New Zealand Journal of Ecology (2022) 46(3): 3500 © 2022 New Zealand Ecological Society.

NEW ZEALAND JOURNAL OF ECOLOGY

RESEARCH

The next frontier: assessing the feasibility of eradicating mammalian pests from Auckland Island

Stephen R. Horn[1*], Rachael L. Sagar[1], Veronika K. Frank[1], Finlay S. Cox[1], Paul M. Jacques[1], James Ware[1], Rose Hanley-Nickolls[1], Estelle P. Leask[1], Norm L. MacDonald[1], Micaela S. Kirby-Crowe[1], Mark E. Le Lievre[1] and Keith G. Broome[2]

[1]Department of Conservation, PO Box 743, Invercargill 9840, New Zealand
[2]Department of Conservation, Hamilton 3240, New Zealand
[*]Author for correspondence (Email: shorn@doc.govt.nz)

Published online: 28 November 2022

Abstract: Auckland Island, the fifth largest island in New Zealand, is the only island in New Zealand's subantarctic region where introduced mammalian pests remain (pigs, *Sus scrofa*; mice, *Mus musculus*; cats, *Felis catus*). The island has unique biodiversity and is a key site for progressing New Zealand's goal to be free of several introduced predators by 2050. Recent island eradication successes have rekindled interest in eradicating pests from Auckland Island, and for the first time considering all three pests in one project. Over a 3-year period, we tested the feasibility of eradicating pigs, mice and cats by looking at what it would take to succeed, rather than what we could practically deliver with the tools we currently have. We proposed adaptations to current methods and used an evidence-based approach by undertaking large-scale field trials to test uncertainties and emerging technologies in-situ. We gathered data and evaluated proposed methods against five established principles of eradication while considering the logistics and infrastructure requirements of the project. Eradicating pigs, mice and cats from Auckland Island is worthwhile and feasible but dependent on further development of emerging technologies and capabilities for efficient delivery with an acceptable level of risk. Three eradication operations are required with specific sequencing and timing, supported by initial establishment of infrastructure. The project needs a large investment spread over 8 to 10 years to yield permanent and internationally important benefits with low ongoing cost to sustain. The feasibility study exposed the project's scale and was used to inform decision makers, who postponed the work in 2020 in response to the economic impacts of COVID-19. The study focusses future preparations on identified planning issues and dependencies to progress project readiness in anticipation of it being launched when economic conditions allow.

Keywords: cats, conservation, eradication, *Felis catus*, invasive species, mice, multi-species, *Mus musculus*, pest, pigs, *Sus scrofa*

Introduction

In a world facing a biodiversity crisis (Butchart et al. 2010), islands comprise just 5.3% of Earth's land area but have hosted ~75% of recent species extinctions (Diaz et al. 2019). While in dire need of conservation intervention, islands also offer unique opportunities for significant conservation gains. Invasive species often drive population declines and extinctions in island systems (Holmes et al. 2019). Eradications of invasive species from islands are one of the most effective interventions for achieving global conservation commitments set under the Convention on Biological Diversity Aichi Targets (Secretariat of the Convention on Biological Diversity 2010). Relative to control programmes for landscape-scale interventions, conservation actions on islands typically achieve more because they are more easily defendable from re-invasion and often require a one-off investment for significant, sustained gains (Holmes et al. 2019). More than 1550 invasive mammal eradication attempts have been undertaken on islands around the world with an average success rate of 88% (Spatz et al. 2022). In recent years the success rate of eradications has increased, with larger, more remote and technically challenging islands cleared of pests, including multi-taxa projects (Fig. 1; Holmes et al. 2019).

Terrestrial mammalian predators have been introduced to New Zealand by humans relatively recently. They have subsequently devastated native biota, which had evolved in their absence. New Zealand conservationists have pioneered techniques for the control of invasive species on a landscape-scale and their eradication from islands (Towns et al. 2013; Russell & Broome 2016). In response to the mounting biodiversity crisis, the New Zealand Government launched the Predator Free 2050 initiative (PF2050) in 2016. PF2050 seeks to eradicate invasive rats (*Rattus* spp.), mustelids (*Mustela* spp.) and the common brushtail possum (*Trichosurus vulpecula*) from New Zealand. PF2050 includes the interim goal of

DOI: https://doi.org/10.20417/nzjecol.46.3500

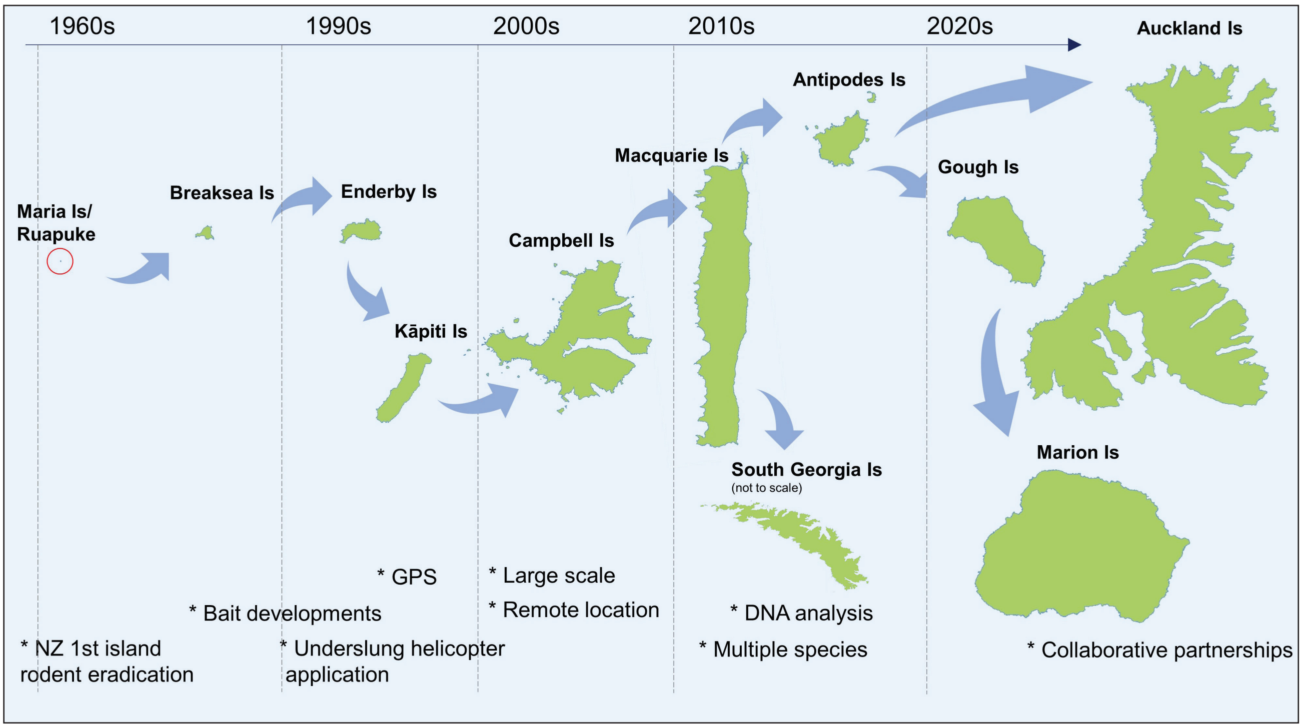

Figure 1. Islands that have eradicated or are in the planning stages and yet to eradicate (Gough, Marion, Auckland Islands) mammalian pests and were considered a step-change in capability during planning. *Indicates key technological and methodological developments that have improved eradication operations.

eradicating all mammalian pests from uninhabited islands by 2025 (Russell et al. 2015; Department of Conservation 2020b). Auckland Island is by far the largest and most significant island included in this interim goal.

The remote and rugged islands of the Auckland Island group are biologically the richest in New Zealand's subantarctic region with diverse communities of avifauna, marine mammals, plants and invertebrates and high levels of endemism (World Heritage Convention 1998). The United Nations Educational Scientific Cultural Organisation (UNESCO) World Heritage site status gives international recognition to the natural and cultural values present, one of only two such sites in New Zealand. Additionally, the island group has a World Centre of Floristic Diversity (International Union for the Conservation of Nature) designation, an Important Bird Area (Birdlife International) status (Russell et al. 2020a) and a National Nature Reserve classification with access by permit only (Department of Conservation 2016). After decades of ground-breaking eradication effort in the New Zealand subantarctic (Torr 2002; McClelland 2011; Horn et al. 2019; Brown & Cox 2022a, b; Brown et al. 2022a, b; Horn et al. 2022), Auckland Island is the last island in the region where mammalian pests persist.

The introductions of pigs (*Sus scrofa*) in 1807, and mice (*Mus musculus*) and feral cats (*Felis catus*) by 1840 have caused severe ecological damage on the main Auckland Island (Fig. 2; Russell et al. 2020a). These invasive species continue to erode the ecological integrity and native biodiversity of the island (Russell et al. 2020a). Pest-free islands in the group (Adams, Disappointment, Enderby; Fig. 3) provide vital refugia for native species (Miskelly et al. 2020; Russell et al. 2020a). Pest eradication on Auckland Island is not a recent idea, though the scale and technical barriers largely limited progress beyond initial investigations for the removal of pigs, and later cats (Russell et al. 2022). Other key challenges concerning the inclement weather, remoteness, lack of existing infrastructure, topography and large areas inaccessible to people precluded action beyond these investigations. Recent conservation initiatives as well as advances in technologies and methodologies (e.g. Horn et al. 2019; Russell et al. 2019; Cox et al. 2022a) have for the first time led to consideration of eradicating all three species in one project.

Eradication projects, especially large scale remote projects, can be complex high-risk investments with potentially severe ecological and reputational ramifications if they fail (Morrison et al. 2011). Such projects are multi-disciplinary, demanding detailed planning not only of technical and scientific approaches, but of logistical, legal, financial, cultural, political and social aspects (Morrison et al. 2011). A peer-reviewed feasibility study to consider all these elements is a standard practice before committing to an eradication project (Pacific Invasives Initiative 2013; Broome et al. 2017a, b). A feasibility study also assesses the costs, benefits, risks and technical challenges to properly size a project, enabling informed decision making on design and resourcing to give the best chance of success (Brown et al. 2019). Alternatively, it allows a project that cannot meet the principles of eradication success to be 'shelved' until issues can be overcome, thus avoiding committing substantial resources to projects with a high chance of failure.

Over 2018–2020, the Department of Conservation (DOC) invested ca. NZ$3m to investigate the feasibility of eradicating pigs, mice and cats from Auckland Island. The project was named 'Maukahuka Pest Free Auckland Island' (hereafter the Maukahuka project) by local iwi Ngāi Tahu who are tangata whenua (indigenous people of the land). In this paper we evaluate and present how we found the project to be feasible. We identify the scale of the undertaking to facilitate appropriate resourcing. Findings inform project planning and highlight the next steps for quality project design.

