NEW ZEALAND JOURNAL OF ECOLOGY

RESEARCH

A local eradication pilot study of methods for feral pig eradication on Auckland Island

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Published online: 28 November 2022

Abstract: Since their liberation in 1807, feral pigs (*Sus scrofa*) have negatively impacted ecosystem health and processes on subantarctic Auckland Island, New Zealand. Eradication of invasive alien species is often critical to restoration programmes and preventing species extinctions. Eradication programmes utilising multiple techniques have allowed feral pig eradications on large islands. Protracted eradication programmes can have a higher risk of failure due to factors such as biological, logistical, social, and funding support. A temporary local pig eradication pilot study was successfully implemented on a densely vegetated fenced 951 ha peninsula on Auckland Island, emulating the principles set out during the Santa Cruz Island (California, USA) eradication. We applied multiple techniques, each delivered at the appropriate pig population density and within a finite period, to reduce the inherent risk of eradication failure. Aerial hunting was used to reduce the pig population before systematic ground hunting by a team using specially trained dogs removed survivors and validated eradication success. The deployment of a high specification thermal or forward-looking infrared (FLIR) camera in a particular manner greatly improved the efficiency of aerial hunting during this pilot study. The use of passive trapping, Judas pigs and division of the island into smaller fenced units are supplementary methods proposed for the Auckland Island eradication to enhance eradication efficiency as the methods implemented here are scaled up.

Keywords: aerial shooting, detection probability, eradication, FLIR, ground hunting, invasive alien species, pig fence, *Sus scrofa*, thermal camera

Introduction

Invasive alien species pose a significant risk to island ecosystems and eradication of these species is often necessary to prevent extinctions of native flora and fauna (Myers et al. 2000; Hutton et al. 2007). Successful eradications traditionally require detailed planning to account for biological, logistical and social challenges. The scale and complexity of island eradications has increased in recent years with larger islands being attempted internationally (Russell & Broome 2016). To satisfy established principles of eradication, all individuals must be able to be put at risk (Bomford & O'Brien 1995). For rodents, all individuals can be targeted with a single tool whereas other larger species, such as feral pigs (*Sus scrofa*), often require a sequence of techniques to achieve eradication.

From the 1950s, New Zealand conservation practitioners begun to apply hunting techniques used for control programmes on the mainland to eradicate feral pigs from small islands (<200 ha; Veitch & Bell 1990). More recently, eradication programmes utilising multiple techniques or variations in the delivery of a single technique, have allowed feral pig eradications on larger islands (Lombardo & Faulkner 2000; Kessler 2002, 2011; Schuyler et al. 2002; Cruz et al. 2005; Parkes et al. 2010). Some of these large island eradications have been delivered over several years and often, as in the case of Santa Catalina Island (California, USA; Garcelon et al. 2005) and Santiago Island (Galápagos Islands, Ecuador; Cruz et al. 2005), have evolved from sustained control efforts (Table 1). In contrast, shorter, more focused eradications were delivered on Santa Rosa Island (Table 1; California, USA; Lombardo & Faulkner 2000) and Santa Cruz Island (Table 1; California, USA; Parkes et al. 2010). Prolonged eradication programmes increase risk of failure due to factors such as biological, logistical and funding support (Cruz et al. 2005; Morrison et al. 2011). Success of eradication programmes for ungulates can depend on ensuring that as a population is reduced, the remaining individuals remain naive to risk and do not develop an avoidance to detection. Rapid reduction by employing a range of field methods in strategic sequence can help maintain these conditions (Morrison et al. 2007).

To eradicate feral pigs on Santa Cruz Island, the island was divided into smaller management units with fencing. Baited corral trapping and aerial hunting were used to rapidly reduce the population in each unit (by c. 95%). These techniques were followed by systematic ground hunting with dogs and monitoring of Judas pigs (Taylor & Katahira 1988; Parkes et al. 2010). Delivery discipline was important so that all techniques left no witnesses or survivors to a lethal

DOI: https://doi.org/10.20417/nzjecol.46.3490

Table 1. Particulars of successful pig eradications on large islands (c. 20 000 ha or larger) with adequate reporting.

Island	Location	Area (ha)	Year of completion	Duration (months)	Number of pigs	Reference
Santa Rosa	California, USA	21 527	1993	33	1175	Lombardo & Faulkner 2000
Santiago Island	Galápagos Islands, Ecuador	58 465	2000	360	c. 18 000	Cruz et al. 2005
Santa Catalina	California, USA	19 400	2003	154	c. 12 000	Garcelon et al. 2005
Santa Cruz	California, USA	25 064	2007	14	5036	Parkes et al. 2010

encounter (of individuals or groups of animals). If a mob of feral pigs was detected during aerial shooting surveys, they were not engaged if there would likely be survivors and instead were subsequently targeted with a baited corral trap. Ground hunting occurred after aerial hunting and trapping so hunters only encountered solitary or small numbers of animals (Caley & Ottley 1995; Parkes et al. 2010). There was overlap in the sequence of techniques being used, so even though the eradication manager applied them at the correct population density, often they continued to be deployed for the duration of the eradication to increase confidence. This strategic approach reduced the duration and importantly the inherent risk of the eradication overall.

The Department of Conservation's Maukahuka – Pest Free Auckland Island project was mandated to investigate the feasibility of removing feral pigs, cats (*Felis catus*), and mice (*Mus musculus*) from subantarctic Auckland Island, New Zealand (45 891 ha) (Horn et al. 2022). Since liberation, feral pigs have negatively impacted ecosystem health and processes on Auckland Island. It is difficult to accurately quantify the impact of pigs on Auckland Island as most of the devastation occurred before ecological observations began (Russell et al. 2020). Extensive rooting and widespread consumption of palatable flora, especially megaherb species such as *Anisotome latifolia*, *Pleurophyllum criniferum* and *Azorella polaris*, were reported by the mid-to-late-19th century (McCormick 1884). Assessment of the impacts of pigs is reinforced by contrasting analogous habitat on adjacent pest-free Adams, Disappointment and Enderby Islands; megaherbs on Auckland Island are now confined to inaccessible areas (Challies 1975; Campbell & Rudge 1984). Feral pigs also consume a wide variety of animal matter including earthworms, insects, molluscs, crustaceans, and beach-wrecked fish and marine mammals as well as seabird eggs, chicks, and even adult birds (Challies 1975; Rudge 1976; Chimera et al. 1995; Turbott 2002; Russell et al. 2020). Reports have included pigs excavating holes of up to 1.5 m^3 to access burrowing Antarctic prions (*Pachyptila desolata*) and there are several observations recorded of pigs eating white-capped mollymawk chicks (*Thalassarche cauta steadi*) (Russell et al. 2020).

Emulating the Santa Cruz Island eradication approach (Parkes et al. 2010), the Auckland Island pig eradication will require the systematic application of a range of eradication techniques in a pre-determined sequence applied at the correct population density. Ground hunting with dogs has the highest detection probability, however, if large groups of pigs are encountered there is a high risk of individuals escaping. Rapid reduction of the population prior to ground hunting will be critical to reduce risk and provide confidence in an eradication result within a finite period. Aerial shooting can rapidly reduce a target population, particularly over large areas with high-density populations of ungulates (Saunders 1993; Choquenot et al. 1999) but will not detect or remove all individuals. Aerial hunting contributed 77% of the 5036 pig dispatches during the Santa Cruz Island eradication (Lombardo & Faulkner 2000; Parkes et al. 2010; Kessler 2011). The use of passive trapping with automatic feeders (Cox & Macdonald 2022), Judas pigs (McInnes et al. 2022) and division of the island into smaller fenced units is proposed to supplement aerial and ground hunting methods for Auckland Island.

