Environment Southland), Brent Beaven (DOC), Kerri-Anne Edge (edge effect), Richard Ewans (Eco-South).

- There is currently no established mouse population on Rakiura. This project would provide a ‘predator-free welcome mat for mice’. Mice are known to occasionally turn up around the township and are presumed to be preyed upon quickly or out-competed by the predators currently present on the island.
- There would be a predator fence. It has been clearly stated by the PFR Governance Group that there will be no HMB Project without the fence to prevent or reduce reinvasion.
- The exclusion of any methods from this document does not preclude them from being recommended for the wider Predator Free Rakiura Project in the future.
- White-tailed deer are not known to be significant predators[6] on Rakiura; therefore, they are not a target species.
- Specific biosecurity measures would need to be tested and implemented before predator removal begins.
- The proposed project is an intensive predator removal project, not the first phase of an ongoing predator control project.

Successful ecosystem restoration on inhabited islands is essentially a social activity [5]. The two major potential constraints on the success of the proposed HMB Project are the likelihood of success using the available methodologies, and social acceptance of those methods and all other potential social impacts of the project (e.g. ongoing biosecurity). This report attempts to strike a balance between being able to use the tools and methodologies with the highest technical likelihood of success and the social acceptance of these methodologies.

The complete removal of all predators from the HMB Project area would require the same strategic approach that eradication requires. The only difference is that eradication is defined in part by a zero or near-zero chance of reinvasion (incursion). Predator removal is the appropriate term used to define this objective of the HMB Project. It gives recognition to the fact that incursion is probable, given the social context of the project and that a predator fence will be installed as a physical barrier along one boundary.

There are five principles of eradication that must be met to make a project such as the HMB Project feasible [1], [6]:

1. Reinvasion can be managed (to zero population establishment).
2. Every individual predator is killed.
3. The target species are killed faster than they can breed at all densities.
4. The project is acceptable to people.
5. The benefits are greater than the costs.

This document addresses principles 2 and 3 with an aim of providing methodological options that address principle 4. Principle 1 is addressed in associated technical documents [2], [3], and the ecological, social and economic benefits of the overall Predator Free Rakiura Project addressing principle 5 are addressed in [1] and [7].

[6] White-tailed deer have been observed eating eggs from nests on Rakiura (Keith Broome, pers. comm., 10 December 2014) and in the USA (Pete McClelland, pers. comm., 28 October 2014).

1.2 Target pest species

A description of each target species is provided in Appendix 1. Of particular importance in the removal of multiple species of predators is the interaction between the target species present. Understanding such interactions is important for maximising the likelihood of the project's success and creating operational efficiencies. Key interactions between the predators described below include: the predator-prey relationship between feral cats and rats, interspecific competition for food between possums and rats, and interspecific and intraspecific competition between the three species of rat.

A major component (approximately 80%) of the diet of feral cats on Rakiura is rats [8]. Therefore, significant secondary poisoning of feral cats could be expected by using the relevant toxin/s i.e. brodifacoum or sodium monofluoroacetate (1080) [9]. If the most effective rat toxin is used (i.e. brodifacoum) then the majority of feral cats in the HMB Project area could be removed via secondary poisoning (i.e. by eating poisoned rats), which represents an efficiency gain for the project [10]. This effect is lost if a trapping-only approach is used.

Competition between rats and possums for food is likely to be an issue on Rakiura with the delivery of toxin via baits in bait stations [1]. Possums can eat large amounts of bait targeted at rats, increasing the risk of individual rats not being exposed to or consuming a lethal dose and increasing the amount of toxin released into the ecosystem.

A similar competitive interaction occurs when all three species of rat are present [11], [6]. Norway rats (mostly ground dwelling in the presence of ship rats) and ship rats (mostly tree climbing) exclude the smaller kiore from access to bait (when bait stations are used), and kiore only become exposed to the bait once the population of the other two species has been dramatically reduced. This interspecific competition increases the risk to the project in terms of not removing every last predator from the HMB Project area, or increasing the time taken to achieve the outcome.

1.3 Operational objectives and result target

A realistic outcome of a successful operation would be the removal of all predators within the area fenced off by the predator fence (the HMB Project area), and establishment of the on-going capability to deal with regular predator (particularly rodent) incursions originating from the township or at the predator fence or coastline.

The objective of the HMB Project is to meet operational success (result and outcome) targets. The overall result target would be the complete removal of all target predator species, while outcome targets could be the reintroduction of native species, such as mohua, and increases in populations of native species currently present. Like many complex pest removal projects, the combination of target species and local environment is unique and would require adaptive management practices to achieve the desired outcomes. In this context an adaptive management approach means the use of new information to adjust a strategy or goal in order to learn from experience. However, due to the size of the proposed project and its associated risks and costs, it would not be appropriate to conduct large-scale experimentation with new techniques or technologies. Therefore, we have not suggested specific experimental targets, other than the pre-operational trials and survey requirements outlined in section 4.

Measuring success in terms of field monitoring to confirm a complete removal of predators may be difficult, expensive and time consuming to carry out. The line between complete removal of predators, detection of survivors and distinguishing survivors from incursions is likely to be blurred. Given the likelihood of rat incursions in particular, and/or mice, and the fact that the methods used to mop up the last survivors and deal with incursions would be essentially the same, this distinction may be somewhat arbitrary for the HMB Project. However, it does not preclude utilising available technology (e.g. genetic sampling) to distinguish survivors from incursions, where possible.

The specific result target that determines the success of the HMB Project predator removal phase should be defined at the operational planning stage. It could be that predators are undetectable for a certain amount of time despite intensive monitoring using a range of techniques. This result target is typical of pest eradication projects. For rats, this target would normally be measured after 2 years. However, given the likelihood of a rat incursion, we suggest that this period be reduced to 1 year (for all target species). Outcome targets would need to be defined in a full operational plan.

While we are deliberately not suggesting setting an eradication objective (but, rather, a predator removal objective), an eradication attempt that is 99% successful can ultimately result in 100% failure [12]. It would be critical to the success of this project that a full eradication mind-set is applied, despite any perceived difficulties in defining the result target (i.e. difficulties distinguishing survivors from incursions). The project would be considerably riskier and cost more if staff, contractors and residents lapse into an ongoing predator control mind-set. For example, with bait station methodologies in a predator eradication project, each bait pellet or block must be counted as it is delivered into every bait station, and every bait taken must be recorded for every bait station, for every check. To maintain this level of best practice and data recording for months across thousands of bait stations in all weather conditions requires a professional, meticulous, committed mind-set from all personnel [6].

2. Methods

In this section we outline the operational area proposed for the HMB Project, potential non-target species, the methods that we have not considered further and why, and the methods that are effective and available for each target species. Multi-species predator removal projects need to be considered as a number of separate eradications occurring concurrently and therefore the methods must be appropriate for each target species. A useful comparative table of pros and cons of the broader technical options (trapping, toxic bait in bait stations, hand broadcast of brodifacoum/1080 baits and aerial broadcast of brodifacoum/1080 baits) is provided in earlier material provided by the Governance Group [13] and is not repeated here. Rather, the key advantages of the methods chosen are outlined, and the key reasons why other methods were omitted are given.

In this report the criteria for assessing methods for predator removal for the HMB Project are primarily:

- The method is generally perceived as socially acceptable
- The method is currently available (e.g. toxins not requiring registration changes)
- The method has an acceptable likelihood of success

Although we have suggested that large-scale experimentation with novel techniques or technologies would not be appropriate, there needs to be operational flexibility to try new approaches or modify existing ones where there is clear evidence of efficacy, regulatory approval can be gained and proven methods can be easily and cost-effectively substituted if required. Such opportunities should be thoroughly assessed in the operational planning phase (although some are mentioned in this report).

2.1 Operational area

Two operational area sizes are presented for the HMB Project area (approximately 4800 ha or 2150 ha). It is proposed that the larger 4800 ha area would be bounded to the west by a predator fence running between Wooding Bay (Māori Beach) and North Arm in Paterson Inlet. The smaller 2150 ha option would be bounded to the west by a predator fence running between the east end of Wooding Bay (Māori Beach) and the west side of Ryan's Creek in Paterson Inlet. The rest of the main boundary is the coastline encompassing the land area to the east of the predator fence. We have included a number of small islands within swimming distance of rats (1 km) in the operational area. These are the Faith, Hope and Charity group and Iona, Native, Kidney fern, Burial, Dirty, Nathans and Mudflat Islands, along with several very small unnamed islands and rocks/nuggets around the HMB Project area.

In the 4800 ha scenario (Option A), approximately 60% of the HMB Project area is Public Conservation Land (40% National Park and 20% DOC Stewardship Land). The other 40% is private land. In Option B (2150 ha), about 40% would be Public Conservation Land (10% National Park and 30% DOC stewardship land) and the rest private land. The entire township of Halfmoon Bay lies within the HMB Project area, irrespective of which option is considered. Outside of the township the HMB Project area is covered mostly by partly-logged podocarp-broadleaved forest, dominated by rimu and kāmahi with miro, Hall's tōtara, and southern rātā also common.

A number of conservation projects are happening already within or close by the HMB Project area:

- Stewart Island Rakiura Community and Environment Trust (SIRCET) predator control and restoration work.
- Dancing Star Foundation predator-fenced sanctuary.
- Partnership between DOC and Air New Zealand to increase biodiversity around the Rakiura Track.
- Ulva Island open sanctuary (with the Ulva Island Trust).
- Trap trial on Native Island, run by DOC.
- Darwin's barberry eradication project, run by DOC.

2.2 Potential non-target species

Non-target species are those animals unintentionally affected by predator removal methods. In this project, three levels of risk to non-target species are broadly considered: mortality at the population level, mortality at the individual level and sub-lethal impacts on individual animals. Potential negative impacts on conservation values are low for all potential native non-target species, as it is generally accepted that any one-off reduction in a non-target population will be off-set quickly by the lack of predation and competition once the target predators are removed, allowing a rapid recovery in numbers of native species [14]. For the HMB Project, the potential risk profiles for non-target species would differ considerably depending on the methods used to complete the project and the time scales at which the methods are deployed. In terms of these time scales, the HMB Project is likely to lie somewhere between a true one-off job (i.e. aerial broadcast) and ongoing control (depending on the frequency of incursions). Particularly susceptible non-target species could be managed by taking a sufficient number of individuals into captivity, if required [15].

Bird species such as paradise shelduck and Stewart Island weka would be at risk from primary poisoning using bait stations only if bait is removed from the bait stations and left exposed by rats or possums. This risk at a population level is considered low as there are very few of these birds in the HMB Project area. Predatory birds or those that scavenge (e.g. black-backed gulls, morepork, Stewart Island weka, Australasian harrier and New Zealand falcon) are at a greater risk from secondary poisoning from consuming poisoned live prey or carcasses (e.g. rats or possums).

In addition, ground-dwelling birds such as Stewart Island brown kiwi and Stewart Island weka, and inquisitive birds such as South Island kākā could be at risk individually from trapping techniques (e.g. leg-hold or kill traps for possums, hedgehogs and cats) but, again, are not likely to be at risk at the population level. This risk can be mitigated by using best practice trapping techniques that minimise non-target captures or kills, provided these techniques do not risk increased trap shyness in the target species or reduce trapping efficacy.

It is our understanding that a particular concern for many local residents is the potential impacts on non-target domestic cats and white-tailed deer. The use of brodifacoum in bait stations would likely result in very few if any deer consuming a lethal dose. Domestic cats could be at risk from secondary poisoning (i.e. by scavenging poisoned rat carcasses); however, this risk is already present on the island with the domestic use of store-bought anti-coagulant toxins for rats. Similarly, pet dogs and chickens could be at further risk than they are currently, depending on the toxins and methodologies used, but are easier to manage. Domestic cats would be susceptible to other methods used to target feral cats if they roam from their properties.

Brodifacoum is the most commonly used toxin for controlling rodents in households and is sold as 'Talon™' and 'Pest-Off™'. Local residents have been using the same or similar toxins (e.g. RidRat™, active ingredient is bromodiolone, a second-generation anticoagulant similar to brodifacoum) sold 'over the counter' on private land and around houses for over 30 years, apparently with few pet mortality issues [1].

A number of potential mitigation measures could be put in place, depending on the methods adopted for predator removal and level of risk associated with each, and provided they did not overly affect the efficacy of the methods. These could include:

- Temporarily removing native species of concern from the HMB Project area.
- Muzzling dogs during the main predator removal period.
- Keeping pets inside, in outdoor enclosures, or removing them from Rakiura during the main predator removal period.
- Using modified traps to minimise non-target captures and kills.
- Using modified bait stations to minimise non-target access to bait.
- Using deer repellent on toxic bait (only available for 1080).
- Implementing non-toxic buffer areas.

Bait station designs that minimise non-target access to bait could be used providing they didn't compromise their effectiveness in removing every last individual predator. Even with using bait stations there may still be a low mortality risk to individual white-tailed deer if cereal pellets are used, as they can be removed from the bait station by rats or possums. If this removal occurs, sub-lethal doses would be likely in some white-tailed deer. The size of such risks depends on the toxin used in the baits.

Deer repellent has only ever been used with 1080 in New Zealand and is only registered for use with this toxin. Further research is needed to determine its efficacy in baits containing other toxins. Research to test its effectiveness with white-tailed deer is also needed. Importantly for island eradications, further research is needed into the effect deer repellents have on the attractiveness, palatability and efficacy of baits, toxins or devices for the target and other non-target species.

Related to non-target risks to white-tailed deer is the potential restriction on harvesting wild game for human consumption. The Ministry for Primary Industries (MPI) sets specific caution periods for each toxin used [16]. MPI defines the caution period as the timeframe following an area of land's exposure to poison within which hunting is not acceptable. Commercial harvest for human consumption is banned during caution periods, and recreational meat hunting is highly inadvisable, although not in breach of any regulations. These requirements mean that there would be a restriction on the ability to commercially hunt wild game for food within the HMB Project area and a buffer area associated with the caution period under some scenarios. The buffer would extend beyond the predator fence. Trophy hunting would be unaffected by caution periods. Individual caution periods are discussed below in section 2.4 and with each scenario (section 3).

Another possible non-target risk is that native predatory birds (notably morepork) may struggle to find food within the HMB Project area if all of the rats are gone. These birds of prey may then move outside of the area or switch to an alternative prey (increasing populations of small birds, lizards and invertebrates should eventually replace rats in the diet), or both. However, little field data is available on this subject and general observations from islands suggest that this may be unlikely[7].

2.3 Methods considered to be 'off the table': aerial and hand broadcast of toxic baits

In technical terms, aerial broadcast of brodifacoum in baits is the best option available to the HMB Project as the primary method for predator removal. This assertion is because, to date, it has been the most successful method used for removing rodent predators from islands around the world [17], [14]. It is also the primary method applied in many multi-species eradications on New Zealand islands (e.g. Rangitoto/Motutapu) [18] and within predator-fenced sanctuaries [19]. This method applied using best practice techniques would have a very high chance of success in fully removing all three species of rat in the HMB Project area and would be highly likely to provide a significant knockdown of possums (via primary poisoning) and cats (via secondary poisoning), as well as offering associated efficiencies for the project. It is not likely to provide a significant knockdown of hedgehogs [18], however, as their current distribution is thought to be immediately around the township area, where aerial application of toxic baits is considered inappropriate.

A preliminary survey of permanent and part-time residents (including some visitors to the island) indicated a large majority do not support the aerial broadcast of toxic baits to remove predators on Rakiura, but do support 'manual' removal of predators (e.g. using bait stations or traps). This survey was conducted by a local Rakiura resident between 16 April and 23 May 2014[8]. The results were considered by the participants at the technical planning workshop[9] and interpreted as evidence of a strong view against the use of aerial broadcast of toxic baits for the HMB Project.

Although not specifically addressed in the survey, hand broadcast of toxic baits at the rate required for full predator removal is essentially no different from aerial broadcast in terms of the expected results and risk factors that are likely to underlie community concerns about aerial broadcast of toxic baits. Therefore, widespread hand broadcast of toxins throughout the HMB Project area was also presumed to have strong opposition from the local community.

Hand broadcast of toxic baits may be an improvement on aerial broadcast in that it could reduce the amount of toxin entering water bodies (depending on the skill and care of the staff/contractors applying the bait). However, there is also an associated increase in the risk of unacceptable gaps in the distribution of the baits. This risk could be mitigated using the same buffer technique used on aerial GPS tracks that ensures aerially-applied bait swaths leave no gaps.

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7 Keith Broome, pers. comm., 10 December, 2014.

8 http://predatorfreestewartisland.org.nz/.

9 Meeting of 6–7 August 2014, DOC, Invercargill.

Because of the obvious general lack of support for aerial application (and, presumably, hand broadcast) of toxic baits, we have not considered either aerial or hand broadcast methods any further in this paper, although limited hand broadcast of toxic baits may be proposed in a full operational plan, to ensure predator removal from steep cliff areas within the HMB Project area.

Several other factors add to the reasons for using methodologies that are ground-based and to use devices to deliver toxins or trap predators. These include:

- The PFR Governance Group has stated publicly that there will be no aerial broadcast of toxic baits around the Halfmoon Bay township (which constitutes around 700 ha of the HMB Project area).
- Biosecurity surveillance and incursion responses for the HMB Project would require extensive ongoing ground-based infrastructure within and around the township and elsewhere within the HMB Project area. Therefore, a ground-based approach serves the dual purpose of predator removal and ongoing biosecurity/incursion response.
- On public conservation land, aerial or hand broadcast of brodifacoum baits is currently approved only for rodent eradications on un-stocked offshore islands or behind predator fences. To use this method on Rakiura would likely require a change in registration, as Rakiura is considered to be part of the New Zealand mainland in terms of toxin use [20].
- Aerial/hand broadcast of brodifacoum baits is not approved for targeting possums on public conservation land.
- Aerial/hand broadcast of brodifacoum baits has the potential to result in high non-target mortality of white-tailed deer (a key hunting resource for many local residents) in the HMB Project area.
- The only other toxin available for consideration for aerial broadcast (approved for aerial use on the target species on public conservation land) is 1080. This toxin is likely to be rejected more strongly by the local community and other stakeholders (e.g. recreational hunters) than brodifacoum, despite it being far less persistent in non-target animals (such as white-tailed deer) [21]. Using 1080 for full predator removal on islands is still unproven and its use would likely provide a substantial knock-down (partial removal) only for rats and possums (and probably some feral cats), rather than complete removal, which would mean that an extensive infrastructure would still be required to complete the job.