Figure 2. Pig rooting has almost denuded Auckland Island of native megaherb species (top right) as exemplified by comparison with similar habitat on pest-free Enderby Island (top left). At the single remaining colony of this declining species on Auckland Island a cat feeds on a freshly killed white-capped albatross (*Thalassarche cauta steadi*) chick (bottom left) and a pig (bottom right) forages amongst nesting white-capped albatross. Pigs have been observed toppling nests and preying on both adult and chick albatrosses at this site and albatross breeding success in pig accessible areas is zero. The impacts of cats on albatross breeding success remains unknown, though cats can access areas of the colony that pigs cannot (Photos: top left, RLS; top right, FSC; bottom left, S. Bradley; and bottom right P. Sagar).

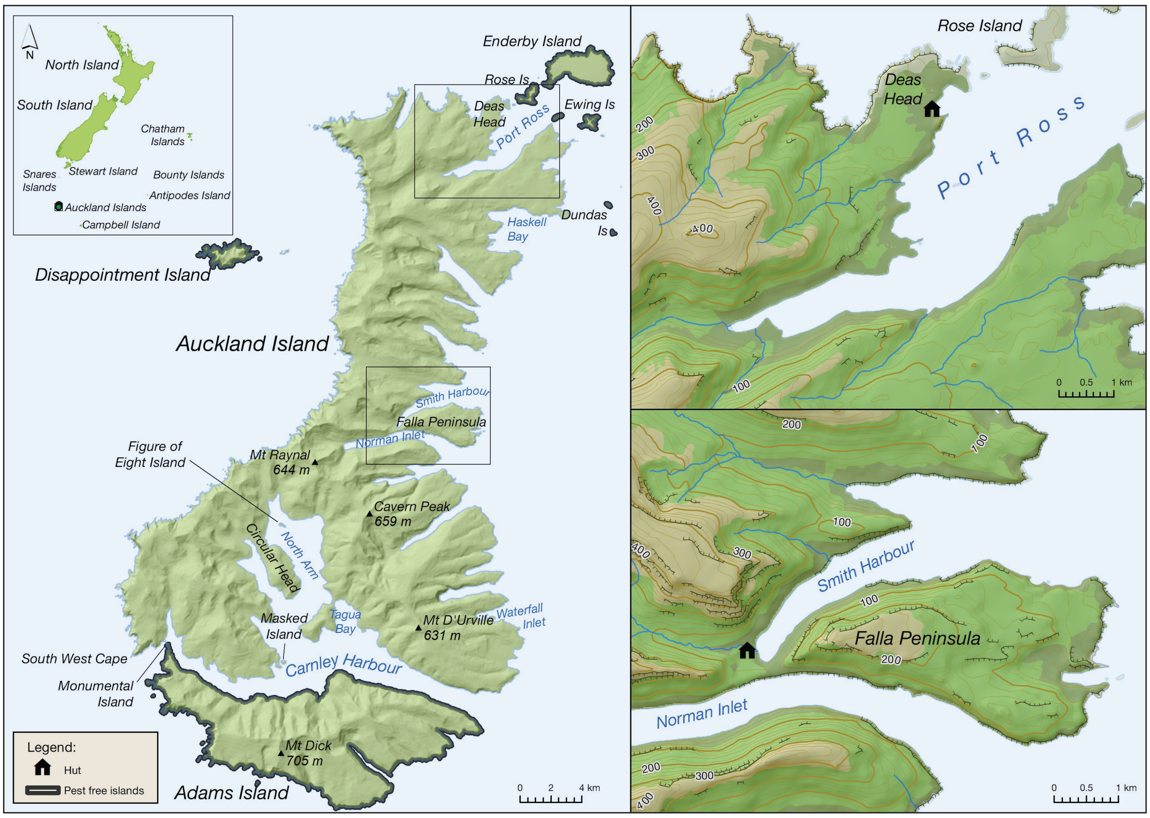

Figure 3. Map of Motu Maha / Auckland Islands and location relative to mainland New Zealand; key sites for field trials, and pest status of islands.

Methods

The feasibility study addressed three key questions (Broome et al. 2005; Pacific Invasives Initiative 2013): why do it; can it be done; and what will it take? We used an evidence-based approach including extensive field trials to reduce uncertainty and test methods. We assessed the feasibility of eradicating each target species individually. We then looked at the synergies and benefits of a multi-species eradication and the implications of sequencing and timing across the individual operations targeting each pest species. DOC's Island Eradication Advisory Group (IEAG) and several other experts provided technical advice and review.

Study site

The feasibility assessment is focussed on Auckland Island (45 891 ha), the largest island of the Auckland Island group (56 816 ha) (also called Motu Maha; 50.69°S, 166.08°E), which lies 465 km south of mainland New Zealand in the Southern Ocean (Fig. 3). Auckland Island is New Zealand's fifth largest island and the largest uninhabited island (Russell et al. 2022).

Auckland Island is approximately 43 km long and 27 km at its widest point and has a convoluted coastline approximately 374 km long with three large harbours – Port Ross, Smith Harbour and Carnley Harbour (Fig. 3). Cool temperatures, persistent wind, frequent rainfall and frequent low cloud levels typify the weather (Fraser 2020). The ancient volcanic terrain, dramatically shaped by ice age glaciation, prevailing westerly winds and rough seas is typically mountainous, with peaks up to 650 m a.s.l. An almost unbroken 50 km line of cliffs up to 400 m high extends along the largely inaccessible western and northern coast. The more sheltered eastern side has deeply incised cirques and fiords and is generally accessible for marine vessels and for people to land. Vegetation cover varies with a narrow coastal swath of New Zealand's southern-most forest dominated by rātā (*Metrosideros umbellate*) transitioning to dense and sometimes impenetrable scrub then extensive tussock grasslands (*Chionochloa antarctica*) above 300 m with meadows of megaherbs and stunted fellfield at higher elevations (Fig. 4; Johnson & Campbell 1975). There is limited existing infrastructure; at study commencement there was one small, basic field hut situated in the north at Deas Head (Fig. 3).

Initial steps

The feasibility study commenced with a literature review of relevant precedent projects and methodologies for each target species. A technical workshop involving eradication practitioners, site experts and DOC's IEAG was used to build on current knowledge and guide study design, incorporating lessons from previous projects. We presented baseline information followed by group discussion and focus groups to look at the project objectives, general strategy options, key planning issues and information gaps.

Eradication criteria

We based the assessment of technical feasibility (can it be done and why do it?) on five established principles of eradication (Parkes 1990; Bomford & O'Brien 1995):
(1) All individuals can be put at risk by the eradication technique(s).
(2) Pests can be killed at a rate exceeding their breeding rate (at all densities).
(3) The probability of the pest re-establishing is manageable.
(4) The project is socially acceptable.
(5) The benefits of the project outweigh the costs.

We also considered the logistics and infrastructure requirements to identify likely constraints. To answer the question 'what will it take?' we assessed the resource, permissions and capability requirements.

Reducing uncertainty

A project scoping report summarising initial desktop analysis was reviewed by DOC's IEAG in April 2018. The process revealed the project had many uncertainties, which fell into two categories:
(A) Uncertainties we could only discover (and resolve) when undertaking the eradication project and collecting the appropriate data in an adaptive management framework.
(B) Uncertainties we could reduce through more investigation.

Examples of category (A) uncertainties are: (1) annual variation in weather conditions, target species population density and food availability – all potentially affecting operational duration and response to eradication tools; (2) behavioural changes (home range, habitat use, detectability) in pigs and cats following rapid population reduction during eradication. Both examples require situational information to guide management activities.

Expert reviewers identified several large category (B) uncertainties to address before feasibility could be adequately assessed (see Appendix S1 in Supplementary Material). A research and development plan was written to capture research questions and guide further investigations. The recommended approach required significant additional resources (funded by DOC) over 24 months between 2018 and 2020. We implemented a series of field trials at three key sites on Auckland Island to answer priority research questions including collecting biological data on pest species and addressing specific uncertainties around proposed eradication techniques (supplementary data). The field trials were located at Deas Head (1350 ha) in Port Ross to the north of the island, Falla Peninsula in Smith Harbour (1000 ha) on the central east coast, and Camp Cove (ca. 1000 ha) in Carnley Harbour in the south (Fig. 3). We reported progressively on each field trial then reassessed feasibility before final review in September 2019 by the IEAG.

Assessing scale, cost and what it will take

We engaged various industries and suppliers during delivery of the field trials, which improved our understanding of the markets for key services such as shipping, helicopters, accommodation infrastructure, fuel supply, and track cutting. We visited or utilised several marine vessels and three helicopter companies during field trials, which informed assessments of logistics, cost and procurement for future delivery of the project. Data from the field trials were extrapolated to estimate the effort, resource needs and operational timeframes. These costs, together with subantarctic eradication project experience, enabled assessment of the infrastructure and logistics needed to support operations. We scheduled proposed activities by year to estimate resource needs and costs.

The eradications depend on helicopter operations, therefore operational duration is dependent on weather. To estimate operational duration and number of helicopters required for each programme, we considered the number of productive helicopter hours required based on trials and previous examples, daylight hours and the predicted percentage of time weather conditions are suitable. A meteorologist analysed over 10