An eradication on Auckland Island presents significant challenges relating to scale, climate, and remoteness as well as thick vegetation and steep terrain affecting accessibility (Horn et al. 2022). As such the practicality and efficacy, as well as the associated logistical challenges, of ground hunting on Auckland Island were uncertain. Aerial hunting will likely be effective on the high altitudinal tussock grasslands, however, detection of target individuals can be hampered by dense vegetation (Kays et al. 2019). One potential tool for enhancing detection probability is thermal or forward-looking infrared (FLIR) cameras that can sense infrared radiation. A FLIR device was trialled on Santa Rosa Island but was ineffective due to the dense vegetation and dismissed (Lombardo & Faulkner 2000). There have been significant developments in high-resolution cameras and their specialised delivery since the Santa Rosa eradication; Airborne Technologies (North Beach, Western Australia, Australia) has been developing the delivery of thermal technology for wild animal control since the early 2000s. Performance is still impacted by vegetation density but also 'wash-out' caused by solar radiation which reduces contrast between the target animals and their background (Witczuk et al. 2018; Kays et al. 2019). In addition, objects in a landscape (such as rocks) can retain solar radiation, which can cause distraction by false detection. Regardless of these performance constraints, indications from mainland trials show a focused camera operator utilising a specialised high-resolution camera can improve the efficacy of ungulate aerial shooting (Macdonald 2018). Macdonald (2018) reports high detection rates and ability to dispatch animals under a closed forest canopy. At the time of this pilot study, the benefits FLIR technology would have for aerial shooting on Auckland Island were uncertain.

To facilitate mouse bait uptake trials (Russell et al. 2019), feral pigs needed to be removed from the mouse treatment area to exclude pig consumption of bait as a confounding factor. This presented an opportunity to trial proposed pig eradication techniques on Auckland Island to resolve uncertainties, inform feasibility of delivery in local conditions and provide data to enable resource estimates for future eradication over the whole island. The pilot study eradication occurred in January 2019 and was split into distinct aerial and ground hunting phases utilising different teams and different helicopter resources. Aerial shooting assisted by a high-resolution thermal camera was delivered first over the whole peninsula and expected to put a high proportion of the feral pig population at risk. In the second phase a team of hunters with dogs systematically covered the whole peninsula to dispatch remaining pigs and confirm eradication. In this way ground hunting was able to validate the results of the aerial shooting to inform efficacy. All operational data were recorded and analysed to inform predictive estimates of island-wide delivery.

Methods

Study system

Feral pigs were first introduced at Port Ross, Auckland Island, in 1807 as a food source for visiting ships and castaways (Russell et al. 2020). Further liberations occurred in the 19th century and pigs were well established in the north by 1840 and throughout the island by 1886 (Russell et al. 2020). Pigs have been recorded through observations and tracking across the whole of Auckland Island except steep areas (≥70° slope) particularly on the western cliffs (Anderson et al. 2022). Population densities fluctuate annually and seasonally with changes to habitat quality and availability of food (Challies 1975; McIlroy 2005). Pigs are highly fecund and the population can respond quickly to additional food resources (McIlroy 2005) – Clarke (1991) estimated 760–1140 pigs on Auckland Island. Anderson et al. (2022) reported annual home range sizes between 1260 and 3640 ha with males having larger home ranges. They also found that the pigs, at a population level, selected areas closer to the coast, however, there was high individual variability and likely seasonal habitat selection.

Site description

The pilot study eradication was carried out on Falla Peninsula on the east coast of Auckland Island (Fig. 1). The 951 ha peninsula lies between the Smith and Norman Harbours, separated by a 258 m isthmus (Fig. 1). The vegetation composition of the peninsula includes a coastal band of Southern rātā (*Metrosideros umbellata*) and canopy height is influenced by the shelter, aspect and degree of the slope (Campbell & Rudge 1984). The rātā forest merges into a thick band of low, tight scrub dominated by *Dracophyllum longifolium*, *Myrsine divaricata* and *Ozothamnus vauvilliersii*. This scrub band breaks into patches and transitions into tussock grassland principally of *Chionochloa antarctica* (Campbell & Rudge 1984). The peninsula has a peak elevation of only 284 m, so the sparsely vegetated fellfield communities that occur at higher elevations on Auckland Island are not represented.

Fence

To preserve the study site from pig dispersal, a temporary electric fence was installed across the isthmus at the neck of the peninsula to discourage or at least indicate reinvasion. The fence was terminated at steep coastal boundaries to minimise migration around the fence ends. A two-metre-wide track was cleared allowing the 1.06 m Gallagher (Hamilton, New Zealand) electrified netting fence to be installed along the centreline. The cleared track minimised vegetation shorting the fence, which was powered by a Gallagher (Hamilton, New Zealand) 12-volt battery energizer (B200). The fence was checked daily by visual inspection and also monitored with five trail cameras installed at likely pressure points such as existing animal trails that intersected the fence line.

Thermal assisted aerial shooting

Airbourne Technologies were contracted to operate and supply a thermal camera using the refined procedure described by Macdonald (2018). A Vayu 1920 x 1080 HD long wave un-cooled camera fitted with a 24 mm lens (Sierra-Olympic Technologies Inc; Hood River, USA) was used. This trial set out to inform the detectability of pigs with thermal imagery in the different habitat types on Auckland Island.

A Eurocopter AS350-B2 (Marignane, France) helicopter was used as the platform for aerial hunting. Configuration for aerial shooting assisted by thermal camera comprised of the shooter in the front seat opposite the pilot and the camera operator harnessed and sitting on the floor in the rear cabin opposite the pilot. The shooter utilised a semi-automatic .223 calibre rifle, which had a 45° optics mount allowing two optics to be fitted: a Thermis 640 x 480 thermal scope (Theon; Athens, Greece) with a 75 mm focal length lens, and an Aimpoint Micro T-1 (Manassas, USA) non-magnifying red dot scope. At times a secondary thermal shooter/camera operator (low resolution) sat behind the pilot in the rear cabin. The secondary shooter/thermal operator was the backup pilot for the expedition and filled the vacant seat during operations. The secondary operator used a FLIR 480 X 320 (FLIR Systems; Wilsonville, USA) thermal monocular to opportunistically survey the opposite direction to the high-resolution primary camera operator. The secondary operator also had a Benelli M1 (Urbino, Italy) shotgun with buckshot in case piglets were engaged and the primary shooter had difficulty dispatching them using the .223.

With this configuration, the helicopter actively canvassed the terrain to put the thermal camera operator in the best position to survey the topography. Once a heat source was detected the thermal camera operator would communicate its location with the team assisted by a high-powered laser that was sighted with the camera. The shooter (on the same side of the helicopter as the camera operator) was then able to see where the thermal camera operator was looking. The pilot in response to the verbal communication and body language of the team also ascertained where the detected heat source was. The pilot would then attempt to position the helicopter and in most cases pursue the heat source to allow species identification of a pig before it was dispatched.

The hunting pattern, distance between flight lines, flight height and flight speed were adapted to the terrain, vegetation type and desired field of view (hereafter FOV) for the thermal camera. During planning, these factors, the number of surveillance passes required and the period spent interacting with detected animals, were considered by Airbourne Technologies and planners to estimate that 20 flight hours would be required to adequately cover Falla Peninsula with thermal camera-assisted aerial hunting. Historic weather data were assessed (Fraser 2020) to inform an appropriate expedition timeframe to facilitate 20 hours of helicopter time and 11 days were planned for the aerial hunting phase. The helicopter tracklogs were recorded and broken down into activity types (ferry flight, survey flight, target interaction, non-target interaction) to allow the review of these estimates.