2.4 Ground control using bait stations and/or traps

Ground-based options for predator removal for the HMB Project are bait stations and/or traps.

A critical component of any predator removal project is the choice of toxin, bait and trap. A range of toxins, baits and traps are available and potentially able to be used for the HMB Project. While many of these tools are proven for (ongoing) control projects, many lack the efficacy required for complete predator removal from an area (or have a very limited track record in this area of work). We only considered, therefore, what we assessed as being the most likely tools to achieve success at the current time. Table 3 (section 5) summarises all of the tools considered but not recommended for widespread use in the HMB Project.

Different toxins and toxic baits have characteristics that suit some uses but not others. For example, using toxins for long-term control of pests in a particular place requires toxins that have low environmental persistence. Toxins are dispersed via baits. The characteristics of the baits that the toxin is delivered in also need careful consideration. All toxin/bait combinations proposed for the HMB Project in this report have been tested and legally registered and approved for the proposed uses. In an eradication context, an 'ideal bait' [14]:

- Is highly palatable.
- Remains palatable for a period that is long enough for the target species to be exposed to it, but short enough to minimise impacts on non-target species.

- Is unlikely to lead to bait shyness/learned aversion.
- Is non-toxic or unpalatable to non-target species.
- Is lethal to the target species after a single feed.
- Has delayed onset of poisoning symptoms.
- Is not persistent in the environment.

In New Zealand, there is no single toxin available that could successfully remove all the target predators and meet all of these requirements. Fundamentally, the use of toxins is often a trade-off between effectiveness and non-target impacts. Other key considerations include environmental persistence and animal welfare impacts.

A range of effective traps is available for all target species and includes live traps (leg-hold and cage traps) and single-action kill traps. Self-resetting kill traps are likely to be a good choice in the future, with the traps that target rats and stoats reducing rats to zero percent rat tracking at two large trial sites in the North Island[10], and one site in Fiordland. However, at this point, self-resetting traps have not been used to successfully eradicate rats from islands and are therefore considered unproven for predator eradication/removal projects and are not considered further in this report.

The Department of Conservation's Island Eradication Advisory Group (IEAG) was established in 1999 and provides expert advice on animal pest eradication operations led by DOC and many similar projects run by other agencies nationally and internationally. This expertise is world-leading and the group provides current best practice documents for a number of the key methods often used in this field, including eradicating rats from islands using bait stations. Only two toxins are currently recommended for rodent eradication using bait stations: brodifacoum and diphacinone [15], and the bait station scenarios presented in section 3 are based on the application of these toxins (for rats). However, the circumstances of the HMB Project are unique and will require a unique solution tailored to achieving the objectives. This approach may mean further investigation into the applicability of some of the other pesticide uses approved by DOC (currently there are 28 approved pesticide uses for rat control on public conservation land).

Legislation and policy govern the use of toxins and traps administered by a range of organisations. Policy can differ between different land administrations (e.g. brodifacoum is permitted for use on any private land for control of possums and rats but its use is highly restricted on public conservation land). Different policy/regulatory requirements which the HMB Project may be required to meet or abide by are listed in section 3.1.1.

The following text provides a description of the methods available for each target species that are most likely to work in the specific context of the HMB Project. In the scenarios (section 3) we describe how the main methods recommended for the operation would most likely be implemented. A wide range of methods needs to be available for the latter part of the predator removal programme, to locate and remove the last remaining individuals. The same applies for incursion response planning.

2.4.1 What other projects can we learn from?

The HMB Project would be unique in terms of the combination of size of the operational area, the presence of a permanently settled township, the mix of predator species being targeted and the proposed methods (i.e. not utilising aerial or hand broadcast of toxic baits).

Therefore, each of the scenarios we present in section 3 are, to some degree, 'untried' for this combination of predators. However, pushing the boundaries of what is achievable in these programmes is unlikely to be detrimental to the HMB Project; practically all of the major innovations in island eradication techniques have come from 'untried' situations where innovations have built on past experience to achieve greater outcomes.

[10] Darren Peters, pers. comm. 26 October 2014. Note: zero percent rat tracking does not imply that there are no rats, only that the population is low enough that they have become undetectable using tracking tunnels during a standard one night survey.

Between 1960 and the mid-1980s, most island rat eradications in New Zealand were completed using ground-based techniques, predominantly for single rodent species on small uninhabited islands [17]. Removal of Norway rats from the larger Breaksea Island (170 ha) in 1988, Mokoia Island (135 ha) in 1989 and Ulva Island (259 ha) in 1992 were successful in their application of brodifacoum bait in bait stations [17], [22].

Bait stations with brodifacoum bait were used to eradicate Norway rats from Langara Island in British Columbia, Canada (3100 ha) in 1995. This project remains the largest successful ground-based rat eradication in the world [17]. A 100 m × 100 m grid with nearly 4000 bait stations was used. Bait stations were checked every 2 days by approximately 40 staff based at five camps. Rats were almost completely eradicated within 1 month of the first baits being laid [23].

Eradication of rodents from larger islands with multiple rodent species (rats and mice) and other predators has been achieved in New Zealand using aerial broadcast of brodifacoum baits to target rodents and a wide range of techniques to target other predators, not always simultaneously. Examples include:

- Kāpiti Island (1965 ha). Norway rats and kiore in 1996. Possums (poison, trapping, shooting, dogs) and cats (shooting) were eradicated previously.
- Whenua Hou/Codfish Island (1396 ha). Kiore in 1998 (bait stations using brodifacoum baits were successfully used in the subalpine vegetation area which harboured high numbers of fernbirds). Possums (poison, trapping, dogs) and weka[11] (trapping, poisoning, shooting) were eradicated previously.
- Tuhua/Mayor Island (1283 ha). Norway rats, kiore and feral cats (eradicated via secondary poisoning and/or possibly starvation) in 2000.
- Raoul Island (2938 ha) Norway rats, kiore and feral cats (primary and secondary poisoning, trapping, dogs) in 2004.
- Rangitoto/Motutapu Islands (3842 ha). Stoats, feral cats, hedgehogs, rabbits (non-predatory), mice, ship rats and Norway rats in 2009. Possums and wallabies (poisoning, trapping, shooting) were eradicated previously.

Since 1999, up to 14 introduced mammal species have been eradicated from predator-fenced 'mainland' sanctuaries in New Zealand at Zealandia (Karori) (225 ha), Maungatautari (3400 ha), Rotokare (230 ha) and Orokonui (315 ha). Each of these projects achieved eradication within a few months of commencing the operation. All but one of the predators identified as targets for the HMB Project were successfully removed at one or more of these sites[12]. Other fenced mainland sanctuaries include Cape Kidnappers Sanctuary (2500 ha), Tawharanui Open Sanctuary (588 ha), Warrenheip (16 ha), Macraes Flat (19 ha), and Bushy Park (98 ha). These sites have struggled to keep some pests (particularly mice) out, so strict eradication where immigration is permanently prevented has not been achieved and may not be feasible in mainland sanctuaries with current technology [24].

On Rakiura, the Dancing Star Foundation successfully eradicated possums, feral cats [1] and rats from a 180 ha predator-fenced sanctuary using bait stations and hand broadcast of brodifacoum, and live-removed cattle and white-tailed deer. Multiple rodent species were eradicated from a small area (20 ha) behind a predator fence in Hawai`i using bait stations and traps. Both of these sites are subject to regular incursions of rodents e.g. [25].

Trapping has been used regularly as one of several tools in many possum and cat eradications [26], [9], and some large islands overseas (with very different habitat to the HMB Project area) have been cleared of cats without using toxins (using traps, hunting and dogs). These include

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[11] Weka were eradicated because they predate the eggs and chicks of kākāpo.

[12] Except for kiore which were not present; however, mice were eradicated from many of these sites.

San Nicolas (5896 ha), Santa Catalina (3890 ha), Monserrat (1886 ha) and Rottnest (1705 ha) [9]. There are far fewer examples of island eradications of rodents or possums being attempted and succeeding using trapping alone (see sections 2.4.5 and 2.4.6).

Large islands (>2000 ha) with resident human populations greater than 200 people where feral cats have been eradicated include Ascension Island (9700 ha) and Tristan da Cunha (9837 ha). Several similar programmes are planned or in progress on inhabited islands, some of which include rodents (e.g. Diego Garcia (3000 ha, feral cat), Lord Howe Island (1455 ha; rat, mouse), Tristan da Cunha (9837 ha, rat, mouse) and Robinson Crusoe (9300 ha, rat, feral cat)) [5].

It is important to recognise that not all pest eradication operations in New Zealand or internationally have been successful and that lessons can be learnt from failures as well as successes. Cited causes of operational failure include inadequate bait deployment, use of inappropriate methods, inappropriate timing, failure to follow established protocols, non-target poisoning issues (observed or suspected) that halted the campaign, bait competition by terrestrial invertebrates and lack of funding/institutional support and public support [14], [9].

Several reviews of New Zealand and international mammal eradications illustrate the continued advancement of island mammal eradications in terms of size and the complexity of natural and social factors [26], [17], [14], [5], [27], [9]. The successful eradication of multiple pests from Rangitoto/Motutapu Islands (3842 ha) in 2009 in the context of multiple crib/bach owners and huge visitation by the public is testament to what can be achieved with meticulous, peer-reviewed planning, appropriate community engagement and support, and total commitment to resourcing and carrying out the job [18].

Internationally, there are no examples of multiple rodent species being eradicated from such a large area using bait stations or trapping along with concurrent eradications of three other predators that are comparable with the HMB Project. Therefore, the HMB Project carries appreciable risk in terms of successfully removing all rodents and keeping them out. However, based on previous New Zealand and international successes, the removal of cats, possums and hedgehogs (if their presumed distribution is accurate) should be very achievable, with little risk of their reinvading from the mainland (i.e. the South Island).

2.4.2 Toxic baits in bait stations v. traps

Ground-based methods of predator removal, particularly those for rats (other than hand broadcast of toxic baits), require extensive infrastructure to establish devices at a density that will put every target animal at risk. The choice of devices is a key decision and a range of bait stations, bait types and traps are available. However, the first decision is whether or not to use toxins or trapping as the primary method of predator removal (the knockdown phase). If the project proceeds, a mix of both will be required for following-up the main phase of predator removal and ensuring that every animal has been removed (the mop-up phase). Table 1 has been adapted from [13] and summarises the relative merits of each approach.

2.4.3 Hedgehogs

There have been two successful island eradications of hedgehogs in New Zealand—Quail Island (85 ha) in 2003 and Rangitoto/Motutapu Islands (2311 ha/1509 ha) in 2009. Hedgehogs are currently thought to be found only around the Halfmoon Bay township area on Rakiura [1], although their distribution needs verifying with a survey. Hedgehogs are capable of moving long distances (10–12 km) and can live in forest as well as in open habitats. They also appear to be relatively difficult to remove so it is important to fully evaluate their distribution within the HMB Project area.

Hedgehogs were eradicated from Quail Island using a mixture of cage traps, wooden treadle traps, accidental capture in Fenn™ traps set for stoats, and search-and-remove using spotlighting. Traps were baited with 'dog roll' [28]. A total of 59 hedgehogs were removed. Assuming a similar density of hedgehogs in the 700 ha township area around Halfmoon Bay, then approximately 500 hedgehogs may require removal.

Table 1. Pros and cons of using bait stations with toxic baits or trapping for knockdown phase of predator removal in HMB Project.

	BAIT STATIONS WITH TOXIC BAITS	TRAPPING
Pros	• Some non-target species can be excluded from accessing the bait. • Bait availability can be manipulated (the amount of bait available can be reduced as bait take reduces). • Unused bait can be removed, reducing the risk of bait entering the environment. • Bait can be made available as long as required. • Bait distribution can be targeted to where it is being taken. • Proven success for rodent eradications on small islands and one large island. • Bait is protected from the weather, allowing the toxin to be available for longer periods. • Less labour intensive than trapping.	• Non-toxic. • Some non-target animals can be excluded through trap covers and trap placement (although this may affect efficacy). • A range of lures can be used where animals have become bait shy. • Public generally have less concern about this method compared with using toxins. • Catch rates can be monitored to target trapping effort.
Cons	• Labour intensive. • Potential for dominant predator exclusion (kiore may not use bait station visited by Norway rats). • Non-target species may still access bait (if they learn to feed from stations or access spilled bait). • Caution periods for hunting of wild game for meat apply.	• Very few examples worldwide of successful rodent eradication using trapping alone. • Most labour-intensive method. • Skilled labour required to ensure maximum efficacy. • Some traps (live-capture) need daily checking to meet legal requirements. • Daily clearance required during the knockdown phase to ensure traps are available to predators for as long as possible. • Follow-up methods (e.g. toxic baits, hunting) are often needed to complete eradication, with associated caution periods. • Poorly set or serviced traps can jeopardise eradication by 'training' animals to become trap shy. • Traps need to be maintained in good condition to ensure their continued effectiveness. • Non-target species (especially weka, kākā, and kiwi) may be caught.

Hedgehogs were the last of six target species removed from Rangitoto/Motutapu Islands between 2009 and 2011. Nearly 300 hedgehogs survived three aerial applications of brodifacoum bait. Eighty-seven were subsequently trapped in DOC200™ stoat traps (modified to allow hedgehogs to enter), 49 caught in leg-hold traps set for cats, 49 located and shot by spotlighting, and 113 found by nocturnal searches with dogs. Only 32 dead hedgehogs were found after the bait application despite intensive searching [18].

The initial trap spacing of the DOC200™ traps on Rangitoto/Motutapu Islands (400 m × 100 m) was found to be too wide for hedgehogs. Traps specifically targeting hedgehogs (DOC150™ and double-set Mk VI Fenn™ in Philproof™ ferret tunnels) were subsequently established on a 100 m × 100 m grid across all areas of ungrazed habitat on Motutapu Island (searching with indicator dogs was sufficient in grazed areas). Various types of pet food used as bait in combination with a fish fertiliser emulsion (Vertefert) lure spread around trap box entrances probably contributed to increased catch rates [18].

No hedgehogs were found or trapped on the forested island of Rangitoto; all hedgehogs were found or trapped on Motutapu Island, which is dominated by grassland. Also, hedgehogs in the Mackenzie Basin showed a habitat selection preference for dense grassland and medium-to-high density shrubs over other vegetation types and were trapped more effectively in low vegetation than on bare substrate [29].

Trapping success for hedgehogs can be highly seasonal, as they hibernate over winter [29], [30]. In the Mackenzie Basin, hedgehogs hibernate from mid April to early September [30]. This reduction in hedgehog activity over winter is also supported by trapping data from the Eglinton Valley in Fiordland, where hedgehogs have been caught as non-target captures during stoat trapping operations in 1998–2015. Less than 5% of all the hedgehogs caught during this period were trapped in the 4 months between May and August each year. Therefore, late spring to early autumn is likely to be the optimal timing for the removal of hedgehogs on Stewart Island. If survey work shows the hedgehog population to be small and restricted to Halfmoon Bay, then removal of this predator may be achievable as stand-alone project [1]. However, this approach would extend the time-frame over which private land would need to be accessed.

Previous experience suggests that removal of hedgehogs may take at least two seasons. It would be best, therefore, to start in the spring, before the removal of the rest of the predators begins, then plan to finish in the summer/autumn after the main predator removal phase. Given their likely distribution around the township and previous experience on Rangitoto/Motutapu Islands, we recommend a non-toxic bait strategy for hedgehogs.

Victor™ soft-jawed leg-hold traps were the most successful at catching hedgehogs at Macraes Flat compared with five other types of trap (including DOC150™ and DOC250™ traps) [31]. However, using leg-hold traps would require kiwi to be absent from the trapped area, which seems highly unlikely in the area that would be targeted for hedgehogs in the HMB Project[13]. While domestic cats could be contained (although they can be caught and released unharmed with these traps [9]), kiwi would be at risk of being caught. Therefore, DOC200™ traps in a trap box with modified entrances to allow hedgehogs (but not cats) to fit through should be used. This approach should reduce or eliminate non-target captures.

Hedgehog densities can vary greatly [30] and the maximum trap spacing should be 100 m x 100 m. Several traps may be required on each property, particularly if there is a lot of uncut grass. Leg-hold traps must be checked daily. DOC200™ traps would also need regular checking as rats would also get caught in these, making them unavailable to trap hedgehogs. A range of fish-based baits combined with a lure (such as that used on Motutapu Island) should be used. Intensive use of trained indicator dogs would be required to track down the last few hedgehogs. Spotlight hunting should be used where it can be done legally. Where firearms cannot be used, spotlights should still be used to find individuals which can then be dispatched humanely.

2.4.4 Feral cats

Feral cat eradications have been attempted on more than 100 islands internationally, with 87 successful campaigns on 83 islands ranging from 5 to 29 000 ha in area. On large islands (>2500 ha), 9 of the 11 successful campaigns utilised primary poisoning with toxic baits, and 2 used leg-hold traps, hunting and dogs [9]. Feral cat campaigns reviewed in [9] had a failure rate of 22%. Failures were usually attributed to lack of institutional support to complete the action, the use of inappropriate methods and inappropriate timing of those methods. All of these issues can be avoided by rigorous peer-reviewed planning, full support from key groups and organisations and realistic resourcing.