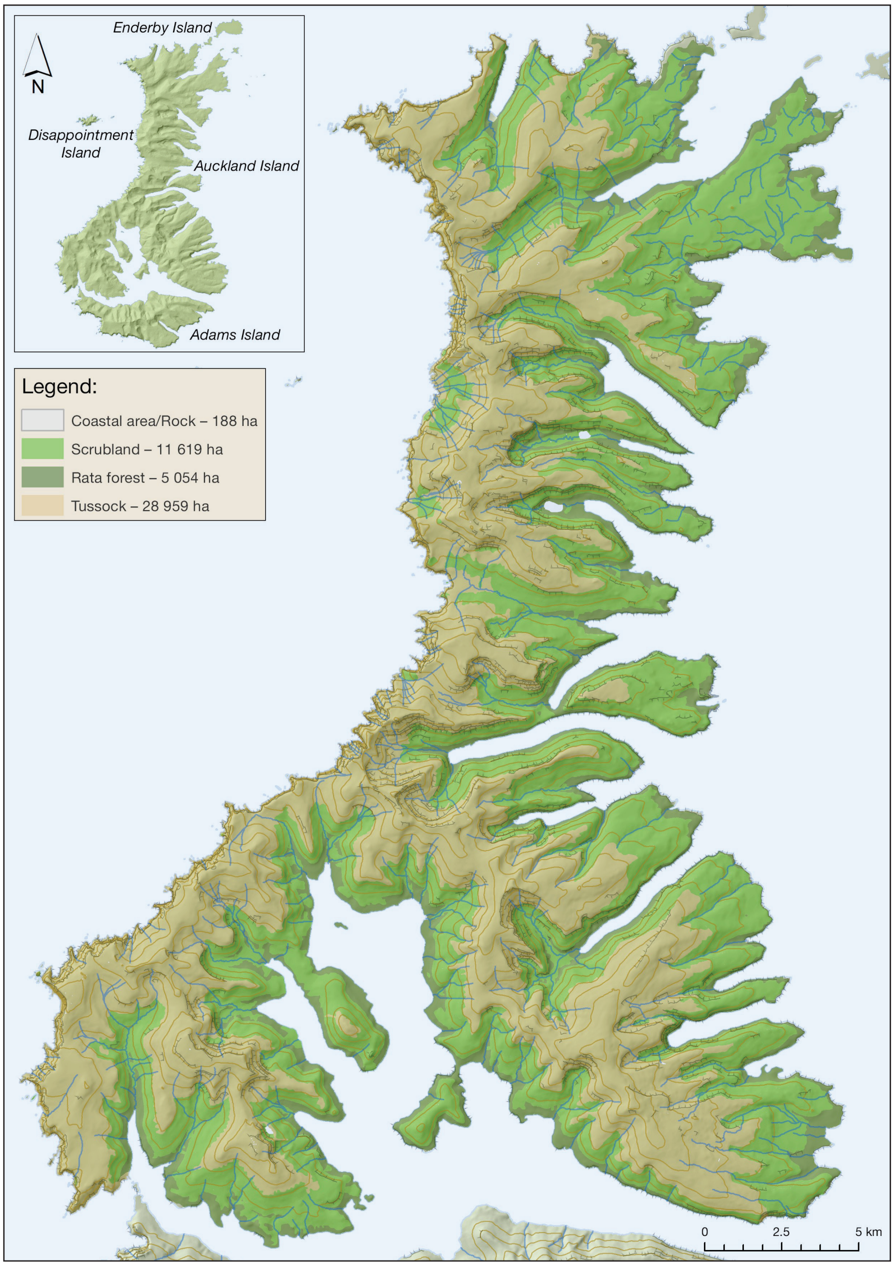

Figure 4. Broad vegetation classification on Auckland Island.

years of weather data to predict the percentage of time weather conditions could enable helicopter activities (Horn et al. 2021; Fraser 2020; Table 2). Parameters for flyable weather conditions were based on knowledge from previous eradications and field trial data (McClelland 2011; Springer 2016; Horn et al. 2019; Russell et al. 2019). Confidence intervals (95% CI) around weather estimates gave a range of time to complete eradication activities (e.g. number of days required to complete aerial bait spread of 500 t of bait; Table 2).

Results

Applicable precedents for large-scale eradication of pigs, mice and cats

Precedent projects provided examples of methods and lessons that informed the proposed approaches for eradicating each of the target species. The rapid eradication of pigs from Santa Cruz Island (25 064 ha) in California provides a sound guide for pig eradication at scale (Table 1; Parkes et al. 2010; Cox et al. 2022a). The Santa Cruz project used a suite of overlapping techniques (feeding sites, trapping, aerial and ground hunting) to put all pigs at risk, with sustained intensive pressure (Parkes et al. 2010). Independently, each technique cannot remove the population but collectively an applied sequence of different techniques can put every individual at risk without compromising or educating the residual population, and simultaneously allow validation of success across temporal and spatial scales.

The only technique capable of putting all mice at risk to eradicate them from sites as large as Auckland Island is aerial distribution of rodenticide-laced cereal baits (e.g. Springer 2016; Broome et al. 2017b; Martin & Richardson 2017; Russell et al. 2019). Baits are applied using specialist spreader buckets underslung from GPS guided helicopters. Mice have been eradicated from other subantarctic islands where they

Table 1. Relevant precedent eradications* for the removal of pigs, mice and cats from large islands.

Target species	Island eradication	Size (ha)	Years	Primary techniques	References
Pig *Sus scrofa*	Santiago Island	58 465	1978 to 2000	Primary poisoning (1080, warfarin), ground hunting with dogs	Cruz et al. 2005
Pig *Sus scrofa*	Santa Cruz Island	25 064	2006	Aerial hunting	Parkes et al. 2010
Mouse *Mus musculus*	Macquarie Island	12 785	2011	Primary poisoning (brodifacoum)	Springer 2016
Cat *Felis catus*	Marion Island	29 541	1977 to 1991	Virus (feline panleucopaenia), hunting, trapping, hunting, 1080 baits	Bester et al. 2002

*Whole island eradication, as opposed to range-restricted species eradications on larger islands.

Table 2. Indicative weather parameters needed for helicopter operations and the percentage of time (95% confidence intervals) estimated to be flyable by helicopter relative to activity.

Helicopter operations	Max daily wind gust (kt)	Minimum cloud base (m)	Favourable year (upper limit 95% CI)	Expected year (mean)	Unfavourable year (lower limit 95% CI)
Baiting and aerial hunting	33	400	24%	20%	16%
Passenger transport	33	600	38%	32%	27%

were the sole target using a range of bait application rates. Precedents include Antipodes Island (2025 ha; 16 kg ha^{-1} + 8 kg ha^{-1}; Horn et al. 2019) and isolated areas of South Georgia where only mice existed (4900 ha; single application of 10 kg ha^{-1}; Martin & Richardson 2019). On Macquarie Island (12 785 ha) the bait application rate (two applications of 24–44 kg ha^{-1}) targeted mice, rats and rabbits simultaneously (Springer 2016). Current best practice for mouse eradication on temperate New Zealand islands is a winter operation comprising two applications of 8 kg ha^{-1} of bait a minimum of 14 days apart with bait containing the rodenticide brodifacoum (Broome et al. 2017b). This approach has had a success rate of over 90% in New Zealand (Broome et al. 2019).

Marion Island (29 541 ha) in the southern Indian Ocean is the largest comparable cat eradication to date (Bester et al. 2002). Like Auckland Island, Marion Island has a subantarctic climate with mice as the primary exotic prey species of cats (Parkes et al. 2014). Feline panleukopenia virus was used on Marion Island to knock down the cat population over 5 years (Parkes et al. 2014). Periods of variable control efforts followed before sustained shooting, trapping and poisoning (day-old chicken carcasses injected with sodium fluoroacetate) were used to complete the eradication between 1986–1991 (Parkes et al. 2014). Where rodents exist, cat eradications have often taken advantage of secondary poisoning by targeting rodents as part of a multispecies approach (Parkes et al. 2014; Fisher et al. 2015; Griffiths et al. 2015). However, a few cats usually survive rodent baiting and require a diversity of methods to dispatch them to achieve eradication (Parkes et al. 2014). Completing and validating eradication depends on reliably detecting surviving individuals. Conversely, stopping requires confidence an absence of sign equates to eradication success for timely completion and to avoid prematurely ending fieldwork (Parkes et al. 2014; Fisher et al. 2015).

Initial assessment

We produced a feasibility study scoping report based on desktop analysis and workshop findings. This report described biodiversity values, the impacts of pests, and included proposed eradication methods for each target species, operational sequencing, and an anticipated timeline. The report was unable to determine if the project was feasible because of outstanding uncertainties with the proposed methods. The desktop exercise ruled out several tools including diseases for pigs and cats because none are currently registered for use in New Zealand, and there are biosecurity and ethical concerns associated with potential options for the respective species (Feline panleukopenia – cats; African swine fever – pigs). Toxins for pigs were initially discounted because better tools are currently available. Sodium nitrite is the only toxin currently registered to target pigs in New Zealand (Bait-Rite paste, Connovation Ltd, New Zealand) and its use is limited to bait stations. Our initial field trial results were poor as pigs shunned the toxic bait despite attraction to the non-toxic pre-feed (FSC unpubl. Data). Recent improvements in efficacy and shelf-life reported for a similar product registered for pigs in Australia (HOGGONE® meSN® Feral Pig Bait, Animal Control Technologies Pty Ltd, Somerton, Australia) have shown promise (Staples & Wishart 2019).

Auckland Island is almost four times larger than the largest mouse eradication globally to date (Horn et al. 2021). The volume of bait required to achieve New Zealand best practice bait application rate at the scale of Auckland Island (ca. 1000 t) is a severe logistical constraint. It would not be possible to handle and spread that much bait in two applications over the winter months (Russell et al. 2019; Horn et al. 2021). Consequently, we investigated an alternative baiting prescription (Table 3) involving a reduction of bait application rates relative to best practice and departure from usual seasonal timing (Broome et al. 2017b).

Governance was established in the first 6 months of the project to support decision making for the feasibility phase. The governance group utilised DOC's project management framework. The group included a representative for the four local hapu (sub-tribes) of Ngāi Tahu (the main Māori tribe of the South Island of New Zealand). Distinguished kaumatua (important māori elders) also represented Ngāi Tahu at key engagement opportunities including a project briefing with the New Zealand Government's Minister of Conservation. We employed an iwi representative to engage further with Ngāi Tahu.

Why do it?

The benefits outweigh the costs

The Maukahuka project is a priority because of Auckland Island's special protection status, the severity of damage from mammalian pests and the consequences if pests invaded nearby Adams Island (Horn et al. 2021). DOC has a clear mandate for the work. It aligns with the New Zealand Government's PF2050 objectives, the Aotearoa New Zealand Biodiversity Strategy and will fulfil statutory obligations (Conservation Act 1987; Department of Conservation 2016, 2020a, b), as well as management expectations associated with World Heritage status. Eradication of mammalian pests is the only sustainable intervention that can halt decline and achieve the desired long-term benefits of biodiversity and ecosystem recovery. Suppression of pests is not feasible at such a large and remote location due to the complex logistics, the prohibitive ongoing cost and limited benefits (short-term relief for some native species at a few sites).

The scope of the project should include all three invasive species. The biodiversity benefits of removing only pigs, or pigs and mice are limited compared to removing all three pest species. Removing pigs alone would lead to an increase in palatable plants and likely subsequent increases in mice and cat populations and predation on native birds and invertebrates (e.g. Marion Island; Cerfonteyn & Ryan 2015; Dilley et al. 2017). This result would suppress the recovery of the island, preventing the return of endemic terrestrial birds and burrowing seabirds, keystone species in this ecosystem. Mice can have extensive detrimental impacts on islands (e.g. Marion Island, Gough Island, Antipodes Island, Midway Atoll), including the local extinction of some invertebrates, severe suppression of land birds and in some cases, preying on large seabirds resulting in zero recruitment (Angel et al. 2009; Dilley et al. 2015; Russell et al. 2020b) and a trajectory to extinction.

Eradicating pigs, mice and cats from Auckland Island would achieve globally significant biodiversity benefits by halting the local destruction of indigenous fauna and flora and enabling permanent recovery and protection of over 500 native species over time. It would increase the total pest-free area in the New Zealand subantarctic area by over 250%, from 30 000 ha to 76 000 ha, and reduce the extinction risk for more than 100 endemic species. Pest-free breeding habitat will complement seabird fishing by-catch reduction work and improve ecosystem health, boosting resilience against projected climate change threats (Phillips et al. 2016; Holmes et al. 2019). The proximity of pest-free islands in the Auckland Island group will enable natural repopulation of native species on the main Auckland Island from nearby breeding populations (e.g. Enderby Island; French et al. 2020). Twenty-five native bird species are expected to repopulate Auckland Island in this way (Miskelly & Fraser 2006; Horn et al. 2022). Recovery of invertebrate populations and vegetation communities will provide resources for returning land birds and nutrient cycling and pollination for plants (e.g. Horn et al. 2019; Houghton et al. 2019). Iconic New Zealand subantarctic megaherbs will again flourish in the largest habitat available to them (Lord et al. 2013).