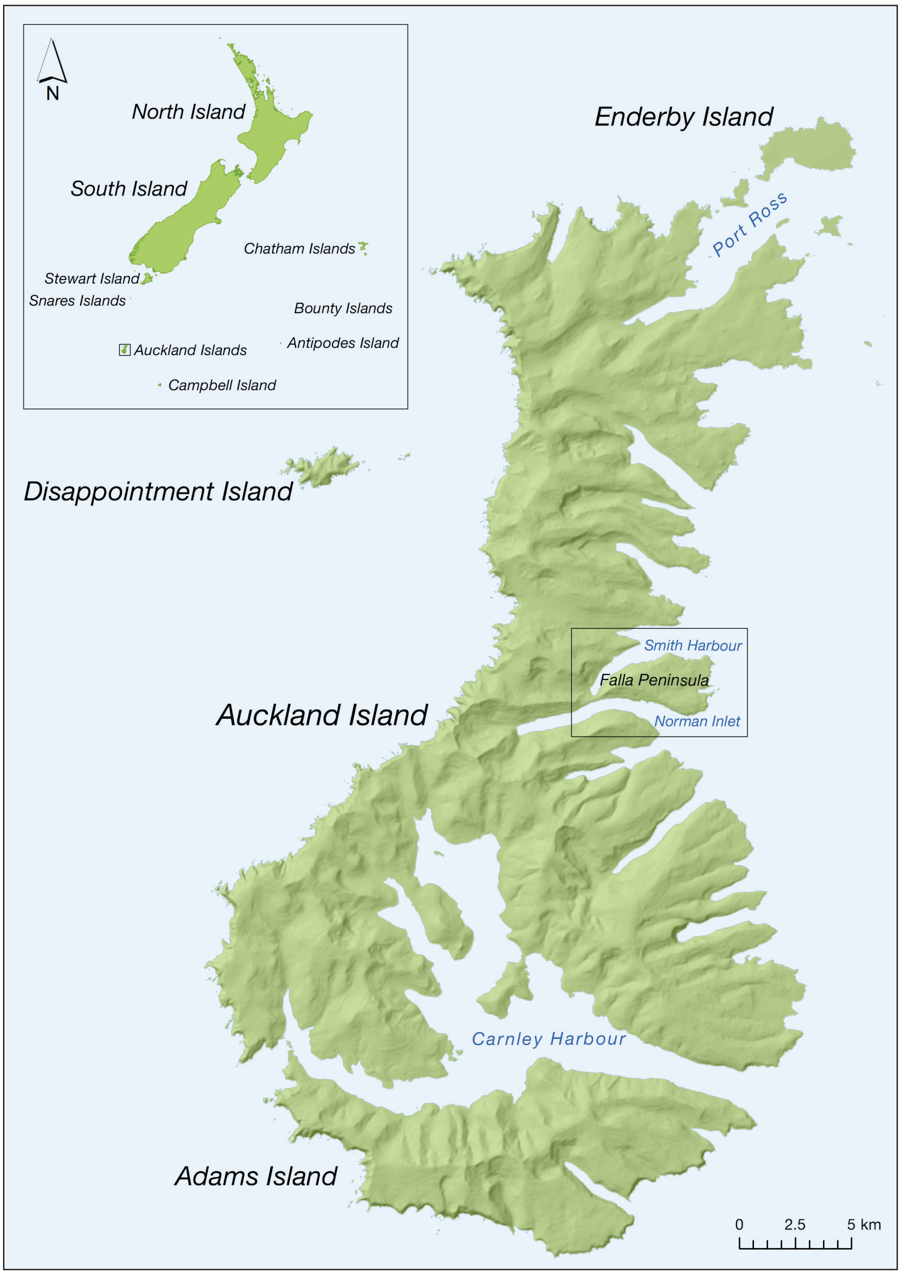

Figure 1. The Auckland Islands, box showing trial site at Falla Peninsula.

Ground hunting

Ground hunting was conducted after the aerial hunting phase enabling an assessment of the thermal camera assisted aerial hunting efficacy. Team ground hunting utilised five hunters each working one dog specifically trained to detect, pursue and bail feral pigs. The hunters worked in parallel and moved in one 'front' or 'line'. The distance between hunters varied between 100–250 m depending on terrain and vegetation to ensure there was an overlap of the area covered by an individual hunter and their dog's 'detection swath'. When a pig was detected, only the closest hunter would respond to the bailing dog (regardless of handler). The rest of the hunters and dogs were intended to remain in line to prevent pigs escaping back through the line. Hunting team candidates were selected for the pilot study by considering hunting experience, the skill level of their dogs and team fit. A subset of this group were further tested during a week-long training programme where the five primary hunters and one back-up hunter were identified. Dogs received aversion training for hoiho (yellow-eyed penguin, *Megadyptes antipodes*) and whakahao/rāpoka (New Zealand sealion, *Phocarctos hookeri*).

Two complete ground sweeps of the peninsula were conducted with focussed follow-up during each sweep whenever there was concern about gaps in coverage or observed sign. Hunting rates recorded on Santa Cruz Island pig eradication and Secretary Island (New Zealand) deer eradication were used to estimate the time required to ground hunt the peninsula (Parkes et al. 2010; Macdonald et al. 2019). A coverage rate of c. 6 ha per hunter per hour was used and adjusted for the expected weather (Fraser 2020). A period of 19 days was allowed to complete two full sweeps of the peninsula with a team of five hunters. The inland and coastal bluff systems on Falla Peninsula would not allow downhill hunting as for other ground hunting programmes, so it was planned for the hunters to hunt along contours. Systematic delivery ensured every engagement was lethal and gave confidence that zero detections accurately equated to an absence of pigs. A team leader role was incorporated (additional to the five hunters) to co-ordinate the team in the field. The main functions of the role were to ensure adequate spacings were maintained between hunters, to interpret the team's feedback, and to maintain motivation and discipline within the team.

Hunters carried Howa (Aichi, Japan) .223 rifles for humane dispatch of pigs. Each hunter utilised a hand-held push to talk, very high frequency (VHF) radio to communicate and/or receive direction from the team leader, and share operational information such as progress, pig sign, and pig interaction amongst the team. Garmin (Lenexa, USA) Alpha 100 global positioning system (hereafter GPS) handheld devices were used by all hunters and the team leader for navigation and to maintain hunter separation. These GPS have VHF capability and each display the location of all other team members and dogs. All dogs were fitted with Garmin T5 VHF collars. Hunting tracks and points of interest such as sign, or dispatch points, were downloaded daily and to inform the next day's plan. These data were collated and contributed to validation of the eradication. A Eurocopter AS350-B2 (Marignane, France) was used to shift hunters to the start and end of hunts; repositioning was often required within a day. If required, the helicopter would also support ground hunters to locate, intercept or dispatch a pig. The team leader was predominantly based in the helicopter, positioned nearby to the ground hunters to allow clear communication. He was also able to aerially shoot a pig if it moved ahead of the hunters or where the hunters could not access.