The strategy for removal of feral cats will ultimately depend on the methods used for the removal of rodents (i.e. whether feral cats will be subject to secondary poisoning or not), non-target avoidance measures and the presence of vulnerable non-target native species such as Stewart Island kiwi and Stewart Island weka.

Secondary poisoning via rodents poisoned with brodifacoum after consuming brodifacoum-laced baits has been used successfully to knock down cat numbers in 11 successful campaigns; knock-down rates upward of 80% can be expected when cats and rodents are targeted simultaneously

[13] S. King, pers. comm. 6 August 2014

using brodifacoum [9]. While most of these campaigns probably used aerial broadcast of brodifacoum pellets to target rodents, a good knock-down of cats would still be expected in the HMB Project using bait stations to deliver brodifacoum baits to rodents, as about 80% of feral cats' diet on Rakiura is rats [8]. A small experiment on the island found 9 out of 10 radio-collared cats were killed via secondary poisoning with 1080 (by scavenging poisoned possums) during an operation targeting possums [20], although 1080 has a different secondary poisoning risk profile to brodifacoum.

Feral cats have highly variable home ranges and population densities, which can make it difficult to accurately assess what resources are required for their removal. Feral cat home ranges in New Zealand vary between 45 ha and 3317 ha [33], [34], [8]. The home ranges of feral cats on some parts of Rakiura are quite large. The average home range recorded from the Rakeahua Valley was 2083 ha, with a range of 1210 ha to 3317 ha [8]. However, work carried out on the north coast of Rakiura suggests that cats may have much smaller home ranges there[14].

Feral cat densities recorded in New Zealand range from 0.17 to 1.18 cats per km^2 [35]. The larger HMB Project area option is approximately 50 km^2, so an estimated population within this area based on reported densities elsewhere could be between 9 and 59 feral cats. The smaller option area of 2150 ha could hold between 4 and 25 feral cats based on the same densities reported elsewhere. Regardless of how many feral cats are present, they are likely to be distributed throughout the HMB Project area.

A variety of methods would need to be available for use to ensure the removal of feral cats. These may include leg-hold trapping, kill trapping, trained dogs with handlers, poison baiting and hunting with spotlights. An experienced specialist feral cat team would need to be brought together. Internationally, padded soft-jaw Victor Oneida #1.5™ leg-hold traps are the most commonly used and successful technique for eradicating feral cats from islands [9]. DOC considers use of this trap to be current best practice in New Zealand for leg-hold cat trapping [36] and is that it is effective because it can be skilfully hazed (i.e. set up to guide the animal onto the trap) and concealed from the feral cat's view. Padded soft-jawed traps must be used to meet New Zealand and international humaneness standards. A special trap set called a 'chimney' set is recommended when native ground birds are present (kiwi are present in the HMB Project area). Good trap placement (such as along pathways used by cats) is critical. Traps should be well concealed, strongly anchored, baited with fresh meat or scent lures (e.g. cat urine and faeces, commercial canine lures), and their location logged using GPS [36].

The use of leg-hold traps in built-up areas such as the Halfmoon Bay township may be restricted. The Animal Welfare (Leg-Hold Traps) Order 2007 states that the use of leg-hold traps is prohibited within 150 m of any 'dwelling house' without the express permission of the occupier or in any area where there is a risk of catching a companion animal (i.e. pet). Ministerial approval may be granted to waive such restrictions for a certain period for conservation purposes. These restrictions and the accompanying social issues would need to be resolved for the use of leg-hold trapping in the HMB Project, as it would be a preferred primary method for hedgehog and feral cat removal, as well as follow-up removal for these species and possums.

Live trapping with cage traps has been used with mixed success worldwide (some operations abandoned their use as they were so inefficient) [9]. They may be useful around the township but it is very important that they are used by experienced staff. Poor use of cage traps (or any trap for cats) can quickly lead to trap shyness and a resident population of un-trappable cats. Live trapping with soft-jaw (padded) leg-hold traps is less risky, as it is considerably more effective at capturing cats after which they can be humanely euthanized or removed unharmed (as with cage traps).

If brodifacoum baits in bait stations were to be used for rodents, a good number of feral cats are likely to succumb to secondary poisoning. Secondary poisoning could also be expected using diphacinone in bait stations, but the lower toxicity of diphacinone and the limited information available on the secondary poisoning effects of the toxin suggest that it is likely to be less effective for secondary poisoning. The most widely used toxin for the removal of feral cats is 1080. This toxin has been used successfully in New Zealand and internationally in feral cat eradication projects and is one of only two toxins available for targeting feral cats in New Zealand [38]. However, much of the success with 1080 targeted at feral cats used 1080-injected fish as bait, which is no longer a registered (i.e. approved) use.

Best practice for targeting feral cats with 1080 uses fish-meal-based 1080 polymer bait (0.10% 1080 Feral Cat Bait) which is placed in bait stations [36]. The bait is long-lasting, so the technique is suitable for areas that cannot be visited regularly; although it should be noted that the bait is not consistently attractive to feral cats and has limited field evidence of success. This bait cannot be applied where weka are present, which would not restrict its much within the HMB Project area, as weka are currently only found in the coastal areas around the township and out to Ackers Point and Wholers Peninsula[14].

1080 is a synthesised version of a naturally occurring compound produced by many species of Australian plant and is widely used in Australia and New Zealand to control mammalian pests such as possums, rats, rabbits, wallabies, foxes and possums. It is an acute poison which may promote bait shyness in some animals but when used appropriately is proven to be effective against feral cats. It is used widely on Rakiura for possum control using ground-based application of cereal pellets in bait bags, and to control feral cats in areas where New Zealand dotterels breed. 1080 in cereal baits may take 1–2 or several weeks to break down, depending on environmental conditions, and 1–4 weeks to break down in soil and sediments under favourable conditions [39]. However, the polymer feral cat baits last indefinitely and the 1080 toxin would remain in the bait. All feral cat baits would be removed after the removal operation ceased. A caution period would remain in place for 5 months after last bait removal. This would include a 2 km buffer beyond the HMB Project area. There is no known antidote for 1080. The use of 1080 for feral cats on Rakiura, needs to be assessed alongside other methods.

The other available toxin approved for use on feral cats is Para-aminopropiophenone (PAPP). PAPP's efficacy for predator removal is still being assessed [37]; however, it should be included in the mix of potential methods for targeting feral cats, as it is an effective and relatively humane acute toxin with a low secondary poisoning risk and a simple antidote [40]. The application of PAPP within the context of the HMB Project would be an appropriate use of a novel method because it can be easily and cost-effectively deployed alongside (and backed up by) proven methods. PAPP is deployed to target feral cats in a meat matrix bait inside bait stations. For this pesticide use in the HMB Project area, a caution period would remain in place for 1 month after last bait removal. This period would include a 2 km buffer beyond the HMB Project area.

Toxin use to remove feral cats would be targeted to areas where feral cats were known to be present (through the use of indicator dogs) and toxic baits would not need to be applied in a widespread manner for this purpose. Baits would need to be deployed at the discretion of the operators, keeping in mind that cats prefer to move widely, although generally close to cover. The best sites are likely to be along narrow pathways through taller vegetation, and along boundaries between dense and open vegetation [36].

The use of toxins to target feral cats would present a risk to free roaming non-target domestic animals. Domestic cats are vulnerable to primary and secondary poisoning (by eating 1080 or PAPP baits meant for feral cats, or scavenging rat carcasses poisoned by brodifacoum or diphacinone). Pet dogs are particularly vulnerable to secondary poisoning with 1080 if they scavenge poisoned feral cat carcasses.

[14] Brent Beaven, pers. comm. 31 October 2014

Non-target native species are also vulnerable to toxins (secondary poisoning with brodifacoum and diphacinone are discussed under rats—section 2.3.6). Some native birds may scavenge or get caught in leg-hold traps. At least 74 native birds were killed during the eradication of feral cats from Little Barrier Island (1977–1980) which used Lanes Ace leg-hold traps. These included North Island brown kiwi, Cooks petrel, kākā, red-crowned parakeet/kākāriki, morepork, Australasian harrier, and North Island robin [41]. Although Lanes Ace leg-hold traps are now illegal, the soft-jaw Victor leg-hold traps used to target feral cats work in a similar way, so a similar range of birds may be at risk from leg-hold trapping.

Potential mitigation measures to avoid domestic cats being killed via secondary poisoning from brodifacoum and 1080 include keeping cats indoors or within outdoor enclosures for the duration of the project, holding cats off the island for the duration of the project or creating a no-toxic-baits buffer around the township. A 2 km no-toxic-baits buffer was recommended after the operation to eradicate feral cats on Ascension Island (9700 ha; completed in 2004) accidentally killed 38% of domestic cats (which ate 1080 baits meant for feral cats), despite a 1 km no-toxic-baits buffer [42]. In this context, a 2 km no-toxic-baits buffer around the township would mean using trapping only for rat removal across approximately third to a half of the HMB Project area, which is likely to have a higher risk of failure. Dogs should be muzzled when outside for the duration of the HMB Project.

Whatever the precautions put in place to protect domestic cats during the pest removal exercise, the long-term role of domestic cats on Rakiura needs discussion and consensus with the local community. All domestic cats would have to be de-sexed, collared and micro-chipped (as in the Regional Pest Management Strategy [43]) prior to the HMB Project commencing.

On Rangitoto/Motutapu Islands (3820 ha), only 15 feral cats were caught or shot after the three applications of aerially applied brodifacoum baits (all on Motutapu Island). Two were found dead after the aerial poison applications, presumably killed by secondary poisoning. Secondary poisoning of feral cats on Rangitoto/Motutapu appeared to be less significant than on Raoul and Mayor Islands [18]. On Rangitoto/Motutapu, 10 feral cats were shot using spotlighting and 5 were caught in traps (3 in Victor™ 1.5 soft-jaw leg-hold traps and 2 in cage traps). During this project, trappers could effectively service a maximum of 30 leg-hold traps per day, even with the use of quad bikes (by law, they must be checked daily), as a high quality of trap-set must be maintained. Up to 100 trap-sets were in operation at any one time. 130 800 trap nights were recorded with 1000 hunter days. The monitoring phase took 14 dog-handler days to complete four comprehensive searches of the operational area [18].

A preferred approach for Rakiura would be to allow the rat removal methods to provide most of the knock-down of feral cats (i.e. secondary poisoning with brodifacoum would likely result in the mortality of most of the feral cats within the HMB Project area). Follow-up could then be achieved using leg-hold trapping, targeted 1080 and PAPP baiting, and hunting with spotlights. This period would need to extend for a minimum of 6 months beyond the identification of the last feral cat sign (or capture) within the operational area. The feral cat programme would then move into a 'confirmation of removal' phase utilising a range of techniques including use of predator indicator dogs, searching for sign, footprint sand traps and, possibly, baited camera traps. The ongoing presence of roaming domestic cats within the HMB Project area would compromise the use of these tools during the 'confirmation of removal' phase. Therefore, the confinement or temporary removal of domestic cats from the island needs to include this period also.

Timing of the removal of feral cats requires careful consideration. Feral cats on Rakiura appear to be under nutritional stress through the summer months [8]. Rats form most of their diet and seasonal depressions in rat abundance limit feral cat numbers. Therefore, the removal of rats is likely to substantially reduce the numbers of feral cats through secondary poisoning. Removing their main food supply may result in some starvation [1] and should increase the trappability of the remaining feral cats. Therefore, removal of cats maybe best timed for late spring and summer after the main possum and rodent removal phases. This approach may be advantageous logistically for the HMB Project by allowing a greater spread of effort over time rather than needing to have all staff available all the time. However, the risk of feral cats prey-switching to native species needs careful assessment. Although limited prey-switching was found among feral cats at two inland Rakiura study sites [44], the predator fence will stop any remaining feral cats from moving out of the HMB Project area and scavenging opportunities may be greater closer to the coast. The limitation of movement and increased supplementary food may result in a higher risk of prey-switching. In this case, follow-up removal of feral cats should be implemented rapidly to minimise the risk of feral cats prey-switching to native species and it may be better to time it for late winter and early spring.

Summer is also when feral cats breed, which is not usually an ideal period for trapping and poisoning animals. Conversely, lactation places additional stress on animals and may increase trappability as they put more effort into finding food. Delaying the removal of feral cats may also lengthen the amount of time non-target avoidance measures (e.g. keeping domestic cats inside, in enclosures, or off the island) need to be in place for domestic cats.

A 2004 review of feral cat eradications [45] found that toxins and biological controls tended to be most effective at the beginning of an operation, while hunting and, especially, trapping using predator detection dogs appear to be the most effective techniques for removing the last few remaining cats.

2.4.5 Possums

Possums have been eradicated from at least 16 islands or predator fenced mainland sanctuaries in New Zealand, the largest being Maungatautari (3500 ha) [1]. Previous experience suggests that a knock down in possum numbers with toxic baits, followed by targeted trapping and hunting with dogs, would be an effective strategy for the removal of possums from the HMB Project area.

Possums should be targeted on the same grid as rats. A 100 m × 100 m spacing for bait stations or kill-traps should be sufficient to achieve a good knock down. With bait station scenarios, possums would be targeted first so that there is less chance of possums interfering with rat bait.

If brodifacoum baits in bait stations are used, targeting possums with this method is prohibited on public conservation land, although it is used widely on private land and by regional councils [46]. In addition, possums can consume large amounts of brodifacoum and can take up to 2 weeks or more to die [47], so would need to be targeted initially using cyanide (Feratox™ pellets with 500 g/kg toxic loading) delivered among non-toxic pre-feed cereal bait. This approach would reduce the potential interspecific competition for food between rats and possums and, consequently, the risk of bait gaps in the rat network.

One round of pre-feed would need to be applied to the 100 m × 100 m grid first to acclimatise possums to using the bait stations and to 'test run' the grid logistics and iron out any problems before rat removal begins. Pre-feeding also has the advantage of attracting many of the dominant Norway and ship rats (which have larger home ranges than kiore) and acclimatising them to using the devices. Although pre-feeding is not necessary for targeting rats with anticoagulants such as brodifacoum and diphacinone, pre-feed would need to be delivered to all bait stations on the grid if an acute toxin such as 1080 was used to target rats and possums simultaneously.

1080 could be used to target both possums and rats at the same time in the bait stations for the knockdown phase, but because it is an acute toxin, it runs the risk of creating toxin or cereal bait aversion among rats, which would then need to be targeted with anticoagulants (brodifacoum or diphacinone) in a mop-up phase. Targeting possums with Feratox™ pellets in a toxic cereal pellet bait mix to target rats simultaneously may be considered to be mixing toxins (i.e. against label instructions and therefore prohibited)[15].

[15] Keith Broome, pers. comm. 1 October 2014.

Cyanide is considered to be a fast-acting, humane toxin for possums and should achieve 70-90% kills, particularly if the target animals are pre-fed with non-toxic baits. Cyanide is highly toxic to humans, which may lead to restrictions on its use in highly public areas (an antidote is available, but is not very effective). In such areas, leg-hold trapping and/or spotlighting (if legal) could be used. Cyanide has a very low persistence in animal tissue [21] and, subsequently, a low secondary poisoning risk. It is also readily biodegradable in the environment. A caution period for this pesticide would remain in place for 2 months after bait removal. Sub-lethal exposure does occur and can result in bait shyness in possums and probably rats too; however, rats are unlikely to be able to break the Feratox™ coating unless it has been degraded [48]. Use of this pesticide is prohibited where weka are present, but, as mentioned above, weka distribution is limited to small areas around the Halfmoon Bay township in the HMB Project Area.

Where rats are present in high densities the risk of rats eating Feratox™ pellets is elevated and 1080 may be a better toxin to use for the possum knock-down[15]. The risk of bait shyness among rats with the use of either toxin needs careful consideration. If neither toxin is considered ideal for possum knock-down in the context of subsequent rat removal, then kill trapping could be considered as a knock-down tool for possums (see Scenario 4; section 3.2.4).

Cyanide encapsulated in pellets reduces risk to humans and non-target animals compared with laying cyanide paste. Intact coatings would be difficult for small birds to break, so the risk to them is considered to be low, provided pellets are not left in bait stations long enough to allow the coating to break down. There is a small risk to dogs less than 10 kg in weight and native birds less than 2 kg in weight for 12–16 months if baits are left in the field [48]. However, all cyanide baits would be removed from bait stations when they are refilled with brodifacoum or diphacinone baits to begin the rat removal, probably within a month of their being deployed.

The removal of possums from the HMB Project area without the use of toxins would be less of a risk in terms of the project objective than not using toxins to kill rats because of the higher detectability of possums. Trapping alone has been used successfully only once on a very small island (Iona Island, 7 ha), but was the principal method used on Codfish and Kapiti Islands (1396 ha and 1965 ha), and a range of traps are available along with other non-toxic methods (such as hunting with dogs and/or spotlighting). We recommend Trapinator™ or Sentinel™ traps as the most effective kill traps if a trapping-only option for the knock down of possums was chosen.

Leg-hold traps (raised sets), Feratox™ (cyanide) strikers and indicator dogs should be used to find the last possums.

2.4.6 Rats

A 2007 review of international rat eradication literature identified 332 successful island rodent eradications [14]. Only two operations on very small islands (<15 ha) used trapping alone. One other operation on a similar-sized (8 ha) island in New Zealand (Motuhoropapa Island) may have eradicated Norway rats inadvertently during a snap trapping study [17]; however, this programme is recorded as a failed operation in the 2007 review [14]. Therefore, the use of trapping alone for rats in the HMB Project is considered a very risky proposition.