Additional consequential benefits include leverage for other large-scale conservation work and authentic collaboration between DOC and Ngāi Tahu, as co-leaders of the project.

Table 3. Comparison between logistics for the proposed baiting prescription for eradicating mice from Auckland Island and best practice.

	Best practice	Proposed
Season	Winter (May to August)	Summer (November to February)
Treatment 1 (kg ha^{-1})	8	4
Treatment 2 (kg ha^{-1})	8	4
Bait (t)	900	450
12% contingency (t)	108	54
Total bait (t)	1008	504
Approximate daylight hours	1085	1865
% daylight hours as productive flight time for baiting	16%	16%
Flight time baiting (hr)#	1336	668
Total flight distance (km)	10 200	10 200

Figures are based on a conservative estimate that good visibility, rain and wind conditions occur 15% of the time (using upper value for days with wind gusts >24 kt; Fraser 2020) and 75% of daylight hours are productive flying (allowing for daily set up, preparations and pack-up procedures).

Eradication of mammalian pests would complete the vision of a pest-free New Zealand subantarctic islands area. It would account for over half the remaining area in scope of the PF2050 initiative's interim goal of eradicating all mammalian pests from uninhabited offshore islands (though this could not occur by 2025). The undertaking will provide important momentum for the national PF2050 goals via development of expertise to support PF2050 programmes and capability in several fields of pest management demanded by the step change in scale. It is a tangible and logical precursor to other ambitious PF2050 projects because it is immediately easily defendable and not constrained by inhabitants. A predator-free Auckland Island will also reduce the risk of incursion to other pest-free islands in the region. It will help avoid catastrophic consequences and response costs, namely for Adams Island (9693 ha globally significant and unmodified) which is within swimming distance (min. 548 m) of pest*s* from Auckland Island, though none have yet established.

The potential for negative impacts, such as by-kill of native species, needs thorough assessment of environmental effects as part of detailed operational planning. However, no major non-target risks arose from the preliminary investigations completed. Release from predatory pressures have been shown to quickly outweigh generally short-term negative impacts (Black et al. 2017; Parker et al. 2017; French et al. 2020; Russell et al. 2020a; Horn et al. 2022). We expect disturbance to vegetation from the infrastructure programme to rapidly reverse over 5–20 years (e.g. Antipodes Island; Horn et al. 2022). Eradication requires a large investment spread over 8 to 10 years, though once complete the site is relatively easy to defend with low ongoing costs, similar to current levels, to sustain outcomes through biosecurity. Other sites in New Zealand would not achieve the same return on investment for biodiversity or low cost of long-term protection.

Can it be done?

All individuals of the target species can be put at risk by the proposed eradication techniques

A field trial testing aerial hunting aided by thermal camera technology and team ground hunting successfully eradicated pigs from Falla Peninsula (temporarily given inevitable reinvasion post-trial) (Cox et al. 2022a). This trial provided confidence we can scale up from 1000 ha to eradicate pigs from all of Auckland Island using intensive and sustained application of a suite of overlapping techniques. These techniques are based on aerial hunting and ground hunting with dogs, plus initial trapping to augment aerial hunting, and use of Judas pigs to add confidence to validation (Cox et al. 2022a; McInnes et al. 2022). Use of the respective techniques at the appropriate time will be critical as population density reduces, to maintain naivety in the residual population and reduce risk of aversion to subsequent techniques (Cox et al. 2022a).

Site inspections showed fencing the island into three blocks is achievable. This separation will aid management of Judas pigs and validation of eradication. A high level of confidence was achieved that all pigs in the tussock area of the Falla Peninsula trial were detected by the aerial hunting team when assisted by thermal imagery technology (Cox et al. 2022a). Terrain modelling across the whole island shows this technology can reduce the area needing to be ground hunted by 20 000 ha and 550 person days per pass (Cox et al. 2022a). The observed efficacy suggests we could also use this tool to effectively aerially hunt the inaccessible, western cliffs. Ground hunting to complete two passes was able to put at risk and remove all remaining individuals during the Falla Peninsula trial (Cox et al. 2022a). Ground hunting with dogs has the highest detection probability, and delivery at low population density can simultaneously validate success. However, ground hunting can be ineffective when pigs are not in very low numbers as the likelihood of escapees increases with density; any escapees will develop aversion behaviour and will significantly increase the risk of failure (Parkes et al. 2010). Judas pigs, automated feeders and additional time for ground hunting close to inaccessible areas of the escarpment are contingencies to be built into the programme and managed adaptively.

Mouse eradication success is dependent on comprehensive bait coverage via two complete treatments of Auckland Island within a discrete period (~3 months). This coverage can be achieved with the proposed bait application rate of 2 x 4 kg ha^{-1} (compared with the New Zealand best practice of 2 x 8 kg ha^{-1}) and applying bait in summer rather than the usual winter. These changes reduce the volume of bait from 1008 t to 504 t and halves associated helicopter time for unloading bait from the ship and subsequent bait spread (Table 3). Applying bait in the summer greatly increases the likelihood of completing bait spread because there are more daylight hours and generally more stable weather for helicopter bait spreading (Table 3). These adaptations are supported by the results of a summer bait uptake trial on Auckland Island (Russell et al. 2019) and recent successful mouse eradications on Adele Island (87 ha; Livingstone et al. 2022) and Maud Island (318 ha; Oyston et al. 2022) in winter using substantially lower bait application rates than New Zealand best practice on temperate islands. With the adjustments to the prescription, baiting can be completed by resourcing enough helicopters and pilots and conservatively planning the operational duration based on known weather trends (Table 2).

To achieve comprehensive bait coverage, bait is spread across the entire island (45 891 ha) along parallel flights with bait swaths overlapping by 50% (across island baiting). This main broadcast is supplemented by additional bait application over approximately 10 500 ha around the coast and onto steep slopes to reduce the risk of gaps (Broome et al. 2017b). Supplementary baiting poses a large demand on helicopter resources as bait spreading in coastal terrain and steep slopes is slow and highly technical. Helicopters must fly approximately 40% slower to navigate the convoluted coastline using a directional bucket (bait thrown in a 180° arc with a swath of approximately 40 m) compared to broadcasting bait with a standard bucket (bait thrown 360° with a swath of approximately 90 m) during across island baiting. On Auckland Island, most cliffs lie along 50 km of coastline on the exposed western side where favourable weather conditions for helicopter baiting will be least frequent. Productivity is further reduced in steep areas with increased ferry time for reloading because smaller volumes of bait are loaded to enhance manoeuvrability. For these reasons, the bait operation planning should assume a 4-month operation with six helicopters (Table 3).

Trials of tools on Auckland Island have greatly reduced uncertainties and provide confidence we can eradicate cats from Auckland Island. No single tool is expected to put all cats on Auckland Island at risk and a suite of tools will be used in sequence. Methods will overlap temporally and spatially and be implemented from the most passive (secondary poisoning from mouse eradication) to the most aggressive (searching assisted with detection dogs) to avoid educating surviving cats. The cat eradication will commence soon after rodenticide baiting targeting mice, to take advantage of potential secondary poisoning of cats (Parkes et al. 2014; Griffiths et al. 2015) and in late autumn/winter conditions where natural resources are scarcer. Success requires the reliable detection of cats, and a range of tools facilitate this over different scales.

An island-wide grid of trail cameras will be installed before the preceding mouse eradication to take a baseline measure of the cat population and will be the primary tool used to detect cats and monitor changes in the cat population throughout the eradication (Glen et al. 2022b). The camera grid will run for the duration of the eradication and will be regularly serviced to facilitate rapid response to cat detections. As proven through successful field trials, the camera grid will be supplemented by detection dogs, food dumps to attract cats, and aerial hunting aided by thermal camera in inaccessible areas and across the tussock tops (Cox et al. 2019a, b). Data from these detection devices will be used to adaptively direct the use of elimination tools: trapping, ground and thermally assisted aerial hunting and a toxic bait to target cats (if available). A targeted response to detections will be used as the scale of the island inhibits blanket use of grid trapping. Moreover, our trials enhanced the efficiency of elimination tools by targeting where we detected cats on the camera network and training cats to a food type or site before setting traps (Glen et al. 2022b). DNA profiling of fresh scat samples in the final stages of eradication will help to verify detection results and provide confidence of success to managers.

Pests can be dispatched at a rate exceeding their rate of increase at all densities
We can design each operation to ensure we apply sustained intensity of treatment and monitoring methods until completion, removing individuals faster than breeding can replace them, although seasonal timing is important. Lured trapping and aerial hunting can quickly reduce the pig population before deploying ground hunters (Cox et al. 2022a). Pig eradication is expected to be completed in 12 months and will commence in winter when food is most scarce and population density lowest. Mice will be breeding during the summer when baiting is planned, but two comprehensive applications over several months can target all individuals (Russell et al. 2019). The bait uptake trial for mice on Auckland Island in 2019 coincided with the middle of a large tussock seeding event (Sagar et al. 2022), which occur infrequently (every 2–4 years; GP Elliott unpubl. data). We conducted additional research into mouse population biology to improve understanding of the risks associated with eradicating mice in summer while breeding (Russell et al. 2019) and the implications of a large alternative food source from tussock masting events. The mouse population response and the availability of bait measured during the baiting trial suggest we can expose all mice and kill them faster than they can breed, irrespective of the stage of a tussock mast (Russell et al. 2019; Sagar et al. 2022).

We can quickly reduce cat population density via secondary poisoning (cats eating poisoned mice) during the mouse eradication and feasibly use targeted trapping methods to eliminate survivors faster than they can replace themselves. Having a toxic bait available to target cats directly (Cox et al. 2022b; Glen et al. 2022a) is highly desirable before trapping occurs and as a supplementary tool to detection dogs and traps for mopping up survivors. An available toxic bait could reduce the time to dispatch all cats and improve likelihood of success (Parkes et al. 2014; Fisher et al. 2015).

The probability of the pest re-establishing is manageable to near zero (sustainable)
The isolation of the site and managed visitation mean the risk of incursion is low and ongoing biosecurity manageable and inexpensive. DOC manages island access, which is limited to management purposes and visitors under tourism concessions with mandatory biosecurity provisions in landing permits (Department of Conservation 2016). A deep-sea fishing fleet regularly shelters nearby but is not permitted to land and should be engaged to manage incursion risk and support surveillance. The extraordinary amounts of equipment, people and supplies to be taken to and from Auckland Island elevates the biosecurity risk during the operational period and additional biosecurity capacity and facilities will be needed. Pest-free status has been maintained on other subantarctic islands post-eradication (e.g. Campbell Island, McClelland 2011; Antipodes Island, Horn et al. 2022) and it can be for Auckland Island.