Results

Ten pigs were dispatched during the aerial hunting phase (1–8 January 2019) and five during the ground hunting phase (10–28 of January 2019). Pig densities vary spatially across Auckland Island, however a crude extrapolation of the 15 pigs detected during this pilot study on the 951 ha Falla Peninsula gives a population estimate at the time of the study of 723 pigs on Auckland Island (0.016 pigs ha^{-1}).

Fence

The temporary electric fence was in place for the duration of the pilot study. Two pigs broke through the fence. The first was pushed to leave from inside the treatment block, presumably by the helicopter activity during the thermal camera hunting phase. The pig caused the electric fence to short out, it walked along the cleared fence track then back into the treatment block. The second pig moved from outside, into the treatment area. This pig was not present on the peninsula during the aerial hunting phase or the first ground hunter sweep. Both pigs were subsequently dispatched during the ground hunting phase of the pilot study. There were six whakahao/rāpoka interactions with the fence, some were deterred, and some flattened the fence and continued on their path.

Aerial hunting

Two sweeps of the peninsula were conducted. Each sweep involved multiple flights or transects over particular areas, for example searching the rātā forest was repeated five to six times to achieve multiple views from different angles and assist with searching the whole forest floor. Transects averaged 75–95 m apart in the steep rātā and scrub and 50–200 m apart on the plateau of the peninsula, which was predominately mixed scrub and tussock. Most flights were undertaken at a speed of c. 18 km hr^{-1}. A total of 18.77 hr and 848 km of flight lines were conducted during surveillance with the thermal camera on Falla Peninsula. The frequency, duration and timing of the surveys were dictated by wind speed, rain intensity, fog and surface solar loading. Surveys were conducted on 6 of 11 planned operational days, but most of the coverage was completed on a single day. Flight statistics for the duration of the aerial hunting phase were broken down by activity (Table 2) and an example of a single day's survey effort symbolized by activity can be found in Figure 2.

A total of 10 pigs were detected in two separate mobs, positively identified and dispatched. The first mob of seven (sow and juveniles) were detected sheltering below a rock face (Fig. 3) and dispatched in this location. The second mob was detected in mixed scrub and mustered/pursued for approximately 50–60 m into a tussock laneway where they were then dispatched (Fig. 3). One other adult-size pig was detected adjacent to a slip near the isthmus as shown in exemplary survey map (Fig. 2). It escaped and avoided further detection mainly due to interference from solar heated objects. Non-target species were regularly detected during the pilot study including pinnipeds and birds. Kekeno (New Zealand fur seal, *Arctocephalus forsteri*) and whakahao/rāpoka had strong heat signatures and were frequently detected. Significant numbers of kekeno were seen on rock coastal areas (in groups of 150–200) and whakahao/rāpoka were detected from the coast to upwards of 2 km inland. Almost 5 hours were spent investigating c. 73 heat signatures that were eventually identified as non-targets (Table 2). Based on elicitation of observations from repeated surveys and recorded data, the thermal camera operator estimated the detectability of feral pigs on Auckland Island for the different habitat types: tussock grasslands (>99%); mixed scrub/swamp scrub (with tussock laneways, 80–90%); tall tight scrub (including rock faces/bluffs, 60%); and in both tall and stunted rātā forest (<30%).

Ground hunting

Two boars and two sows were detected and dispatched on the first sweep which took 5 days of hunting to complete (Table 4). A single boar was detected and dispatched during the second sweep, which took 6 days to complete (Table 4). This boar, as evidenced from camera data captured on the temporary fence, had migrated into the peninsula between the two sweeps and was detected and dispatched within a day of entry into the block. Track logs of the ground hunters and dogs were collected and analysed for coverage rates in different vegetation strata

Table 2. Flight statistics from helicopter track logs during aerial hunting phase of trial pig eradication on Falla Peninsula, Auckland Island.

	Time (hr)	**Distance (km)**
Ferry flight	4.77	119.43
Target interaction	1.04	10.69
Non-target interaction	4.79	38.52
Survey flight	12.94	798.82
Total	**23.54**	**967.45**

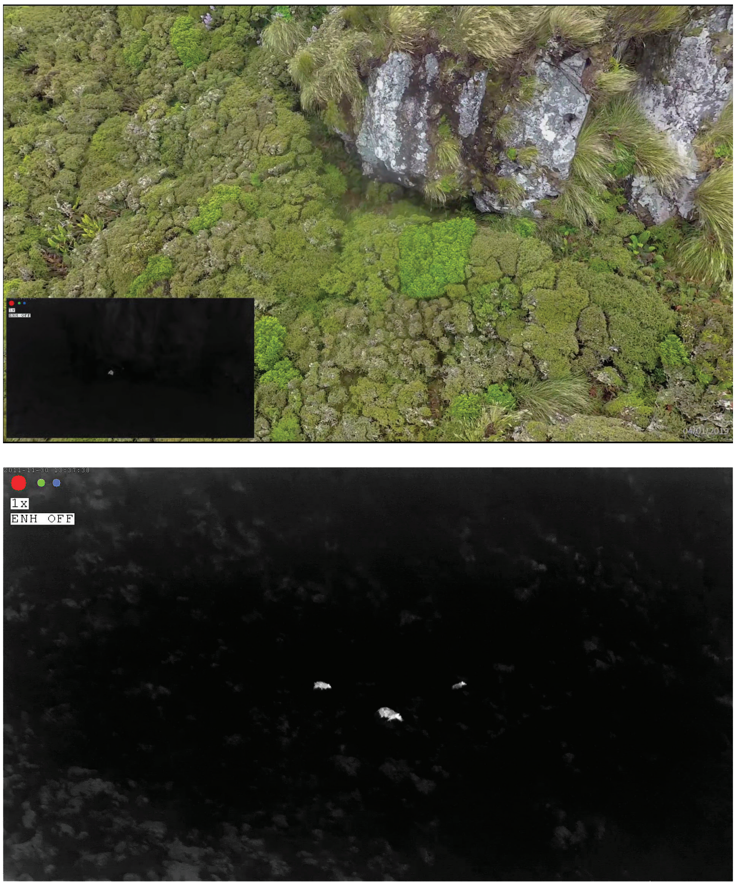

Figure 2 (above). An exmple of survey effort during thermal camera and aerial hunting on Falla Peninsula, Auckland Island.

Figure 3 (left). (top) Thermal view of first pig mob detected overlaid on normal view of forested terrain versus (bottom) thermal view of the second mob that were detected and mustered into the open before being dispatched.

(Fig. 4; Table 4). These data were averaged for the two sweeps and the different vegetation types (Table 3). It took 13 days to get suitable weather within which there could be 11 team hunting days (Table 4) to complete the two sweeps. With one exception, all pigs detected during the ground hunting phase were dispatched by the ground hunters. One pig moved to the coast when detected and helicopter support allowed rapid aerial dispatch when it was exposed in the coastal area.

Table 3. Summary effort (area in hectares per hunter per hour) of pig hunters in three habitat types (mean ± SD) on Falla Peninsula, Auckland Island during the trial pig eradication. Sweep 1 and 2 were undertaken in the same geographical areas but on differing lines.