All of the 330 other successful rodent eradications identified from the literature used rodenticides (toxic bait), with brodifacoum used in 71% of operations and over 91% of the total land area treated [14]. The most frequent bait application methods (from most to least) were bait stations, hand broadcasting and aerial broadcasting. However, campaigns using aerial broadcast made up 76% of the total area treated [14]. In other words, bait stations have been used most frequently and successfully on smaller islands; moderate-to-large islands have almost exclusively been successfully treated using aerial broadcast of brodifacoum in pellet baits. This approach is due primarily to the somewhat daunting logistics involved in using bait stations on large islands at the densities required for rodent eradication, the considerable efficiencies in time and money conferred by using aerial broadcast of baits, and the very successful track record of the aerial broadcast method.

Despite differences in topography and habitat between the HMB Project area and Langara Island in Canada, the successful eradication of a single species of rat (Norway rats) from this large island (comparable in size (3100 ha) with the HMB area (2150–4800 ha)) using bait stations and brodifacoum bait suggests that the HMB Project is currently feasible with existing technology.

Island eradications in New Zealand that are led by DOC must adhere to strict best practice guidelines that have been developed over 40 years of world-leading innovation in this area by conservation staff and scientists. The current agreed best practice for eradicating rodents from islands using bait stations recommends the use of only two toxins—brodifacoum (recommended first) and diphacinone (considered a higher-risk alternative) [15]. These options are the only two that we have developed as scenarios in this report for use in the HMB Project to target rats. The key difference in effectiveness between the two toxins is that rats will die after a single dose of brodifacoum, whereas they need multiple feeds over several days to get a lethal dose of diphacinone.

Another international study in 2011 of 546 rodent eradication attempts (including mice) found little difference in the success rate of brodifacoum (143 attempts) and diphacinone (37 attempts) used in a variety of ground-based methods, although brodifacoum was significantly more successful than diphacinone when applied aerially [49]. This study concluded that precedence and logic point to brodifacoum as the toxin of choice for eradicating rodents, providing non-target impacts are acceptable or can be mitigated cost-effectively.

On islands with human populations, an important distinction must be made between wild rodents and commensal rodents (i.e. rodents that live in natural environments versus those that live in close association with humans). Differences in habitat, food availability and population densities between wild and commensal rodents could be appreciable and the methods used to remove each population must be adjusted accordingly (see section 3.1.2).

Brodifacoum

Brodifacoum is a well-known and highly effective second-generation anticoagulant poison primarily used to kill rodents in and around buildings. Brodifacoum is currently the most common poison used to control rodents in households and is sold 'over the counter' as 'Talon™' and 'Pest-Off™'. Although toxic to livestock, pets and humans if accidentally consumed, an antidote is readily available. All target rat species in the HMB Project are highly susceptible to brodifacoum, establishing it as the most effective poison for the HMB Project. It has a high probability of killing all individuals of all target rat species and has been well tested and proven in numerous successful rodent eradication projects throughout the world.

Internationally, brodifacoum is the most successfully used toxin for rat eradications in terms of the number of operations carried out and the area treated [49], [14]. It has proved effective and is recommended for one-off use in eradication programmes, as the benefits generally significantly outweigh the negative effects on non-target species [40]. Around the coast of Rakiura, brodifacoum has been used to successfully remove rats from Ulva Island, Bench Island, Pearl Island, Rarotoka/Centre Island, Putauhina, Codfish Island/Whenua Hou, Pukeweka, Rerewhakaupoko/Solomon Island, Horomamae/Owen Island (along with other toxins) and Mokinui and Taukihepa. Further, south, it was used in the successful campaign to rid subantarctic Campbell Island/Motu Ihupuku of rats [1].

Norway rats tend to die 4–7 days after consuming a lethal dose of brodifacoum. With current formulations, a lethal dose for Norway rats is likely to be consumed in one feed. The 'single-feed' efficacy of brodifacoum, with delayed death greatly reducing the risk of bait shyness, is highly advantageous to rodent removal operations [47]. Where 'one off' applications of brodifacoum are successful in achieving rodent eradication or removal, the need for further widespread application of brodifacoum into the environment is negated, provided that robust biosecurity measures are in place. This distinction between eradication or removal programmes versus sustained field applications of brodifacoum for ongoing control (particularly on mainland sites where incursions or reinvasion are likely) is important.

The high-risk period during eradications until animal tissue containing the toxin breaks down is relatively short (a few months). All unused toxic bait in bait stations would be removed at the end of the predator removal phase, so large amounts of exposed bait are not left to biodegrade, as would be the case in an aerial or hand broadcast operation. Some bait stations would be re-baited in areas where incursion is a known risk (e.g. near the ends of the predator fence). The risk of accidental exposure to brodifacoum would then drop off, although some toxin in some animals or in cereal baits spilt from bait stations may remain in the environment for a number of months, biodegrading over time.

Brodifacoum toxin does not dissolve in water, unlike the cereal component of the bait that is mixed with toxin. The toxin remaining after the cereal component has broken down binds strongly to soil particles. These characteristics prevent it contaminating or leaching into waterways, and run-off into the marine environment is negligible. Brodifacoum is also less likely than other toxins to accumulate in either aquatic systems or plant material [50]. The half-life of brodifacoum in the soil is reasonably short (12–25 weeks, depending on soil type and conditions), so there is no long-term contamination of soils [50]. Brodifacoum cereal pellet baits (e.g. Pestoff Rodent Bait 20R™) and larger block baits (e.g. Pestoff Rodent Block™, Talon 50WB™) have been used with success throughout the world. The larger bait blocks can be secured inside some bait station types, further minimising non-target exposure and allowing tooth marks from rats to be seen clearly as evidence of continued rat activity at the station. Rats can easily remove cereal pellet baits from a bait station, which can be an advantage for targeting sub-dominant animals that are unlikely to remain in the station feeding [15]. The dominance hierarchy that exists between Norway rats, ship rats and kiore is a particularly important consideration for the HMB Project and may require research as part of the pre-operational trials to determine how much of an issue it may be. A combination of cereal pellet bait for the first few feeds followed by block bait when bait take diminishes would be ideal if other considerations did not preclude using both [15].

Although there are significant benefits in using brodifacoum, there are some risks. However, as a result of previous research and experience in eradication projects, including the local projects listed above, such effects can often be predicted and avoided or mitigated against.

The poison persists in the liver of sub-lethally dosed animals for long periods (over 9 months) [47]. Bioaccumulation and secondary exposure are a higher risk when repeated applications of brodifacoum are used over long periods, such as for possum control on private land. Primary poisoning of particularly vulnerable native non-target species (such as paradise shelducks) should be minimal using bait stations. However, some secondary poisoning of predatory birds or scavengers would be harder to avoid. Such birds in the HMB Project area include Australasian harriers, southern black-backed gulls and moreporks.

Low numbers of native non-target species deaths have been recorded during bait station operations using brodifacoum [51]. Brodifacoum is known to have lethal consequences for 16 non-target native New Zealand bird species and another 12 species are considered to be at risk of dying following pest control operations [52].

The potential mortality risk to invertebrates from brodifacoum is considered low, as they have different blood coagulation chemistry than mammals, but sub-lethal doses in reptiles means there may be risk of secondary poisoning of the reptiles' native avian predators [46]. However, reptiles are likely to be at very low densities on Rakiura because of the presence of rats, so the risk of their' causing secondary poisoning is very low. No populations of native non-target species have ever been extirpated from New Zealand islands as a result of pest eradication operations [1], although some species populations have required management to mitigate the effects of the operations.

Besides potential lethal or adverse sub-lethal effects on native wildlife, there is also concern for human exposure through consumption of meat from wild game animals that carry brodifacoum residues. Brodifacoum residues have been found in the liver of some deer following brodifacoum operations. Residues from sub-lethal doses will probably last in the liver and, possibly, lungs and kidneys for a year and possibly for life [51].

The impact on white-tailed deer populations should be minimal if the methods outlined in this document are used, although individual mortality or contamination cannot be ruled out if deer get access to bait. Further work should be done with local Rakiura hunters and wider groups with hunting interests on the island to fully evaluate and mitigate the risk of the rat removal operations to white-tailed deer and the impacts on hunting.

Potential mitigation measures to avoid domestic cats being killed via secondary poisoning from brodifacoum or diphacinone include: keeping cats indoors and/or using outdoor enclosures for the duration of the project, holding cats off the island for the duration of the project, or creating a non-toxic buffer around the township (see section 2.4.4). Dogs should be kennelled or kept inside and muzzled when being exercised to stop them from scavenging carcasses. An effective antidote is readily available if brodifacoum poisoning is picked up early [1]. Anticoagulant poisoning takes several days to become evident and vets could be easily briefed to recognise symptoms in pet animals. Most animals appear to fully recover within a month of receiving a high sub-lethal dose of brodifacoum, providing they receive treatment [51].

The long-term effect of sub-lethal poisoning is uncertain. The persistence of brodifacoum means repeated sub-lethal doses will accumulate, but this outcome is less likely if full predator removal is successful and biosecurity is well managed (to avoid the need for regular and repeated incursion responses using brodifacoum).

Diphacinone

Diphacinone is a first-generation anti-coagulant which is less toxic than brodifacoum. Rats are able to survive relatively high single doses of this toxin, but are not able to survive when eaten toxic baits are eaten regularly over 5 days. Diphacinone has a lower acute toxicity than brodifacoum, particularly for birds, and is rapidly eliminated from the liver [40]. Diphacinone is an alternative to brodifacoum for repeated applications [47]. An antidote is readily available.

Diphacinone is generally considered the second-best option for rodent eradication [49], [15], offering lower hepatic (liver) persistence than brodifacoum but relatively high toxicity to rodents compared to rodenticides other than brodifacoum [47]. Mice require a much higher dose than rats[49], which would be a major disadvantage if mice were found to be present on Rakiura at any stage of the predator removal.

The 2007 review of rat eradications found only 2 out of 330 successful rat eradications used diphacinone baits alone in bait stations; both programmes were on islands less than 80 ha in size [14]. However, it has also been used successfully more recently for rodent eradications on the small (7–41 ha) San Jorge Islands (Mexico) [27] and on numerous small islands (0.8–112 ha) in the USA [12]. The largest successful rat eradication using diphacinone in bait stations was on the Isle of Canna (1126 ha) in 2008 [53].

The successful application of diphacinone baits in bait stations to eradicate rats has been largely confined to small areas, many times smaller than the HMB Project area. This track record combined with lower toxicity (requiring rats to have longer feeding times and multiple feeds to get a lethal dose and, possibly, more frequent checking of bait stations) means it carries a greater uncertainty of success compared with the use of brodifacoum. However, its potential efficacy for the HMB Project should be considered higher than that of trapping alone. It is registered for use in New Zealand with bait stations using cereal pellets and blocks.

Although this toxin has a lower risk of non-target impacts than brodifacoum, it is not as well studied and, under the precautionary principle, the non-target avoidance and mitigation methods outlined above for brodifacoum (such as muzzling pet dogs when walking them, or keeping cats indoors) apply equally to the use of diphacinone.

Trapping

Using trapping only for the complete removal of three species of rat over an area the size of the HMB Project Area (2150–4800 ha) is unprecedented and must be considered very high risk compared with the use of brodifacoum in bait stations and, to a lesser degree, using diphacinone in bait stations. The key elements for kill traps are that they catch effectively, kill humanely, are easy to use and maintain, and are light-weight, portable and cheap [54]. The three trap types that have met animal welfare standards are the Victor™ professional snapback trap, DOC150™ and DOC200™ traps. The Victor™ snapback traps are considerably cheaper and more lightweight but carry a risk of allowing large rats to survive and escape. All traps would be contained within a wooden box to avoid non-target captures.

3. Scenarios

Here we present the four scenarios we have examined for the removal of predators from the HMB Project area. We have divided the information into fixed operational requirements and variable operational requirements. For example, all options require an extensive network of routes to be marked and cut throughout the HMB Project area, but the mix of devices and toxins used is variable. All scenarios attempt to target all predators simultaneously or sequentially, providing targeting one predator does not risk the efficacy of targeting another. We consider each of these scenarios to have a realistic (but differing) chance of success using the current available technology and are not reliant on future developments in toxins or traps.

The scenarios presented assume two options for the HMB Project area, either 4800 ha or a smaller area of 2150 ha. The exact location of the proposed predator fence that makes up the western boundary is unknown, and some small islands will require treatment. The scenarios also assume the entire area would be treated in the same way, although this blanket approach is clearly not the case for dwellings around the township area (c. 700 ha). Individual property assessments would be required to accurately determine the total resourcing requirements for the township area. Whichever grid size is determined to be optimal for rodents (refer to section 3.1.3), it can be assumed that the same maximum spacings should be applied to the township area. Dwellings and built-up areas would require additional devices of varying kinds due to the differences in behaviour between commensal and wild rats; therefore, the total number of devices required may be underestimated in this paper.

Timing

Best practice suggests the timing of the rat removal phase should be from winter to early spring for wild rodents. This is when natural food availability is typically at its lowest, resulting in lower numbers of rats with no or low numbers of offspring in the nest (reducing the chance of young in the nest not eating bait), and increased attractiveness of the bait. Lower winter temperatures also reduce activity for many invertebrate and lizard species, which may help minimise their potential to be exposed to bait or toxin residues [17], [15]. This timing appears to be best for kiore and ship rats, which breed between spring and autumn [55], [56], but Norway rats breed all year round and appear to be most abundant in winter (lowest in summer) on Rakiura [8], [57]. Ship rats and kiore also appear to be most abundant in winter on the island [8], [57], although this pattern for all the rat species may reflect increased trappability in winter rather than actual increased abundance [58].

Feral cats and hedgehogs are likely to be breeding between spring and autumn [35], [30], while possums generally breed in autumn, but sometimes also in spring [59]. The greatest operational risk to the HMB Project is rats not being successfully removed, so appropriate timing for this part of the operation is critical.

Rat numbers periodically (every few years) peak to plague proportions on Rakiura due to high levels of rimu (mostly) fruit during mast periods [60]. Monitoring of rimu fruiting would need to be undertaken regularly in the years leading up to the predator removal phase to ensure the operation did not coincide with or immediately after a rimu mast event. Monitoring should continue after predator removal to identify high-risk years for rat incursion into the HMB Project area from the rest of the island.

Feral cats on Rakiura appear to be under nutritional stress through the summer months [8]. Rats formed 81% of their diet and seasonal depressions in rat abundance were found to limit cat numbers. Depending on the methods used, the removal of rats may reduce feral cat numbers, therefore feral cat removal should be timed for summer, after the main rat and possum removal phases. This approach may confer logistical advantages, as it would spread staffing requirements more evenly across the year.

3.1 Fixed operational requirements

3.1.1 Operational planning and infrastructure

Large complicated operations like the HMB Project require meticulous planning and implementation and robust peer review [17], [6]. Planning usually takes a number of years and may require several full-time staff.

Operational planning for the HMB Project will require:

- The development of a project plan outlining what needs to be done and an appropriate timeline.
- Early engagement and on-going consultation with Ngāi Tahu whānui.
- Early engagement and regular consultation with local residents and other stakeholders.
- Clearly defined 'stop/go' points which identify the critical factors that the project depends on to be able move forward.
- The development of a full operational plan including predator fence construction and biosecurity.
- The coordination of research and surveys to meet pre-operational information needs, including pilot trials (see section 4).
- The procurement of infrastructure, bait, bait stations/traps and human resources (and, once the project is finished, the removal of surplus infrastructure and bait/bait stations/traps).
- The development of individual property plans for private land (see section 3.1.2).
- Gaining of approvals and consents from an array of organisations. Such regulatory requirements are likely to include: Assessment of Environmental Effects (AEE), landowner and/or occupier consents, Resource Consent, public health permission and DOC permissions.

Infrastructure requirements would be likely to include an office, vehicle, and secure storage for toxic bait (new and used) in Halfmoon Bay that can be serviced by helicopter, as well as wash-down (decontamination) facilities. Storage would also be required for up to 19 700 bait stations or 24 700 traps (potentially significantly more or less depending on the grid density or size of the project area) and other project gear. During the main predator removal phase there may need to be over 100 extra people in Halfmoon Bay, and possibly considerably more under some scenarios.

To better understand the implications of delivering a project of this nature, consider that for the 4800 ha option a 50 m × 50 m grid with 19 700 bait stations being checked every 3 days would require 132 staff if each person checks 50 bait stations per day (see scenarios below in section 3.2). Assuming North Arm and Port William Huts (which can accommodate 24 people each) are closed to the public and available for the HMB Project over the main predator removal period, 84 staff would need to be accommodated in Halfmoon Bay for up to 2 months, as well as permanent staff and, potentially, specialist feral cat, hedgehog and possum follow-up teams. The number of staff would obviously vary considerably depending on the block option size, device spacing and the frequency with which each device needs to be visited (see section 3.2 for individual scenarios). Temporary secure storage (possibly shipping containers) for toxic bait (new and used) would also be required at North Arm and Port William Huts.

Accommodation on Stewart Island is tight in the peak (summer) season and many of the smaller providers close during the winter. There are approximately 62 commercial accommodation providers on the island, providing a total of 222 beds/rooms with a total maximum capacity of 552 people (during the summer season). The range includes backpackers, holiday houses, B&Bs, motels, hotel and small lodges, with the majority only able to accommodate less than 10 visitors (33 out of the 62), and only 6 able to accommodate more than 20 visitors [61]. Therefore, considerable planning will be required to accommodate the number of staff required for the HMB Project.

Such a large operation is likely to put additional pressures on the township infrastructure (e.g. rubbish disposal, sewerage, etc.) These pressures must be well planned for in advance with local residents and councils involved.

The following estimate of staffing requirements is provided as an indication of the size of the permanent team needed to carry out the HMB Project predator removal phase (note: this assessment does not include predator-proof fence construction and maintenance staff or biosecurity staff). Specific numbers would be identified as part of the full operational planning phase. It is assumed permanent staff would rent or purchase their own accommodation.