The project is socially acceptable to the community involved
The Maukahuka project is strongly supported by Ngāi Tahu. We wrote a relationship vision document (Pera-Leask 2020) to capture how DOC and Ngāi Tahu wanted to work together to plan and implement the Maukahuka project. We consulted affected stakeholders, which included five tourism concessionaires and two medical research groups who currently manage quarantined herds of Auckland Island pigs on mainland New Zealand. Auckland Island pigs are of interest for research because of their limited exposure to disease (Trotter & Willis 2022). DOC's project to rid Antipodes Island of mice achieved recognition and public support (Horn et al. 2019) and we expect similar public interest for Maukahuka. The project aligns with the Aotearoa New Zealand Biodiversity Strategy (Department of Conservation 2020a), statements of intent in the local Conservation Management Strategy (Department of Conservation 2016), Ngāi Tahu's vision document Te Tangi a Tauira (Rūnanga Papatipu o Murihiku 2008), and the protection afforded as part of the New Zealand Subantarctic World Heritage Area (World Heritage Convention 1998). The use of toxins will draw some negative response despite their use being a one-off event on an uninhabited island. However, project support is expected to far outweigh any criticism and DOC, supported by Ngāi Tahu, would have authority to proceed. The extensive cultural heritage values on the island (Dingwall et al. 2009) can be preserved and enhanced through increased access to the island during the project and the public profile of the project. Activities disturbing the ground can be managed to avoid damaging heritage values using standard protocols and archaeological authorisation where necessary (e.g. Antipodes Island eradication; Horn et al. 2019, 2022).

Infrastructure and logistics can be managed
Establishing appropriate infrastructure and reliable logistics are essential to facilitate operations and address the challenges of remoteness and isolation. Two field huts were installed at Smith Harbour to facilitate field investigations and inform installation effort and functionality. Helicopter and accommodation facilities should be placed at three locations spanning the length of the eastern coastline to reduce ferry time and periods of helicopter inactivity due to poor weather (Horn et al. 2021). Weather conditions during trials often restricted helicopter movements over high passes while localised flying operations were still possible, thereby enabling greater opportunity to progress eradication objectives to completion (Horn et al. 2021). The pig programme will take approximately 1 year to deliver,

mice up to 6 months (set up and baiting) and cats between 1 and 3 years depending on the progression of improvements to tools (Horn et al. 2021).

Land-based operational delivery will be far less costly than ship-based operations given the long operational duration. Accommodation facilities are needed to support year-round island occupancy for several years and facilitate regular access to all parts of the island by ground hunters. Supporting infrastructure includes boat sheds, helicopter hangars and large fuel stores, particularly for Jet A1 helicopter fuel. Satellite internet worked well during field trials, enabling access to current weather forecasting and low-level data and imagery transfer to the mainland. Internet access should be rolled out across the island to support efficient operational delivery and social cohesion. An infrastructure programme of this scale could be delivered over a 2 to 3 year period with pre-fabrication on the mainland. Buildings should be kitset or flat-pack with simple construction and anchoring systems not reliant on concrete and heavy equipment to enable later removal. The water tank ballast system designed to anchor the temporary hangar on Antipodes Island is an example of a suitable temporary anchoring system (Horn et al. 2019).

Over 1000 t of supplies and materials will need to be moved over the life of the project. Operational preparations include several large expedition style tasks such as offload and placement of 500 t of mouse bait at several bait loading sites. Marine vessels able to be unloaded by helicopter are needed, to transport large volumes of cargo for at least four deployments. Two of these deployments (main infrastructure installation; mouse eradication setup of bait and fuel) would be most efficient with a large cargo vessel with a capacity for at least 15 shipping containers and bunkerage for jet fuel. Shipments over the operational period are expected to include 400 000 L of Jet A1 helicopter fuel, transferred to onshore storage.

Purchase of a large helicopter capable vessel (>70 m length) was ruled out due to cost, specialised management demands and the reliance on and need to utilise a single large vessel for all service requirements, many of which would be more efficiently achieved by a smaller vessel. Certified helicopters can fly the 465 km directly to Auckland Island from Invercargill to offload a vessel, under current rules (Civil Aviation Authority NZ, Part 91). This simplifies logistics by avoiding the need to find a vessel capable of shipping helicopters and would broaden the market for shipping. With this option, medium sized vessels (<50 m length) conducting more voyages between Bluff and Auckland Island are a viable alternative to single voyages with larger cargo ships. A vessel based in the lower half of the South Island would avoid repeated and costly positioning voyages from elsewhere in New Zealand. Delivery of each operation will occur while concurrently planning and preparing for the next stage. Dedicated project and contract management capacity is an important function for each stage and must be adequately resourced.

Each eradication depends on helicopter support, ranging from two helicopters for the pig eradication up to six for baiting mice. Overall, approximately 700 days of helicopter support on island is required, in addition to helicopter transits to and from the South Island. The helicopter tasks and pilot skills are specialised and different for each eradication and logistics operation (e.g. heli-hunting vs baiting vs pilots with specialist long-lining experience for unloading ships at sea) (Horn et al. 2019). Using six helicopters to complete an estimated 668 hours of flight time to spread bait for mice (Table 3) will provide contingency and enable rapid progression when the weather allows. This capacity to progress rapidly is particularly important for baiting along the tops and western coast where exposure, cap cloud and persistent westerly winds mean baiting opportunities will be infrequent (Horn et al. 2021). Managing the large boundaries between baited and un-baited areas will also be important. Repeat sowing will be required if baiting is interrupted for more than 4 days to avoid the risk of mice moving behind the baiting boundary and not being exposed to palatable bait (Horn et al. 2021).

Enough helicopters could be leased for the operations with more than a year of lead-in for suppliers. A small pool of highly skilled pilots is available in New Zealand with the required skillsets and remote deployment of several months is achievable. New Zealand helicopter pilots have regularly been deployed around the world on remote island eradications lasting several months, including on Campbell Island, Macquarie Island, South Georgia Island, Antipodes Island and, most recently, four pilots for a mouse eradication on remote Gough Island in 2021 (McClelland 2011; Springer 2018; Horn et al. 2019; Martin & Richardson 2019; Samaniego et al. 2022).

Biosecurity for the vast amounts of gear and supplies will require a mainland facility and island facilities to transfer and handle goods. Logistics will need coordination by dedicated roles with a fit for purpose inventory system. Regular passenger transport services to resupply and changeover island teams will be required. Aviation options (helicopters, floatplanes) cannot provide a complete solution due to payload limitations and cost, so marine transport will be necessary. Maritime activities for cargo, passenger and resupply services equate to approximately 45 individual voyages.

What will it take?

Maukahuka will be the largest eradication project that DOC has undertaken. The operational cost of the project is estimated at NZ$84m, based on conservative estimates of operational duration due to weather constraints and modelled on short staffing rotations (Horn et al. 2021). Per hectare costs of approximately NZ$1800 are comparable to other island eradication projects, such as Macquarie Island and Antipodes Island (Horn et al. 2021). However, the project is currently unaffordable for DOC and its investment partners. DOC's preferred funding model was based on a 50:50 partnership with third party investors. Commitment from government or investment partners was not achieved before the completion of the feasibility phase.

A multi-species approach to eradications is more efficient for some species due to primary and secondary poisoning (Griffiths 2011) but simultaneously targeting all pests on Auckland Island is not possible. Four to five years of sequenced operations are needed, and seasonal timing is important to maximise assistance from the environmental conditions. Three operations in short succession under a single project are the most efficient and likely way to achieve success. Pigs must be eradicated first to facilitate the attempts on mice and cats (pigs will create gaps in bait coverage for mice and interfere with traps and baits for cats). Pig and cat eradication attempts should commence during winter to take advantage of a decrease in food availability. Efficiently eradicating cats relies on secondary poisoning from mice. Mouse baiting is timed for summer to maximise the likelihood of completing helicopter bait spread (Russell et al. 2019). Therefore, we would aim to complete mouse baiting by late summer to enable time to demobilise the mouse operation and establish the cat team in readiness to target surviving cats in the following winter.

Mice and cats could be targeted in a separate project as they are not influenced by methods to eradicate pigs. However, an interval of more than 2 years following pig eradication would risk there being rapid vegetation recovery, seen on other subantarctic islands (Springer 2018; Horn et al. 2021), hampering access and the efficiency of ground hunting cats. Disestablishing and re-establishing a specialised project team and supplier relationships would be an inefficient and high-risk approach due to the reliance on specialist skills and logistics that are difficult to source and typically involve complex contractual arrangements that can take years to develop (Springer 2011; Horn et al. 2019). Project delivery within 8 to 10 years is contingent on certainty of these skills and services. Because of the seasonal dependency for timing operations, short delays could extend the timeframe by a year, incurring additional costs and risk losing specialist skills.

The project will take between 8 and 10 years from commencement of the infrastructure operation. The first 2 years are for establishing infrastructure and preparation of eradication teams and tools. Eradication operations will last for 4 to 6 years, and the last 2 years are for demobilisation. The timeframe could reduce if preferred tools are available, and operations go well. Organisational wide commitment and funding are required to enable the project and continuation to completion once started. Managing external disruptions such as changing socio-economic factors, natural disaster or change of government must be done collaboratively with government and partners holding each other to account. The inclement weather of the subantarctic may delay or inhibit completion of operations resulting in cost over-runs or programme failure. The project must be resourced well and budgeted with enough contingency to account for overruns in time. Obtaining committed funding for the entirety of the project before it commences was a key lesson in the success of the Macquarie Island eradication (Springer 2018).

Personnel and helicopter costs are the largest cost components of the project. Operational teams of 25–30 people are needed for each eradication operation. A support team of 15–20 people on the mainland will service island work and prepare operations to run sequentially, as well as undertake the full range of project management tasks. Costs are based on rotations of 6 weeks on island for the pig team, a single 5-month deployment for the mouse baiting team and 6-monthly for the cat teams. Longer staff deployments could reduce cost and simplify logistics (Springer 2016; Horn et al. 2019; Martin & Richardson 2019), though the pool of available personnel will reduce. We need to resource operations to deliver them quickly with sustained intensity in a systematic and persistent way. Eradication success is critically dependent on quality delivery by meticulous, skilled and motivated staff (Cruz et al. 2005; Parkes et al. 2010; Brown & Brown 2015). Sourcing and developing the personnel capability needs to be planned and will take time and teams need to be functioning as a cohesive unit before deployment. For example, selection and training of six pig hunters for the field trials in 2019 took 3 months. Increased capacity is required for cat detection dogs and handlers, which will require active development and 2–3 years for selection and training. Eradication experienced dog trainers and a Conservation Dogs programme exist in New Zealand that could achieve that goal.

The operations involve extensive work in critical risk categories identified by DOC (helicopters, boats, chainsaws, firearms, remote fieldwork and construction). Training and resourcing a high level of medical competency on site will be important as a patient may require several days of intensive management before medical evacuation is possible. A dedicated safety management role should be embedded in the operational team. The presence of helicopters on the island through most of the operational period vastly improves the ability to retrieve an injured person to a safe location for patient care.