	Effort (ha per hunter per hour)
Sweep 1	6.62
Sweep 2	7.90
Shrubland	6.86 ± 4.88
Coastal rātā forest	6.52 ± 3.59
Tussock/shrubland	10.18 ± 2.56

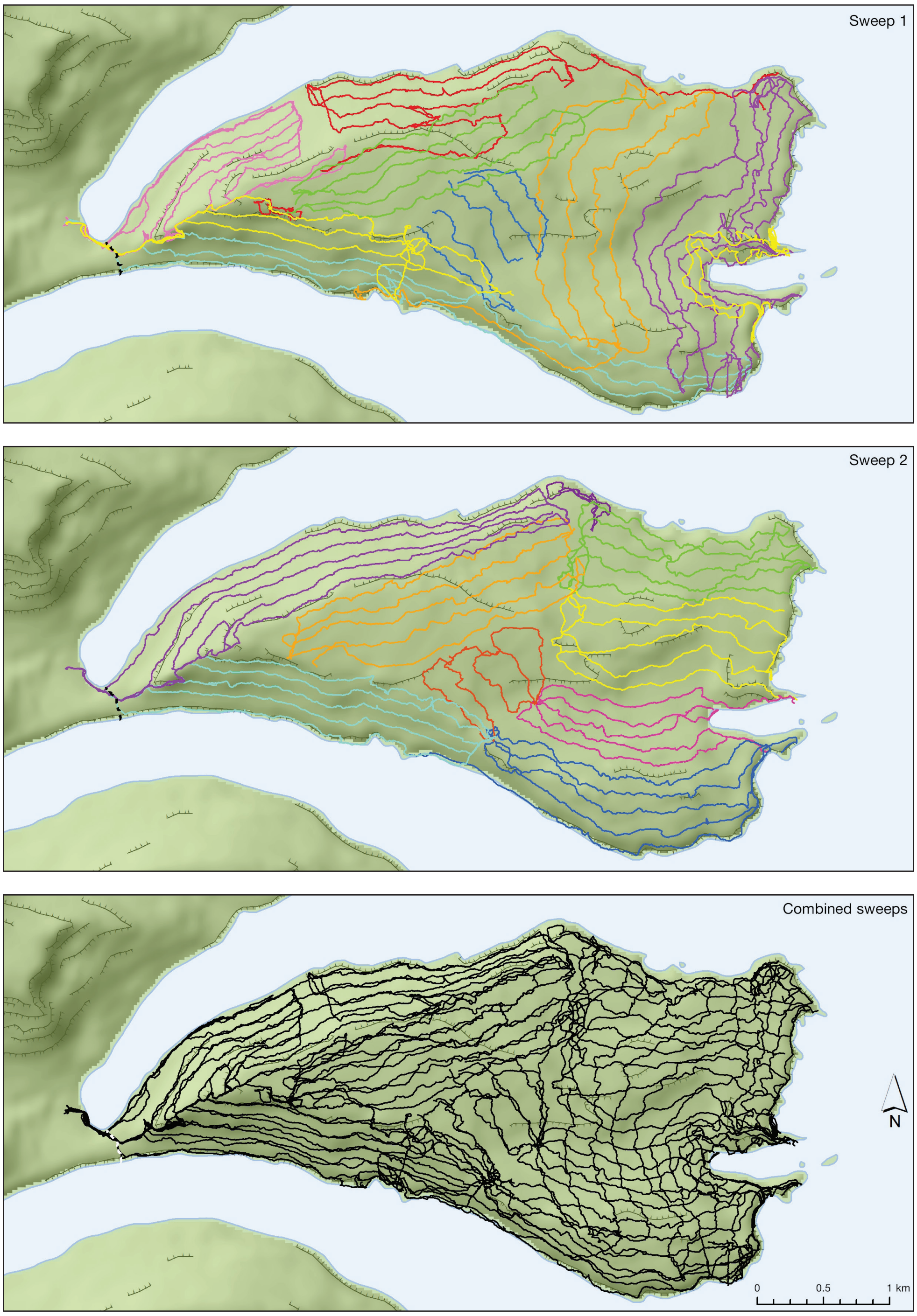

Figure 4. Tracks of individual pig hunters, shown by different coloured lines, on Falla Peninsula, Auckland Island. Showing coverage on sweep one (top), sweep two (middle) and combined (bottom).

Table 4. Summary of effort undertaken by ground-based pig hunters on Falla Peninsula, Auckland Island. Each row represents a single hunt (if hunters were repositioned it was considered a new hunt).

Sweep I.D	Date (2019)	Vegetation of worst line	Distance hunted total (km)	Linear distance (km)	Distance travelled by dogs total (km)	Hours hunted per hunter	Total area (ha)	No. hunters	Effort (ha per hunter per hour)
Sweep 1	12 Jan	Shrubland	35.01	1.91	29.01	6:40:34	106.30	6	2.65
	13 Jan	Shrubland	26.48	2.62	29.13	5:09:29	242.80	5	9.41
	13 Jan	Shrubland	16.90	2.41	23.88	2:58:47	249.90	5	16.77
	14 Jan	Coastal shrubland	46.76	4.56	54.29	9:37:53	281.90	6	4.88
	15 Jan	Shrubland	14.86	3.54	21.20	5:31:57	122.20	5	4.42
	15 Jan	Tall tussock	6.24	1.20	5.14	2:03:24	36.60	3	5.93
	17 Jan	Tall tussock/shrubland	6.20	0.96	10.79	1:40:13	88.60	5	10.61
	17 Jan	Tall tussock/shrubland	14.28	2.36	18.25	2:43:29	159.20	5	11.69
Sweep 2	18 Jan	Coastal shrubland	17.50	2.93	29.84	2:33:31	151.82	5	11.87
	18 Jan	Shrubland	11.20	2.15	15.80	3:56:50	96.46	5	4.89
	19 Jan	Tall tussock/shrubland	27.46	1.97	52.87	4:24:55	241.76	5	10.95
	21 Jan	Coastal shrubland	19.43	2.67	39.03	5:20:38	139.35	5	5.22
	22 Jan	Tall tussock	15.13	2.46	21.35	2:32:25	168.09	5	13.23
	22 Jan	Tall tussock/shrubland	6.70	0.88	11.14	1:37:07	70.23	5	8.68
	23 Jan	Shrubland	25.07	3.84	39.92	5:39:03	173.29	5	6.13
	24 Jan	Coastal shrubland	3.05	0.61	1.62	1:26:40	11.90	2	4.12

Discussion

The pilot study was successful; there was high confidence that pigs had been temporarily eradicated from Falla Peninsula. Ground hunting confirmed 11 of the 14 pigs (c. 79%) originally present on Falla Peninsula were detected with the thermal camera during the aerial hunting phase. Systematic delivery was necessary to ensure all areas were aerially surveyed. Multiple passes were carried out to provide several different aspects or views through the canopy and account for the mobility of pigs. None of these detections would have been made with traditional aerial hunting; the thermal camera underpinned the efficiency of aerial hunting during this pilot study. The ground hunters dispatched five pigs in total which included one that was detected during the aerial hunting phase and another which penetrated the fence after the thermal work had been completed. The pig that was detected during the aerial hunting phase and unable to be dispatched was detected as solar conditions were deteriorating, demonstrating the environmental constraints of this technique. The preferred operating conditions were overcast or early morning before surfaces absorb heat. Nevertheless, the thermal camera-assisted aerial hunting reduced the pig population to low densities without affecting the naivety of pigs to ground hunters and dogs.