An indicative timeframe suggests the predator removal phase could take 2 years, with a monitoring phase of 1 year, resulting in total of 3 years before the project moved into an ongoing biosecurity phase. The planning phase could easily take another 3 years.

The size of the team required for the main field work phase (rat removal) depends on the operational area size (2150 ha or 4800 ha) and methods chosen (bait stations or traps, brodifacoum or diphacinone, 50 m × 50 m or 25 m × 25 m grid), as some are more labour intensive (for longer periods) than others. The plan needs to be as simple as possible, with staff having clearly defined roles and daily work plans. Therefore, a number of specialised teams should be used rather than training and/or recruiting all staff to do all tasks. For much of the work, specialist expertise would be required. Specialist teams should be employed for hedgehog and cat removal and for possum follow-up (possum knock-down via bait stations could be effectively done by the same team undertaking the rat work). A separate team would also be needed in the township area for rat work, as this programme would be complex and rely on staff building and maintaining excellent relationships with landowners. Last, a large team would be required for rat removal over the rest of the HMB Project area.

The full-time permanent staff requirements may include:

- Project Manager—to oversee the predator removal, predator fence and biosecurity work streams (6 years).
- Assistant Project Manager (predator removal/technical coordinator)—responsible for planning and execution of the predator removal phase, including pre-operational surveys and trials and human resources, including contract management (6 years).
- Logistics, procurement and infrastructure position—responsible for sourcing materials, goods and space required for the project (4 years).
- Geospatial analyst and computer systems/technology specialist—responsible for acquiring, refining and testing required hardware and software, GIS expertise, and information management systems (4 years). May require additional support during main rat removal phase.

- Consents, permissions and safety officer—responsible for acquiring all relevant consents and permissions and compliance with health and safety legislation (4 years).
- Township property action plan (PAP) and vessel plan officer—responsible for carrying out risk assessment and property action plan requirements on private land and all vessels and vehicles (4 years).

Boats would be required to access the many small islands requiring treatment around the HMB Project area. It is suggested that this work is done using local DOC staff or water taxi operators who have local knowledge of the coastline and conditions. It is not recommended that boats be used for regular movements of staff around the main HMB Project area to service the main bait station and/or trap network. This is because it would increase the level of operational risk when weather or sea conditions prevent access to the coast, particularly during critical phases of the operation. Furthermore, staff may get stranded if they are unable to be picked up due to adverse coastal conditions. Helicopter support would be required throughout the rat removal phase of the operation to deliver bait (and remove old bait) and supplies to the huts.

It is essential that field trials be carried out to inform the logistics of the operation and to better ensure its efficacy. Pilot projects are commonly carried out for operations of this size, particularly where the methods (type or scale of application) are not well tested against the target species (e.g. The Langara Island (3100 ha) operation in 1995 studied rat density and distribution on site and piloted their methods on a nearby island before proceeding [23] (see section 4)). As a comparison, the bait station operation to eradicate Norway rats on Langara Island was based on a 100 m × 100 m grid and had 60 staff (30 bait station operators, 30 management, technical support and research) during the baiting phase of the operation [23]. Bait stations were checked every second day.

3.1.2 Township

Successful rat removal requires toxic baits and/or traps to be placed in every domestic structure and area associated with human inhabitants. Ensuring complete coverage is a major challenge, as it interferes with people's privacy and may present a hazard to domestic animals. Access issues that cause delays or an inability to treat all potential predator home ranges (particularly those of rodents) may pose an unacceptable risk to the success of the HMB Project. Therefore, a high level of community support from local residents is required for a project like the this to proceed [5]. There are about 400 local residents and 186 dwellings plus other buildings within the HMB Project area. The settlement covers approximately 700 ha, with a further 1600 ha of private land surrounding the township.

Although we have not distinguished between the Halfmoon Bay township and the rest of the HMB Project area in the methods and scenarios presented here, removal of predators from the township area poses a unique set of planning challenges. Commensal rodents need to be treated differently to wild rodents, as dwellings and residential activities provide significant additional food and shelter (e.g. houses, woodsheds, rubbish/compost, chicken houses etc.) The treatment of commensal rodents in the HMB Project is essentially a separate exercise to the treatment of the wild rodent population, and would begin earlier and finish later than field work for wild rodents. In order to increase the number of bait types available for alternating, consideration should be given to the use of 'over the counter' anticoagulant rodenticides which could be applied for commensal rodents under current labels (i.e. approved pesticide uses).

The best scenario for individual properties would be for property/business owners to develop their own (robust) plan for eliminating predators and for monitoring and surveillance in conjunction with the HMB Project team. Staff/contractors of the project would carry out the work on private property to ensure consistency of effort and reporting. Inadequate coverage of predator removal methods for commensal rodents is a high risk area for the project and expert assessment considered that asking individual property owners or occupants to carry out the work would introduce additional risk of the project failing.

Best practice for rodent eradication using bait stations requires bait to be applied in, around, and, where practical, under all buildings in all parts of the building (e.g. cellars, attics etc.). Baiting in buildings should be done following the label instructions of the rodenticide formulation being used. Baiting in buildings would need to commence before and continue long after the application of bait elsewhere in the HMB Project area (although checks could reduce in frequency). On islands with permanently occupied human habitation like Rakiura, baiting in buildings should continue for 6 months or longer after baiting has stopped elsewhere [15] due to the increased risk of rats surviving in buildings where they have good shelter and food opportunities. It is also recommended that the removal of commensal rodents start 3–6 months before field operations for wild rodents commence to ensure contractors achieve coverage of private property before they begin the main predator removal phase.

There would need to be plans for checking and removing rodents from vessels moored within and/or regularly entering the HMB Project area. All vehicles on the island would also need to be inspected during the predator removal operation. Teams operating around the township would need to coordinate access to private property to minimise disruption for local residents. Technical advice to the PFR Governance Group recommends the use of glue-board traps to target commensal rodents in hard-to-reach places, as these may be a critical alternative method in targeting any rodents that have not consumed bait. These devices are prohibited due to animal welfare considerations; however, exemptions can be sought from MPI under special circumstances. We recommend an exemption be sought and that their use be carefully managed.

Property survey, risk assessment and individual action plans

Input from and participation of all permanent and part-time residents and businesses on Rakiura is critical to the success of any predator removal project. Residents' opinions around some key aspects of the project have been sought and should continue to be sought. In the event that the project proceeds, engagement should include continued assessment of the biosecurity measures after the predator removal phase has been completed. Information flow to all residents needs to be reliable and ongoing.

For the predator removal phase, property survey and risk assessment would involve the development of individual property risk assessments and action plans. These action plans should be agreements between the PFR Governance Group (or appointed agency / management group) and individual property/business owners on how the project would be undertaken on each property. Property Action Plans (PAPs) should be developed to ensure the project can be effective and safe and would be used to assess the following: what predators are encountered regularly on the property, previous predator control undertaken, particular risk areas, and individual preferences for predator removal within a range of effective options. PAPs would undergo expert review to ensure efficacy. PAPs that did not meet the appropriate standards would not be endorsed and would require revision. The following list[16] (not exhaustive) illustrates some of the issues PAPs should address:

- Existing predator control methods, including the use of common shop-bought rodenticides, some of which contain brodifacoum, but also other anticoagulants not registered for field use. Many shop-bought rodenticide baits contain higher levels of anticoagulant toxin than those used for field application and therefore may present higher residue risks.
- The best ways for residents to control rats in the lead-up to the predator removal operation.
- Methods to be used and how and where devices will be placed on each property (including residences, outbuildings, gardens, and pens/enclosures of domestic stock and other pets) during the predator removal phase.

[16] Adapted from [50].

- How pets will be managed during the predator removal phase and, for domestic cats, during the confirmation of removal phase.
- How to ensure the health and safety of all family members and pets during the predator removal phase.
- How to deal with food waste, compost and waste disposal in the lead-up to, and during, the predator removal phase.
- Other actions to contribute to the success of the predator removal operation.
- A point of contact for information flow.

The removal of predators from the HMB Project area would have a much greater chance of success if access by predators to alternative non-natural food sources is reduced during the predator removal phase. This criterion is particularly important in the Halfmoon Bay township area. The list below[16] (not exhaustive) shows ways in which residents are likely to be asked to help, including:

- Cleaning up poultry pens.
- Stopping composting prior to the operation.
- Removing food scraps from areas used by domestic animals.
- Storing feed for domestic animals in rat-proof containers and cleaning up spills.
- Taking care in waste disposal.
- Storing edible dry goods in rat-proof containers.
- Storing linen and excess bedding in rat-proof containers or cupboards.
- Keeping doors and cupboards closed when they are not in use.
- Tidying up other possible refugia.

Island residents should be asked to grant permission for HMB Project staff/contractors to do the work and suitable access arrangements would be made. The Darwin's barberry eradication project, initiated in 2001 and run by DOC staff on Rakiura, is a testament to the high level of acceptance by the community for conservation programmes directly affecting individuals and householders on the island.

Regular reporting on exactly what is undertaken in each building would be essential and all work would, ideally, be subject to regular auditing to ensure the highest chance of project success. Reporting would be via the person in the HMB Project technical coordinator role, who would manage the data. Although HMB Project staff would carry out the trapping and/or poisoning around the township, residents would still play a vital role in monitoring rat activity during the predator removal phase and in perpetuity with ongoing biosecurity [3].

Monitoring during the predator removal phase would include:

- Monitoring bait take.
- Checking for rodent sign (e.g. droppings) at bait stations or at sites where baits have been placed.
- Cleaning up all rat droppings carefully so that any fresh droppings will be easily seen.
- Checking for other signs of rodent (including mice) activity regularly and reporting any findings to the HMB Project team.

The PAP process prior to the predator removal phase would involve developing risk assessment and survey requirements, writing of PAPs, establishing and maintaining a property/business owner database, and expert review of action plans to ensure efficacy. PAPs would need to be designed as part of the full operational planning phase alongside the proposed pest-free warrant process outlined for biosecurity in dwellings in [3]. A permanent position is allocated in the finance paper [4].

3.1.3 Grid

All of the scenarios presented in this paper require an extensive systematic network of routes to be marked and cut between devices (bait stations and/or traps). The critical variable for the removal methods is the maximum allowable spacing (distance) required between devices. The fundamental aim would be to establish a device within the territory of every individual of every target species, and maintain enough fresh bait for as long as it takes for every individual to consume a lethal dose of toxin or be killed in a trap. Therefore, knowing the minimum home range size of the target species is particularly important, as every individual from the species with the smallest home range (kiore) must encounter at least one appropriate device.

For Norway and ship rats, a 50 m × 50 m grid would be sufficient to expose all individuals to kill devices. Successful island eradications of kiore have used bait station spacings of 50 m on small islands (e.g. Korapuki (18 ha) and Motuara (59 ha)) [62], but kiore have a smaller home range than the other two rat species present and it is possible that a smaller grid (25 m × 25 m or 25 m × 50 m) may be required to confidently expose all individuals to kill devices [15] [11]. Devices would also have to be run for longer due to interspecific competition between the rat species and intraspecific competition within a species' population. Larger rat species (e.g. Norway rats) would exclude smaller rats (e.g. kiore or subdominant individuals from the same species) from kill devices until the number of larger animals decreases substantially.

The grid network should be able to be established using GIS (Geographical Information System) software to overlay a grid onto the HMB Project area and create a GPS waypoint for each grid point and GPS tracks in between them. The grid waypoints and tracks can then be loaded into GPS units for staff (route/grid markers and cutters) to follow, provided GPS accuracy is always ≤8 m in the field. A three-dimensional (3D) terrain model of the HMB Project area created in GIS software should be used (rather than a flat 2D grid). This approach generates a more accurate assessment of the number of devices required at the operational planning phase and decreases the risk of inaccurate spacing and gaps between devices due to steep terrain.

The grid network would need to be marked first (including marked and field-GPS'd device locations), and then checked using GIS to assess any potential gaps in the network. Routes between devices would then be cut. The distance of route to be established would be dependent on whether or not the grid needs to be accessed for work from all directions. For example, if only the vertical North-to-South (or horizontal West-to-East) lines are cut, then the amount of route marking and cutting required is half that required if both vertical and horizontal lines[17] are marked and cut. The workings and estimates for this report assume routes will only be cut vertically or horizontally.

We have based our calculations on two grid dimension sizes for the purpose of estimating costs. Further research into rat home ranges under rat removal scenarios and field testing to establish the optimal grid size should be carried out on Rakiura close to, but not within, the HMB Project area (see section 4). Larger grids confer significant cost savings. For example, in an area of approximately 5000 ha, a 50 m × 50 m grid requires roughly 1000 km of route and 20 000 devices compared with a 25 m × 25 m grid which requires roughly 2000 km of route and 80 000 devices. However, a 50 m × 25 m grid doubles the number of devices of a 50 m × 50 m grid (40 000) but still only requires 1000 km of route to be marked and cut.

The grid would need to be permanently marked and labelled in the simplest way practicable. Additional marking would be required for devices that target possums. Once the grid is established, the HMB Project area should be divided into workable blocks and devices deployed. Baiting should begin a minimum of 2 weeks after the bait stations have been deployed [15] and the same is likely for traps. Traps should be left unset inside the boxes (rat traps) or on the tree (possums). Note that bait stations were in place for 2 months before poisoning began on Breaksea Island [22].

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[17] Drawn in two-dimensions.

Modified Philproof™ bait stations with internal spikes should be used, as these devices allow possums and rats to be targeted at the same stations. They also allow for cereal pellet baits to be subsequently replaced by secured blocks. The Novopipe™ type station (0.5 m long and 100 mm in diameter with opening on top) used successfully on Breaksea and Langara Islands (and many others) could be used in between Philproof™ bait stations if a smaller than 50 m × 50 m grid spacing is required. These bait stations were the type most attractive to ship rats in a 2007 study of four different types of bait station [63] and could be manufactured to be stacked and thus more easily moved around. Trap types are discussed in Scenario 4 (section 3.2.4).

The establishment of such a large grid will undoubtedly have environmental effects on the ground cover of the area through the necessary clearing of some low-to-medium-height vegetation to establish the routes and persistent trampling by people walking the grid. Routes have to be cut to a certain level to make the grid accessible. This impact is one of the disadvantages of ground-based methods.

3.1.4 Data capture for adaptive management

GPS and GIS capability should be utilised extensively to ensure complete coverage of devices and search methods (e.g. predator indicator dog teams). All field team members should carry a handheld GPS with 'tracking' on all day every day. Track logs and data should be downloaded to computer and backed up to an external hard drive and preferably cloud storage every night.

The Langara Island operation in 1995 monitored progress through an electronic database using GIS software. Maps showing active stations and the changing status of the rat population were regularly returned to the crew supervisors. The database was updated daily from bait station operator records [23].

The information management requirements of the HMB Project should not be underestimated. For example, data for the 4800 ha option data would need to be entered and analysed for a minimum of approximately 19 700 devices every 3 days (6567 devices per day) at the height of the predator removal phase. The plans and processes for managing this amount of data would require field testing before the operation begins.

On San Nicolas Island, the integration of field-hardy handheld computers with integrated GPS and custom databases facilitated the acquisition, management and interpretation of large amounts of data [9]. Such electronic devices should be investigated for use in the HMB Project, although for the main rat removal phase it may be more cost-effective to simply pay extra staff to enter data from notebooks into a laptop each night. This information could then be saved to a cloud service (internet capabilities would be required) and then accessed by the main base for analysis. Staff and contractors must illustrate full proficiency in the use of these electronic devices and backups must be available if devices fail.

GIS should be used to map bait take and all other aspects of the operation in the field to enable an adaptive management approach to be applied where appropriate. A specialist GIS analyst should be employed or contracted for the duration of predator removal project and be involved in operational planning to maximise the efficient use of this tool and advise on hardware and software requirements. Project managers and GIS specialists should agree on what data needs collecting and analysing, what form it is to be reported on, and to whom, for the duration of the predator removal phase. This reporting includes monitoring and data capture of all individual PAP actions and results every 3 days during the predator removal phase. Equipment and systems would require rigorous testing before the main operation begins. One full-time position is allocated in the finance paper [4] for data management and GIS expertise.

3.1.5 Predator detection dogs

Detection dogs which find and indicate target animals (but do not attack or kill them) are a critical component of a predator removal operation of this scale, and were used extensively and successfully on Rangitoto/Motutapu Islands for the removal of several predators [18] and in many other operations. Specialist detection dogs are used more at the follow-up and monitoring phases of predator removal operations, but may be required earlier for some target species. For the HMB Project predator removal phase the following needs for detection dogs are envisaged:

- In a pre-operation hedgehog distribution survey.
- During the knock-down phase for hedgehogs (and feral cats if no toxins are used on rats).
- In the follow-up removal and monitoring phase for rodents (including mice), feral cats, possums and hedgehogs.

There are several options available to the HMB Project for employing dog teams: dog handlers purchase and train dogs, trained dogs are supplied to the project (and suitably experienced staff are appointed as handlers), dog teams are contracted for short terms, and existing expertise within the DOC Conservation Dogs Programme is used[18]. Lead-in time for dog and handler training can be 2–3 years, so operational planning for the HMB Project would need to identify specialist dog and handler needs very specifically and ensure the expertise will be available when required.

For rodents we have estimated that one predator dog team can effectively hunt 50–60 ha per day [20]. A full sweep of the larger (4800 ha option) area over 30 days would require three dog-handler teams. Several sweeps may be required (we have estimated three full sweeps). Dog teams hunting for feral cats and possums should be able to cover more ground due to the higher detectability and/or range of these animals. Rodent, feral cat, hedgehog and possum dog handlers are all costed at contract rates, although it may make sense to employ staff full time for the rodent dog-handler roles depending on biosecurity requirements.