Discussion

The eradication of pigs, mice and cats from Auckland Island is worthwhile, achievable, and sustainable. Eradicating all three target species is the only way to fully realise the benefits and avoid detrimental trophic shift responses (e.g. Van Aarde et al. 2004; Angel et al. 2009; Dilley et al. 2017). Doing this in a collective project is the most cost effective and likely way to succeed.

Ambitious eradication projects typically succeed due to disciplined, strategic delivery and the application of advanced technologies, with intense effort and resourcing sustained across the life of the project (Morrison 2007; Parkes et al. 2010; Springer 2016; Horn et al. 2019; Martin & Richardson 2019). A project management approach to eradication embeds these traits by properly scoping the project before commencing. Other projects have evolved from sustained control and may take a long time or never succeed because the target species may have learned to be wary (Morrison 2007). Some of these projects succeed through perseverance (for example, pig eradication from Santiago Island 58 465 ha took 30 years) but protracted projects carry a higher risk of failure and overspend (Parkes et al. 2009). Maukahuka cannot proceed in this way because logistics are too costly to sustain.

The ramifications of failure (ecological, opportunity cost, reputational impact) are greater and increasingly important as projects get larger, more complex and more expensive (Holmes et al. 2019). Accordingly, the level of investment in the Maukahuka feasibility study was appropriate. The study and its use of field trials to reduce uncertainties has been critical for properly understanding and sizing the project. The feasibility study revealed the scale of the project is larger than anticipated but feasible at an annualised funding level with third party input. The remote location and infrastructure needs inflate the project's cost, complexity and timeframes compared with other large island eradications, which have usually had base facilities for permanent staffing and logistics for regular activities already in place (e.g. Campbell Island, Macquarie Island, Gough Island, Marion Island). The knowledge gained through the feasibility study provides confidence for a project team, sponsors, decision makers and stakeholders that they are making informed decisions.

Improving eradication tools

Eradication is technically feasible for each species, but requires further development of emerging technologies via achievable pathways. Improvements in detection and eradication tools (for example a toxic bait to target cats; Cox et al. 2002b; Glen et al. 2022a) could reduce operational timeframes and cost and have extensive application elsewhere in New Zealand.

The pig eradication needs at least two capable aerial hunting teams equipped with high-resolution thermal camera technology to scale up to the whole island but also to allow rostering and redundancy (Cox et al. 2022a). The camera and set up used for aerial hunting during the trial was the only one of its type in New Zealand at the time and suitable equipment and skills are still not widely available. Development requires construction of replicate cameras using available technology and establishing a work programme for suppliers to build capability (Cox & Macdonald 2022). To eradicate mice, the bait bucket mechanism needs improvement to reliably sow 2 g baits at the required low application rates (Russell et al. 2019; Livingstone et al. 2022; Oyston et al. 2022). Agricultural machinery already uses automated variable flow rate integrated with GPS ground speed which is adaptable to bait spread for invasive pests (Alameen et al. 2019). To eradicate cats, software for automated processing of trail camera data is needed to manage a camera network across the size of Auckland Island. This development relies on improving image processing capability to reliably filter falsely triggered images (without an animal in frame) and preferably identify when a cat is present (Glen et al. 2022b).

Several other developments should be pursued to improve efficiency. A toxic bait to target cats (cat bait) would improve the likelihood of success and opportunity for rapid completion (within 12 to 18 months) by efficiently exposing all surviving cats over the whole island, including on terrain inaccessible to trappers (Parkes et al. 2014; Fisher et al. 2015; Cox et al. 2022b; Glen et al. 2022a). Trappers could then more quickly move to mopping up surviving cats with the aid of the island-wide network of trail cameras to target effort (Glen et al. 2022b). There would then be less risk of cats becoming wary and avoiding detection than when relying on trapping alone. Confidence to validate eradication could then also be achieved more quickly. A toxic bait to target pigs would also enhance the efficiency of the pig programme by reducing reliance on more aggressive tools (aerial shooting and ground hunting) and the likelihood of pigs learning to avoid techniques through non-fatal interactions (Parkes et al. 2009). Sodium nitrite baits for pigs are used in bait stations with likely similar labour requirements to traps as both must be pre-fed (Staples & Wishart 2019). In-field methods to neuter Judas pigs and reliably tag them with internal transmitters were successfully tested recently (McInnes et al. 2022), adding to the suite of detection tools that can locate a residual population or verify eradication (Cox et al. 2022a).

Adaptive management

The project design will have to manage issues arising during implementation and build in an adaptive management framework to clearly establish:
(1) the priority questions
(2) the data collection, collation and analyses required
(3) how results will inform decision making.

For mouse eradication on Auckland Island this means monitoring the progress of the bait spread in relation to weather to prioritise areas where topography and weather means access to spread bait is least frequently achievable. Completing the eradication of pigs and cats is dependent on rapidly reducing their populations then detecting and eliminating survivors as quickly as possible and adapting to behavioural change as the population reduces (Cruz et al. 2005; Parkes et al. 2010, 2014). Investment in improving detection probability and reducing the time between detection and response as much as possible is the priority. For pigs, reducing the response time relies on helicopters with thermal cameras and ground hunters responding to information from dogs, pre-fed sites and Judas pigs. For cats, reducing the response time relies on extracting data from the island-wide network of trail camera, with the ideal tool being automated real-time notification of a cat detection by a camera. However, feasibility was assessed based on a servicing frequency of 2 to 4 weeks (depending on the operational phase) for people checking the camera network manually. Detecting behavioural response to control methods is important to allow addition and adaptation of techniques, particularly if the surviving animals become wary (Ramsay & Wills 2012; Parkes et al 2014).

Knowing when eradication has been achieved and activities should be stopped must be evidence-based. Stopping without adequate validation of success risks project extension and presents the greatest danger to budget over-runs (Parkes et al. 2010). Conversely, opportunities to complete the project early (while retaining confidence in the result) will offer the most savings (Parkes et al. 2014). For these reasons, investment in advancing landscape scale monitoring capability (Morrison 2007) and understanding detection probability (e.g. Glen et al. 2022a, b) offer significant potential payback.

Dependencies and planning issues

Several remaining challenges require high-level attention during project design and are critical to success. Feasibility (Can it be done?) should be reassessed if we cannot deliver these elements.

Failure to secure shipping and helicopter services for the duration of operations is one of the biggest risks of the project stalling, and the market is small. Feasibility is also dependent on the continued ability to fly single-engine helicopters to Auckland Island by direct flight from mainland New Zealand. Shipping and helicopter industry expertise should be embedded in the project team to design and manage complex compliance and contract scenarios and bespoke procurement options should be explored. Large scale shipping services have been procured in New Zealand on a one-off basis for previous eradications on Campbell Island and Antipodes Island (McClelland 2011; Horn et al. 2019) though securing services for the long life of this project are more complex, will likely take more than a year and will require ongoing management. Government procurement processes are not geared well for extraordinary activities with few potential suppliers and take a long time (Springer 2016; Horn et al. 2019).

On-island fuel storage capacity of approximately 100 000 L is unresolved but believed to be surmountable. Additional permanent fuel stores are not allowed in the New Zealand subantarctic under the current Conservation Management Strategy (Department of Conservation 2016). Engagement with regulatory authorities and industry expertise is required to design an efficient and compliant solution for supply of Jet A1 helicopter fuel and temporary storage for at least three locations on Auckland Island. Similar issues have been managed previously, though at a smaller scale and for shorter periods using fuel in drums in temporary bunds (Horn et al. 2021). Double skinned fuel bladders, flyable by helicopter and used in Antarctica, may be a solution (Phillips 2015).

Next steps

The economic uncertainty of the COVID-19 pandemic in 2020 meant initiating the project was not an option for DOC or interested parties at the completion of the feasibility assessment in 2020. In the interim the project is being maintained by DOC's National Eradication Team. Draft operational plans have been developed and planning issues are being addressed as opportunities arise. Specialist fundraising skills and an investment plan with government commitment are needed to engage external funders at the various levels required for this goal.

Consideration of the remaining challenges and dependencies can start early in anticipation of project initiation. Steps that can be taken immediately include initiating and continuing development of required capabilities, progressing permissions, design of buildings and facilities, completion of site management plans, securing funding and completing key project design tasks such as governance and procurement planning. As governance and an operating model are agreed, a project plan should be written to capture and guide the management of the project throughout its life. These actions will aid in minimising the lag between a decision to proceed and achieving the readiness required to commence implementation. Meanwhile biodiversity values at Auckland Island continue to decline. Costs and compliance complexities also inevitably increase over time. A decision to proceed and a committed investment strategy are needed to allow critical path tasks to commence as soon as is viable.

Conclusions

Assessed against well-established criteria, the Maukahuka project is feasible because available or emerging methods were tested that can be scaled up to put all pigs, mice and cats at risk. Underestimating the scale, cost and timeframe risks a prolonged pathway to failure or an abandoned project (Parkes et al. 2014). The feasibility study has illustrated the scale so the project can be set up to succeed in eradicating pigs, mice and cats from Auckland Island. The project is now understood and is the largest island project in PF2050 ready to proceed. Understanding planning issues, dependencies and next steps has focussed subsequent planning effort by providing an immediate and staged way to progress towards the goal. Investment in tools will have flow on benefits for conservation across New Zealand. The project will help build the eradication efficiency needed for PF2050 and the capability for the increasing scale of other projects. Maukahuka is an example of the ambition that DOC has demonstrated in its history of acting to protect and undo damage in our most treasured but challenging places. The feasibility of this project carefully builds on the lessons from the past. Armed with this knowledge, the wero of kaitiakitanga has been laid down to restore the mana of Auckland Island.

Author contributions

SRH, RLS, VKF, FSC, PMJ, JW, RHN, EPL, NLM, MSKC, MELL and KGB designed the study; all authors undertook fieldwork; and SRH, RLS and FSC wrote the manuscript with input from KGB.

Acknowledgements

This project was supported by many technical experts from within and external to the Department including DOC's current and former IEAG members (Keith Broome, Kerry Brown, Chris Golding, James Reardon, Stephen Horn, Finlay Cox, Peter Corson, Euan Kennedy, Peter McClelland and Andy Cox), Alastair Fairweather, Elaine Murphy, James Russell, Grant Harper, Graeme Elliott, Nick Torr, and Richard Griffiths. Particular thanks to Ngāi Tahu, especially Gail Thompson, Tā Tipene O'Regan and Matapura Ellison for your representation. Thank you to the skilled and passionate field teams, who braved the seas and scrub to test tools and techniques that proved this project feasible and worthwhile. Special thanks to Steve Kafka and the crew of the MY Evohe for going above and beyond to provide safe, enjoyable passage to the island. Thanks to the Murihiku district team and the quarantine store team for your support. Thank you to the project's governance group and New Zealand's Department of Conservation and the international visitor levy for funding the work. We acknowledge the suppliers, stakeholders, project partners and conservation community who support the vision of this project. Many thanks to two anonymous reviewers, whose feedback improved this manuscript.