Ground hunting has been a critical technique in most pig eradications including all islands detailed in Table 1. Thirty-three percent (5 of 15) of pigs were dispatched by ground hunting on Falla Peninsula during this pilot study. For reference, 77% of pigs were dispatched with ground hunting as part of the Santa Rosa Island pig eradication (Lombardo & Faulkner 2000). In contrast, only 5% of the pigs were dispatched by ground hunters on Santa Cruz Island (Parkes et al. 2010). The lower proportion dispatched in the Santa Cruz Island eradication compared to Santa Rosa Island was by design and timed to ensure that all ground hunters typically only encountered naïve individuals or small groups. Although this was the approach for our pilot study, the higher proportion during our study (33%) compared to Santa Cruz Island (5%) reflects the lower population density of Auckland Island pigs observed in summer 2018/19. Given this lower density, it could be suggested aerial hunting is not required and should be omitted due to cost. Pig populations on Auckland Island fluctuate spatially and annually (McIlroy 2005). Even with the observed population density prior to aerial hunting during this trial, an eradication proposal with ground hunting as the sole technique would have a high risk of being prolonged and/or of failure because of educated pigs avoiding hunters and/or breeding at a rate faster than they can be removed. There is also a portion of Auckland Island that is inaccessible to ground hunters where resident pigs can only be exposed to aerial hunting. Given the scale of Auckland Island, the fluctuation of pig densities, and the lead in time for planning a conservative multi-technique approach, utilising thermal cameras to assist aerial hunting is recommended.

Detection probability rates with the thermal camera were qualitatively assessed and based on multiple passes, conditions of low solar heating, and low wind, rain and humidity. The considerable variation in these detection probabilities of pigs between habitats (ranges <30% to >99%) can be attributed to the concentration and size of vegetation as infrared radiation cannot penetrate solid masses such as tree trunks and branches (Kays et al. 2019). With the adaptive and somewhat fluid hunting methodology and the overlap between habitat types it was not feasible to design a rigorous trial to give absolute detection rates for each habitat. The estimate of >99% probability of detection in tussock grasslands is important as this habitat equates to approximately c. 40% of Auckland Island and includes the exposed and difficult to access western side of the island. Having confidence that all pigs in tussock habitat can be put at risk with aerial hunting aided by thermal camera, significantly reduces the area to be ground hunted. This equates to a huge gain in eradication efficiency (i.e. resource and cost benefits).

The aerial hunting team experienced constant high wind and turbulence across the peninsula that made surveys difficult. The stability of the helicopter model proved valuable in handling turbulence while still having the manoeuvrability for hunting and pursuing pigs. The high wind also affected thermal detectability due to its conduction cooling effect resulting in poor image contrast between the surface temperature of pigs and the environment. With these variables changing rapidly the team regularly needed to suspend operations or shift to different locations with more favourable conditions. Teamwork and clear communication were critical for the quality of delivery, from adjusting the pilot's flying technique to improve the efficacy of the thermal camera operator, to rapidly pursuing and dispatching targets when detected. This result can only be achieved by a team well experienced at working together (the team had over 100 hours prior experience working together). The smaller lower resolution handheld thermal camera used by the secondary shooter was not essential but increased the detection rate by c. 10% simply by looking in different areas than the primary thermal camera operator. Investigating the use of two high-resolution thermal cameras at the same time in future trials would be worthwhile to see if this can further increase efficacy. The thermal scope fitted to the rifle of the primary shooter proved to be the critical component that enabled the shooter to identify and dispatch pigs that were moving and obscured by vegetation to the naked eye. There were no concerns of misidentification as the team collectively agreed on the identity of the target beyond all doubt before engaging or discharging the firearm. The thermal scope was helpful in conjunction with the thermal camera for improving the efficiency of distinguishing pigs from whakahao/rāpoka and other non-target detections. Each non-target detection still required closer investigation to positively identify the heat source which added to the flight time (Fig. 3; Table 2). Camera developments such as resolution, zoom capability and/or artificial intelligence classification could reduce this identification time further.

The use of the highly specialised thermal camera technology in this trial will likely improve performance of aerial shooting programmes across New Zealand, but uptake has been slow. Capacity and capability need to be built to allow its use at the scale of Auckland Island. Ungulate managers have regularly dismissed it due to their exposure to poor delivery or by not distinguishing the difference between the specialised deployment and commercially available handheld FLIR devices. Quality delivery is dependent on experienced operators in all roles, efficient teamwork and the right environmental conditions. A relevant study investigating surveillance sensitivity of Bennett's wallaby (*Macropus rufogriseus*) found traditional surveys (observer) had a higher detection probability than thermal camera surveys (Latham et al. 2019). Latham et al. (2019) acknowledged the lower detection probability reflected a high level of 'wash out' or interference from solar heated objects as survey timing did not consider solar loading and optimum conditions. There were also limitations to their study design as the thermal imaging camera was fixed in the helicopter and flew at a constant height above the ground to allow calculation of the survey area. They did not deploy the thermal camera within its constraints and as such could not accurately assess its realised potential. The success of the thermal camera during the Falla Peninsula trial relied on the camera operator manipulating the thermal camera (actively searching) to get multiple views of different aspects through gaps in the canopy to detect heat emanating from the animal that might have otherwise been obscured by vegetation. This undoubtably will result in higher detection rates than using the fixed position as trialled by Latham et al. (2019) in their wallaby study.

Aerial hunting was broken down by activity to extrapolate the method across the whole of Auckland Island to estimate future effort and cost. Of the 23.5 hours flying time used to complete the trial, ferry time accounted for 4.8 hours flying (c. 20%). This was surprising given the proximity of the helicopter base to the peninsula but can be attributed to frequent ferry flights during the operation to utilise small weather windows. Aerial hunting interactions with target animals are likely to decrease as animal population density declines. Given the high proportion of coastal habitat and dense vegetation on Falla Peninsula, the time interacting with non-targets is expected to have been higher than it would be on other parts of Auckland Island; although whakahao/rāpoka travel significant distances inland they are more prevalent on the coast. In the dense vegetation non-targets were occasionally detected in small gaps with only a few pixels, so it took more time observing and or moving closer to be confident it was not a pig. In more open vegetation like the tussock habitat, identification will be rapid.

Team ground hunting was delivered as intended demonstrating its practicality in Auckland Island conditions. As anticipated, Falla Peninsula was predominantly hunted along contours due to the bluff systems. To maintain a single hunting front hunters walked in a coordinated line. Progress through the block was determined by topography and the density of understory; the team's resulting speed was that of the slowest hunter (in some cases to the one crawling through the thick *Myrsine divaricata* scrub). This is reflected in Table 3 where hunters were able to cover more total area when the slowest line was through tall tussock/scrub. The helicopter greatly enhanced the efficiency of ground hunting by enabling hunters to access all parts of the peninsula and further supported operations with its function as a hunting platform. It ensured most operational time was active hunting time and maintained quality as hunters and dogs were fresh. On Santa Cruz Island, eradication hunters were positioned on high points to allow downhill hunting, increasing efficiencies (Parkes et al. 2010). This offers the obvious benefits of the hunters walking downhill but also means all hunters are usually working in the same vegetation type at any one time. This approach will be the preference for the proposed eradication, where topography allows.

As with Santa Cruz Island, the ground hunting programme not only removed the final pigs but it provided confidence in eradication success. Overlooking the pig that migrated into the trial block between sweeps, all pigs were detected in a single sweep and the second sweep validated the result. In contrast, Parkes et al. (2010) reported that of the total 5036 pigs dispatched on Santa Cruz Island, 210 were dispatched in the first sweep of the hunting blocks, 47 during the second sweep and only four during follow-up hunting when there were suspected survivors. Although ground hunting with dogs can provide a 100% detection probability (Parkes et al. 2010), as we observed in our trial, pigs can migrate behind the 'rolling front' between hunts and remain undetected (this relates to individual pigs' home ranges that are impossible to accurately predict). There are also times when the systematic approach changes as managers must adapt to accommodate factors such as weather or helicopter breakdowns. To account for these issues but also to confidently validate the eradication, a minimum of two intensive systematic ground hunting sweeps are recommended.