3.1.6 Post-operational monitoring

Post-operational monitoring to enable the predator removal project to be declared successful would begin 2 months after the last confirmed presence (individual is killed or sign of individual seen) for each species. The period of post-operational monitoring depends on the result targets for the project (earlier we suggested that 1 year may be appropriate). Once the result targets have been met, the post-operational monitoring phase is complete and biosecurity surveillance begins. After this time the detection of an animal (one of the target species) is considered an incursion and responded to as such [3].

Monitoring for the presence of rodents (including mice) should begin once the rat removal phase is thought to be complete (when there is no more bait-take from bait stations). Widespread placement of chew cards, use of specialist predator-detection dogs, and some rodent tracking tunnels would be the main methods used for detection of rats (or mice). Normally, two rat breeding seasons would be enough time to allow rat populations to build up sufficiently to be detectable if present [15]. However, as discussed earlier, a 1 year post-operational monitoring period may be more appropriate given the likelihood of rodent incursion and that the response to a detection would be identical for either survivors or new incursions of rats.

Detection methods to find and remove the last feral cats and confirm successful removal are crucial to the project. Ideally, some of the detection methods would differ from the predator removal methods so that use of these tools is not compromised by any aversion induced in the animals [9]. Commonly used methods are searching for sign (footprints, latrines, scat, prey remains), trapping, spotlighting, track pads and dogs. Other detection tools include camera traps, baiting, audio and olfactory attractants, hair snares and local residents reporting sightings. Telemetry-based trap monitoring systems which allow trappers to know which individual traps have been sprung have been used recently on San Nicolas Island. This approach yielded greater efficiency in fulfilling checking requirements for cat traps, thus saving staff time, and improved animal welfare standards by allowing quicker removal of trapped animals [9]. For Rakiura, the

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[18] Sandy King, pers. comm. 26 September 2014.

presence of roaming domestic cats within the HMB Project area would compromise the use of some of these tools during this phase. Therefore, the period of confinement or temporary removal of domestic cats from the island should include this phase as well.

Monitoring to confirm the presence of possums would use a combination of chew cards, trap catch monitoring, wax tags and extensive searching by indicator dogs. Confirming the absence of hedgehogs could be achieved by checking for absence in traps and tracking tunnels, and extensive searching with detection dogs. Dogs should be used for 1 year following predator removal to cover the areas between detection devices and island incursion contingency measures should be implemented for any detections.

Variables to be considered when declaring predator removal successful include length of time with no detections, search effort, effectiveness of biosecurity and the urgency for confirmation of success [15]. Although a result target has been suggested in this paper, the operational plan would define the result target and therefore what constitutes success and when it occurs.

A predator removal campaign would only provide long-term benefits if the target species do not re-colonise the operational area. When it is unclear whether individuals have survived an eradication or predator removal campaign, or arrived in the months after the campaign, the cause of failure becomes ambiguous. Therefore, strict biosecurity measures are essential to the evaluation of the outcome of this operation. These measures need to be in place and rigorously tested by everyone before the start of the operation [3].

3.1.7 Post-operational logistics

Considerable work would need to be done after the predator removal operation is completed. This may include the removal of some or most of the bait station or trap network, disposal of leftover toxic baits, and the completion of operational reporting requirements.

It is likely that a permanent island-based staff would be required to maintain the predator fence, monitor biosecurity devices and respond to any incursions.

3.2 Variable operational requirements

As indicated, further preliminary work on the home range size for each of the three rodent species will be needed to determine the best grid size for the HMB Project area. In the following scenarios we have costed the work based on both a 50 m × 50 m and 25 m × 25 m grid. These are considered the likely grid sizes that will be required.

3.2.1 Scenario 1—Bait stations with second generation anticoagulant (brodifacoum) toxic baits for rats

The first scenario (and the one most likely to succeed) uses bait stations filled with brodifacoum in cereal baits to target rats across the HMB Project area. Rats should be initially targeted with 10 mm cereal pellet bait Pestoff Rodent Bait 20R™ with a 0.02 g/kg toxic loading. The modified Philproof™ bait stations with internal spikes should be used to deliver bait so possums can be targeted with the same bait stations, and to allow bait change from cereal pellets to secured blocks. Possums would be targeted first as described in section 2.4.5.

Possum knock-down would be achieved using Feratox™ pellets in a pre-feed cereal pellet matrix in bait stations at 100 m spacings. Bait stations would then be filled with brodifacoum cereal pellet baits (as above) to target rats on the grid. This method would further reduce possum numbers (via primary poisoning) and knock down feral cats (via secondary poisoning). Bait stations would need checking and refilling every 3 days for up to 1 month or more, depending on bait take. Once bait-take starts to reduce, checks would be every 7–10 days, then once per month with reducing quantities of bait. Brodifacoum bait should be changed from cereal pellets to blocks (Pestoff Rodent Blocks™ with 0.02 g/kg toxic loading), secured in the bait station, when monthly checks begin. Block bait lasts longer and has the advantage that rat chew marks can be seen on the bait, indicating that rats are still present. Blocks would also be novel bait for any surviving rats that may have an aversion to the cereal bait. Each bait station should remain baited for at least 1 month after the last evidence of rat bait take or suspected bait take.

Using brodifacoum as the toxin is highly likely to have the greatest secondary poisoning effect on feral cats of the four scenarios. Feral cats would then be targeted after the main rat removal phase for follow-up removal using predator dogs, leg-hold and cage trapping, 1080 and PAPP baiting, and spotlight hunting (as described in section 2.4.4). Possums remaining after the knock-down phase may also succumb to brodifacoum via primary poisoning (i.e. eating the rat bait). Follow-up possum removal would follow using predator detection dogs, Feratox™ strikers, leg-hold trapping and spotlight hunting as described in section 2.4.5. Follow-up possum removal would begin once the main rat knock-down is complete (i.e. when rat bait changes from cereal bait to blocks). Unless removed separately from the main HMB Project, hedgehogs would be removed throughout the predator removal period using predator detection dogs, leg-hold and kill trapping, and spotlight hunting (as described in section 2.4.3).

Very steep areas (i.e. where slopes exceed 50°) over 25 m in vertical height need to have additional or specialised treatment. Consideration of how bait could be placed in adequate density on steep cliffs would be required and, if necessary, methods trialled to position bait as far as possible up, down or across cliff areas [15]. For larger cliff areas (where all other options may leave gaps of more than 25 m × 25 m for rats), abseiling to service bait stations may be an option, or consideration should be given to localised hand broadcasting (although this method has been discounted for the main operation).

It is estimated that twenty rounds of toxin checks will be required to complete the rat removal: 1 month of 3-daily checks (10 checks, cereal bait), 1 month of weekly checks (four checks, cereal bait) and 6 months of monthly checks (six checks, block bait). Best practice suggests changing all the bait every 2 weeks to maintain bait palatability (or more often, if required). This method is particularly important for the cereal pellet Pestoff Rodent Bait 20R™ which is considered a short-life bait, whereas bait palatability should be maintained for longer in the long-life Pestoff Rodent Blocks™ which should remain highly effective for the period between the monthly checks [64], although this will require close monitoring and more regular bait changes if bait begins to deteriorate.

In this scenario, and those following that use toxic baits in bait stations to target rats, we estimate the amount of cereal pellet bait required for each bait station as follows: 1 kg for the first fill, 0.5 kg for each full bait replacement, 0.2 kg for each other check. The amount of block bait required is estimated at three blocks per station (approximately 0.1 kg). We estimate that staff/contractors could check and refill 50 bait stations per day in the 50 m × 50 m grid. Note: staff logistics are likely to be complex, so for the purpose of costing labour for each bait station check, in the finance paper [4] we use a rate of $7.50 per bait station for the 50 m × 50 m grid and $5.00 per station for the 25 m × 25 m grid.

For the 4800 ha project option, the number of bait stations required is roughly estimated to be 19 700 for a 50 m × 50 m grid and 78 000 for a 25 m × 25 m grid. At each check, every bait station needs careful counting of baits and checking for rat sign. We estimate that in a Rakiura winter, when daylight hours are minimal, checking and refilling every bait station (on rotation using the maximum days available and minimum amount of staff) on a 50 m × 50 m grid every 3 days would take 132 staff; every 7 days, 56 staff; and once per month, 13 staff. To check and refill every bait station on a 25 m × 25 m grid every 3 days would take 520 staff; every 7 days, 223 staff; and once per month, 52 staff.

Caution period

Use of brodifacoum would, at least for the predator removal phase or as long as the toxin is in use, have a caution period of 36 months after the last date of bait removal. This caution period would preclude commercial hunting of deer for human consumption within the HMB Project area and within a 2 km buffer surrounding the area (i.e. beyond the predator fence; see Figs 2 & 3). Recreational trophy hunting would not be restricted provided it was safe (i.e. people were not working in the area). Recreational hunting for meat would be strongly inadvisable but not illegal, provided it was safe (i.e. people were not working in the area).

Required licences and consents

The use of brodifacoum cereal pellet baits in bait stations (specifically Pestoff Rodent Bait 20R™) on public conservation land is restricted to un-stocked islands or predator-fenced mainland sites for the purposes of rodent eradication [38]. The DOC Performance Standards for this pesticide use state that uses other than on un-stocked islands can follow the approved Code of Practice for aerial and hand broadcast of this pesticide [65], which allows for use in 'Specified Areas' such as islands, predator-fenced mainland sanctuaries and predator-fenced peninsulas. The HMB Project could qualify as a predator-fenced peninsula.

Therefore, a key decision point for the type of brodifacoum bait used on public conservation land is whether the operation qualifies as a one-off island eradication or mainland eradication behind a predator fence. If the operation qualifies, then Pestoff 20R™ cereal pellet bait can be used. If not, then DOC policy states that captive bait (i.e. bait blocks) secured in bait stations must be used [66]. However, this restriction is open to exemption on a case-by-case basis. Clarification would need to be sought on this subject.

3.2.2 Scenario 2—Bait stations with first generation anticoagulant (diphacinone) toxic baits for rats

Scenario 2 uses bait stations filled with the first generation anticoagulant diphacinone to target rats across the HMB Project area. Scenario 2 carries a higher risk of operational failure than Scenario 1; however, the key advantage of diphacinone is that it is less toxic and less persistent in the environment than brodifacoum [47]. Diphacinone has an overall higher failure rate in rodent island eradications worldwide [49], probably because its lower toxicity requires rodents to consume more to get a lethal dose, thus requiring multiple feeds. Diphacinone lacks the secondary poisoning advantages towards feral cats that brodifacoum has, but this difference also means there would be a lower risk to non-target animals. Rats require multiple feeds of diphacinone to get a lethal dose, so the baiting operation would require more regular checking of bait stations and may have to run for a longer period, with higher associated costs and a greater impact on the vegetation and ground along marked routes.

Diphacinone is not registered for possums in New Zealand (i.e. its use for this purpose is prohibited), as possums need to consume vast amounts of the toxic baits to get a lethal dose. Therefore, if diphacinone was used to target rats in the HMB Project, possums would have to be targeted first using Feratox™ pellets in a pre-feed cereal pellet matrix as detailed in section 2.4.5.

Following possum knock-down, bait stations would be filled with diphacinone to target rats. Diphacinone would not provide further knock down of possums (unlike brodifacoum) and any knock down of feral cats (via secondary poisoning) is likely to be significantly less than if brodifacoum was used.

Rats should be initially targeted with 10 mm cereal pellet Pestoff Rat Bait 50D™ baits with 0.05 g/kg toxic loading. The modified Philproof™ bait stations with internal spikes should be used to deliver bait so possums can be targeted with the same bait stations as rats and allow for a bait change from cereal pellets to secured blocks.

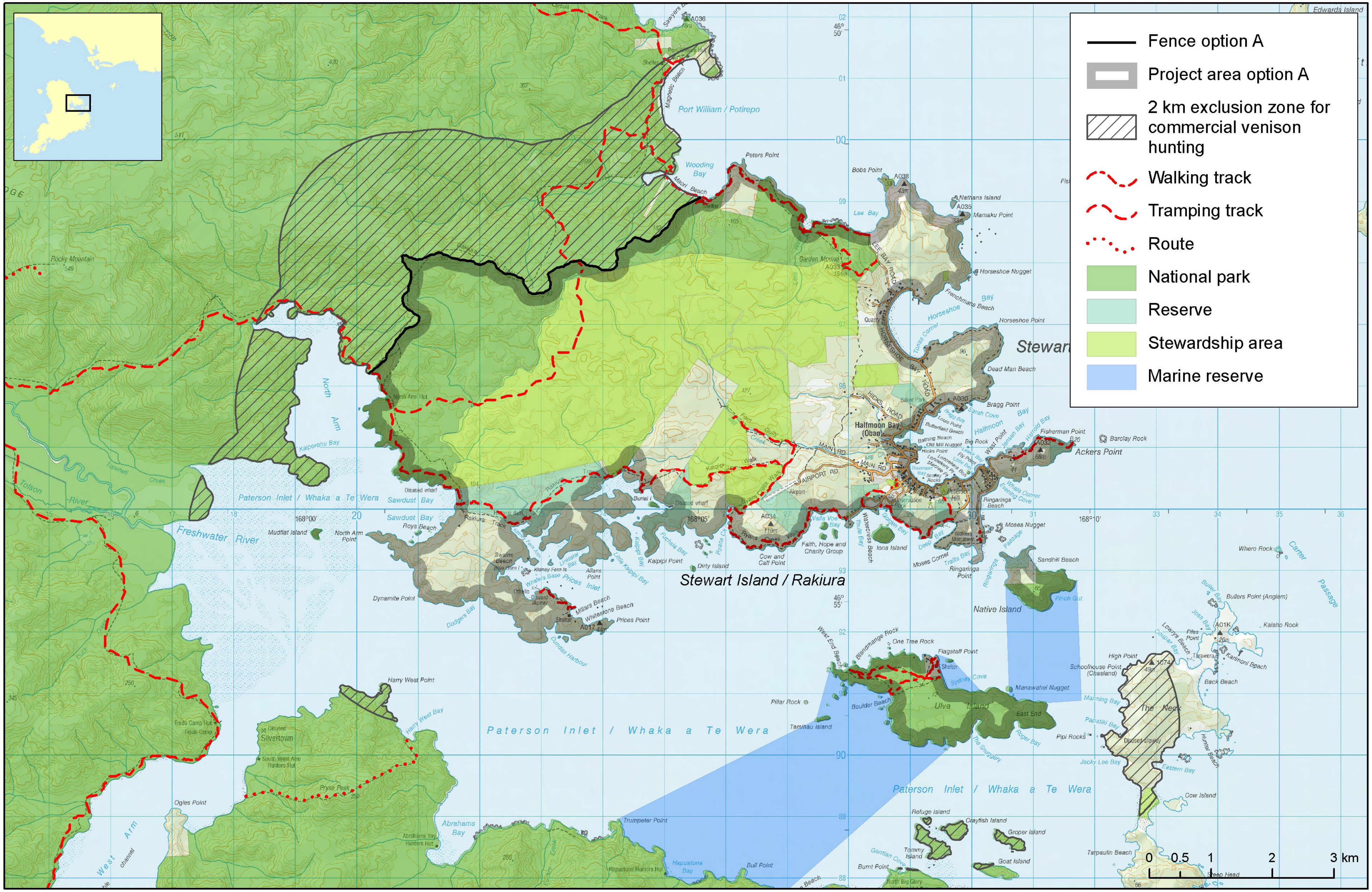

Figure 2. Halfmoon Bay (HMB) Project area showing location of predator fence for Option A (4800 ha) and 2 km exclusion zone for commercial venison hunting.

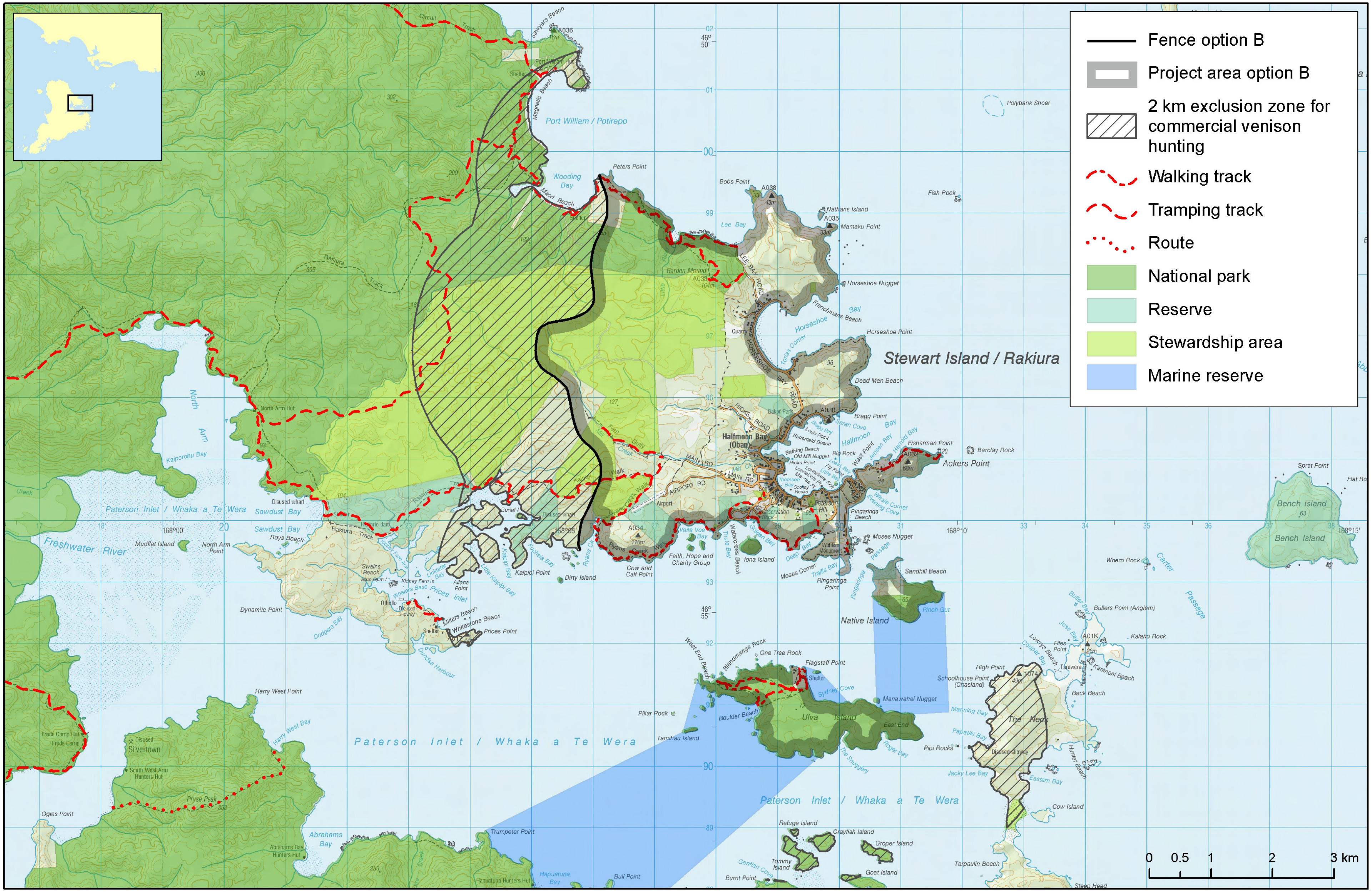

Figure 3. Halfmoon Bay (HMB) Project area showing location of predator fence for Option B (2150 ha) and 2 km exclusion zone for commercial venison hunting.