Lastly, we would like to recognise the contributions of the late Norm Macdonald to the Maukahuka Pest Free Auckland Island project as well as countless ungulate eradications both domestically and internationally. When Auckland Island is cleared of feral pigs, it will be partly thanks to Norm's aptitude and willingness to share his expertise and lifelong contribution to conservation. Okioki i te rangimarie Norm.

This study builds on decades of pioneering research, development and implementation of eradication capability in New Zealand. We stand on the shoulders of giants.

References

Alameen AA, Al-Gaadi KA, Tola EK 2019. Development and performance evaluation of a control system for variable rate granular fertilizer application. Computers and Electronics in Agriculture 160: 31–39.

Angel A, Wanless RM, Cooper J 2009. Review of impacts of the introduced house mouse on islands in the Southern Ocean: are mice equivalent to rats? Biological Invasions 11: 1743–1754.

Bester MN, Bloomer JP, Van Aarde RJ, Erasmus BH, van Rensburg PJJ, Skinner JD, Howell PG, Naude TW 2002. A review of the successful eradication of feral cats from sub-Antarctic Marion Island, Southern Indian Ocean. South African Journal of Wildlife Research 32: 65–73.

Black AD, Lee JG, Parker GC, Rexer-huber K 2017. Non-target mortality monitoring in South Georgia rodent eradication. Final report to GSGSSI. Report to the Government of South Georgia and the South Sandwich Islands. Dunedin, Parker Conservation. 47 p.

Bomford M, O'Brien P 1995. Eradication or control for vertebrate pests? Wildlife Society Bulletin 23: 249–255.

Broome K, Cromarty P, Cox A 2005. Rat eradications – how to get it right without a recipe. Proceedings of the 13th Australasian Vertebrate Pest Conference. Lincoln, New Zealand, Maanaki Whenua Press. Pp. 152–157.

Broome KG, Golding C, Brown KP, Corson P, Bell P 2017a. Rat eradication using aerial baiting: current agreed best practice used in New Zealand (Version 3.1). Internal Document DOC-29396. Wellington, New Zealand. 25 p.

Broome KG, Golding C, Brown KP, Horn S, Corson P, Bell P 2017b. Mouse eradication using aerial baiting: current agreed best practice used in New Zealand (Version 1.0). Internal Document DOC-3034281. Wellington, New Zealand. 30 p.

Broome KG, Brown D, Brown K, Murphy E, Birmingham

C, Golding C, Corson P, Cox A, Griffiths R 2019. House mice on islands: management and lessons from New Zealand. In: Veitch CR, Clout MN, Martin AR, Russell JC, West CJ eds. Island invasives: scaling up to meet the challenge. Proceedings of the International Conference on Island Invasives 2017. Occasional Paper of the IUCN Species Survival Commission 62. Gland, Switzerland, IUCN. Pp. 100–107.

Brown DA, Cox FS 2022a. The eradication of cattle from Enderby Island and subsequent ecological response. New Zealand Journal of Ecology 46: 3485.

Brown DA, Cox FS 2022b. The hunting-assisted demise of Campbell Island cattle. New Zealand Journal of Ecology 46: 3484.

Brown DA, Broome KG, Timpson KG 2022a. The eradication of feral goats from Auckland Island. New Zealand Journal of Ecology 46: 3486.

Brown DA, Cox FS, Fergus AJ 2022b. The eradication of Campbell Island sheep and subsequent ecological response. New Zealand Journal of Ecology 46: 3483

Brown K, Brown D 2015. Control to eradication of *Tradescantia fluminensis* on Stephens Island (Takapourewa): the importance of systematic and persistent effort. DOC Research & Development Series 346. Wellington, Department of Conservation. 11 p.

Brown K, Phillips CB, Broome KG, Green C, Toft R, Walker G 2019. Feasibility of eradicating the large white butterfly (*Pieris brassicae*) from New Zealand: data gathering to inform decisions about the feasibility of eradication. In: Veitch CR, Clout MN, Martin AR, Russell JC, West CJ eds. Island invasives: scaling up to meet the challenge. Proceedings of the International Conference on Island Invasives 2017. Occasional Paper of the IUCN Species Survival Commission 62. Gland, Switzerland, IUCN. Pp. 364–369.

Butchart SHM, Walpole M, Collen B, van Strien A, Scharlemann JPW, Almond REA, Baillie JEM, Bomhard B, Brown C, Bruno J, Carpenter KE, Carr GM, Chanson J, Chenery AM, Csirke J, Davidson NC, Dentener F, Foster M, Galli A, Galloway JN, Genovesi P, Gregory RD, Hockings M, Kapos V, Lamarque J, Leverington F, Loh J, McGeoch MA, McRae L, Minsyan A, Morcillo MH, Oldfield TEE, Pauly D, Quader S, Revenga C, Sauer JR, Skolnik B, Spear D, Stanwell-Smith D, Stuart SN, Symes A, Tierny M, Tyrrell TD, Vie J, Watson R 2010. Global biodiversity: indicators of recent declines. Science 328: 1164–1168.

Cerfonteyn M, Ryan PG 2015. Have burrowing petrels recovered on Marion Island two decades after cats were eradicated? Evidence from sub-Antarctic skua prey remains. Antarctic Science 28: 51–57.

Cox FS, Macdonald NL 2022. Use of automatic feeders to attract feral pigs on Auckland Island. New Zealand Journal of Ecology 46: 3491.

Cox F, Horn S, Jacques P, Sagar RL, Ware J 2019a. Maukahuka Pestfree Auckland Island – 2018/19 summer trials operational report. Internal Report - Department of Conservation. Invercargill, New Zealand, Department of Conservation Te Papa Atawhai. 121 p.

Cox F, Jacques P, Kirby-Crowe M, Ware J 2019b. Maukahuka Pestfree Auckland Island – 2019 winter trials operational report. Internal Report - Department of Conservation. Wellington, New Zealand, Department of Conservation Te Papa Atawhai. 86 p.

Cox FS, Horn SR, Bannister WM, Macdonald NL 2022a. A local eradication pilot study of methods for feral pig eradication on Auckland Island. New Zealand Journal of Ecology 46: 3490.

Cox FS, Jacques PM, Kirby-Crowe MS, Murphy EC 2022b. Field palatability and degradation of a selection of feral cat bait matrices on Auckland Island. New Zealand Journal of Ecology 46: 3495.

Cruz F, Donlan JC, Campbell K, Carrion V 2005. Conservation action in the Galàpagos: feral pig (*Sus scrofa*) eradication from Santiago Island. Biological Conservation 121: 473–478.

Department of Conservation 2016. Southland Murihiku Conservation Management Strategy. Invercargill, New Zealand, Department of Conservation Te Papa Atawhai, New Zealand Government. 343 p.

Department of Conservation 2020a. Te Mana o Te Taiao - Aotearoa New Zealand Biodiversity Strategy. Wellington, New Zealand, Te Papa Atawhai Department of Conservation, New Zealand Government. 73 p.

Department of Conservation 2020b. Towards a predator free New Zealand - predator free strategy. Wellington, New Zealand, Department of Conservation Te Papa Atawhai, New Zealand Government. 44 p.

Diaz S, Settele J, Brondizio ES, Ngo HT, Guèze M, Agard J, Arneth A, Balvanera P, Brauman KA, Butchart SHM, Chan KMA, Garibaldi LA, Ichii K, Liu J, Subramanian SM, Midgley GF, Miloslavich P, Molnár Z, Obura D, Pfaff A, Polasky S, Purvis A, Razzaque J, Reyers B, Roy Chowdhury R, Shin YJ, Visseren-Hamakers IJ, Willis KJ, Zayas CN 2019. Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Bonn, Germany, IPEBES Secretariat. 60 p.

Dilley BJ, Schoombie S, Schoombie J, Ryan PG 2015. 'Scalping' of albatross fledglings by introduced mice spreads rapidly at Marion Island. Antarctic Science 28: 73–80.

Dilley BJ, Schramm M, Ryan PG 2017. Modest increases in densities of burrow-nesting petrels following the removal of cats (*Felis catus*) from Marion Island. Polar Biology 40: 625–637.

Dingwall P, Jones K, Egerton R 2009. In care of the Southern Ocean: an archaeological and historical survey of the Auckland Islands. Monograph 27 of the New Zealand Archaeological Association. Wellington, New Zealand, New Zealand Archaeological Association. 317 p.

Fisher P, Algar D, Murphy E, Johnston M, Eason C 2015. How does cat behaviour influence the development and implementation of monitoring techniques and lethal control methods for feral cats? Applied Animal Behaviour Science 173: 88–96.

Fraser A 2020. The climate and weather of the Auckland Islands. Unpublished Report - prepared for the Department of Conservation Te Papa Atawhai. Invercargill, New Zealand, 45˚S Weather Service Ltd. 40 p.

French RK, Miskelly CM, Muller CG, Russ RB, Taylor GA, Tennyson AJD 2020. Birds of Enderby Island, Auckland Islands, New Zealand subantarctic. Notornis 67: 189–212.

Glen AS, Howard SW, Jacques PM, Sagar RL, Cox FS 2022a. Feral cats on Rakiura Stewart Island: population attributes and potential eradication tools. New Zealand Journal of Ecology 46: 3496.

Glen AS, Sagar RL, Brav-Cubitt T, Jacques PM 2022b. Monitoring and detection of feral cats on Auckland Island.