We planned for 19 days to complete the two sweeps of Falla Peninsula and it took 11 team hunting days over a 13-day period. Two days in the 13-day period were unsuitable due to weather. Concluding that the planning was too conservative, given the short period compared to the planned 19 days, would be inappropriate as Auckland Island can have frequent and lengthy periods of poor weather (Fraser 2020). However, it builds confidence in our planning. The hunting coverage rates presented in Table 3 offer Auckland Island-specific rates that can be used to estimate effort and time for the island-wide eradication. Hunters covered more ground per hour during the second sweep than the first (Table 3). Whether this speed increase was the result of differing lines between sweeps, or the hunters became accustomed to the terrain and were able to move more efficiently as time went on, is unclear.

The stringent team hunting formation was only made possible with real-time communication using VHF radios and communicating GPS units. It allowed complete coverage reducing the risk of pigs being missed and/or escaping. A larger total hunting team than was feasible during this trip would allow larger swaths to be searched at once, reducing edge effect. During some hunts the team leader worked as an additional hunter (Table 4), which was valuable for understanding the conditions, assessing team coverage and adapting to changing conditions in real-time. For this trial the team leader did not have a dog, but this would offer benefits for the main eradication as they would effectively be an additional hunter, increasing the team size and the area covered per day. The hunters selected for this work were highly skilled providing confidence in the results. Careful team selection, requiring months of lead-in time, will be important. This preparation is to ensure the hunting team are adequately skilled, are amiable and considerate of colleagues, and most importantly motivated and focussed on the outcome of the eradication rather than who among them dispatches a given pig (Brown & Brown 2015). Especially important is selection of the team leader and their ability to manage the team. Maintaining motivation is critical to the quality of delivery, particularly when there are few detections. Although there were not many rounds fired, firearms were essential for quick and humane dispatch of caught pigs. Having accurate multi-shot firearms suitable for carrying through the bush and hunters skilled in their use is essential as not all pigs can be bailed or held, and the implications of an escapee are significant.

The dogs coped well in the conditions. Working different dogs on alternate days facilitated their sustained performance. The strategic plan is designed so ground hunters will only be hunting a relatively small population of pigs and in the final stages. But low density will be challenging for dogs and handlers who are used to regularly catching pigs. Refreshing pig dogs with successful pig hunts on the mainland to maintain their motivation and hence performance during an extended eradication programme will be important. Hunters not involved in an encounter with a pig should prevent their dog from going to the bail. Individual dogs often behave differently when multiple dogs are at a bail, they can exhibit more confidence in numbers and can be inclined to hold pigs. Dogs that hold pigs are more prone to injury than bailing dogs; it will be important to select bailing dogs to reduce the risk of injuries. Critically, having multiple dogs respond to a detection weakened the security of the hunting line, risking escape if a pig fled in that direction. There were several near misses of dogs falling off bluffsduring this study which will need to be considered during planning. There were no hoiho–dog interactions however all dogs showed interest in whakahao/rāpoka. Althought there were no incidents recorded, aversion to native species should be built into dog training.

The installed fence preserved the integrity of the trial site. Two pigs broke through the temporary electric fence both occurring when the pigs were 'pushed' (the second pig to breach the fence was likely pushed during investigations west of the fence). The daily checks and trail camera monitoring enabled these observations allowing their consideration when interpreting the wider trial results (if the immigration of a pig between the two ground hunting sweeps was not identified our assessment of detectability would have been different). A pig-proof fence was installed before the eradication effort on Santa Cruz Island, it facilitated planning and implementation of the project by creating five distinct blocks (Parkes et al. 2010). In contrast, on Santa Rosa Island an existing cattle fence was not impermeable to pigs and the cost to make it pig proof was deemed not worthwhile (Lombardo & Faulkner 2000). Additional surveys were needed in treated management units adjacent to untreated units to detect immigration and shifts in distribution by pigs in response to management activities. In similar conditions to Auckland Island, fences were utilised on the sheep eradication on Campbell Island (11 268 ha) in the 1970s and 80s, however they were not established to facilitate island-wide eradication delivery but allowed different management by unit before island-wide eradication was completely supported (Brown et al. 2022). Brown et al. (2022) also suggest the fence made the eradication only marginally easier than attempting a single operation covering the whole island.

Balancing the benefit against the cost of fencing to split large islands into smaller management blocks can be challenging (Bode et al. 2013). Fences are considered necessary for eradicating pigs from Auckland Island due to the island's large size, the significantly higher occurrence of vegetated areas and the ability for pigs to learn if sub-lethally exposed to eradication techniques. Fences will not only improve operational efficiency by increasing the security of individual blocks but will also confine Judas pigs outside an actively hunted block until they are required. Two fences to split the island into three management blocks are proposed. The style of electric fence used in this trial was solely a deterrent and not a useful indicator of the security for all fences. Fence construction will be based on the netting and barbed wire design proven by Hone and Atkinson (1983). Fences are achievable due to narrowing of the island in certain locations due to deep glacial inlets on the eastern side. Only c. 8 km of fence will be needed with an expected direct cost of approximately NZ$60 000 per km. If migration is not eliminated, the fences will still enable monitoring (with cameras and observations) of movement between blocks. The impact of a fence on wildlife will be evaluated in an Assessment of Environmental Effects if the project is initiated. Given there was no concern with the level of impact on the six whakahao/rāpoka interactions with the trial electric fence, and that the fences will be removed on completion of project, their effect should be minimal.

With the lessons from other large-scale eradications and the experience gained during this trial, there is confidence that a pig eradication on Auckland Island is feasible with the described methods and systematic delivery. Variations in this described methodology may prove successful but need to be evidence based. Eradication validation will occur by building certainty, informed by understanding how techniques were delivered and how operational data were used to inform daily decision making. The technique with the highest detectability needs to be implemented last. Applying a suite of overlapping tools with adequate coverage will give confidence that zero detections actually reflects an absence of pigs. Even though they are applied in the order of most passive to most aggressive at the appropriate population density, passive tools could continue to be deployed for the duration of the eradication. The strategy demands every engagement is lethal and therefore engagement should only occur if there is high confidence in the pig(s) being dispatched. The implication of an educated individual can at best be a costly intercept (Macdonald et al. 2019), but at worst an individual that permanently evades detection risks the success of the whole eradication (Morrison et al. 2007). Factors discussed here need to be considered when planning the island-wide eradication. Suitable contingency should be applied to operational timeframes given that eradication techniques rely on helicopters with their associated weather and environmental constraints. The trial suggests the strategy recommended here has a high likelihood of success and is most appropriate for achieving a rapid result.

Author contributions

FSC, SRH and NLM designed the study; FSC and SRH undertook fieldwork; FSC and WMB analysed the data; and FSC and NLM wrote the manuscript with input from SRH.

Acknowledgements

Gaven Burgess and Fraser Sutherland of Te Anau Helicopter Services Ltd (Te Anau, New Zealand), the late Grant Halverson of Airbourne Technologies as well as Sean Jacques and Terry McDowell for assistance with the delivery of the aerial hunting phase. Bryan Patterson of Amuri Helicopters Ltd (Hanmer Springs, New Zealand), Ben Crouchley, Peter Kirkman, Callum Kyle, Kurt Shearing, Anthony Buchanan, Gregor Goble, and Rory Gentle for assistance with the delivery of the ground hunting phase. Kaitiaki Roopu for their support of the Maukahuka Project and field trials. Steve Kafka with the crew of the MY Evohe and the crew of the MV Searanger for safe passage to and/or from the island. Paul Jacques, Rachael Sagar, James Russell and two anonymous reviewers made helpful comments on this manuscript.