Feral cats would then be targeted after the main rat removal phase for follow-up removal as described for Scenario 1 and in section 2.4.4. Follow-up possum removal would proceed as described in Scenario 1 and section 2.4.5 and could begin straight after possum knock-down. It is likely that additional effort would be required for feral cats and possums, compared with using brodifacoum, due to the lower additional primary and secondary poisoning effects on these species using diphacinone. Unless they are removed separately from the main HMB Project area, hedgehogs would be removed throughout the predator-removal period as described in Scenario 1 and section 2.4.3.

Bait stations would need checking and refilling every 3 days for 5–6 weeks or more depending on bait take. It is critical that bait stations do not run out of diphacinone baits while rats are still feeding from them, so a regime of checking every 2 days for the first 3 weeks, then moving to every 4 days for the next 3 weeks (depending on bait take) may be more appropriate (this regime would increase the number of staff required for the first 3 weeks). Once bait take declines, checks would be every 7-10 days, then once per month with reducing quantities of bait. Diphacinone rat bait should be changed from cereal pellets to blocks (D-Blocks with 0.05 g/kg toxic loading), secured in the bait station, when monthly checks begin. Block bait lasts longer and has the advantage that rat chew marks can be seen on the bait indicating that rats are still present. Blocks would also be novel bait for any surviving rats that may have developed an aversion to the cereal baits.

The same issues with the application of bait in very steep areas (i.e. slopes exceeding 50°) over 25 m in vertical height as described for Scenario 1 apply equally to this scenario and the following scenarios.

It is estimated that 24 rounds of toxin checks would be required to complete the rat removal: 6 weeks of 3-daily checks (14 checks, cereal bait), 1 month of weekly checks (four checks, cereal bait) and 6 months of monthly checks (six checks, block bait). Best practice suggests changing all the bait every 2 weeks to maintain bait palatability. Like the brodifacoum bait formulations, the block bait should maintain palatability and effectiveness for the period between monthly checks, although it would need monitoring to ensure that this was the case.

As with Scenario 1, it is difficult to estimate bait take and therefore the amount of bait required for this scenario. At Ka`ena Point (20 ha) in Hawai`i, the total diphacinone bait take by ship rats and mice was 0.85 kg per bait station on a 25 m × 25 m grid [25]. However, the Ka`ena Point project also used snap traps in between bait stations and the HMB Project has three species of rat, so if total take is estimated at 1.5 kg per bait station, then approximately 30 tonnes of bait would be required on a 50 m × 50 m grid in the 4800 ha area.

The estimates for diphacinone bait take use the same projections of bait take as Scenario 1 (brodifacoum). The key difference between Scenarios 1 and 2 is that under Scenario 2 diphacinone must be available at every bait station for several feeds in a row for rats to consume a lethal dose. In Scenario 1, brodifacoum is lethal after one feed with current formulations. Therefore, using diphacinone rather than brodifacoum increases the amount of bait required and extends the rat knock-down phase and increases the cost of the operation [4].

Caution period

Use of diphacinone would, at least for the predator removal phase or as long as the toxin is in use, have a caution period of 5 or 6 months after the last date of bait removal. This caution period would preclude commercial hunting of deer for human consumption within the HMB Project area and within a 2 km buffer surrounding the area (i.e. beyond the predator fence; (see Figs 2 & 3).

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[19] Meeting of 6 and 7 August 2014, Department of Conservation, Invercargill.

Recreational trophy hunting would not be restricted provided it was safe (i.e. people were not working in the area). Recreational hunting for meat would be strongly inadvisable, but not illegal, provided it was safe (i.e. people were not working in the area).

3.2.3 Scenario 3—Bait stations with second generation anticoagulant (brodifacoum) toxic baits for rats, except around Halfmoon Bay township (diphacinone baits to be used here)

Scenario 3 is essentially a mix of scenarios 1 and 2 above. The main part of the HMB Project area would use bait stations with brodifacoum toxic baits as in Scenario 1, but in more sensitive areas (e.g. the area around the Halfmoon Bay township—700 ha), bait stations with diphacinone toxic baits would be used as in Scenario 2.

The advantage of Scenario 3 is that it reduces the amount of brodifacoum put out into the HMB Project area, lessening the overall risk to non-target species. For example, a 2 km buffer around the township where diphacinone was used instead of brodifacoum would reduce (but not eliminate) the risk of secondary poisoning of domestic cats. The disadvantage of Scenario 3 is the higher risk of operational failure presented by using the less-potent diphacinone, and the greater cost to the operation than using brodifacoum alone. The amount of extra cost would depend on the size of the area for which diphacinone is used, as more bait has to be applied for longer in that area.

The use of diphacinone around the township would not reduce the impact of the 36 month brodifacoum caution period applied to commercial and recreational meat hunting, as the caution would also apply within a 2 km buffer around the area containing brodifacoum and this buffer area would likely reach the township.

3.2.4 Scenario 4—Traps only (no toxic baits)

In this last scenario (4), toxic baits are not used for any of the target predators in the predator removal phase. It is imperative to note, however, that using the approach outlined in Scenario 4 would not preclude the use of toxins for subsequent incursion response and biosecurity [3]. The reality is that toxic baits are already being used on Rakiura to control rodents around private houses and buildings, and any incursion response would require toxins to be available as response tools.

We consider Scenario 4 to be the most operationally risky of the four scenarios, primarily because of the lack of proven eradication technologies using traps alone for rodents over large areas. There is considerable difference of opinion among technical experts as to whether this option should even be considered achievable with current technologies, as most consider it to have a high risk of failure.

Trapping has a higher risk of creating device aversion in target animals if traps are not set correctly or maintained properly. Animals quickly become un-trappable if they have a scare but are not killed upon entering a trap, or see another animal alive in a trap (e.g. feral cat in cage traps). Trap devices may require maintenance at more regular time intervals than bait station devices, which compounds the on-going costs of the project.

To ensure every trap is available for as much time as possible, traps (even those that kill rather than restrain an animal) require daily checking for the initial knock-down period. When set, leg-hold traps require checking and clearing every day to meet animal ethics standards required by law. It is possible that trapping for rats would require a smaller grid than that required for bait stations; our technical working group[19] suggested a 25 m × 25 m trapping grid is more likely to be required than a 50 m × 50 m grid.

[19] Meeting of 6 and 7 August 2014, Department of Conservation, Invercargill.

Effective traps are available for all target species. Rats could be targeted with kill traps (DOC200™'s in wooden boxes, or Victor™ professional snapback traps in wooden boxes baited with peanut butter and/or chocolate buttons). This report presumes that DOC200™ traps in wooden boxes would be used due to the risk of survival and escape of large Norway rats using snapback traps. Possums could be targeted primarily with kill traps (Trapinator™ or Sentinel™) on the grid at 100 m × 100 m spacing. Trapinator™ traps would be preferable, as they are generally considered to be easier to use by a wide range of people.

A key difference between Scenario 4 and the other three scenarios is that possums are targeted simultaneously for knock-down with rats in Scenario 4, rather than prior to rat removal under the three toxic bait scenarios. Another difference is that it takes longer to deploy trap devices in wooden boxes (i.e. rat traps) than the lighter-weight and stackable bait stations. The same issues with the application of bait in very steep areas (i.e. slopes exceeding 50°) over 25 m in vertical height described for Scenario 1 apply equally to the deployment of traps in this scenario. It is likely that these areas could not be trapped and that they would need to be poisoned (for rats).

The trap knock-down period for rats would be expected to take 7–12 days with daily checks (cost estimates are based on 10 days), then follow-up for 3 months of weekly checks (12 checks) and 3 months of fortnightly checks (6 checks); a total of 28 checks. Possum knock-down follows the same routine of checks as for rats, then follow-up using predator detection dogs, leg-hold trapping and spotlight hunting. Feral cats would primarily be targeted with Victor™ 1.5 leg-hold soft-jaw traps, cage traps, spotlight hunting and predator detection dogs to direct effort as detailed in section 2.4.4. Hedgehogs would be removed throughout the predator removal period as described in Scenario 1 and section 2.4.3.

We estimate that staff/contractors could check 50 traps per day in a Rakiura winter when daylight hours are minimal and each sprung trap needs careful resetting. Traps also need regular weight testing and maintenance. To check every trap, including possum traps, (on rotation using the maximum days available and minimum amount of staff) on a 50 m × 50 m grid across 4800 ha every day would take 494 staff; every 7 days, 71 staff; and once per month, 16 staff. To check every trap (including possum traps) on a 25 m × 25 m grid over the same 4800 ha area every day would take 1660 staff; every 7 days, 237 staff; and once per month, 55 staff. (Note: as with the previous scenarios we used a rate of $7.50 per trap for the 50 m × 50 m grid, and $5.00 per trap for the 25 m × 25 m grid in [4]).

Caution period

No caution periods would apply unless toxins were used to supplement trapping where traps could not be deployed (e.g. very steep cliff areas).

Required licences and consents

No licences would be required unless toxins were used to supplement trapping where traps could not be deployed (e.g. very steep cliff areas).

4. Pre-operational needs

4.1 Addressing information gaps

Pest removal projects on the scale and complexity of the HMB Project require a significant period of operational planning and field testing of methods (e.g. [23], [18]). Operational planning can take years to refine before the work on the ground actually begins. There are a number of information gaps in the proposed HMB Project that would require investigation for full operational planning to be completed. These are addressed below.

4.1.1 Baseline monitoring for the presence of toxins in the HMB Project area

The local Halfmoon Bay community have used shop-bought brodifacoum or similar anticoagulant toxic baits for rodent control around dwellings for many years and a number of areas around the township (wharves, Dancing Star Foundation property) have used toxins to control rats [1]. Any areas where there is a high risk of potential bait shyness in rats needs to be identified and alternative methodologies included in strategies for rat removal. Captive groups of rodents from local populations should be used to assess which bait type/s should be used. It would also be important to obtain baseline data on the level of toxin already in the environment before the programme commences; future levels could then be compared against this baseline. Testing should include non-target species such as domestic animals (e.g. cats, dogs and chickens and white-tailed deer).

4.1.2 Survey of hedgehog distribution

Current hedgehog distribution is thought to be limited to the Halfmoon Bay township area. A survey using specialist dog teams should be carried out to confirm the distribution of hedgehogs throughout the HMB Project area. If their distribution appears to be limited, it may be feasible and desirable to remove hedgehogs prior to the full predator removal project. Such a survey may not detect every last hedgehog and operational planning should account for contingencies where hedgehogs are detected during the main predator removal phase outside of the area identified in the pre-operational survey.

4.1.3 Pilot study—field trials of rat home range, optimal device grid density and logistics

The presence of three rat species within the HMB Project area introduces risk of failure because of intraspecific and interspecific competition. Each species has a different characteristic home range and preferred habitat in the landscape which will likely change as predators (including other rats) are removed. For example, it is likely that kiore will be excluded from kill devices by the two other more dominant rat species until enough Norway and ship rats have been removed to allow kiore to access kill devices. There is a risk that kiore may not enter bait stations used by other rat species for some time (if at all), even after removal of the dominant species[20]. Kiore also have smaller home ranges.

Successful predator removal requires every predator to be exposed to a lethal dose of toxin or to be trapped. This objective requires the placement of a kill device within the home range of every predator within the HMB Project area. Current best practice suggests a 25 m × 25 m grid would be required to confidently expose all individuals of the species with the smallest home range (kiore) to kill devices. Considerable efficiencies or potential weaknesses could be discovered by refining grid density to local conditions. For example, if kiore home ranges on Rakiura were found to be of sufficient size, the 25 m × 25 m grid could be abandoned in favour of an altered 50 m × 50 m grid, which is likely to be far more cost-effective (see Fig. 4).

[20] Keith Broome, pers. comm. 1 October 2014.

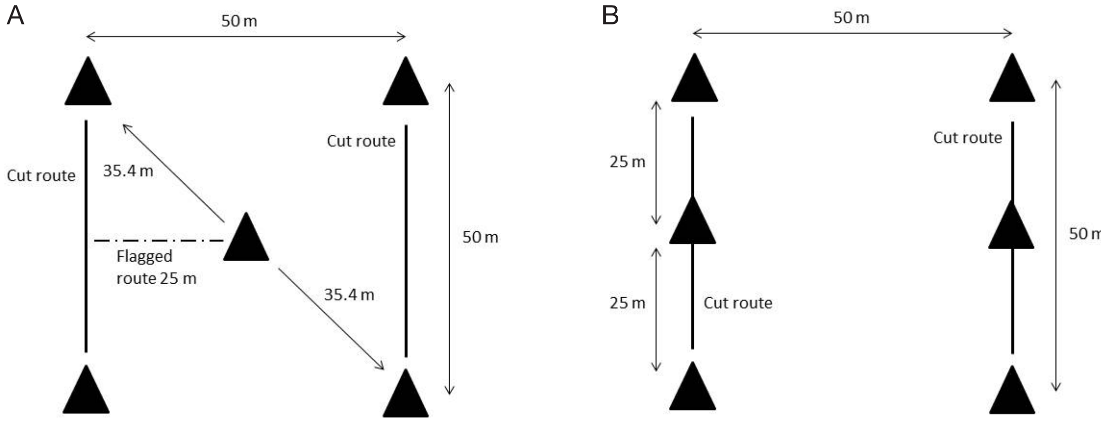

Figure 4. Alternative grid designs for HMB Project (triangles represent devices).

The alternative grid designs shown in Fig. 4 would result in the same amount of route infrastructure as the 50 m × 50 m grid with (roughly) an additional 10 000 (Fig. 4A) or 20 000 (Fig. 4B) devices (saving 1000 km of route from needing to be cut and either 50 000 or 40 000 devices to be purchased, deployed and serviced compared with the 25 m × 25 m grid, based on the 4800 ha option). Also, the additional bait stations required could be of a cheaper type (such as the yellow plastic Novopipe™ types used successfully to remove rats on Breaksea and Langara Islands [23], [17]).

Alternatively, home range studies of rats may reveal that even a 25 m × 25 m grid is too large to enable all rats to be exposed to traps or bait stations. Fundamentally, determining the optimum grid size for ground-based eradication forms a critical decision point in determining the best approach and, ultimately, the success of the project if it were to proceed. Whatever the results of these investigations, the minimum home-range size for kiore would need to inform the size of the grid selected. It needs to be recognised that researching a sample of rats will give an indication of home range sizes but will not be able to identify the absolute smallest home range in the wider population in the HMB Project area. Therefore, any grid size that is larger than what has worked in the past to eradicate kiore introduces more risk and is likely to require additional contingency planning to change to a smaller grid if required.

Grid size is likely to be the single largest variable for costings and logistics [4]. The rat home range and grid design pilot study should be large enough to assess the staffing requirements for bait station filling or trapping for the predator removal phase of the project, which is when the greatest numbers of people will be required. The two key variables here are the amount of kill devices that can be checked, refilled/cleared and reset, and accurately recorded in a day (assuming winter hours), and the amount of days between checks. Savings in either area will provide significant compounding savings for the project. The pilot study should also assess bait take rates so that the amount of bait likely to be needed can be more accurately assessed. Bait take rates could also inform the size of the bait stations required; larger bait stations can be checked less frequently as they hold more bait, which could create large savings for the project.

4.1.4 Testing for toxin residues in meat carcasses

We considered toxin residues in white-tailed deer to be of significant importance for many local and part-time residents who hunt for meat around Halfmoon Bay. Brodifacoum is the toxin which is most persistent in the environment (of the toxins recommended for use in this report), accumulating mostly in the livers of deer. Although using bait stations should minimise the amount of brodifacoum available to deer in the environment, a caution period would remain for 36 months after the last bait has been laid. If regular incursions occur after rodents are removed from the project area and brodifacoum is used to detect and target the invading animals, it is likely that the caution period could remain in place indefinitely (or until such a time as rats could be removed from the entire island and incursion becomes significantly less likely). Although caution periods only legally restrict the commercial harvest of wild animals for human consumption, recreational hunters are likely to require assurance that toxins are not present in the meat they wish to consume. This knowledge may be a key factor in determining support for the use of this toxin, which is the tool most likely to succeed in removing all rats from the HMB Project area. A field test for brodifacoum residues in meat is currently considered unlikely to be feasible, so a streamlined sample-laboratory test-report system should be established in co-ordination with MPI for deer shot for home consumption. There is also leeway to advise recreational meat hunters to discard offal as a residue risk throughout the caution period, but that muscle tissue may be safe to consume after a much shorter period. This approach would require a systematic testing and communication regime to be designed and approved (by relevant authorities and hunters) at the operational planning stage. The same principles apply for use of diphacinone, although the caution period is much shorter (5–6 months) for this toxin.