New Zealand Journal of Ecology 46: 3494.
Griffiths R 2011. Targeting multiple species – a more efficient approach to pest eradication. In: Veitch CR, Clout MN, Towns DR eds. Island invasives: eradication and management. Proceedings of the International Conference on Island Invasives. Occasional Paper of the IUCN Species Survival Commission 42. Gland, Switzerland, IUCN; and Auckland, New Zealand, Centre for Biodiversity and Biosecurity. Pp. 172–176.
Griffiths R, Buchanan F, Broome K, Neilsen J, Brown D, Weakley M 2015. Successful eradication of invasive vertebrates on Rangitoto and Motutapu Islands, New Zealand. Biological Invasions 17: 1355–1369.
Holmes ND, Spatz DR, Oppel S, Tershy B, Croll DA, Keitt B, Genovesi P, Burfield IJ, Will DJ, Bond AL, Wegmann A, Aguiree-Muñoz A, Raine AF, Knapp CR, Hung CH, Wingate D, Hagen E, Méndez-Sánchez F, Rocamora G, Yuan HW, Fric J, Millett J, Russell JC, Liske-Clark J, Vidal E, Jourdan H, Campbell K, Springer K, Swinnerton K, Gibbons-Decherong L, Langrand O, de Brooke ML, McMinn M, Bunbury N, Oliveira N, Sposimo P, Geraldes P, McClelland P, Hodum P, Ryan PG, Borroto-Páez R, Pierce R, Griffiths R, Fisher RN, Wanless R, Pasachnik SA, Cranwell S, Micol T, Butchart SHM 2019. Globally important islands where eradicating invasive mammals will benefit highly threatened vertebrates. PLoS One 14: e0212128.
Horn SR, Greene T, Elliott GP 2019. Eradication of mice from Antipodes Island, New Zealand. In: Veitch CR, Clout MN, Martin AR, Russell JC, West CJ eds. Island invasives: scaling up to meet the challenge. Proceedings of the International Conference on Island Invasives 2017. Occasional Paper of the IUCN Species Survival Commission 62. Gland, Switzerland, IUCN. Pp. 131–137.
Horn SR, Cox FS, Hanley-Nickolls JR, Jacques P, Pera-Leask E, Ware J, Frank V, Sagar RL 2021. Technical feasibility study report for eradication of pigs, mice and cats from Auckland Island. Invercargill, New Zealand, Department of Conservation Te Papa Atawhai.
Horn SR, Cox FS, Elliott GP, Walker KJ, Russell JC, Sagar RL, Greene TC 2022. Eradication confirmation of mice from Antipodes Island and subsequent terrestrial bird recovery. New Zealand Journal of Ecology 46: 3488.
Houghton M, Terauds A, Shaw J 2019. Methods for monitoring invertebrate response to vertebrate eradication. In: Veitch CR, Clout MN, Martin AR, Russell JC, West CJ eds. Island invasives: scaling up to meet the challenge. Proceedings of the International Conference on Island Invasives 2017. Occasional Paper of the IUCN Species Survival Commission 62. Gland, Switzerland, IUCN. Pp. 381–388.
Johnson PN, Campbell DJ 1975. Vascular plants of the Auckland Islands. New Zealand Journal of Botany 13: 665–720.
Livingstone J, Horn SR, Broome KG, Sagar RL 2022. How low can you sow? House mouse eradication on Motuareronui/Adele Island. New Zealand Journal of Ecology 46: 3498.
Lord JM, Huggins L, Little LM, Tomlinson VR 2013. Floral biology and flower visitors on subantarctic Campbell Island. New Zealand Journal of Botany 51: 168–180.
Martin AR, Richardson MG 2019. Rodent eradication scaled up: clearing rats and mice from South Georgia. Oryx 53: 27–35.
McClelland PJ 2011. Campbell Island – pushing the boundaries of rat eradications. In: Veitch CR, Clout MN, Towns DR eds. Island invasives: eradication and management. Proceedings of the International Conference on Island Invasives. Occasional Paper of the IUCN Species Survival Commission 42. Gland, Switzerland, IUCN; and Auckland, New Zealand, Centre for Biodiversity and Biosecurity. Pp. 204–207.
McInnes K, Jenson MA, Bolt I, Howard P, Lee SP, Macdonald NL, Cox FS 2022. A field test of the anaesthetics, surgical methods and radio-transmitters required for producing Judas pigs for an eradication programme. New Zealand Journal of Ecology 46: 3492.
Miskelly CM, Fraser JR 2006. Campbell Island snipe (*Coenocorypha* undescribed sp.) recolonise subantarctic Campbell Island following rat eradication. Notornis 53: 353–359.
Miskelly CM, Elliot GP, Parker GC, Rexer-Huber K, Russ RB, Taylor RH, Tennyson AJD, Walker KJ 2020. Birds of the Auckland Islands, New Zealand subantarctic. Notornis 67: 59–151.
Morrison SA 2007. Reducing risk and enhancing efficiency in non-native vertebrate removal efforts on islands: a 25 year multi-taxa retrospective from Santa Cruz Island, California. In: Witmer GW, Pitt WC, Fagerstone K eds. Managing vertebrate invasive species. Fort Collins, USDA/APHIS/ WS, National Wildlife Research Centre. Pp. 398–409.
Morrison SA, Faulkner KR, Vermeer LA, Lozier L, Shaw MR 2011. The essential non-science of eradication programmes: creating conditions for success. In: Veitch CR, Clout MN, Towns DR eds. Island invasives: eradication and management. Proceedings of the International Conference on Island Invasives. Occasional Paper of the IUCN Species Survival Commission 42. Gland, Switzerland, IUCN; and Auckland, New Zealand, Centre for Biodiversity and Biosecurity. Pp. 461–466.
Oyston ED, Horn SR, Murphy EC 2022. A trial on Te Pākeka/Maud Island for reducing aerial baiting sow-rates for the eradication of house mice. New Zealand Journal of Ecology 46: 3499.
Pacific Invasives Initiative 2013. Resource kit for rodent and cat eradication. http://www.pacificinvasivesinitiative.org/rce/index.html (accessed 2 February 2021).
Parker GC, Rexer-Huber K, Thompson D 2017. Grey petrel population on Campbell Island 14 years after rodent eradication. Antarctic Science 29: 209–216.
Parkes JP 1990. Eradication of feral goats on islands and habitat islands. Journal of the Royal Society of New Zealand 20: 297–304.
Parkes JP, Ramsey DSL, Macdonald N, Walker K, McKnight S, Cohen BS, Morrison SA 2010. Rapid eradication of feral pigs (*Sus scrofa*) from Santa Cruz Island, California. Biological Conservation 143: 634–641.
Parkes JP, Fisher P, Robinson S, Aguirre-Muñoz A 2014. Eradication of feral cats from large islands: an assessment of the effort required for success. New Zealand Journal of Ecology 38: 307–314.
Pera-Leask E 2020. Maukahuka Pest Free Auckland Island. Treaty Partners relationship vision document: restoring the mana of Auckland Island. Invercargill, New Zealand, Department of Conservation Te Papa Atawhai. 25 p.
Phillips C 2015. Expanding logistics support to science programmes in Antarctica: long distance traverse capability options for Antarctica NZ. Christchurch, University of Canterbury. 31 p.

Phillips RA, Gales R, Baker GB, Double MC, Favero M, Quintana F, Tasker ML, Weimerskirch H, Uhart M, Wolfaardt A 2016. The conservation status and priorities for albatrosses and large petrels. Biological Conservation 201: 169–183.
Ramsey D, Will D 2012. Framework for undertaking eradication programs on insular populations of vertebrate pests. Melbourne, Arthur Rylah Institute for Environmental Research. 40 p.
Runanga Papatipu o Murihiku 2008. The cry of the people: Te Tangi a Tauira: Ngai Tahu Ki Murihiku Natural Resource and Environmental Iwi Management Plan 2008. Christchurch, New Zealand, Iwi Management Committee. 318 p.
Russell JC, Broome KG 2016. Fifty years of rodent eradications in New Zealand: another decade of advances. New Zealand Journal of Ecology 40: 197–204.
Russell JC, Innes JG, Brown PH, Byrom AE 2015. Predator-free New Zealand: conservation country. BioScience 65: 520–525.
Russell JC, Griffiths R, Bannister WM, Le Lievre ME, Cox FS, Horn SR 2019. Mouse bait uptake and availability trials on Auckland Island. Department of Conservation Research and Development Series 363. Wellington, Department of Conservation Te Papa Atawhai. 15 p.
Russell JC, Horn SR, Miskelly CM, Sagar RL, Taylor RH 2020a. Introduced land mammals and their impacts on the birds of the subantarctic Auckland Islands. Notornis 67: 247–268.
Russell JC, Peace JE, Houghton MJ, Bury SJ, Bodey TW 2020b. Systematic prey preference by introduced mice exhausts the ecosystem on Antipodes Island. Biological Invasions 22: 1265–1278.
Russell JC, Horn SR, Broome KG 2022. Restoration of New Zealand subantarctic islands. New Zealand Journal of Ecology 46: 3482.
Samaniego A, Jolley W, McClelland P 2022. A lesson for planning rodent eradications: interference of invasive slugs during the Gough Island mouse eradication attempt in 2021. Wildlife Research: in press.
Sagar RL, Cox FS, Horn SR, Russell JC 2022. Population trends of house mice during tussock mast seeding on Auckland Island. New Zealand Journal of Ecology 46: 3497.
Secretariat of the Convention on Biological Diversity 2010. Aichi biodiversity targets. https://www.cbd.int/sp/targets/ (accessed 27 January 2021).
Spatz DR, Holmes ND, Will DJ, Hein S, Carter ZT, Fewster RM, Keitt B, Genovesi P, Samaniego A, Croll DA, Tershy BR, Russell JC 2022. The global contribution of invasive vertebrate eradication as a key island restoration tool. Scientific Reports 12: 13391.
Springer K 2011. Planning processes for eradication of multiple pest species on Macquarie Island – an Australian case study. In: Veitch CR, Clout MN, Towns DR eds. Island invasives: eradication and management. Proceedings of the International Conference on Island Invasives. Occasional Paper of the IUCN Species Survival Commission 42. Gland, Switzerland, IUCN; and Auckland, New Zealand, Centre for Biodiversity and Biosecurity. Pp. 228–232.
Springer K 2016. Methodology and challenges of a complex multi-species eradication in the sub- Antarctic and immediate effects of invasive species removal. New Zealand Journal of Ecology 40: 273–278.
Springer K 2018. Eradication of invasive species on Macquarie Island to restore the natural ecosystem. In: Garnett S, Latch P, Lindenmayer D, Woinarski J eds. Recovering Australian threatened species: a book of hope. Clayton South, Australia, CSIRO Publishing. Pp. 13–22.
Staples L, Wishart J 2019. Use of HOGGONE® meSNTM feral pig bait for the reduction of feral pig populations in Australia. In: Sydes T ed. Proceedings of the 1st Queensland Pest Animal and Weed Symposium. Brisbane, Weed Society of Queensland Pty Ltd. Pp. 91–96.
Torr N 2002. Eradication of rabbits and mice from subantarctic Enderby and Rose Islands. In: Veitch CR, Clout MN eds. Turning the tide: the eradication of invasive species. Proceedings of the international conference on eradication of island invasives. Occasional Paper of the IUCN Species Survival Commission 28. Gland, Switzerland, IUCN. Pp. 319–328.
Towns DR, West CJ, Broome KG 2013. Purposes, outcomes and challenges of eradicating invasive mammals from New Zealand islands: an historical perspective. Wildlife Research 40: 94–107.
Trotter M, Willis M 2022. Introduction, rescue and subsequent history of Auckland Island livestock. New Zealand Journal of Ecology 46: 3487.
Van Aarde RJ, Ferreira SM, Wassenaar TD 2004. Do feral house mice have an impact on invertebrate communities on sub-Antarctic Marion Island? Austral Ecology 29: 215–224.
World Heritage Convention 1998. New Zealand Sub-Antarctic Islands. United Nations Educational, Scientific and Cultural Organization http://whc.unesco.org/en/list/877/ (accessed 2 March 2018).

Editorial board member: James Russell
Received 24 February 2021; accepted 29 September 2022

Supplementary Material

Additional supporting information may be found in the online version of this artıcle:

Table S1. How, when and where priority research questions were addressed to assess the feasibility of eradicating invasive pigs (*Sus scrofa*), mice (*Mus musculus*) and cats (*Felis catus*) from subantarctic Auckland Island.

The New Zealand Journal of Ecology provides online supporting information supplied by the authors where this may assist readers. Such materials are peer-reviewed and copy-edited but any issues relating to this information (other than missing files) should be addressed to the authors.