We would like to recognise the contribution Grant Halverson made to this research trial, the Maukahuka Pest Free Auckland Island project and the wild animal management thermal camera industry. Okioki i te rangimarie Grant.

References

Anderson DP, Latham MC, McClelland P, Latham ADM 2022. Analysis of spatiotemporal patterns of home range use and habitat selection to inform management of feral pigs on Auckland Island. New Zealand Journal of Ecology 46: 3489.

Bode M, Brennan KE, Helmstedt K, Desmond A, Smia R, Algar D 2013. Interior fences can reduce cost and uncertainty when eradicating invasive species from large islands. Methods in Ecology and Evolution 4: 819–827.

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

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

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

Caley P, Ottley B 1995. The effectiveness of hunting dogs for removing feral pigs (*Sus scrofa*). Wildlife Research 22: 147–154.

Campbell DJ, Rudge MR 1984. Vegetation changes induced over ten years by goats and pigs at Port Ross, Auckland Islands (subantarctic). New Zealand Journal of Ecology 7: 103–118.

Challies CN 1975. Feral pigs (*Sus scrofa*) on Auckland Island: status, and effects on vegetation and nesting sea birds. New Zealand Journal of Zoology 2: 479–490.

Chimera C, Coleman MC, Parkes JP 1995. Diet of feral goats and feral pigs on Auckland Island, New Zealand. New Zealand Journal of Ecology 19: 203–207.

Choquenot D, Hone J, Saunders G 1999. Using aspects of predator-prey theory to evaluate helicopter shooting for feral pig control. Wildlife Research 26: 251–261.

Clarke CMH 1991. The acceptance of non-toxic polymer baits by feral pigs on Auckland Island. Forest Research Institute Contract Report FEW 91/20. Christchurch, Forest Research Institute. 10 p.

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

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

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.

Garcelon D, Ryan K, Schuyler P 2005. Application of techniques for feral pig eradication on Santa Catalina Island, California. In Proceedings of the Sixth California Islands Symposium. National Park Service Technical Publication, CHIS-05-01. Arcata, California, Institute for Wildlife Studies. Pp. 331–340.

Hone J, Atkinson B 1983. Evaluation of fencing to control feral pig movement. Wildlife Research 10: 499–505.

Horn SR, Sagar RL, Frank VK, Cox FS, Jacques PM, Ware J, Hanley-Nickolls R, Leask EP, MacDonald NL, Kirby-Crowe MS, Le Lievre ME, Broome KG 2022. The next frontier: assessing the feasibility of eradicating mammalian pests from Auckland Island. New Zealand Journal of Ecology 46: 3500.

Hutton I, Parkes JP, Sinclair ARE 2007. Reassembling island ecosystems: the case of Lord Howe Island. Animal Conservation 10: 22–29.

Kays R, Sheppard J, Mclean K, Welch C, Paunescu C, Wang V, Kravit G, Crofoot M 2019. Hot monkey, cold reality: surveying rainforest canopy mammals using drone-mounted thermal infrared sensors. International Journal of Remote Sensing 40: 407–419.

Kessler CC 2002. Eradication of feral goats and pigs and consequences for other biota on Sarigan Island, Commonwealth of the Northern Mariana 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. 132–140.

Kessler CC 2011. Invasive species removal and ecosystem recovery in the Mariana Islands; challenges and outcomes on Sarigan and Anatahan. 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. 320–324.

Latham ADM, Warburton B, Latham MC, Anderson DP, Howard SW, Binny RN 2019. Comparative detection probabilities, surveillance sensitivity and costs of four survey methods for managing invasive Bennett's wallaby in South Island, New Zealand. Manaaki Whenua – Landcare Research Contract Report LC3648. Lincoln, Manaaki Whenua – Landcare Research. 37 p.

Lombardo C, Faulkner K 2000. Eradication of feral pigs (*Sus scrofa*) from Santa Rosa Island, Channel Islands National Park, California. In: Browne DH, Chaney H, Mitchell K eds. Proceedings of the fifth California islands symposium. Santa Barbara, California, Santa Barbara Museum of Natural History. Pp. 300–306.

Macdonald N 2018. Five Fingers Peninsula thermal camera trial. Internal Report - Department of Conservation. Wellington, Department of Conservation Te Papa Atawhai. 13 p.

Macdonald N, Nugent G, Edge K, Parkes JP 2019. Eradication of red deer from Secretary Island, New Zealand: changing tactics to achieve success. 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. 256–260.

McCormick R 1884. Voyages of discovery in the Arctic and Antarctic seas and round the world, 2 Vols. London, Sampson Low, Marston, Searle and Rivington. 843 p.

McIlroy JC 2005. Feral pig. In: King CM ed. The handbook of New Zealand mammals. 2nd ed. Melbourne, Oxford University Press. Pp. 334–345.

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.

Morrison SA, Macdonald N, Walker K, Lozier L, Shaw RM 2007. Facing uncertainty the dilemma of absence at eradication's end: uncertainty and the Lazarus effect. Frontiers in Ecology and the Environment 5: 271–276.

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.

Myers JH, Simberloff D, Kuris AM, Carey JR 2000. Eradication revisited: dealing with exotic species. Trends in Ecology and Evolution 15: 316–320.

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.

Rudge MR 1976. A note on the food of feral pigs (*Sus scrofa*) of Auckland Island. Proceedings of the New Zealand Ecological Society 23: 83–84.

Russell JC, Broome K 2016. Fifty years of rodent eradications in New Zealand: another decade of advances. New Zealand Journal of Zoology 40: 197–204.

Russell JC, Griffiths R, Bannister WM, Le Lievre ME, Cox F, Horn SR 2019. Mouse bait uptake and availability trials on Auckland Island. DOC Research & Development Series 363. Wellington, Department of Conservation Te Papa Atawhai. 11 p.

Russell JC, Horn SR, Miskelly CM, Sagar RL, Taylor RH 2020. Introduced land mammals and their impacts on the birds: of the subantarctic Auckland Islands. Notornis. 67: 247–268.

Saunders G 1993. Observations on the effectiveness of shooting feral pigs from helicopters. Wildlife Research 20: 665–671.

Schuyler PT, Garcelon DK, Escover S 2002. Eradication of feral pigs (*Sus scrofa*) on Santa Catalina Island, California, USA. 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. 274–286.

Taylor D, Katahira L 1988. Radio telemetry as an aid in eradicating remnant feral goats. Wildlife Society Bulletin 16: 297–299.

Turbott G 2002. Year away: wartime coastwatching on the Auckland Islands, 1944. Wellington, Department of Conservation Te Papa Atawhai. 153 p.

Veitch CR, Bell BD 1990. Eradication of animals from New Zealand islands. In: Towns DR, Daugherty CH, Atkinson IAE eds. Ecological restoration of New Zealand islands. Conservation Sciences Publication No. 2. Wellington, Department of Conservation Te Papa Atawhai. Pp. 137–146.

Witczuk J, Pagacz S, Zmarz A, Cypel M 2018. Exploring the feasibility of unmanned aerial vehicles and thermal imaging for ungulate surveys in forests – preliminary results. International Journal of Remote Sensing 39: 5504–5521.

Editorial board member: James Russell
Received 24 February 2021; accepted 19 September 2022