4.1.5 DNA sampling of rats

Genetic comparisons should be made between rats in the HMB Project area and those from areas that are likely sources of incursion (e.g. Bluff, Riverton and other parts of Rakiura). This data would provide a basis for comparison if rats are found after predator removal—to determine whether the predator removal programme has failed or an incursion has occurred (and, probably, from where it occurred). DNA sampling of rodents would be a critical source of information for ongoing adaptive management of biosecurity operations. Mouse DNA should also be sampled from mainland locations that are likely to be sources of incursions. Similar genetic comparisons could be made for possums, feral cats and hedgehogs if this assessment was thought to be worthwhile.

4.1.6 Risk assessment of mice

Currently, mice are not thought to be established on Rakiura, but have been recorded occasionally around Halfmoon Bay and at the salmon farm [20] where, presumably, they were subsequently killed by rats and/or cats. The HMB Project could provide a 'predator-free welcome mat for mice, by removing their main predators. If mice are present, the strategy for targeting rodents during removal would need to reflect this change. A thorough survey to confirm their presence/absence may therefore be needed prior to the HMB Project work beginning.

A survey of local residents may be useful for determining the risk of mice more accurately, and whether a detection-survey for mice would be required. Mice have never been detected within the Dancing Star Foundation management area (including in the buildings) in the 6 years that it has been managed to zero-density for the same predators targeted in the HMB Project [20]. This result suggests mice are not present in that area of the island. However, mice are notoriously hard to detect and may not have been actively searched for elsewhere.

The presence/absence of mice is a critical knowledge gap, particularly when planning a ground-based operation with bait stations and/or traps. The unplanned presence of mice in an operation such as that proposed here would be a significant game-changer due to the difficulty of eradicating them using the techniques being evaluated for this operation.

4.2 Key decision points for predator removal

Some key decision points and/or knowledge gaps and their probable consequences for predator removal in the HMB Project area are listed in Table 2.

Table 2. Key decision points and probable consequences for predator removal in the HMB Project area.

DECISION/KNOWLEDGE GAP	PROBABLE CONSEQUENCE
Are mice on the island? If so, what is their distribution?	Changes logistics of operational planning; increases risk of failure.
What is the necessary grid size for a ground-based operation to successfully target and remove all three species of rat within the project area?	Decision about whether to proceed or a change to the proposed size of the operational area for ground-based predator removal around HMB.
How will domestic cats be managed during the operation and into the future?	De-sexing, collaring and micro-chipping of all domestic cats must be carried out if the operation is to proceed. Management of domestic cats must be acceptable to the local community without placing too much risk on operational success.
Can recreational harvest of white-tailed deer continue under the extended (36 month) and possibly indefinite (in some areas) caution period for brodifacoum use?	Restrictions on recreational hunting of white-tailed deer for meat are likely to render the project unworkable. Therefore, a streamlined testing regime for brodifacoum residues in deer meat may be an option to safely allow for continued hunting. The risk of not using brodifacoum to target rats may place too much risk on operational success.
Is the local community willing to fully commit to an extended period of allowing workers onto their properties to plan and/or carry out the work?	Rat removal means placing devices in every 'nook and cranny' within the HMB Project area. Devices in dwellings need to be in place for a long time after the rest of the operation has finished (6 months or so—some permanently for ongoing biosecurity). Without universal support from the local community there may be too much risk to operational success.

5. Spreadsheet of tools

A wide variety of tools is available for the HMB Project. While many of these tools are appropriate for ongoing control operations, or specific small-scale predator removal/eradication projects, they may not be optimal for broad-scale use in the predator removal scenarios we have outlined. Table 3 briefly summarises a number of other options potentially available for the target species in the HMB Project area, but not pursued as main methodologies by our technical working group. This exclusion does not preclude their use in specific circumstances, or further consideration of their use if necessary.

Table 3. Toxins and traps considered but not recommended for widespread use in the HMB Project.

NAME	DESCRIPTION	TARGET/S	REASON/S NOT PURSUED
Cholecalciferol	Non-anticoagulant acute toxin	Rats, possums	Requires pre-feeding, variable results, very rarely used for eradication, low chance of success. Possible issues with avoidance by mice.
Zinc phosphide	Non-anticoagulant acute toxin	Possums	Lack of a track record for large possum eradications.
Pindone	First generation anticoagulant	Rats, possums	A more potent first generation anticoagulant is available for rats (Diphacinone).
Coumatetralyl	First generation anticoagulant	Rats	A first generation anticoagulant is available with less persistence in living tissue (Diphacinone).
Bromodiolone	Second generation anticoagulant	Rats	Only registered products in New Zealand are wax-based and contain bitrex (which affects palatability). Lack of information on efficacy and environmental effects compared with Brodifacoum.
Floucomafen	Second generation anticoagulant	Rats	Lack of information on efficacy and environmental effects compared with Brodifacoum.
Spitfire	Device that applies liquid toxin to target animal which is ingested while grooming	Cats (with PAPP), rats (with 1080), possums (with zinc phosphide)	Trials into efficacy still being carried out. Not registered.
Goodnature A24	Self-resetting trap for rats/stoats	Rats	Trials into efficacy still being carried out. Unproven for island eradications.
Goodnature A12	Self-resetting trap for possums	Possums	Trials into efficacy still being carried out. Unproven for island eradications.

6. List of scientific names

Common and scientific names of plant and animal species mentioned in this report.

Australasian harrier	*Circus approximans*
Black-backed gull	*Larus marinus*
Blackbird	*Turdus merula*
Brown teal	*Anas chlorotis*
Brushtail possum	*Trichosurus vulpecula*
Cook's petrel	*Pterodroma cookii*
Darwin's barberry	*Berberis darwinii*
Dog	*Canis lupus familiaris*
Domestic fowl/chickens/hens	*Gallus gallus*
Feral cat	*Felis catus*
Fernbird	*Bowdleria punctata*
Hall's totara	*Podocarpus cunninghamii*
Hedgehog	*Erinaceus europaeus occidentalis*
Kākā (South Island)	*Nestor meridionalis*
Kākāpo	*Strigops habroptilus*
Kāmahi	*Weinmannia racemosa*
Kiore/Polynesian rat	*Rattus exulans*
Miro	*Prumnopitys ferruginea*
Mohua (yellowhead)	*Mohoua ochrocephala*
Morepork	*Ninox novaeseelandiae*
Mouse	*Mus musculus*
New Zealand dotterel	*Charadrius obscurus*
New Zealand falcon	*Falco novaeseelandiae*
North Island brown kiwi	*Apteryx mantelli*
North Island robin	*Petroica longipes*
Norway rat	*Rattus norvegicus*
Paradise shelduck	*Tadorna variegata*
Red-crowned parakeet/kākāriki	*Cyanoramphus novaezelandiae*
Red deer	*Cervus elaphus scoticus*
Rimu	*Dacrydium cupressinum*
Ship rat/black rat	*Rattus rattus*
Southern rata	*Metrosideros umbellata*
Stewart Island brown kiwi	*Apteryx australis lawryi*
Stewart Island weka	*Gallirallus australis scotti*
Stoat	*Mustela erminea*
Tree fuchsia	*Fuchsia excorticata*
Wallaby (brush-tailed rock-wallaby)	*Petrogale penicillata*
White-tailed deer	*Odocoileus virginianus*

7. Glossary

Acute toxin: A toxin which has fast-acting poisonous effects, often from single doses (usually fatal within 24 hours) (e.g. cyanide).

Adaptive management: the use of new information to adjust a strategy or goal in order to learn from experience.

Biosecurity: Systems to prevent possums, feral cats, hedgehogs, rats and mice from reinvading and potentially re-establishing inside the HMB Project area.

Biodiversity: The variety among living organisms. This includes diversity within and between species and ecosystems.

Caution period: As defined by DOC: the timeframe (usually number of months) after the last date of toxic bait application (or removal) when DOC expects that the risk of pesticide residues to the public will have passed. As defined by MPI: the timeframe following an area of land's exposure to poison within which hunting is not acceptable.

Chronic toxin: A toxin which is slow-acting and may require repeated doses to be fatal (e.g. diphacinone).

CIMS: Coordinated Incident Management System, used for planning complex projects or emergency response management.

Consultation: An invitation to give advice, and the consideration of that advice.

Eradication: The complete removal of a species from a location into which there is zero risk of reinvasion by natural dispersal.

Extirpation: The local extinction of a species.

First generation anticoagulant: Group of anticoagulant rodenticides developed between the 1940s and 1960s.

Halfmoon Bay Project (HMB Project): The proposal to remove possums, cats, hedgehogs and rats from one of two option areas (approximately 2150 or 4800 ha) surrounding Halfmoon Bay, including the predator-proof fence and biosecurity requirements.

Incursion: Direct evidence (live or dead animals or unequivocal sign) of possums, feral cats, hedgehogs, rats, mice or mustelids into the HMB Project area after they have been removed. Incursions can be 'suspected' until proven.

Interspecific competition: Competition between different species.

Intraspecific competition: Competition between individuals of the same species.

Neophobic: Fear of new things or objects.

Ngāi Tahu whānui: The name given to the collective of people who are recognised as the tāngata whenua (iwi or hapū with customary authority in a place) for Stewart Island/Rakiura.

Outcome target: The desired change in the ecosystem (usually native species) as a consequence of reaching the result target.

Pathway: The progression of an unwanted organism into an area.

PFR Governance Group: Representatives of the community who are responsible for overseeing decisions for Predator Free Rakiura and the Halfmoon Bay Project.

Predator detection dog: Dogs trained as part of the official DOC Conservation Dogs Programme to indicate the presence of certain predator species.

Predator Free Rakiura: The long-term vision to remove all predators from Stewart Island/Rakiura.

Predator removal (Elimination): The complete removal of a species from a location into which there is a risk of reinvasion by natural dispersal, i.e. the complete removal of possums, feral cats, hedgehogs and rodents from the HMB Project area.

Prey-switching: Ecological process when predators switch from one dominant prey type to another (e.g. from rats to birds), usually in response to one prey type becoming hard to find.

Quarantine: Activities that prevent predators from travelling into the HMB Project area.

Re-incursion: Direct evidence (live or dead animals or unequivocal sign) of the target species only (possums, feral cats, hedgehogs, rats) in the HMB Project area after they have been removed. We use the term incursion as a synonym in the technical documents. Re-incursions can be 'suspected' until proven.

Response: Activities to remove predators after an incursion.

Result target: The desired change in the abundance of the target predator animals.

Second generation anticoagulant: Group of anticoagulant rodenticides developed in the 1970s and 1980s which have the same mode of action as first generation anticoagulants but are more toxic.

Surveillance: Activities that search for predator incursions.

Withholding period: As defined by the Agricultural Compounds and Veterinary Medicines (AVCM) Group of the New Zealand Food Safety Authority (NZFSA): the period for which a particular agricultural produce must be withheld before entering the food chain after application of an agricultural compound (e.g. antibiotics to cows, insecticides to crops).

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Appendix 1

Target species

Norway Rat [67]

Norway rat *Rattus norvegicus* (or brown rat, water rat, sewer rat) is the largest rat species in New Zealand. Most weigh in the range of 200–300 g (maximum weight approximately 450 g). Head-body length averages 250 mm, with the tail clearly shorter than the head-to-body length (total length averages about 335 mm). They can climb with agility, but where they co-exist with ship rats (as they do on Rakiura) they usually remain on the ground. Norway rats tend to live near water and regularly stow away on boats, which has led to their current extensive worldwide distribution and presents a large risk factor in keeping the proposed HMB Project area predator free.

Norway rats swim readily and well, and can cross distances up to 1 km, depending on sea conditions and water temperature [68]. Effectively, any island with a Norway rat population within 1 km of the proposed HMB Project area will also need to have rats removed. These islands are listed in section 2.1.

On Rakiura, Norway rats have been reported to be most common in subalpine shrubland and were associated with plants of damp sites. Small numbers of Norway rats were found in all vegetation/habitat types and their abundance fluctuated throughout the year, with minimum abundance in early summer and maximum abundance in early winter [8].

Norway rats are omnivorous, eating a wide range of foods including seeds, fruits, leaves, fern rhizomes (underground stems) and invertebrates, along with eggs, birds and lizards. They are both predators and scavengers, with shoreline foods forming a considerable component of their diet in coastal areas. Native animals that live, roost or nest on the ground are particularly vulnerable to Norway rat predation (e.g. seabirds and many large invertebrates), and the larger size of Norway rats enables them to predate larger birds than other rat species.

Ship rat [56]

Ship rat *Rattus rattus* (or black rat) is smaller than the Norway rat, most weigh around 120–160 g (maximum weight approximately 225 g). Head-body length averages 225 mm, with the tail much longer than the head-to-body length. They are nocturnal, shy, and often spend most of their time in trees (arboreal). Ship rats are very skilled climbers in forest, with the ability to scale rough vertical surfaces and traverse wires. Ship rats are capable of swimming at least 500 m [69].

On Rakiura, ship rats have been reported from all vegetation types (suggesting generalist habitat use), and were the dominant rat species in podocarp-broadleaved forest and riparian shrubland [8]. The seasonal abundance of ship rats was very similar to that of Norway rats (see above).

Ship rats are also omnivorous, with invertebrates forming the main part of their diet. They eat a variety of fruit and leaves, and due to their climbing ability, are efficient predators of birds, particularly forest passerines (e.g. Stewart Island robins and small hole nesters such as mohua). They are also likely to be a significant cause of mortality of native bats where they are present [71].

Kiore [55]

Kiore *Rattus exulans* (or Pacific rat, Polynesian rat) is the smallest of the rat species present in New Zealand, weighing about 60–80 g with average head-body length about 180 mm (with a tail of similar length). They climb well, and feed both in trees and on the ground. Kiore do not swim well or willingly, but can swim about 100 m (maximum 130 m) if forced to [1]. Kiore are predated by the other two larger rat species, which makes them more cryptic in the presence of these rats.

On Rakiura, kiore have been found to be the dominant species in manuka shrubland, [8] but were also found in riparian shrubland. High densities of kiore were found in grassland habitat on the island. The seasonal abundance of kiore was very similar to that of Norway rats (see above).

Kiore are also omnivorous, eating a wide range of animal and plant foods including invertebrates, lizards, birds, flowers, fruits, stems and leaves. Removal of kiore from several islands has resulted in significant and sometimes spectacular increases in native invertebrate and lizard density [1].

Feral cat [35]

Feral cat *Felis catus* populations have established in New Zealand from domesticated cats 'going wild'. They most likely became established in the wild in the 1830s. Feral cats weigh about 2–4.5 kg (with females averaging 75% the weight of males), and have a head-body length of approximately 400–600 mm. Cats have sensitive hearing (they are able to hear the ultrasonic sounds made by rodents), excellent night vision and a good sense of smell, making them efficient hunters of prey. Feral cats are not good swimmers but have been known to cross water gaps of 50 m.

On Rakiura, feral cats appear to prefer podocarp-broadleaved forest as habitat, possibly because it provides them with shelter from adverse weather. Feral cat numbers on the island are limited by the seasonal availability of rats (their primary prey, making up 81% of their diet) and therefore their population density is low [8].

Apart from rats, feral cats eat mostly birds, lizards and invertebrates, and scavenge readily. They are also likely to be a significant cause of mortality of native bats where they are present [71]. On Stewart Island, feral cats have caused the local extinction of kākāpo and brown teal. Feral cats also severely impacted the New Zealand dotterel population before their control was implemented in 1992 [43], [1]. Feral cats have caused many species extinctions on numerous islands throughout the world.

Brushtail possum [59]

Possums *Trichosurus vulpecula* were introduced to New Zealand to establish a fur trade, with liberations occurring between the 1850s and 1920s. They are now present throughout the country. Adults have a total length of 650–900 mm, and their weight can range from 1.4 to 6 kg. Possums are nocturnal, generally emerging from their den 30 minutes after sunset and returning just before dawn. They are largely arboreal, but do spend approximately 10–15% of their time on the ground.

Possums were liberated on Rakiura in 1890 [70]. Local DOC staff have suggested that possum distribution is patchy on the island, possibly driven by the availability of preferred habitat. In the HMB Project area, possum abundance is around 14% RTC (raised-sets)[21]. They are known only from the main Island, Native Island and Bravo Island. Possums generally breed in autumn.

Although primarily herbivorous, possums are opportunistic feeders, eating anything from leaves, flowers and fruit through to eggs, chicks, and deer and pig carcasses. Selective browsing of palatable species causes mortality of these species, leading to forest compositional changes (as evidenced on Rakiura by the lack of tree fuchsia in many areas away from the main township where it should be abundant, e.g. coastal gullies). Possums also compete with native birds for resources and predate directly on them and their eggs. They are significant predators of kākā and are also known to consume lizards and invertebrates.

Hedgehog [30]

Hedgehogs (*Erinaceus europaeus*) have a total length of 150–270 mm, and weigh between 550 and 700 g (depending on the season). Hedgehogs are largely nocturnal and are most active in the early evening. They are generally insectivorous, but are known to heavily predate lizards as well as eating ground-nesting birds' chicks and eggs. Hedgehogs are excellent swimmers and climbers.

Hedgehogs were released on Rakiura in 1930 and a small population is known to exist around the township. The exact size and distribution of this population is unknown and requires surveying in order to plan their removal.

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[21] Brent Beaven, pers. comm., 31/10/2014.